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Teaching materials

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Teaching Materials

Water resources management

Water treatment

Wastewater treatment

Industrial wastewater treatment

Entrepreneurship

Academic writing

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Water Resource Management

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Lesson 1. Availability of Water and Multiple Users

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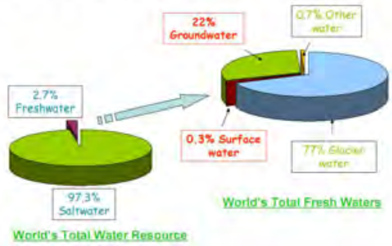
World Fresh Water Resource



At global level, three fourth of the earth's surface is covered with water resources comprising 97.3% salt water and the balance 2.7% as fresh water. Of the latter, 77% occurs polar ice and glaciers, 22% groundwater, 0.3% in lakes and rivers and 0.7% in soil moisture and atmospheric vapour.

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Global water consumption ......

▶The global water consumption is doubling every 20 years and is more than twice the rate of population increase.

▶By 2030, more than half of the world population will face a shortage of water.

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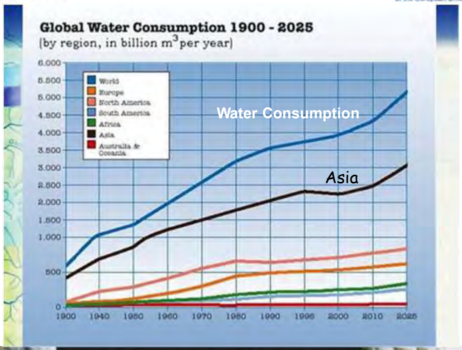

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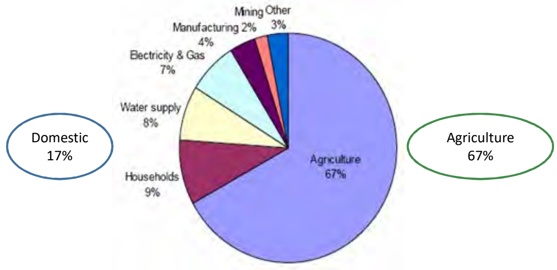
Global water consumption in different sectors ......



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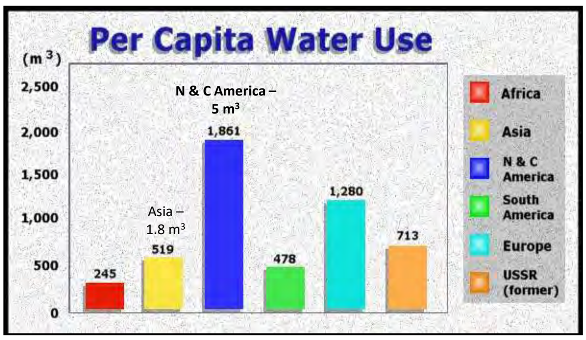
Per capita Water use in different regions



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Three Messages: Global Water & the Future

1. The world's water resources are under rapidly growing pressure

2. Without major water investments, many poor economies cannot grow

3. Without 'riparian' cooperation, water will increasingly breed conflict

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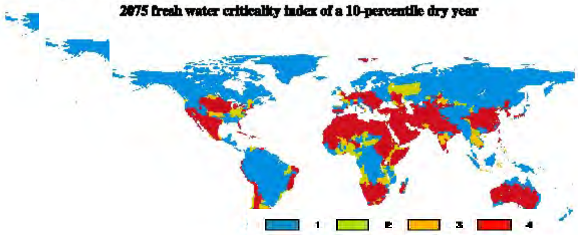
Growing water scarcity(1995-2075)

1995 fresh water criticality index of a 10-percentile dry year

2025 fresh water criticality index of a 10-percentile dry year

2075 fresh water criticality index of a 10-percentile dry year



SEI - Criticality index (Source: WaterGAP)

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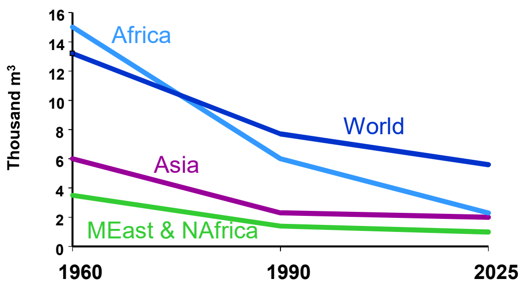
Per capita water availability



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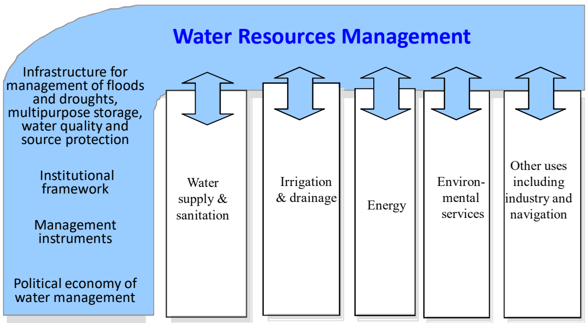
Multiple Water Users



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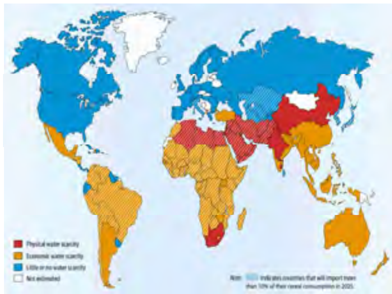
Physical, economic water scarcity



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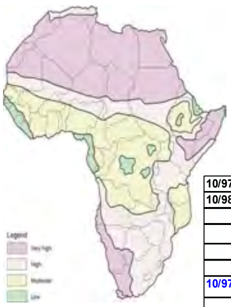
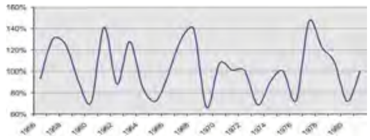
Climate Variability & Growth





Kenya: variability & shock

10/97 – 2/98 Flood	Infrastructure Damage		$2.39 b
10/98 –5/00 Drought	Crop loss	$0.24 b	
	Livestock loss	$0.14 b	
	Reduction in hydropower	$0.64 b	
	Reduced industrial prod.	$1.39 b	
	TOTAL	$2.41 b	$2.39 b
10/97 – 05/00	Cost of Climate Variability		$4.8 b
	Approx (annual) GDP	($9 b/yr)	$22 b
	Impact as % GDP/annum		22%

Natural legacy: extreme climate variability

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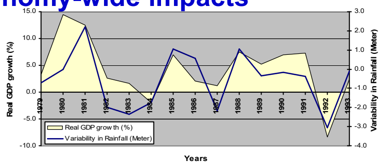
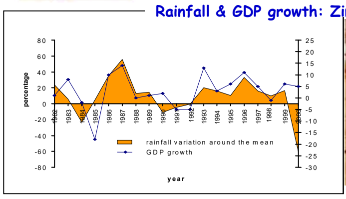
Economy-wide impacts



Rainfall & GDP growth: Zimbabwe 1978-1993



Rainfall & GDP growth: Ethiopia 1982-2000

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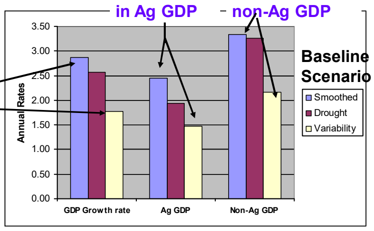
Ethiopia – Impacts of historical levels of variability on projected GDP growth/economic performance

➔ Hydrological variability slows growth rates 38%



38% decline in avg. projected GDP growth rate when historical levels of variability are assumed

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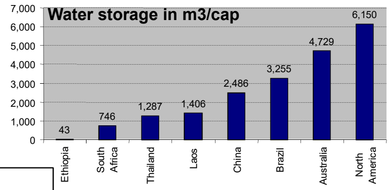
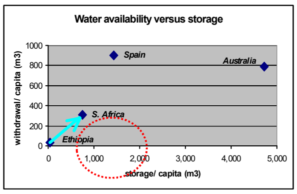
Water storage and the poverty trap





- Stable pop. & GDP, raising Ethiopia's storage to South Africa (12% of USA)
- ~ 6 X GDP
- Or 5% of GDP for over 100 yrs

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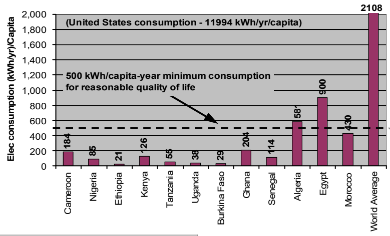
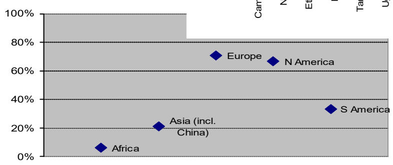
The electricity gap





Hydropower potential tapped

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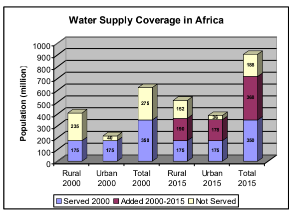
The Water Supply & Sanitation Gap

Africa's MDG Challenge



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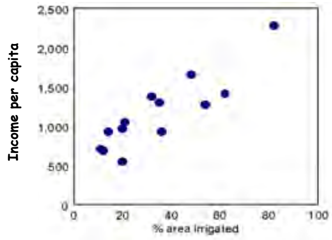
Irrigation can lift rural poor out of poverty



Average income levels & irrigation intensity in India

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260 international basins: +/- tensions: longstanding, always, growing with demand

"Fierce competition for fresh water may well become a source of conflict & wars in the future." Kofi Annan, March 2001

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FT, June 18, 2001: Rain in India…

"Every one of my budgets was largely a gamble on rain." Finance Minister of Government of India

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Africa's historical legacy: numerous international rivers

- 60+ international rivers
- many countries per basin
- many basins per country
- weak capacity

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Three Messages: Global Water & the Future

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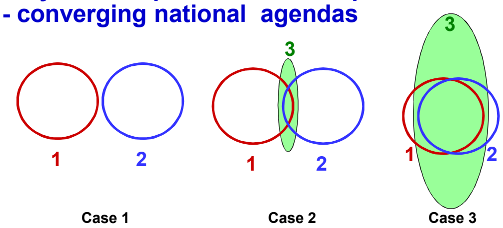
Why would riparian states cooperate? - converging national agendas



Country 1's preferred agenda
Country 2's preferred agenda
Cooperative agenda 3

…all cases can be rational. The choice among them will depend upon ***perceptions*** of their relative benefits.

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A Cooperation Continuum

- •Communication and notification
- •Information sharing
- •Regional assessments

- •Identify, negotiate & implement sets of national investments that capture cooperative gains
- •Adapt national plans to mitigate regional costs
- •Adapt national plans to capture regional gains

- •Joint project assessment and design
- •Joint ownership
- •Joint institutions
- •Joint investment

Dispute — Cooperation Continuum — Integration

Unilateral Action — Coordination — Collaboration — Joint Action

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Benefits of Cooperation: changing perceptions

	The Challenges	The Opportunities
Type 1: **Increasing Benefits** ***To the river***	Limited water resour. management: degraded watersheds, wetlands, biodiversity, & water quality.	Improved water quality, riverflow characteristics, soil conservation, biodiversity
Type 2: **Increasing Benefits** ***From the river***	Sub-optimal water resources development	Improved hydropower & agricultural production, flood-drought management, environmental conservation & water quality
Type 3: **Reducing Costs** ***Because of the river***	Tense (+/-) regional relations & political economy impacts	Policy shift to cooperation & development, from dispute; from food & energy self-sufficiency to security; reduced conflict risk & military expenditure (+/-)
Type 4: **Increasing Benefits** ***Beyond the river***	Regional fragmentation	Integration of regional infrastructure, markets & trade

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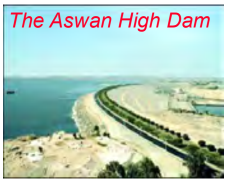
Development Diplomacy & the World Bank



"Those were the two most important things … when I was at the Bank"

Eugene Black
President of the World Bank (1942-62)

Eugene Black was asked about the most significant events during his presidency. He talked about his involvement in the Middle East, in connection with the Aswan Dam and the Suez Canal. " and I was also very much involved in India and Pakistan, the Indus River dispute. I was trying to get the Indian government and the Pakistani government together …. That took a very long time [1952 to 1960]."

The Bank's World, May 1988

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Nile Basin Initiative

- ➢10 countries: Burundi, D.R. Congo, Egypt, (Eritrea), Ethiopia, Kenya, Rwanda, Sudan, Tanzania, Uganda
- ➢300 m people (600m 2025)
- ➢Extreme:
  - ➢poverty: 4 of 10 poorest
  - ➢climate variability
  - ➢landscape vulnerability
- ➢Very limited infrastructure….
- ➢Yet major opportunities:
- ➢The Bank
  - ➢as facilitor: 1997-2003
  - ➢as partnership coordinator
  - ➢as investor: 2004 ->

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Nile: "Cooperation replaces conflict"

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Three Conclusions: Actions and Consequences

1. The world's water resources are under rapidly growing pressure

Solutions can be found – although costs will be high ('economic scarcity')

2. Without major water investments, many poor economies cannot grow

De-linking rain from the economy is a condition for growth, poverty eradication

3. Without 'riparian' cooperation, water will increasingly breed conflict

Riparian cooperation can catalyze growth, economic integration & peace

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Rivers are political systems….

- Management of rivers is political; management of international rivers is very political…
- Rivals… dwellers on opposite banks of a river
- The Chinese got it right long ago:

river + dyke = Political order

Lesson 2: Water Resources System

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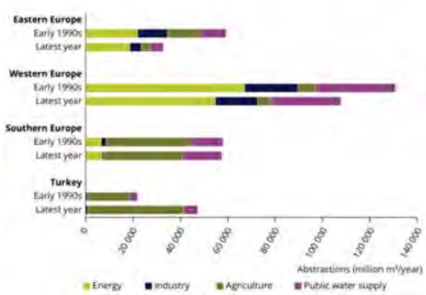
Outline

- Water users
- Water quality and quantity issues
- Ground water management & use
- Surface water management & use
- Rainwater harvesting
- Desalination
- Water reuse
- Remediation of water resources
- Pollution issues

Water consumption and users

- Water supply to households
  - Drinking water, wastewater, food production
- Irrigation
  - Food production, environmental watering
- Aquaculture
- Industrial production
  - Process water, cooling water
- Production of electricity
- Recreation
- Recipient for wastewater
- Transport



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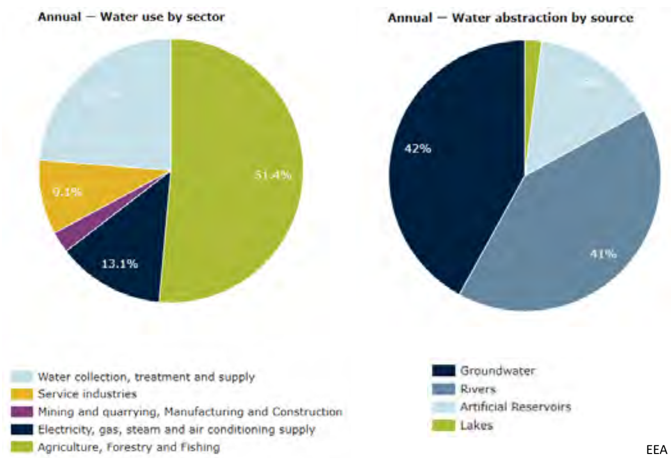


EEA

Typical water usage in Europe

- Private Household 130-180 liters a day per person
- Farms 130 to 180 liters a day per person
- School 10 to 30 liters a day per person
- Office 25 liters a day per employee
- Hotels 200 to 500 liters a day per bed
- Restaurant 300-500 liters a day per employee
- Horse 30-60 liters a day per horse
- Dairy cattle from 45 to 130 liters a day per person
- Swine 15 liters a day per pig
- Sheep 8 liters a day per sheep

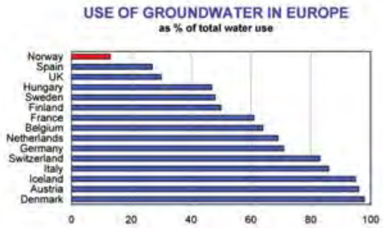
Sources of water

- Surface water (lakes, rivers)
- Ground water
- Harvested rainwater
- Desalinated seawater
- Reclaimed water from wastewater

Ground water management & use

Ground water sources

- Wells in rock
- Wells in (reservoirs in) soil
- River bank infiltration
- Infiltration/artificial groundwater



Assumed water quality advantages for groundwater compared to surface water

- Hygienic safety with regard to pathogenic micro-organisms
- Usually no need for disinfection
- Usually need for simple water treatment only

Ground water; potential water quality problems

- Low oxygen level
- Iron
- Manganese
- High turbidity
- Too much chloride
- Too much fluoride
- Too much carbon dioxide
- Low pH
- High pH
- Sulphide
- High hardness

- Radon
- Pathogenic micro-organisms (contaminated wells)
- Pesticides,
- Arsenic,
- Nitrite/nitrate
- Sink
- Chromium
- Nickel
- Lead
- Other contamination (oil, chemicals)

Challenges facing ground water

- Seawater intrusion due to over extraction
- Contaminated raw water (ground water or surface water) combined with insufficient or no disinfection is the major reason for sickness (and death) related to drinking water in USA and Canada
- Flooding increases the risk for contamination from pathogenic organisms
- Drought
- Contamination from chemicals due to insufficient well security (e.g. phenol, Denmark)

Surface water management & use

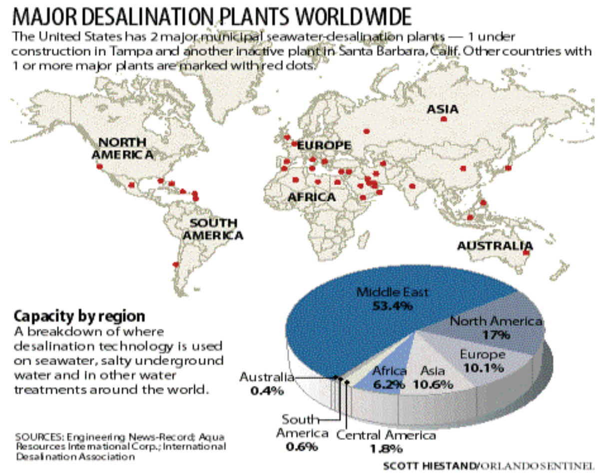
- Surface water is water on the surface of the planet such as in a river, lake, dam, wetland (or ocean).
- Surface water is more exposed to pollution from humans, birds, animals etc.
- NOM – Natural Organic Matter and Suspended Solids are common natural pollutants

Rainwater harvesting

- Collection and storage of **rainwater** into natural reservoirs or tanks, or the infiltration of surface **water** into subsurface aquifers

Desalination

- **Desalination** is a process that extracts mineral components from saline water.
- Seawater is desalinated to produce water suitable for human consumption or irrigation.
- One by-product of desalination is salt.
- Due to its energy consumption, desalinating sea water is generally more costly than fresh water from rivers or groundwater, water recycling and water conservation.

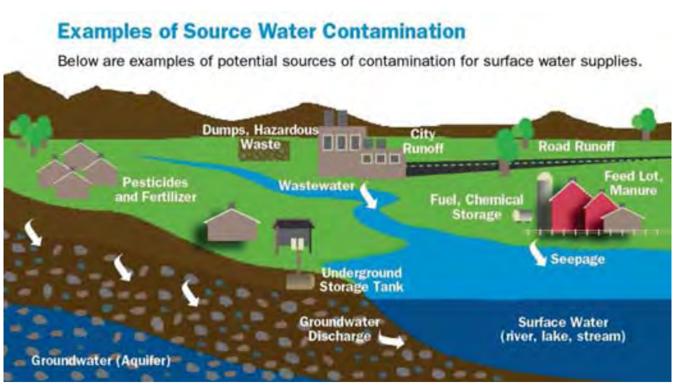


Water reuse

Remediation of water resources

- **Groundwater Remediation**
  - process of treating polluted water below the earth
- **Surface Water Remediation**
  - process of treating polluted water in rivers and lakes
- **Soil Remediation**
  - process of removing contaminants from soil, prevents water pollution
- **Sediment Remediation**
  - treatment of sediments accumulated at the bottom of a water body that contains toxic materials at high levels.

Pollution of surface water



© American water

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Lesson 3: Hydrologic Processes

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Hydrology

Hydrology: Study of the hydrologic cycle; occurrence, distribution, movement, physical and chemical properties of waters of the earth and their environmental relationships.

Study and practice of hydrology: aids in explaining and quantifying the occurrence of water on, under and over the earth's surface.

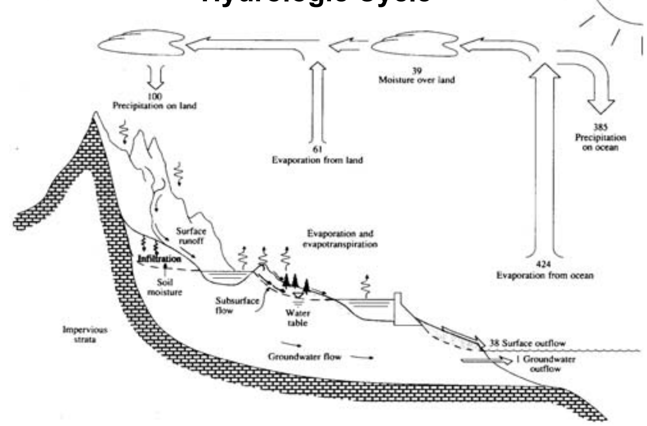
Hydrologic Cycle

Earth's water resources are in a state of continuous circulation linking the atmosphere, land and the oceans. This endless process, which is powered by the forces of nature is called the Hydrologic Cycle.

It is the basic framework upon which the science of hydrology is built.

There are many processes that constitute the hydrologic cycle.

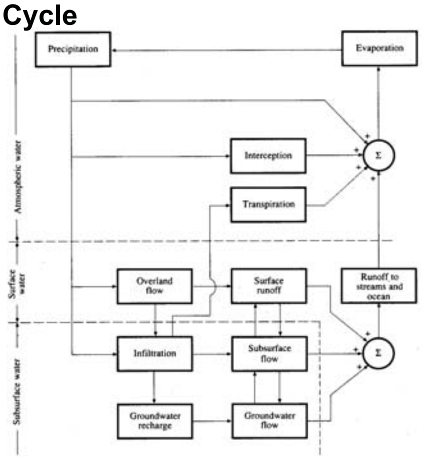
Hydrologic Cycle



Ref: Applied Hydrology by Ven Te Chow, David R. Maidment, Larry W. Mays

Hydrologic Cycle

Block diagram representation of the global hydrologic system



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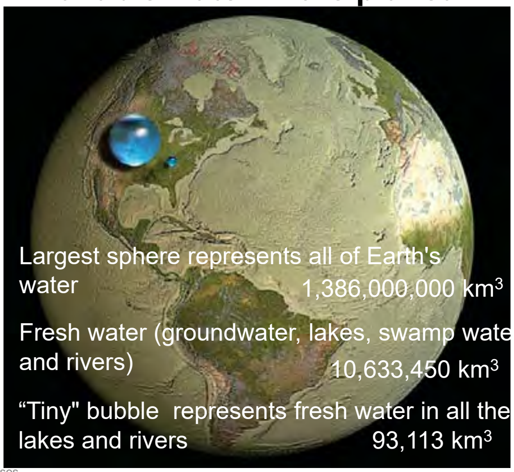
Estimated world water quantities

Item	Area (10^6 km^2)	Volume (km^3)	Percent of total water	Percent of fresh water
Ocean	361.3	1338000000	96.5	
Groundwater				
Fresh	134.8	10530000	0.76	30.1
Saline	134.8	12870000	0.93	
Soil Moisture	82.0	16500	0.0012	0.05
Polar ice	16.0	24023500	1.7	68.6
Other ice and snow	0.3	340600	0.025	1.0
Lakes				
Fresh	1.2	91000	0.007	0.26
Saline	0.8	85400	0.006	
Marshes	2.7	11470	0.0008	0.03
Rivers	148.8	2120	0.0002	0.006
Biological water	510.0	1120	0.0001	0.003
Atmospheric water	510.0	12900	0.001	0.04
Total water	510.0	1385984610	100	
Fresh water	148.8	35029210	2.5	100

Ref: Applied Hydrology by Ven Te Chow, David R. Maidment, Larry W. Mays

Available water in the planet



Global annual water balance

		Ocean	Land
Area (km^2)		361300000	148800000
Precipitation	(km^3/yr)	458000	119000
	(mm/yr)	1270	800
Evaporation	(km^3/yr)	505000	72000
	(mm/yr)	1400	484
Runoff to ocean			
Rivers	(km^3/yr)	-	44700
Groundwater	(km^3/yr)	-	2200
Total runoff	(km^3/yr)	-	47000
	(mm/yr)	-	316

Ref: Applied Hydrology by Ven Te Chow, David R. Maidment, Larry W. Mays

Precipitation

- Air is forced to rise
- Rising air cools because the *ideal gas law* says that the temperature falls when the air pressure decreases.
- The air cools at the *dry lapse rate* until it reaches its *dewpoint*.
- Once the air reaches its *dewpoint*, the relative humidity reaches 100%, and clouds form.
- As the air continues to rise, the air cools at the *wet lapse rate*, causing precipitation to form because the colder air can not hold the excess moisture.

Precipitation

- The condensing water generates heat, causing the air to warm slightly, so that the wet air lapse rate is less than the dry rate.
- The excess heat generated by the condensing water causes the air to rise faster (because warmer air rises through colder air).

Precipitation

Three primary steps for formation of precipitation

•creation of saturation conditions in the atmosphere (typically some type of lifting of air)

•phase change from vapor to liquid (cloud formation)

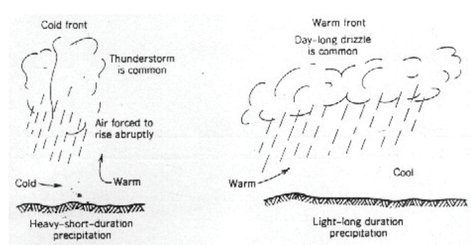
•growth of droplets to precipitable size (able to overcome upward velocity)

Lifting Mechanisms

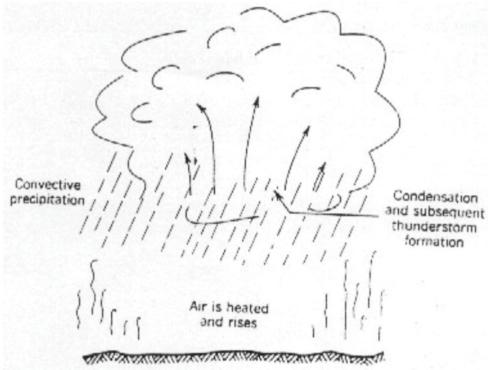
Front: the boundary between two adjacent air masses of different temperature and moisture content.

Warm Front: Warm air advancing on colder air

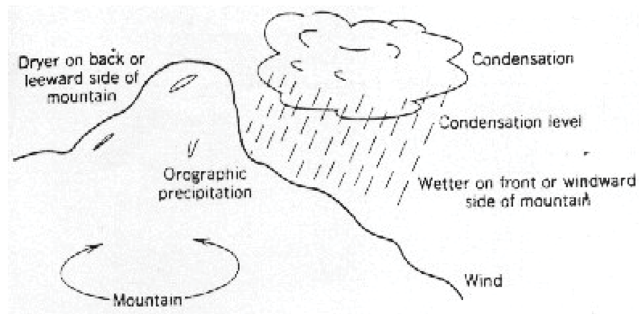
Cold front: Cold air advancing on warm air



Convective Precipitation



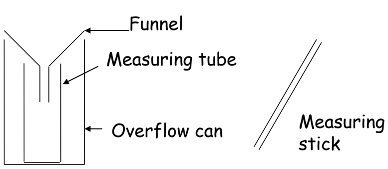
Orographic Precipitation

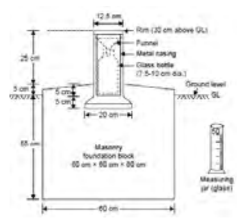


Measurement of Precipitation

Measured as a depth of water on a flat level surface if all the precipitation remained where it had fallen
Units: inch, mm

<u>Non Recording Gauge</u>





Measurement of Precipitation

US Standard Weather Bureau Gauge,
Diameter, Φ = 8 in (20.32 cm)
Area of the tube is 0.1 that of the funnel

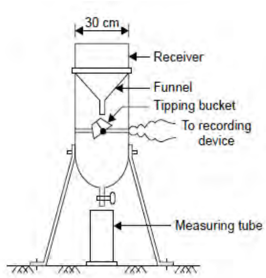
<u>Graduated Scale</u>: To measure precipitation
<u>Excess</u>: Overtops the inner tube and collects in the overflow can

Rainfall is measured by an observer at regular intervals

Recording Gauges

Tipping Bucket Gauge

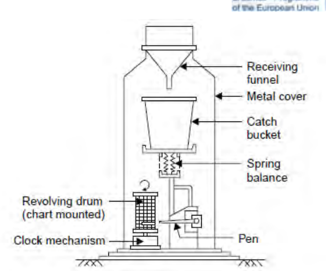
Consists of a pair of buckets pivoted under a funnel



When one bucket receives 0,25 mm (0.01 in) of precipitation it tips, discharging its content into the bucket, bringing the other bucket under the funnel

Recording mechanism: Time of occurrence of each tip measures rainfall intensity for short periods

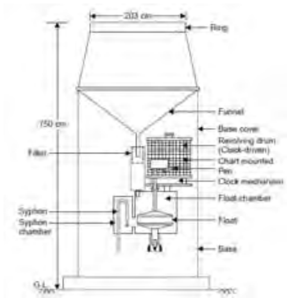
Weighting Type Gauge



Has a bucket supported by a spring or lever balance
Movement of the bucket is transmitted to a pen, which traces a record of the increasing weight of the bucket and its contents on a clock driven chart

Record: Accumulation of precipitation
Slope of mass diagram: Rate of rainfall

Floating type Gauge



Has a pen actuated by a float on the water surface in the bucket
Automatic siphoning arrangement empties the bucket when it is full

Radar

Radar records a signal reflected of particles (raindrops) at a high frequency. This signal is converted to cumulative rainfall. This data can provide information on location and movement of storms, data in ungauged regions.
However, there are difficulties or error in the measurements due to various types of particulate (hail, snow, high intensities)

Design of Rain Gauge Networks

A well distributed network of rain gauge stations within the catchment is essential

To obtain reliable results, rain gauges should be evenly and uniformly distributed

Total number of rain gauges installed within a given catchment area should neither be too many as to be costly nor should be too less as to give unreliable results

Design of Rain Gauge Networks

Areal density of rain gauges may vary considerably from region to region in any country

Density of gauges may also depend upon the basic purpose behind their installation

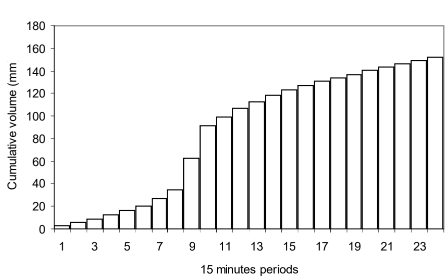
Guidelines: World Meteorological Organization

•(flat) temperate, mediterranean and tropical; 230 – 350 mi^2 per station
•(mountainous) temperate, mediteranean and tropical; 40 – 100 mi^2 per station
•arid polar zones 600 to 4000 mi^2 per station

Data Representation

Cumulative Mass Curve

Typically the output from a recording gauge is in the form of cumulative rainfall over time



At any given time during a storm, the intensity is the slope of the cumulative rainfall curve at that point in time

Rainfall Hyetograph

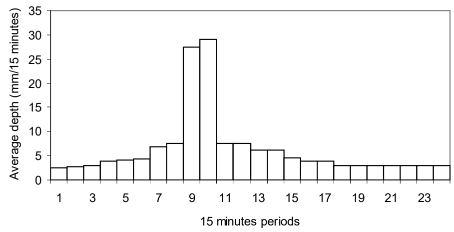
The slope of the cumulative mass curve at any point represents the rate of rainfall (depth/time).

Typically we represent the rainfall distribution in discrete time intervals using the cumulative mass curve to calculate the depth over each time interval.

Next the depth or intensity is plotted versus time to generate a hyetograph characterizing the time distribution of a storm or selected time period.

The hyetograph is the most common input to hydrologic models (surface hydrology models).

Rainfall **Hyetograph**



It is expressed in depth units per unit time, usually as mm per hour (mm/h) (or in/hr)

Missing Data Points
(also rainfall at ungauged locations)

This is usually done for one or two years, months or days for a long term record. Three methods commonly used and are based on long term records of surrounding gauges (minimum of three)

Precipitation measuring stations sometimes fail in providing a continuous record of precipitation

Eg. Due to malfunction of instruments, failure to record data or miss a visit to site

Simple average of surrounding gauges

must be equal distance from point of estimate should have fairly equal rainfall at known gauges

Normal Ratio Method (missing data)

when surrounding gauges differ by greater than 10% in measured rainfall, stations are weighted based on normal annual precipitation ratio's

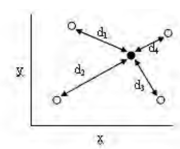
$$P_x = \frac{1}{k}\left(\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2}P_2 + \ldots + \frac{N_x}{N_k}P_k\right)$$

where:

Nx	=	normal long-term annual precipitation at location x
Pk	=	event precipitation at gauge k
Nk	=	normal long-term annual precipitation at gauge k
Px	=	estimated event precipitation at location x

Reciprocal Distance Method (missing data & ungauged location)

Surrounding gauges are weighted based on reciprocals of the sum of squares of distance away from the point of interest. Sometimes called inverse weighted distance method



X and y are distances from the unknown point (missing data location) where precipitation is being estimated

$$W_i = \frac{1}{d_i^2}$$

$$d_i = \sqrt{x^2 + y^2}$$

$$P_x = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i}$$

Hydrologic Abstractions

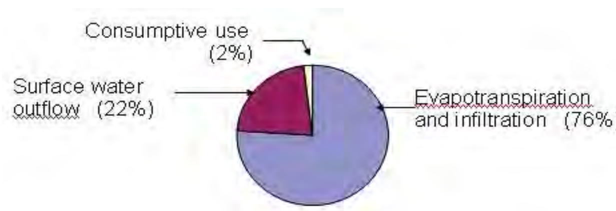
Hydrologic abstractions are the losses of precipitation, which prevent precipitation from becoming surface runoff

Eg.
Out of the 4300×10^6 m^3 of rainfall receiving on the Walawe Ganga catchment in Sri Lanka
only 945×10^6 m^3 is discharged to the sea

85×10^6 m^3 of water is used for drinking and industrial purposes

Balance of 3270×10^6 m^3 is evapotranspirated and infiltrated

Hydrologic Abstractions



Average disposition of precipitation in the Walawe Ganga catchment in Sri Lanka

Evaporation

The process by which water is transferred from land and water masses of the earth to the atmosphere

There is a continuous exchange of water molecules between an evaporating surface and its overlying atmosphere

Evaporation is the net rate of vapour transfer

Evaporation

It is a function of
- solar radiation
- difference in vapour pressure between water surface and the overlying air
- temperature
- wind
- atmospheric pressure
- the quality of evaporating water
- size of the water body

Rate is highest from open water

Ground surface: Rate depends on the type of soil and saturation with water

Evaporation

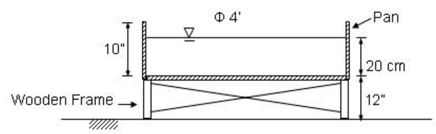
Storm periods: vapour pressure gradients are reduced and evaporation is usually not significant

Evaporation varies from day to day
Daily evaporation in Sri Lanka varies from 1 to 10 mm/day but on average it is taken as 4 mm/day

Evaporation is determined based on
- water budget
- energy budget
- empirical formulae
- pan-evaporation data

Evaporation Pans

Most widely used method



A standard evaporation pan

The standard weather bureau Class A pan: unpainted, galvanized iron 4-ft diameter (122 cm), 10 in (25.4 cm) deep, circular container, mounted 12 in above the ground on a wooden frame

Usually filled to a depth of 20 cm and refilled when the depth has fallen to less than 18 cm

Water surface is measured with a hook gauge

Evaporation Pans

Pan evaporation estimates lake evaporation

Lake evaporation (E_L) is usually calculated by multiplying the pan evaporation by a factor called pan coefficient (P_C)

$$E_L = P_C E_P$$

Pan coefficient on an annual basis varies between 0.65 and 0.82

Evaporation rates vary with the time of the year

Greatest is during periods of intense sunlight and least is during cold cloud-covered days

Evaporation Reduction

Evaporation losses can be greatly significant at any location Consequently, the concept of evaporation reduction is receiving widespread attention

Evaporation losses from soils can be controlled by employing various types of mulches or by chemical alteration

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Evaporation Reduction

They may be reduced from open waters by;

a) storing water in covered reservoirs

b) making increased use of underground storage

c) controlling aquatic growths

d) building storage reservoirs with minimal surface area

e) through the use of chemicals

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Transpiration

Process by which water is drawn from the soil by plant roots and transferred to the leaves, from which it evaporates

Controlled by

- solar radiation
- temperature
- wind velocity
- vapour pressure gradient
- characteristics of plants
- plant density
- soil moisture content

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Estimation of Transpiration

For small plant areas: determined by a closed container in which humidity changes are measured

Soil is sealed to prevent evaporation from soil

These experiments are performed on site or by use of a phytometer (a container with a particular plant rooted in it). Soil surface is sealed so that the only escape of moisture is by transpiration. Transpiration can be determined by weighting the planted container at desired intervals of time

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Estimation of Transpiration

Precise determination is difficult

Extrapolations to other areas can be misleading

Water budgets are valuable, but again requires estimates of other variables and thus the transpiration estimates are only as accurate as the measurement of the other variables

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Transpiration Reduction

Methods of control include

•use of chemicals to inhibit water consumption

(chemicals are applied in the root zone)

•harvesting of plants

•improved irrigation practices

•actual removal or destruction of certain vegetative

types a day when in leaf

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Evapotranspiration

Sum total of water returned to the atmosphere from surface and ground (soil) water and vegetation

Evaporation + Transpiration

Difficult to separate the effect of evaporation and transpiration over land areas

Mostly, only total evaporation from an area (combined evaporation plus transpiration: consumptive use) is of practical interest to a hydrologist

Potential evapotranspiration

- The maximum value of evapotranspiration

It is relatively easy to calculate potential evapotranspiration for a saturated surface (open water), using local meteorological parameters such as humidity, temperature and wind speed

Actual evapotranspiration is always less than potential evapotranspiration

Estimation of Evapotranspiration

Lysimeters

Penman's Equation

Empirical formulae

Evapotranspiration from satellite data

When a surface evaporates, it looses energy and cools itself. This cooling can be observed from space.

Satellites can map the infrared heat radiated from Earth, thus enabling to distinguish the cool surfaces from the warm surfaces.

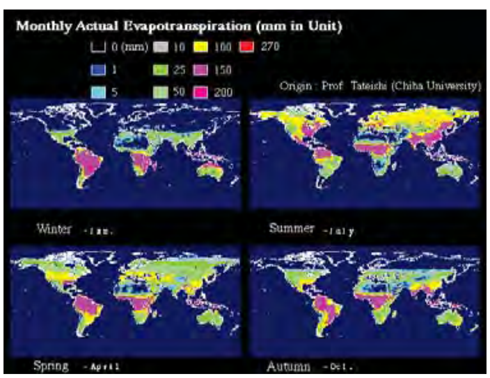
Very dry and desert-like surfaces show easily as they get hotter than their surroundings.

From this qualitative reasoning, the scientific objective is to determine quantitatively the amount of evapotranspiration that occurs at given locations.

Evapotranspiration from satellite data

In practice, it consists in entering various types of satellite observations (not just infrared) into mathematical models of the atmosphere.

The models, of various complexities, are run in algorithmic form on computers.



Initial Loss

Interception process + Depression storage

This represents the quantity of storage that must be satisfied before overland runoff begins

Interception

Segment of gross precipitation input, which wets and adheres to above ground objects until it is returned to the atmosphere through evaporation

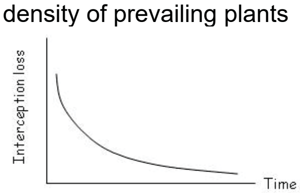
Interception

It is part of a subcycle of the hydrological cycle

Precipitation striking vegetation may be retained on leaves or grass, flow down the stems of plants and become stem flow, or fall off the leaves to become part of the throughfall

Interception is a function of
a) the storm character
b) the species (type), age and density of prevailing plants and trees
c) the season of the year

Typical interception loss curve



Interception

Most interception loss develops during the initial storm period and the rate of interception rapidly approach zero thereafter

Determined by comparing precipitation in gauges beneath the vegetation with that recorded nearby under the open sky. Intercepted precipitation is dissipated as stemflow (measured by catch devices around tree trunk) down the trunk of the trees and evaporation from the leaf surface

Depression Storage

Precipitation that reaches the ground may infiltrate, flow over the surface or become trapped in numerous small depressions from which the only escape is evaporation or infiltration

The nature of depression as well as their size is largely a function of the original land form and local land use practices

All depression must be full before overland flow supply begins

Infiltration

The movement of water through the ground surface into the soil and on downwards

Infiltration rate and quantity are a function of

- soil type
- soil moisture
- soil permeability
- ground cover
- drainage conditions
- depth of water table
- intensity and volume of precipitation

Infiltration

Infiltrated water percolates downwards by gravity until it reaches the zone of saturation

Rate of downward movement is controlled by the transmission characteristics of the underlying soil profile

Due to the infinite combinations of soil and other factors existing in nature no general relationship exists to quantify infiltration

Measuring Infiltration

Infiltrometer studies

a) Rainfall simulators

b) Flooding infiltrometers

Hydrograph analysis

Calculation of Infiltration

Calculations vary in sophistication from the application of average rates to the use of conceptually sound differential equations

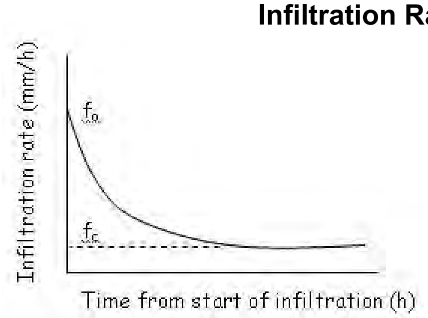
Horton (1930s) studied infiltration process and suggested the following relationship for determining infiltration

$$f = f_c + (f_o - f_c)\, e^{-kt}$$

Where,

f = infiltration rate as a function of time, (depth/time)
fc = final or ultimate (equilibrium) infiltration rate
fo = initial infiltration rate
k = a constant representing the rate of decrease in infiltration capacity

Infiltration Rate



Temporal and Spatial Variability of Infiltration Capacity

Infiltration rate generally varies both in space and time

Spatial variations are due to differences in soil type and vegetation

Accommodate this type of variation by subdividing the total region into compartments having approximately uniform soil and vegetal cover

The infiltration capacity at a given location in a watershed varies with time as shown before

Streamflow

Streamflow = surface runoff + underground flow

Throughflow: flow through the soil in the zone of aeration (above the water table)

Baseflow: groundwater

River discharge (streamflow): Volume of water that flows past a point in a certain time

Streamflow Measurements

The measurement, or gauging, of river discharge is important for assessment of water resources, design of water supply schemes, flood-control projects, hydroelectric projects etc.

Measurement techniques can be broadly classified into two categories as,

a) direct determination
(Area-velocity methods, Dilution techniques)

b) indirect determination
(Hydraulic structures [eg., weirs, flumes])

Streamflow Measurements

Flow measuring methods can also be classified as shown below too

Stage (water surface elevation)	Discharge	Discharge (structural)
Visual observation Float Pressure Sensor Electrical Resistance	Current meter Dilution Float Indirect via Manning's equation	Direct volume collection Weirs Flumes Orifices

Streamflow is the general term used to represent volumes or rates of flow.

Streamflow Measurements

Continuous measurement of stream discharge is very difficult (very time-consuming and costly)

Hence, a two-step procedure is followed

First, the discharge is related to the elevation of the water surface (stage)

Next, the stage of the stream is observed routinely in a relatively inexpensive manner and the discharge is estimated by using the previously determined stage-discharge relationship

Measurement of Stage

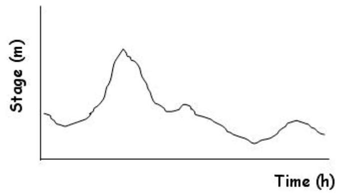
Stage: water surface elevation recorded relative to some horizontal datum elevation, frequently MSL

Record of stage is called "stage hydrograph"

A stage recorder can be as simple as a ruler along a bridge or other structure. It can be read periodically

Stage data

Stage data is presented as a plot of stage against chronological time (stage hydrograph)



Stage hydrograph

Besides its use in the determination of stream discharge, stage data itself is of importance in flood warning and flood protection works

Stream Discharge

Velocity-area method:

Based on continuity equation $Q = A\hat{V}$

Where,

Q = volume rate of discharge (m^3/s)

A = cross sectional area (m^2)

V = mean velocity in the cross section (m/s)

Discharge is determined by measuring cross sectional area and the velocity

Velocity-area Method

Cross-sectional area is determined from measurements of depth of water taken at known intervals across the river

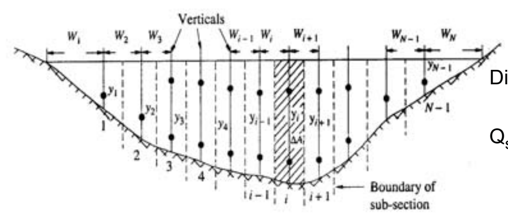
Velocity is measured by floats, by a pitot tube (restricted to pipes or to experimental channels) or by using a current meter

Current meter is mostly used.

Calculation of Mean Velocities

Type	Depth in vertical	Observation point	Mean velocity
Single point	1 - 2 ft	0.6D from surface	$v = v_{0.6}$
Two point	2 - 10 ft	0.2D & 0.8D	$v=1/2[v_{0.2}+v_{0.8)}]$
Three point	10 - 20 ft	0.2D, 0.6D & 0.8D	$v=1/4[v_{0.2}+2v_{0.6}+v_{0.8)}]$
Five point	Over 20 ft	S, 0.2D, 0.6D, 0.8D & B	$v=1/10[v_s+3v_{0.2}+2v_{0.6}+3v_{0.8)}+v_B]$

V_S is measured 1 ft below surface, and V_B is measured 1 ft above stream bottom

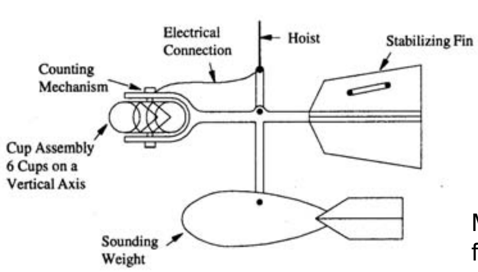


Discharge in subsection

$Q_{sub} = A_{sub} \times V_{sub}$

Cross section of a river - current meter measurements

a) Price current meter

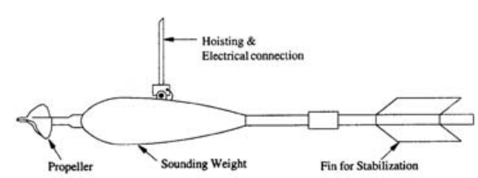


Meter is suspended from a cable

This consists of six conical cups rotating about a vertical axis

Electrical device is used to count the revolutions

b) Propeller Current Meter



Rotating element is a propeller turning about a horizontal axis

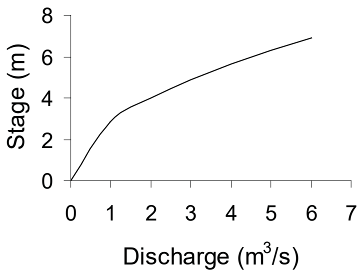
The relation between revolutions per second N of the meter cups and water velocity v in m/s is given by an equation of the form

$v = a + bN$

Where, a is the starting velocity or velocity required to overcome mechanical friction

Stage - Discharge Relations

Stage-discharge relation (or rating curve) is constructed by plotting measured discharge against stage (water surface elevation) at the time of measurement



Stage - Discharge Relations

Assumption: if the stage at that point is the same, the discharge will be the same

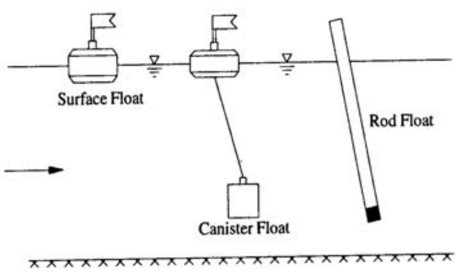
River discharge can be estimated from measurement of stage alone

Constructed by plotting successive measurements of the discharge and gauge heights on a graph

Rating curve must be checked periodically to ensure that the relationship between the discharge and gauge height has remained constant: scouring of the stream bed or deposition of sediment in the stream can cause the rating curve to change so that the same recorded gauge height produces a different discharge.

Floats

A floating object on the surface of a stream is timed: provides surface velocity



$$V_s = \frac{S}{t}$$

Where,

S = distance traveled in time t

Floats

Though primitive still finds applications in special circumstances, such as:

(i) a small stream in flood

(ii) small stream with a rapidly changing water surface

(iii) preliminary or exploratory surveys

Any floating object can be used

Normally specially made leakproof and easily identifiable floats are used

Mean velocity is obtained by multiplying the observed surface velocity by a reduction coefficient

Floats

Surface floats are affected by surface winds

To get the average velocity in the vertical, floats in which part of the body is under water (rod floats) are used

The method is restricted to straight rivers having almost uniform cross section throughout

The method is not good if the depth of water exceeds 1.5 m or more

Weirs and Flumes

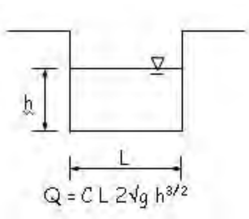
Employed where a high degree of precision or reliability of the discharge measurements are required

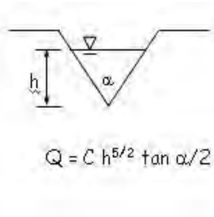
Confined (or limited) to streams and fairly small rivers

For wide rivers this is extremely expensive

Stream discharge is made to behave according to certain well known hydraulics laws

Weirs and Flumes





Dilution Method

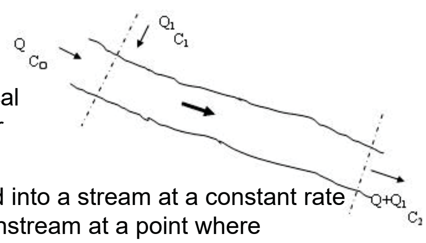
Used where the conventional velocity-area method can not be used

(eg. boulder - strewn stream)

Discharge is determined over a length of the stream rather than at a single point

A known quantity of some exotic substance (a tracer) is introduced. Samples are withdrawn at a downstream point

Dilution Method



The tracer may be a chemical tracer or a radioactive tracer

If a tracer solution is injected into a stream at a constant rate and samples are taken downstream at a point where turbulence has achieved complete mixing, the steady flow rate Q in the stream is given by

$$Q = Q_t \left(\frac{C_1 - C_2}{C_2 - C_0}\right)$$

Where,
Qt = Steady dozing rate
C0 = Concentration of the tracer in the undosed flow
C1 = Concentration of the tracer in the dose
C2 = Concentration of the tracer in the dosed flow

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Lesson 4: Water Governance

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Outline

- Stakeholders
- Decision making process
- Transboundary water resources
- Water conflicts

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Understanding and involving stakeholders

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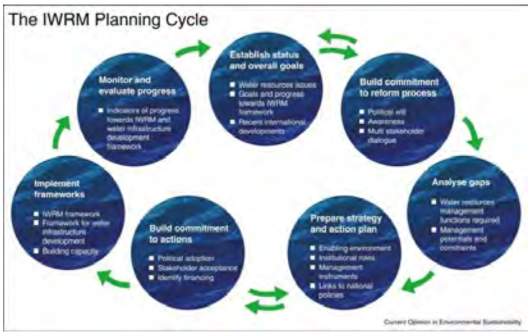
Decision making process



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Transboundary water

- Transboundary waters – the aquifers, and lake and river basins shared by two or more countries
- There are 263 transboundary river basins and approximately 300 transboundary aquifers.
- 145 states have territory within transboundary lake or river basins, and 30 countries lie entirely within them.
- Since 1948, history shows only 37 incidents of acute conflict over water, while during the same period, approximately 295 international water agreements were negotiated and signed.
- Around two-thirds of the world's transboundary rivers do not have a cooperative management framework.

UNESCO/SIWI

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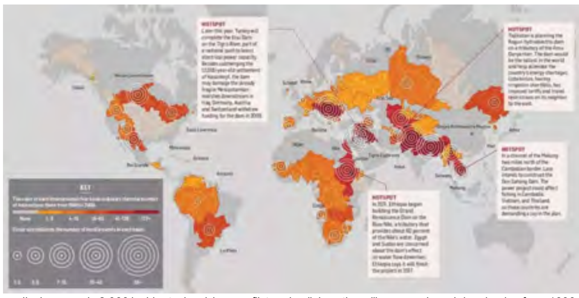
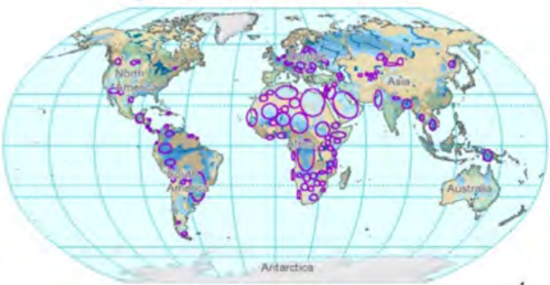
Water conflicts in the world



The map displays nearly 2,000 incidents, involving conflict and collaboration alike, over shared river basins from 1990 to 2008. The circles in the sidebar compare about 2,200 events—including another 200 disputes over resources other than shared rivers—from the same period. *Pitch Interactive; River locations courtesy The Global Runoff Data Centre, 56068 Koblenz, Germany)*

Groundwater flows unseen across political boundaries



http://www.whymap.org

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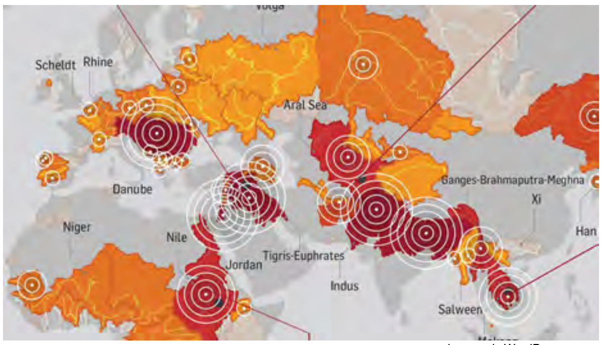
Water conflicts in the world



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Lesson 5. Water and Environmental Law

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Outline

- Right to water (UN Resolution 64/292)
- Need for sharing & sound management
- Legal basis including EU directives
  - Water Framework Directive
  - Urban Waste Water Treatment Directive
  - Drinking Water Directive
  - Groundwater Directive
  - Flood Risk Directive
- Water use and discharge permits: Implementation of European water law in EC member states, Example Germany
- Conflict management and negotiations

Right to Water

Milestone: UN Resolution 64/292

- Ratification on 28 July 2010
- Explicit recognition of the **human right to water** and sanitation
- Acknowledgement that **clean drinking water** and sanitation are essential to the realization of all human rights
- Call to states and international organizations to provide **sufficient, safe, acceptable, accessible and affordable drinking water** and sanitation for all

Action plans: UN Millennium Declaration, adopted in 2000: Definition of 8 **Millennium Development Goals** (MDGs)

UN 2030 Agenda for Sustainable Development, adopted in 2015: Definition of 17 **Sustainable Development Goals** (SDGs) with 169 associated targets

Right to Water

Milestone: UN Resolution 64/292

What is ...?

- **Sufficient**

The water supply for each person must be sufficient and continuous for personal and domestic uses. These uses ordinarily include drinking, personal sanitation, washing of clothes, food preparation, personal and household hygiene. According to WHO, between **50 and 100 liters** of water per person per day are needed to ensure that most basic needs are met and few health concerns arise.

- **Safe**

The water required for each personal or domestic use must be safe, therefore free from micro-organisms, chemical substances and radiological hazards that constitute a threat to a person's health. Measures of drinking-water safety are usually defined by national and/or local standards for drinking-water quality. The **WHO Guidelines for drinking-water quality** provide a basis for the development of national standards that, if properly implemented, will ensure the safety of drinking-water.

Right to Water

Milestone: UN Resolution 64/292

What is ...?

- **Acceptable**

Water should be of an acceptable colour, odour and taste for each personal or domestic use. [...] All water facilities and services must be **culturally** appropriate and sensitive to **gender, lifecycle** and **privacy** requirements.

- **Physically accessible**

Everyone has the right to a water and sanitation service that is physically accessible within, or in the immediate vicinity of the household, educational institution, workplace or health institution. According to WHO, the water source has to be within **1,000 meters** of the home and collection time should not exceed **30 minutes**.

- **Affordable**

Water, and water facilities and services, must be affordable for all. The United Nations Development Programme (UNDP) suggests that water costs should not exceed **3 per cent** of household income.

Right to Water

UN Millennium Declaration

Target no 7.C for water: Increase of water supply coverage to 88% **by 2015**

Situation in 2015: **147** countries met the MDG drinking water target, global average is 91%.

MDG target achievement for drinking water (WHO, 2015)

Right to Water

UN 2030 Agenda for Sustainable Development

Target no 6.1+6.2: By 2030, achieve universal and equitable **access to safe and affordable drinking water** and to sanitation and hygiene **for all**

Target 6.3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, **halving the proportion of untreated wastewater** and **increasing recycling and safe reuse** globally

Target 6.4: By 2030, substantially **increase water-use efficiency** across all sectors and **ensure sustainable withdrawals** and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

Target 6.5: By 2030, implement **integrated water resources management** at all levels, including through transboundary cooperation as appropriate

Right to Water

UN 2030 Agenda for Sustainable Development

Target no 6.6: By 2020, protect and restore **water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers and lakes

Target 6.a: By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including **water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies**

Target 6.b: Support and strengthen the participation of local communities in improving **water and sanitation management**

Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected [...] by disasters, including **water-related disasters** [...].

Need for sharing & sound management

Groundwater: Resources not confined by political borders

Map of global groundwater resources (1. World Water Development Report, UN 2003)

Need for sharing & sound management

Groundwater: Legally covered by UN convention and domestic laws

Rieu-Clarke, et al.: UN Watercourses Convention – User's Guide (2012)

Need for sharing & sound management

Guidelines for the sustainable management of groundwater

- A sound system of water abstraction and use rights
- Active groundwater user participation
- Avoidance of over-consumption
- Adequate investment in water saving technologies
- Incentives to increase water harvesting and aquifer recharge

General problems in practice

- Conflict of interests between different users (Water supply, industries, agriculture)
- Lack of proper pricing systems for groundwater abstraction and use
- National interests predominate, transnational agreements difficult to achieve

Need for sharing & sound management

Large river basins: Crossing political borders

Major river basins of the world (1. World Water Development Report, UN 2003)

Need for sharing & sound management

Large river basins: International conventions (I)

- Helsinki Convention (1996) for the protection and use of trans-boundary water courses and international lakes – updated in 2013
  - → Prevention, control and reduction of water pollution
  - → Provisions for reasonable and equitable water use
  - → Provisions for monitoring, research and development
  - → Consultations, warning and alarm systems
  - → Information exchange and public access to information

Parties to the Convention: 41 countries sharing trans-boundary waters in the region of the United Nations Economic Commission for Europe (UNECE)

Need for sharing & sound management

Large river basins: International conventions (II)

- UN Convention on the law of the non-navigational uses of international watercourses (1997) – entered into force 2014
  - → General principles relating to equitable and reasonable use of resources
  - → Duties not to cause significant harm
  - → Ecosystem protection, management obligations
  - → Information sharing, conflict resolution
  - → Resource protection during armed conflicts

Signer of the convention: At present 38 countries sharing trans-boundary waters (12 from Africa, 8 from Asia, 16 from Europe, 2 from South America)

Legal basis including EU directives

UN guidelines

- Drinking water guideline (WHO, 2011): Maximum permissible values for
  - → 2 bacteriological parameters (Principle of indicator organisms)
  - → 39 inorganic and organic constituents
  - → 33 pesticides
  - → 18 disinfectants and disinfection by-products
- Water quality for agriculture guidelines (FAO, 1985)
- Attempt: Development of International Water Quality Guidelines for Aquatic Ecosystems (Global Water System Project, ongoing)

Legal basis including EU directives

European Water Framework Directive 2000/60/EC

Establishment of a framework for the **protection** of inland surface waters, transitional waters, coastal waters and groundwater by

→ Coordination of administrative arrangements within river basin districts, development of river basin management plans

→ Monitoring of surface water status, groundwater status and protected areas (goal: achievement of „good" ecological and chemical status for as many as possible water bodies)

→ Control of point and diffuse emission sources

→ Development of strategies against pollution of surface and ground waters (ultimate goal: elimination of initially 33 priority hazardous substances)

→ Recovery of costs for water services, including environmental costs

Legal basis including EU directives

European WFD 2000/60/EC, Directive on Environmental Quality Standards 2008/105/EC, amended by Directive 2013/39/EU

→ List of **45 priority substances** in the field of water policy (extension of the original list by 12 species)

→ Definition of **annual average** and **maximum allowable** concentrations in inland surface waters (rivers, lakes) and other surface waters, further-more (only for 15 substances) **maximum contamination of biota** (fish) in µg/kg wet weight

Remark:

Originally 3 pharmaceuticals (17 alpha-ethinylestradiol (EE2), 17 beta-estradiol (E2) and Diclofenac) were also proposed, but have not been included in the list yet.

Legal basis including EU directives

European Urban Waste Water Treatment Directive 91/271/EEC, amended by Directive 98/15/EC

→ imposes an obligation to **collect** and **treat** wastewater from all settlements and agglomerations but the very small ones

→ sets treatment objectives for BOD_5 (25 mg/L), COD (125 mg/L), and TSS (35 mg/L) for secondary treatment (biological carbon removal)

→ sets treatment objectives for total-N (15 mg/L resp. 10 mg/L)[1)] and total-P (2 mg/L resp. 1 mg/L)[1)] in the catchment of so-called sensitive areas (either eutrophic or potentially eutrophic), thus requiring nutrient removal here

→ imposes an obligation to establish national regulations for **industrial** waste-water discharged **directly** into receiving waters, and to define sampling and monitoring routines for all treated wastewaters at the point of discharge

1) Depending one size of treatment plant

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Legal basis including EU directives

European Directive on the Quality of Water Intended for Human Consumption 98/83/EC

- Drinking water quality: **Maximum permissible values** for
  → 2 microbiological parameters (Principle of indicator organisms)
  → 26 chemical parameters
  → 20 indicator parameters
  Point of compliance: place of delivery ("tap")
- Quality assurance of **treatment, equip**ment and **materials**
- Regular **monitoring** of drinking water quality
- Adequate **reporting** and up-to-date **information to consumers**

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Legal basis including EU directives

European Directive on the Protection of Groundwater from Pollution and Deterioration 2006/118/EC

→ Procedure for assessing the **chemical status** of groundwater

→ Establishment of specific measures in order to **prevent** and **control groundwater pollution**

Quality standards:

I. Concentration of nitrates ≤ 50 mg/l
Concentration of active substances in pesticides ≤ 0.1 µg/l

II. Threshold values for arsenic, cadmium, lead and mercury
Threshold values for ammonium, chloride, sulphate, conductivity
Threshold values for trichloroethylene and tetrachloroethylene
to be set by the member states

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Legal basis including EU directives

European Directive on the Assessment and Management of Flood Risks 2007/60/EC

Establishment of a framework for the **assessment** and **management** of flood risks by

→ Execution of a preliminary flood risk assessment for each river basin district, also for international river basins

→ Identification of areas for which potential significant flood risks exist

→ Preparation of **flood hazard maps** and **flood risk maps**

→ Establishment of **flood risk management** plans that include prevention, protection, preparedness, flood forecasts and early warning systems

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Federal Water Act** of 31.07.2009

Definition of the principles of water resources management, in particular:

→ Designation of **river basin districts**
→ Definition of water use, permission and approval
→ Rules for the management and maintenance of **surface waters**
→ Rules for the management of **coastal waters**
→ Rules for the management of **groundwater**
→ **Public water supply**
→ **Wastewater disposal**
→ Handling of substances hazardous to waters; appointment of water deputies

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Federal Water Act** of 31.07.2009

Definition of the principles of water resources management, in particular:

→ Development of surface waters (river engineering)
→ Construction of dikes and coastal protection structures
→ Planning of **flood control measures**
→ Development of management plans including **action plans** for surface waters
→ Liability for (negative) changes of water bodies
→ Compensation for financial losses of land owners
→ Inspection and monitoring of water bodies

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Drinking Water Ordinance** (2016)

Purpose: Protection of human health from the adverse influences of contaminated water intended for human consumption

→ Compliance with **bacteriological** and **chemical** requirements according to Directive 98/83/EC
→ Regulation of **treatment agents** and **disinfection** procedures
→ Duties of the entrepreneur of other owner of a water supply system
→ Requirements on **installations** for the abstraction, treatment or distribution of drinking water
→ **Surveillance** by the health authorities
→ **Information** of the consumer

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Groundwater Ordinance** (2010)

Purpose: Protection of groundwater bodies

→ Classification of groundwater bodies regarding their **quantity** (no depletion)
→ Definition of threshold values for 10 chemical parameters given in Directive 2006/118/EC
→ Classification of groundwater bodies regarding their **quality** according to these parameters and the concentrations of **nitrates** and **pesticides**
→ Design of monitoring programs
→ Preparation of **action plans** for improving groundwater bodies that have a poor status

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Wastewater Ordinance** (2004)

Purpose: Specification of the **minimum requirements** on wastewater for a discharge permit directly into a water body

→ General requirements: **Pollutant load** must be kept as **low** as the use of water-saving procedures permit; it must not be transferred to other environmental media such as air or soil, contrary to the state-of-the-art
→ Definition of analysis and measurement procedures
→ Compliance with **threshold values** given in the Appendix for **53 different sources** of wastewater generation, including domestic wastewater

Remark: For companies discharging into a public sewer, the threshold values from this ordinance apply at the point of discharge **for hazardous substances**

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Water use and discharge permits

Implementation of European water law in EC member states, Example Germany: **German Wastewater Charges Act** (2005)

Purpose: Collection of a charge (wastewater charge) for discharging wastewater into a water body

→ Determination of the **noxiousness** of wastewater based on the parameters COD, total-P, total-inorganic N, AOX, mercury, cadmium, chromium, nickel, lead, copper and the toxicity to fish eggs
→ Calculation of **noxiousness units** from these parameters and the annual amount of wastewater; one noxiousness unit equals **35.79 Euro**
→ Accounting for investments in improved wastewater treatment technologies via a **reduction** of the charge
→ **Increase** of the charge if the minimum requirements according to the wastewater ordinance are not met

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Conflict management and negotiations

Integrated Water Resources Management (IWRM) approach

Now being accepted internationally as the way forward for
- efficient,
- equitable, and
- sustainable

development and management of the world's limited water resources and for coping with conflicting demands

Stages in IWRM planning and implementation, after UNDESA

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Lesson 6: Economics of Water Resources Projects –
A Case Study of Water Treatment Projects in Ukraine

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Economics of Water Resources Projects - A Case Study of Water Treatment Projects in Ukraine

Outline

- Investment costs
- Operation and maintenance (O&M) costs
- Costing of wastewater treatment plants (WWTPs)

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1. Investment costs

Prior to the military conflict (February 2014), the most powerful distribution systems of water supply were operating in:

- Donetsk region – 20.5 thousand. km,
- Autonomous Republic of Crimea – 14.2 thous. km, being now temporarily occupies territories.

And just these systems are the most technically outdated ones:
44,5 % - Donetsk region;
49,4 % - Autonomous Republic of Crimea.

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76% – Water supply system
13% – Water treatment plants
6% – Water intake facilities
4% – Pump stations
1% – Storage plants

Fig. 1 – Distribution of fixed production assets of water supply companies [1]

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With the degradation of technical condition of water supply systems, their efficiency is noticeably reduced, while unreasonable losses of water and leaks are increasing.

The largest leaks and unaccounted water losses in 2008 were found (prior to the military conflict of 2014) in :

- Lugansk (60.7% - temporarily occupied territory);
- Donetsk (49 % - temporarily occupied territory);
- Zakarpattya (44.4 %);
- Sevastopol (43.9 % - temporarily occupied territory)
- Dnipropetrovsk (42.9 %) regions.

It was caused, as in the previous years, by critical condition of water distribution systems, the relevant equipment, fittings etc. [2].

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Losses at water supply companies

In addition to un accounted and leak water losses, there are other, equally important, categories of losses at water supply companies. They include:

- environmental losses including damage caused to the health of citizens by poor quality water;
- losses associated with accidents on the roads as a result of leakages and breakdowns of water supply systems;
- energy expenditures which are equal to 40-60% of water supply companies' products costs, according to analytical findings;
- losses occurring as a result of thefts, i.e. unauthorized connection to water supply networks;
- damage from flooding, as a result of water leaks from pipelines of water supply system;
- losses of the state funds, arising from provision of subsidies to cover mismanagement and non-payments;
- losses of industrial and commercial enterprises, high rates for which compensate reduced rates for citizens;
- reduction of stability and reliability of water supply system as a whole.

Losses at water supply companies

So, we can validly assume, that losses may include, except generally recognized direct losses, the following:

- loss,
- over-expenditures,
- loss of benefit,
- delay of payment funds in time,
- unused potential, i.e. loss of resources, facilities, rates of development, level of financial stability.

Let's consider the example of implementation of investment project "Development and improvement of operation of centralized water supply, water disposal, and effluent treatment systems" of the Utility Company (UC) "Dniprovodokanal" in Dnipropetrovsk region of Ukraine. Participants of the project were UC "Dniprovodokanal" (Ukraine) and VEMA S.A. (Switzerland).

30.11.2004 – Starting date of realization of all project activities.
31.12.2012 – Deadline of realization of all project activities.

Table 5 – Indicative volumes of financial support of the program "Drinking water of Dnipropetrovsk for 2006 – 2020 years", thous. UAH. [4]

Activities	Period of implementation, years	Indicative volume of funding							
		Total volume	By years						
			2006	2007	2008	2009	2010	First stage, total	Next stage, total
1. Protection and rational use of sources of drinking water supply and protection of water bodies from pollution by wastewaters, including:	2006 - 2010	121000	1315	1655	865	780	780	5395	115605
water supply		23040	370	630	830	630	580	3040	20000
water disposal		97960	945	1025	35	150	200	2355	95605
2. Regulatory support	2006 - 2010	1140	180	50	20	160	50	460	680
3. Development and reconstruction of water supply and water disposal system, including:	2006 - 2010	325770	25894	26244	27044	26194	23334	128710	197060
Construction and reconstruction of water supply facilities and networks		226700	15804	15804	15504	15404	15544	78060	148640
Construction and reconstruction of water disposal facilities and networks		99070	10090	10440	11540	10790	7790	50650	48420
4. Education, training, provision of public awareness	2006 - 2010	1500	100	100	100	100	100	500	1000
Total		455880	28379	28939	28459	27774	24894	138445	317455

Table 1 – Basic pre-project power consumption of UC "Dniprovodokanal" (water supply and sewage pump stations, water treatment plants) [3]

Year	Basic power consumption, thous. kW·h
1998	193 527,9
1999	196 429,6
2000	186 329,0
2001	183 505,1
2002	186 292,8
2003	185 737,3
2004	182 888,4

Table 2 – Objects participated in the project within the boundaries of Dnipropetrovsk city [3]

Quantity of water intake structures, pc.	2
Quantity of water supply pump stations, pc.	9
Quantity of local booster pump stations, pc.	43
Length of mains systems, km	452,5
Length of municipal water distribution networks, km	1529,1
Quantity of wastewater treatment plants, pc.	4
Length of sewage collectors, km	182
Quantity of sewage pump stations, pc.	50
Length of sewage networks without collectors, km	1023,3

NPV and BCR

Principal formula of NPV calculation is written as [5]:

- with annual costs under the project:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

- with one-time capital investments:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - C_t$$

where B_t – profit (non-inflicted loss) in year t,
r – discount factor,
C_t – investment costs in year t (estimated project cost),
T – duration of reference period.

Return on investments:

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{C_t}$$

$$BCR = \frac{\sum_{t=0}^{n} \frac{(B_t + B_{et})}{(1+r)^t}}{\sum_{t=0}^{n} \frac{(C_t + C_{et})}{(1+r)^t}}$$

where B_{et} – ecological component of profit (non-inflicted loss) in year t (may be neglected in calculations),
C_{et} – ecological component of investment costs in year t (may be neglected in calculations).

Table 3 - Schedule of the project [3]

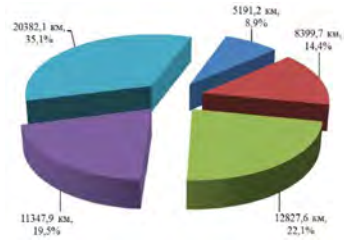
No	Project stages	Period
1	Development of Project design documentation	2004 -2012
2	Modernization of pumping equipment	2004 -2012
3	Replacement of pumping equipment	2004 -2012
4	Optimization of technological process of water pumping, that is, changing of regimes of pump stations' operation	2004 -2012
5	Replacement of valves	2004 -2012
6	Replacement of water supply and sewage networks	2004 -2012
7	Installation of a new group of metering devices	2004 -2012
8	Installation of frequency regulators	2004 -2012
9	Modernization of aeration systems at treatment facilities (aerotanks)	2004 -2012

Table 4 – Additional financial costs for modernization, mln. UAH [3]

Period	Cost of modernization, mln. UAH						
	Modernization of pumping equipment (trimming of impeller)	Replacement of pumping equipment	Replacement of valves	Replacement of water supply and sewage networks	Installation of a new group of metering devices	Installation of frequency regulators	Modernization of aeration systems at treatment facilities (aerotanks)
30/11/2004 - 31/12/2012	1,04	41,7	3,2	55,42	0,26	18,19	9,83

2. Operation and maintenance costs

In Ukraine, only 9% of water supply networks are not in critical condition: their life cycle does not exceed 25 years, as informed by the National Commission for State Regulation of Energy and Public Utilities.



8,9% – less than 25 years
14,4% – 26-50 years
22,1% – 50-75 years
19,5% – 76-90 years
35,1% – over 90 years

Fig. 2. Structure of water supply networks (47 companies) by wear-out rates and years of service [6]

Structure of water supply networks

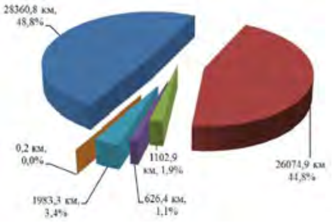


Fig. 3 Structure of water supply networks (47 companies) by material of pipes [6]

48,8% - Steel
44,8% - Cast iron
1,9% - Reinforced concrete
1,1% - Asbestos cement
3,4% - Plastic
0,0% (0,2 km) - Others

Production assets

Flow of production assets at the companies, which characterizes the degree of equipment upgrade, is investigated using indicators below:

1. Coefficient of renewal of fixed assets:

$$C_r = FAps / FAep \cdot 100$$

where
FAps – sum of new fixed assets at cost, put into service in the reporting period;
FAep – sum of fixed assets at cost as at the end of the reporting period.

2. Coefficient of fixed asset retirement:

$$C_{ret} = FAret / FAbp \cdot 100$$

where
FAret – sum of fixed assets retired in the reporting period because of aging and wear and tear;
FAbp – sum of fixed assets as at the beginning of the reporting period.

3. Costing of wastewater treatment plants

During the recent years the rates for centralized water supply and water disposal were approved for citizens at a loss. Therefore, they fail to cover the losses of water services' company for provision of their services.

Rates for services on water supply/water disposal should be economically justified. In connection with it, the Cabinet of Ministers in 2015 approved the Resolution which terminates the practice of use of the uniform rate for centralized water supply/ water disposal.

Table 6 – Rates for centralized water supply/water disposal services (using systems arranged in houses) with structures [6]

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Donetsk region		
1	Production Utility Company "Kramatorsk Water Services Company"	9,00	4,75	No. 3218 as of 29.12.2015 (registered with the Ministry of Justice on 25.01.2016 with No. 128/28258) amendments to No. 2868 as of 26.11.2015	Operating since 16.02.2016
2	UC "VBAKHMUT-VODA"	13,42	8,45	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 26.08.2016

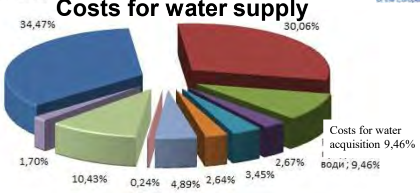
Table 6 – Rates for centralized water supply/water disposal services (using systems arranged in houses) with structures [6]

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Dnipropetrovsk region		
1	UC "Dniprovodokanal" of Dnipropetrovsk Municipal Council	7,25	5,20	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
2	Production Utility Company "Miskvodokanal" of Dniprodzerzhinsk Municipal Council	6,13	6,29	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
3	UC "Zhovti Vody Water Services' Company" of Dnipropetrovsk Regional Council	10,59	10,64	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 26.08.2016
4	UC "Nikopol PD WSU"	6,29	10,40	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 26.08.2016
5	UC of Dnipropetrovsk Municipal Council "Aulskyi Watercourse"	3,65	4,02	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
6	UC "Novomoskovsk Water Services' Company"	10,54	8,03	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
7	UC "Kryvbasvodokanal"	5,50	6,05	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
8	UC "Pavlograd Production Directorate of Water and Sewage Utilities (PD WSU)" at Pavlograd Municipal Council	14,26	8,14	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
9	Municipal Utility Company "Ordzhonikidze Production Directorate of Water and Sewage Utilities"	8,54	8,88	No. 2868 as of 26.11.2015 (registered with the Ministry of Justice on 11.01.2016 with No. 24/28154)	Operating since 29.01.2016

Table 6 – Rates for centralized water supply/water disposal services (using systems arranged in houses) with structures [6]

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Kyiv region		
1	UC "Irpinvodokanal"	5,80	9,29	No. 1142 as of 16.06.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
2	UC WSU "Boryspilvodokanal"	10,08	7,45	No. 811 as of 19.05.2016 (registered with the Ministry of Justice on 16.06.2016 with No. 866/28996) amendments to No. 2868 as of 26.11.2015	Operating since 05.07.2016
3	UC "Brovary-teplovodoenergiya"	7,00	6,97	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
4	UC "Fastivvodokanal"	12,70	18,82	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
5	"BILOTSERKIVVODA" LLC	8,65	11,93	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016
6	UC "Vyshnivskvodokanal» of Vyshneve Municipal Council, Kyiv-Sviatoshyn district, Kyiv region	7,29	5,07	No. 1142 as of 16.06.2016 (amendments to No. 2868 as of 26.11.2015)	Operating since 02.08.2016

Costs for water supply



34,47% - Labor costs with deductions
30,06% - Electric power costs
9,46% - Costs for water acquisition/ wastewater treatment by other companies
2,67% - Fuel and lubricants' costs
3,45% - Repair (materials) costs
2,64% - Reagent costs
4,89% - Depreciation
0,24% - Financial costs
10,43% - Other costs (taxes, dues, banking charges, occupational safety, communication services, booster pump services, other services of third parties)
1,7% - Profit

Fig. 4. Weighted average structure of rates for centralized water supply in Ukraine since 01.05.2015, according to estimates of the National Commission for State Regulation of Energy and Public Utilities (NCSREPU) [6]

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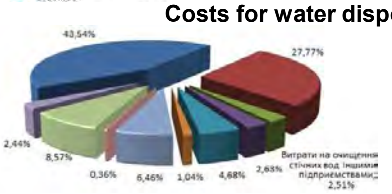
Costs for water disposal



Costs for wastewater treatment by other companies 2,51%

43,54% - Labor costs with deductions

27,77% - Electric power costs

2,51% - Costs for water acquisition/ wastewater treatment by other companies

2,63% - Fuel and lubricants' costs

4,68% - Repair (materials) costs

1,04% - Reagent costs

6,46% - Depreciation

0,36% - Financial costs

8,57% - Other costs (taxes, dues, banking charges, occupational safety, communication services, booster pump services, other services of third parties)

2,44% - Profit

Fig. 5 Weighted average structure of rates for centralized water disposal in Ukraine since 01.05.2015 according to estimates of the National Commission for State Regulation of Energy and Public Utilities (NCSREPU) [6]

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Thank you for attention!

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Lesson 7: Managing Water Resources

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Meeting needs in urban areas and rural areas

- Analysis on water resource supply and demand balance
  - Concept:
  - Objective of supply and demand analysis
    - Current status of total water resource and existing problems
    - Predict the situation in the future
    - Guarantee the water supply
  - Principle
    - Combination of long-term and immediate
    - Combination of watershed and region
    - Combination of comprehensive utilization and protection

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Meeting needs in urban areas and rural areas

- Analysis method on water resource supply and demand balance
  - Series method
    - Analyze the historical data of the water supply and demand year by year
  - Typical year (representative year) method
    - Only analyze the typical year's data of the water supply and demand

Water Harmony Erasmus+

Meeting needs in urban areas and rural areas

- Typical year (representative year) method
  - Regional division for calculation

    Principle:
    - division according to watershed and river system
    - consider the integrity of the administrative division

    try not to upset the water supply system, water usage system and water drainage system
  - Time interval division for calculation
    - Time interval should be appropriate
    - Year, season, month, day can be used as time interval
    - Time interval should objectively reflect the water supply and demands of the calculation area

Water Harmony Erasmus+

Meeting needs in urban areas and rural areas

- Typical year (representative year) method
  - Determination of typical year

    Selection of water supply amount of typical year

    Method: statistic analysis
    - Procedure: 1. selection of calculation site
      2. calculation of frequency
      3. selection of typical year
      4. calculation of total water supply of this typical year
    - Distribution of typical year water supply
    - calculation of several year with the same frequency
    - choose the relatively disadvangeous year
    - water supply distribution
  - Determination of target year
    - Current target year (reference year)
    - Short-term target year (5 years or 10 years after the reference year)
    - Long-term target year (15 years or 20 years after the reference year)
    - Prospective assumption target year (30 years or 50 years after the reference year)

Water Harmony Erasmus+

Meeting needs in urban areas and rural areas

- Water availability and water demands calculation
  - Water availability for water supply

    Influencing factors
    - Hydrological condition
    - Water usage condition
    - Project condition
    - Water quality
  - Water supply guarantee rate

$$p = \frac{m}{n+1} \times 100\%$$

p –water supply guarantee rate, m—number of year ensuring water supply
n—total number of years

Water availability and water demands calculation

- Water demands
- Industrial water demands calculation

$$Q_1 = Q_C + Q_D + Q_R$$

Q_1– total water demands
Q_c—water consumption
Q_D—water drainage
Q_R—reused water amount

Water availability and water demands calculation

- Water demands
- Industrial water demands prediction

Trend analysis method

$$S_i = S_0(1+d)^n$$

S_i – predicted value of water demands in a specific year
S_0 —water demands of the beginning year
d —average annual increasing rate of the water demands
n— number of years from the beginning year to the predicted year

Water availability and water demands calculation

- Water demands
- domestic water demands prediction

$$\text{Q} = 365\text{qm}/1000$$

- Q – predicted value of domestic water demands
- q —domestic water demands per capita, L/c·d
- m— number of habitants in the predicted period

Water availability and water demands calculation

- Water demands

Agricultural sector water demands

1. Irrigation water demands

$$\text{M} = mw$$

- M –water consumption in a single irrigation for a specific crop
- m —irrigation quota, m³/acre
- w— irrigation area, acre

Water availability and water demands calculation

2. rural residents water demands

$$\text{W}_{residents} = 0.365\sum n_i m_i$$

W –rural residents water demands
m_i —domestic water quota, L/c·d
n_i— number of rural residents

3. livestock water demands

$$\text{W}_{livestocks} = 0.365\sum n_i m_i$$

W –livestocks water demands
m_i —livestocks water quota
n_i— number of livestocks

Water availability and water demands calculation

4. Fishery water demands

$$\text{W}_{fishery} = w[\alpha E - P + S]$$

- W –the pond area, m^2
- E —evaporation from water surface, mm
- n_i— evaporation coefficient
- P—annual precipitation, mm
- S—annual leakage, mm

Water Resources Planning

- Concept:
  harmonizing the multiple function of the water resource in the watershed comprehensive planning in order to meet all kinds of the water demands, allocate the water quantity, analyse the water supply and demands balance, protect the water quality and carry out the pollution prevention and protection planning.

- Water resources planning includes:
  the manipulation, utilization and conservation of the water resource control,

Objective and task of the water resource planning

- Objective:
  - regarding the natural condition, social and economical development level, work out the development, utilization and management measure of the water resource in the future target year, to realize the water resource sustainable utilization and management.
- General task:
  - water resource's investigation and evaluation, investigation and evaluation on the water resource's development and utilization situation, prediction of the water demands, water saving, water resource protection, prediction of water supply, allocation, entire distribution and execute solution of the water source, evaluation of the plan's implementation effect.

Theoretical basis of the water resource planning

1. Science of water resources
   - including hydrology, hydraulics, groundwater and soil water dynamics

2. Basic engineering technology
   - including:
     - engineering mechanics, hydraulic structure, irrigation and water conservancy, hydropower station
     - modern information technology, such as computer science, communication, automatic control
     - geology, geography, agriculture science, forestry, meteorology, surveying and mapping, ecology and project management

Theoretical basis of the water resource planning

3. Basis of environmental engineering and science
   - Environmental pollution problem, ecological problem
4. Foundation in economics
5. Foundation in systems engineering
   - optimization techniques, simulation techniques, network techniques, queuing theory, inventory theory, control theory

Main contents of water resource planning

1. Problem identification
   - Situational analysis and evaluation of the water resource, status survey and evaluation of the water resource development and utilization
2. Drawing up the scheme
   - Draw up the package of scheme.
   - Including: determining the standard of water usage quota
   - Analysis of water saving potential
   - Analysis of social and economic development objective
   - Drawing up the water resource management and protection measure

Main contents of water resource planning

3. Scheme calculation
   - after the package of scheme was prepared, analysis and calculation should be done with analytical model to realize the quantitative evaluation of the schemes and preliminary select the suitable scheme
4. Impact assessment
   - Measure the impact of the planned scheme on economy, society and environment
5. Scheme comparison and selection
6. Scheme implementation

Protection of water resource

Objective of water resource protection

- Guarantee the sustainable usage of the water resource

Content and task of the water resource protection

- Reform the water resource management system and reinforce the ability, realize the reasonable water resource distribution
- Increase the level of water pollution control and wastewater recycling, protect the eco-system related to the water resource
- Reinforce the strategic study about effect of the climate change on the water resource
- Study and develop the modern theory and technical system on water pollution control and remediation
- Reinforce the water environmental monitor.

Protection of water resource

Water pollution

- Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater)

Characteristic of water pollution

- Surface water pollution
  - Visible
  - Short cycle time
  - Easy to treat and restore the water quality
- Ground water pollution
  - invisible
  - Hard to reverse
  - Delayed

Protection of water resource

Water pollution sources

- Man-made pollution
  - Point pollution
    - Domestic wastewater
    - Industrial wastewater
    - Solid waste
    - mining
  - Non-point pollution
    - runoff
    - Agriculture
  - Internal source pollution
- Natural pollution
  - Seawater
  - poor quality ground water with high level salt

Protection of water resource

- Water pollutants
  - Toxic matter
  - Non-toxic matter
    - Bio-degradable organic matter
    - Nutrient
    - Oxygen consumption substances
    - organism
    - Suspended solid
    - Radioactive substance

Protection of water resource

Ways of water pollution

- Surface water
  - Continuous injection
  - Intermittent injection
- Groundwater
  - Intermittent infiltration
  - Continuous infiltration
  - Leakage (transfluence)
  - Injection of runoff

Protection of water resource

- Water resource protective measures
  - Reinforce water resource protection legislation, realize the unified management
  - Water resource optimized allocation
  - Water saving, increase the water reuse rate
  - Synthesis develop groundwater and surface water resource
  - Reinforce the artificial recharge of groundwater
  - Build efficient water resource conservation zone
  - Reinforce the water pollution control and treatment
  - Realize the watershed water resource unified management

Water in agriculture

Current situation of water in agriculture

- Water Quantity

Agriculture accounts for 65%~70% of overall water use

A ton of water is taken to produce 1.9 kg of biomass

Table: Crop water requirement

crop	L/kg
potatoes	500
wheat	900
Corn	1400
Rice	1912
Soybean	2000
Chicken	3500
beef	100000

Water in agriculture

- Water pollution
  - agricultural activity was identified as a source of pollution for 48% of stream and river water, and for 41% of lake water
  - Sources of Pollutants
    - Fertilizer
    - Animal waste
- Agricultural water usage
  - In 2000, 41% of all freshwater used by humans in the United States was used for agriculture
  - In 2014, 63.5% of all freshwater used by humans in China was used for agriculture

Types and Effects of Pollutants

- Nutrients, such as nitrogen and phosphorous
  - From the fertilizer
  - Algal bloom, kill fish
- Ammonia and Nitrates
  - Livestock manure is high in ammonia concentrations
  - Highly toxic to fish, convert to dangerous nitrate
- Pathogens and other microorganisms
  - Manure contains a high level of pathogens
  - The impact is severe
- Antibiotics and Hormones
  - commonly used on industrial farms, either injected directly into the livestock or added to their feed
  - compromise the reproductive processes of fish

Types and Effects of Pollutants

- Heavy Metals and Salts
  - animal feed, so, farm animals excrete excess heavy metals in their manure
  - increase the salinity of waterways, leading to changes in aquatic ecosystems and making water brackish, and therefore unfit for drinking
- Organic Matter and Other Solids
  - Present in manure, animal bedding, wasted feed, soil, dust, hair and feathers
  - decomposition of organic matter can cause increased levels of bacteria, which in turn reduces oxygen levels in water and kills fish, negatively affect the color, taste and smell of water

Agricultural water saving technology

Field surface irrigation: replace the earth canal with water-tight channel, this measure can save water by 20%.

- Irrigation with pipe: distribute the irrigating water to the cropland with low pressured pipe.
- Micro-irrigation: including micro-sprinkling irrigation, drip irrigation, infiltrating irrigation. This method pressure the water and distribute the water to the area near the crop root. This measure can save water by 80~85%.
- Spray irrigation: spray the pressured water onto the land by the spraying nozzle.
- Critical period irrigation: irrigate the crops only in the period significantly influencing the productivity.

Water in agriculture

It will be important for policy makers to

1. Recognize the complexity and diversity of water resource management in agriculture, in the context of varying regional and national water resource supply and demand balances.
2. Strengthen institutions and property rights for water management in agriculture.
3. Ensure charges for water supplied to agriculture at least reflect full supply costs.
4. Improve policy integration and coherence between agriculture, water, energy and environmental policies.
5. Enhance agriculture's resilience to climate change and climate variability impacts.
6. Address knowledge and information deficiencies to better guide water resource management.

Water harvesting

Methods of water harvesting:

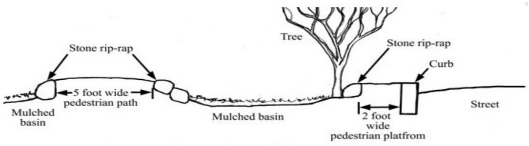
- rainwater harvesting:
- Runoff harvesting:
- Forestry harvesting:
- Dew harvesting:

Water harvesting

- Rainwater harvesting
- Definition: accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off.
- Advantages:
  - supplement the main supply
  - help mitigate flooding of low-lying areas
  - free of salinity and other salts
  - reduces demand on wells
  - reducing the need for clean water in water distribution system
  - reduction in stormwater runoff polluting freshwater bodies

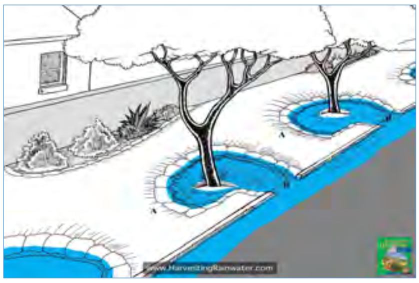
Water harvesting

- Runoff harvesting
  - Rather than having water run erosively off the land's surface, encourage it to stick around, "walk" around, and infiltrate into the soil. Slow it, spread it, sink it.



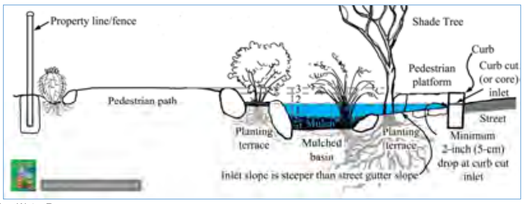
Runoff harvesting

- Eddy basins



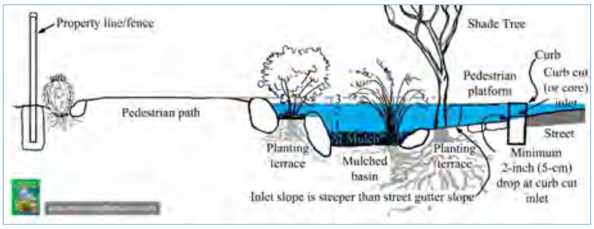
Runoff harvesting

- Backwater basins
  - Maintain a minimum 2-inch (5-cm) drop at inlet
  - Inlet slope is steeper than street-curb-gutter slope
  - Bottom of basin, and the top of the mulch, is lower than the elevation of the curb-cut inlet



Runoff harvesting

- Backwater basins
  - Pathway elevation is level with, or no more than two inches (5 cm) higher than, top of street curb.



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Forestry water harvesting

- Definition: forestry harvests water by catching precipitation on leaves or on the mulched ground.
- Advantage:
  - Turn into valuable goods and services
  - Reduce rainfall impacts on soil surface
  - Water purification
  - Build-up of fertile soil systems
  - reducing flooding and sediment transport

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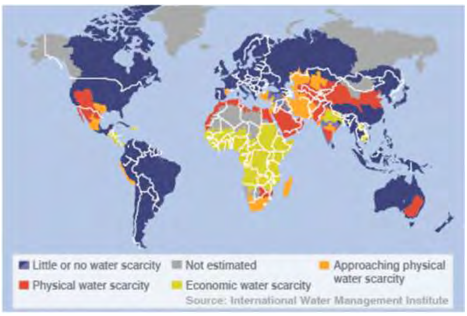
Water reuse and recycling



Water scarcity affects every continent and around 2.8 billion people around the world at least one month out of every year. More than 1.2 billion people lack access to clean drinking water

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Water reuse and recycling

- Approach to resolve water scarcity
- Increase the water repeating use rate, water saving, reinforce water usage management
- Long distance water transfer, change the situation of uneven water distribution
- Wastewater reuse and recycling
- Importance of reclaimed water
  - Reclaimed water is generally more reliable than other water resources because it is produced in predictable quantities even during periods of drought or other water supply reduction

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Water reuse and recycling

- Water source of reclaimed water
  - Taking domestic wastewater as the principal reclaimed water source, reducing the proportion of industrial wastewater
- Advantage of using domestic WW as reclaimed water source
  - Reliable
  - Economic
  - Reducing the impact on the environment
  - Reducing the pressure on the urban water supply

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Water reuse and recycling

- reclaimed water use pattern
  - Direct use
    - Wastewater from public building and residential building are treated on site and then reused.
    - Reclaimed wastewater treatment plant supplies the water to the big factory by some specific pipes.
    - Constructing the reclaimed water supply pipe system in the city to supply the water to industry and for urban use.
  - Indirect use
    - Discharge the reclaimed water into natural water body
    - Discharge the reclaimed water into underground aquifer

Water reuse and recycling

- Application of reclaimed water
  - Industrial use
    - Cooling water
    - Process water
    - Washing water
    - Boiler water
    - miscellaneous water
  - agricultural use
  - Domestic miscellaneous water
  - Water for environment
  - Supplement water source

Water reuse and recycling

- Calculation of wastewater quantity
  - objective
    - Determine the planning wastewater treatment quantity and the reclaimed water quantity
  - Calculating methods

    1. Wastewater discharge coefficient method

$$Q_C = Q_G \alpha$$

- Q_c—daily average wastewater quantity, m^3/d
- Q_G—daily average water consumption, m^3/d
- α--wastewater discharge coefficient,
- 0.70~0.80 (domestic wastewater), 0.80~0.90 (synthetic wastewater), 0.70~0.90 (industrial wastewater)

Water reuse and recycling

2. Water consumption quota method

$$Q_L = 0.365 A \cdot F \cdot \alpha$$

- Q_L—prediction of annual domestic wastewater, m^3/a
- A—predicted annual resident number
- F—predicted annual synthetic water consumption quota, L/d·c
- α--synthetic wastewater discharge coefficient

Water reuse and recycling

3. Pollution producing coefficient method

$$Q_I = D \cdot G$$

- Q_I—predicted industrial wastewater discharge, m^3/a
- D—predicted industrial output value/ product quantity
- G—predicted wastewater generation per unit industrial output value/ wastewater generation per unit product
- 4. trend analysis method
- On the base of the practical statistic data, the wastewater generation amount of a specific year in the future will be predicted using statistic method or mathematic model.

Water reuse and recycling

- Reclaimed water in a residential area
- Reclaimed water source
  - Cooling water
  - Bath drainage
  - Washing drainage
  - Laundry drainage
  - Kitchen drainage
  - Toilet flushing drainage

Water reuse and recycling

- Reclaimed water in a residential area
- Procedure of the water quantity balance calculation
  - 1. determining the water consumption of the toilet, kitchen, bath, washing, laundry and irrigation in different building
  - 2. preliminary determining the reclaimed water supply object, calculate reclaimed water consumption

$$Q' = \sum q_i'$$

  - Q'—total consumption of the reclaimed water, m^3/d
  - q_i'– all kinds of reclaimed water consumption in different building, m^3/d

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Water reuse and recycling

- Reclaimed water in a residential area
- Procedure of the water quantity balance calculation
  - 3. calculation of wastewater quantity need to be treated to produce reclaimed water

$$Q_1 = (1+n)Q'$$

  - Q_1—treated wastewater quantity, m^3/d
  - n – water consumption coefficient of the treatment facility

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Water reuse and recycling

- Reclaimed water in a residential area
- Procedure of the water quantity balance calculation
  - 4. preliminary determine the raw water collection object, and calculate raw water quantity which should be collected

$$Q = \sum q_i$$

  - Q—total quantity of the available raw water, m^3/d
  - q_i– quantity of all kinds of available raw water, 80%~90% of the water supply, the rest part of the water supply is not available, m^3/d

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Water reuse and recycling

- Reclaimed water in a residential area
- Procedure of the water quantity balance calculation
  - 5. calculation of overflow rate and the water recharge

$$Q_2 = |Q - Q_1|$$

  - Q_2—when $Q>Q_1$, Q_2 is the overflow which is not treated by the treatment facility, m^3/d
    when $Q<Q_1$, Q_2 is the recharged water.

Recharged water source: (1) kitchen drainage
(2) tap water
(3) other water source, such as rainfall

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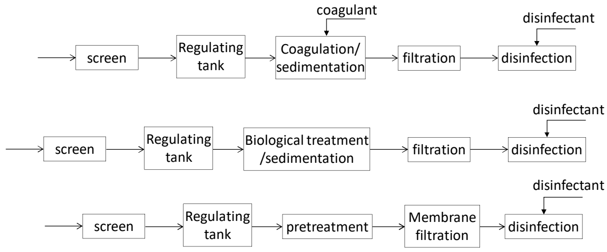
Water reuse and recycling

- Reclaimed water treatment technology
- When grey water was used to generate the reclaimed water



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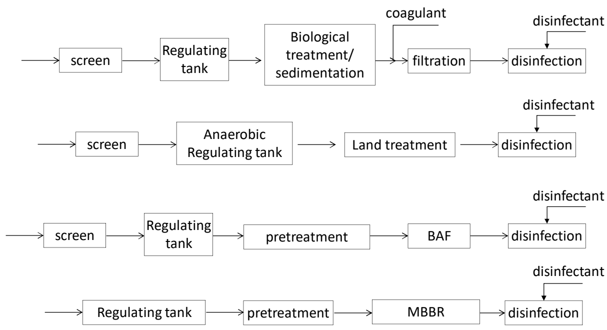
Water reuse and recycling

- When synthetic wastewater was used to generate the reclaimed water



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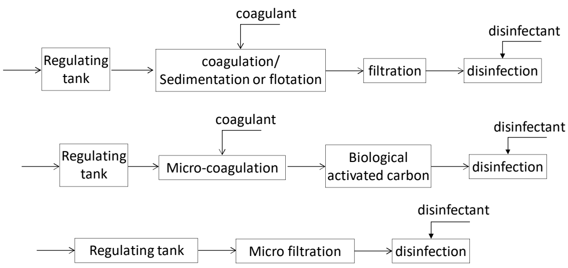
Water reuse and recycling

- When the treated water from WWTP was used to generate reclaimed water



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Thank you

Lesson 8: Water Quality Monitoring

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Water – the facts

- The Earth's crust is composed largely of water
- Freshwater comprises only 3% of the total water available for us
- Of that, only 0.06% is easily accessible
- More than 80 countries now have water deficits

Satinder Ahuja, Monitoring water quality, pollution assessment, and remediation to assure sustainability

Potable water

It is any water suitable for human consumption

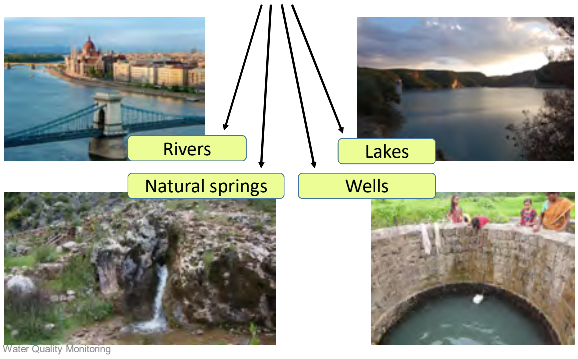
Water-quality characteristics:

- physicochemical,
- organoleptic,
- microbiological,
- radioactive componds.

Water-quality regulations vary in the different parts of the world

Minimum frequency of analysis of water samples is dependent on the volume delivered or produced water in the supply zone

Sources of potable water



Organoleptic and physicochemical requirements*

Parameter	Maximum value ranges
Aluminum	200 µg/L
Ammonium	0.50 mg/L
Chlorides	250 mg/L
Conductance	2.500 µS/cm
Iron	200 µg/L
Manganese	50 µg/L
Oxidibizality with $KMnO_4$	5 mg/L
pH	6.5-9.5
Sulfates	250 mg/L
Sodium	200 mg/L
Turbidity	1NTU

* Polish legislation

Additional chemical requirements*

Parameter	Permissible ranges**
Bromodichloromethane	0.015 mg/L
Chlorine (free)	0.3 mg/L
Chloramines	0.5 mg/L
Chlorates and chlorites (total)	0.7 mg/L
Ozone	0.05 mg/L
Formaldehyde	0.050 mg/L
Dibutyl phthalate	5 mg/L
Magnesium	30-125 mg/l
Silver	0.010 mg/L
Tetrachloromethane	0.002 mg/L
Trichlorobenzenes (total)	0.020 mg/L
2,4,6-trichlorophenol	0.200 mg/L
Trichloromethane	0.030 mg/L
Hardiness	60-500 mg/L

* Polish legislation
** In the case of single value the minimum value of the range is equal to zero

Maximum permissible concentration of chemical contaminations*

Contamination	Maximum permissible concentration
Acrylamide	0.1 μg/L
Antimony	5 μg/L
Arsenic	10 μg/L
Benzene	1.0 μg/L
Benzopyrene	0.01 μg/L
Boron	1.0 mg/L
Bromate	10 μg/L
Cadmium	5 μg/L
Copper	2.0 mg/L
Chromium	50 μg/L
Cyanides	50 μg/L
1,2-dichloroethane	3 μg/L
Epichlorohydrin	0.10 μg/L
Fluorides	1.5 mg/L

Contamination	Maximum permissible concentration
Lead	10 μg/L
Mercury	1 μg/L
Nickel	20 μg/L
Nitrates	50 mg/L
Nitrites	0.50 mg/L
Pesticides	0.10 μg/L
Pesticides (total)	0.50 μg/L
Polyaromatic hydrocarbons (total)	0.10 μg/L
Selenium	10 μg/L
THM (total)	100 μg/L
Trichloroethene and tetrachloroethene (total)	10 μg/L
Vinyl chloride	0.50 μg/L

THM – trichloromethane, bromodichloromethane, dibromochloromethane, thibtomomethane

* Polish legislation

Nonpoint sources of pollutions

Overwhelming majority of water-quality problems are now caused by diffuse nonpoint sources of pollution:

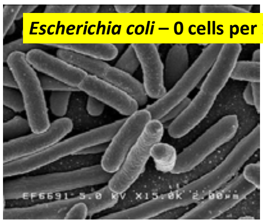
- agricultural land
- urban development
- forest harvesting
- the atmosphere

Nonpoint source contaminations are more difficult to effectively monitor, evaluate, than those from point sources, such as discharges of sewage and industrial waste

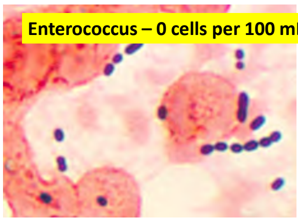
Microbiological requirements*

Maximum permissible numer of microorganisms

Escherichia coli – 0 cells per 100 mL



Enterococcus – 0 cells per 100 mL



* Polish legislation

Contamination arised from the materials we use frequently to improve the quality of life

- Combustion of coal and oil
- Detergents
- Disinfectants
- Drugs (pharmaceuticals)
- Fertilizers
- Gasoline (combustion products) and additives
- Herbicides
- Insecticides

Radioactive contaminations*

Parameter	Maximum permissible value
Radon	100 Bq/L
Tritium	100 Bq/L
Approximate radiation dose	0.1 mSv/year

Natural radionuclide	Parametric concentration**
U-238	3.0 Bq/L
U-234	2.8 Bq/L
Ra-226	0.5 Bq/L
Ra-228	0.2 Bq/L
Pb-210	0.2 bq/L
Po-210	0.1 Bq/L

Artificial radionuclide	Parametric concentration**
C-14	240 Bq/L
Sr-90	4.9 Bq/L
Pu-239/Pu-240	0.6 Bq/L
Am-241	0.7 Bq/L
Co-60	40 bq/L
Cs-134	7.2 Bq/L
Cs-137	11 Bq/L
I-131	6.2 Bq/L

* Polish legislation

** Values calculated for a dose of 0.1 mSv and the annual water consumption 730 L

Some of contaminants are not monitored on a regular cycle

- MTBE (methyl tertiary buthyl ether)
- Herbicides
- Fertilizers
- Pharmaceuticals
- Perchlorate
- Mercury
- Arsenic

Bisphenol A – endocrine disruptor, extracted from plastic containers, dangerous for infants

Another dangerous contaminators, what shoud be monitored:

- ✓ Hexavalent chromium
- ✓ Six perfluorocarbons
- ✓ Seven sex hormones

Слайд 10

A1 Admin; 14.03.2017

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Arsenic contamination

Countries where the arsenic contamination of ground water was reported:

- Argentina
- Australia
- Bangladesh (the most suffered from this contamination)
- Cambodia
- Chile
- China
- Ghana
- Hungary
- India
- Mexico
- Nepal
- Thailand
- Taivan
- United Kingdom
- Nited States

Prolonged drinking of arsenic-contaminated water can lead to arsenicosis in a large numer of people, eventually resulting in a slow and painful death.

It is estimated that arsenic contamination of groundwater can seriously affect the health of more than 200 milion people worldwide.

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Water quality monitoring strategy

- Tiered approach to monitoring water is prefered.
- System would check for general changes in water quality and screen for possible contaminations.
- More specific testing would identify the type and extent of contamination.
- The quatity of testing methods may depend on financial restrictions as well as regulatory requirements.
- Prioritization should be given to tests are easy to perform, especially on-site and can detect substances causing a high risk to public health or give a wide description of the quality of water.

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Water quality monitoring methods

Real-time monitoring

Near real time - within 1-4h

Traditional monitoring of water quality: sampling, transport, and analysis in laboratory

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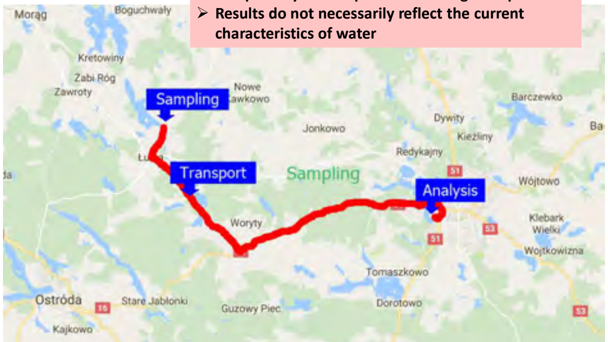
Traditional monitoring of water quality

- Laboratory methods are lenghty and expensive
- Sample may be compromised during transportation
- Results do not necessarily reflect the current characteristics of water



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Real time water quality monitoring

Real-time monitoring applications are based mainly on one or more following water quality parameters:

- turbidity
- conductivity
- temperature
- dissolved oxygen (DO)
- pH
- chlorophyll-a
- ultraviolet absorbance at 254 nm

Detection methods are more limited than laboratory methods, but their variety and capabilities are continously improving.

Most of advanced laboratory methods are not implemmented for field applications.

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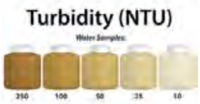
Sensor technology

Sensor technology and computer network determine water characteristics in a dynamic way. Online real-time monitoring and screening methods can be used to provide up-to-date information on water systems and warn against contamination.

This enables faster response times and quicker adjustments to treatment methods, reducing the risk to public helath.

Multiparameter water quality sensor

Turbidity

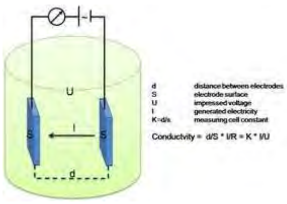


Potable water should have turbidity lower than 1 NTU

Turbidity sensor:
- Range 0-400 NTU
- Resolution 0.1 NTU

Conductivity

Portable conductivity meter



Specific resistance of ultra-pure water: 18.2 MΩ·cm

Conductivity sensor

Dissolved Oxygen (DO)

important gauge of water quality

Changes in dissolved oxygen levels indicate the presence of microorganisms from sewage, urban or agriculture runoff or discharge from factories.

A right level of oxidation-reduction potential (ORP) minimizes the presence of microorganisms such as *E. coli, Salmonella, Listeria*. Levels of Turbidity below 1 NTU indicates the right purity of drinking water.

Dissolved Oxygen (DO) in fresh water

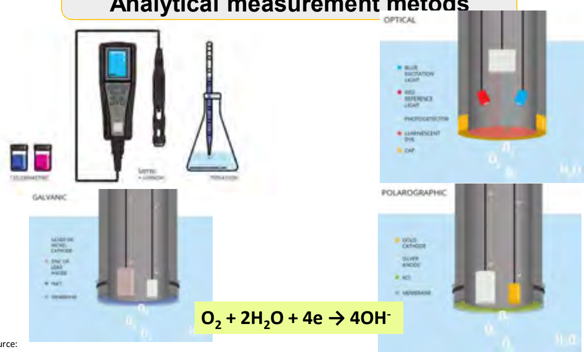
Concentration of O_2 in water with 100% air saturation, temp. 20˚C, determined by the Henry's law:

$[O_2]$ = 0.282 mmol/kg
$[O_2]$= 9.03 mg/kg

Dissolved oxygen concentrations can fluctuate daily and seasonally.

Source:
http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/

Dissolved Oxygen (DO) Analytical measurement metods



$O_2 + 2H_2O + 4e \rightarrow 4OH^-$

Source:
http://www.fondriest.com/environmental-measurements/equipment/measuring-water-quality/dissolved-oxygen-sensors-and-methods/

Dissolved Oxygen (DO) Colorimetric methods

The rhodazine D method is used to determine very low dissolved oxygen concentrations. Able to measure in the parts per billion (ppb).

The indigo carmine method can be used for measuring dissolved oxygen concentrations between 0.2 and 15 ppm (mg/L).

Measuring dissolved oxygen by a colorimetric methods can be done with a spectrophotometer, colorimeter or a simple comparator.

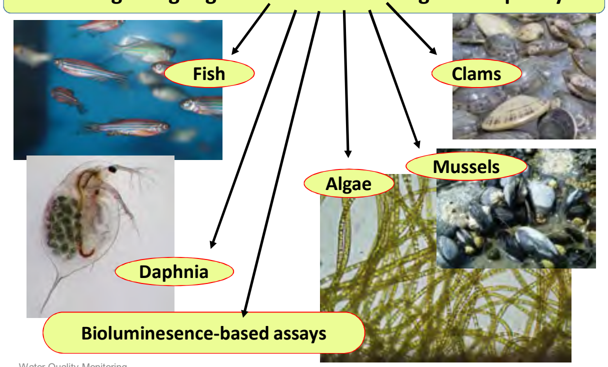
Source:
http://www.fondriest.com/environmental-measurements/equipment/measuring-water-quality/dissolved-oxygen-sensors-and-methods/

Dissolved Oxygen (DO) Titration (Winkler method)

Samples are collected, fixed and titrated, either in the field or in a lab. The sample should be fixed with the reagents as soon as possible to prevent oxygen levels from shifting due to agitation or atmospheric contact.

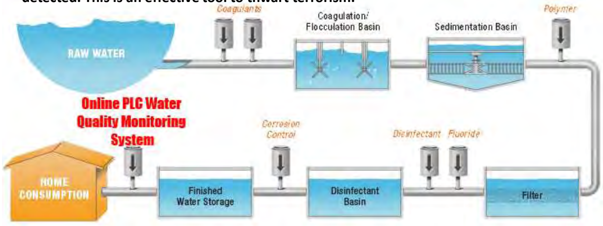
Source:
http://www.fondriest.com/environmental-measurements/equipment/measuring-water-quality/dissolved-oxygen-sensors-and-methods/

Utilizing living organisms for monitoring water quality



Drinking water contamination warning system

Turn-key systems (including valves, meters, sensors, pumps, automated remote software, etc.) and processes monitor water quality levels online and real-time to ensure that drinking water remains inside accepted safe levels. These water quality testing systems may be strategically place throughout municipal water systems at key points and may be programmed to alarm and communicate directly to the municipality officials by cell phone when contaminants are detected. This is an effective tool to thwart terrorism.



http://www.watercontaminationmonitoring.com/content/drinking-water-contamination-warning-systems

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Lesson 9. Water Systems Modelling

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Why Manage Water ?

Too little water

Too much water

Polluted water

Other issues such as;
- Navigation
- Ecosystem degradation
- Environmental and morphological impacts
- Etc.,

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Water Resources System

Includes all elements required to produce water and water-related goods and services

Elements

- Natural - (Lakes, rivers, etc.)
- Physical / Man-made - (Weirs, canals, etc.)
- Administrative – (Regulations, etc.)

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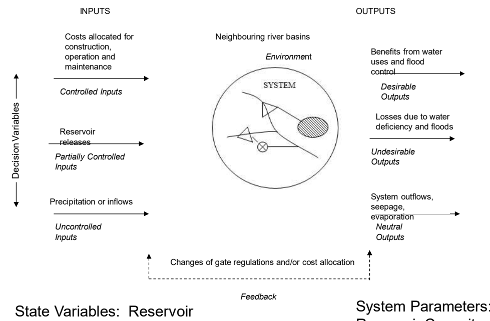
Water Resources System as an Input-Output System



State Variables: Reservoir Volume, soil moisture, etc.

System Parameters: Reservoir Capacity, Soils, Slopes, etc.

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Scales

Spatial Scales
- Basin
- Inter-basin
- Administrative units
- etc.,

Temporal Scales

- Time horizon
- Time step
- etc.,

Sustainability

Best serving people living today and in the future

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Modeling

Hydrological Modeling

For assessment of available water resources (eg., streamflow, groundwater, etc.,)

Water Resources System Modeling

For planning and management of water resources systems infrastructure (eg., dams, canals, power plants, etc.,)

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Hydrological Modeling

Typical tasks for hydrological models include:

- Modeling existing catchments for which input-output data exist,
(eg., Extension of data series)

- Prediction of effects of catchment change,
(eg., Land use change, climate change)

- Coupling hydrological models with various other models for an inter-disciplinary application,
(eg., water quality models and meteorological models)

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Classification of Hydrological Models

- *Physical models* – scaled physical model
- *Analog models* – electrical identity
- *Mathematical models* – based on math relationships
  - *distributed model* - with spatial variation considered
  - *lumped model* - with spatial variation ignored

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Physical Models

Reduced-dimension representations of real world systems.

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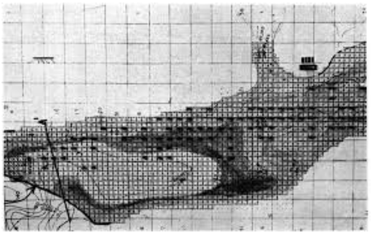
Analog Models

Represents the flow of water with the flow of electricity in a circuit.



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Mathematical Models

An equation or a set of equations that represents the response of a hydrologic system component to a change in hydrometeorological conditions.

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Water Resources Modeling

Assessment and prediction of availability of water resources

Traditional approach is based on water balance and demand prediction

It does not capture temporal and spatial dynamics of main variables such as climatic change, socio-economic change, institutional change, environmental change, etc., and how they affect water use

Therefore, the prediction of future water use and balance is subject to a wide margin of error

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System Dynamics Approach

“**system dynamics**” approach offers a way of modeling the future dynamics of complex systems increasing the ability to correctly assess and predict availability, use and balance of water, which enhances sustainable management of resources.

The model considers the dynamic interactions between quantitative characteristics of the available water resources and water use that are determined by the socio-economic development, population, agricultural development and food production in a country

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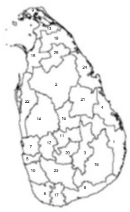
Example: Water Resources in Sri Lanka

Model structure

Sri Lanka is divided into twenty five units (water units)

administrative district borders are their boundaries



1	Ampara
2	Anuradhapura
3	Badulla
4	Batticaloa
5	Colombo
6	Galle
7	Gampaha
8	Hambantota
9	Jaffna
10	Kalutara
11	Kandy
12	Kegalle
13	Kilinochchi
14	Kurunagala
15	Mannar
16	Matale
17	Matara
18	Monaragala
19	Mulllaitivu
20	Nuwara Eliya
21	Polonnaruwa
22	Puttalam
23	Ratnapura
24	Trincomalee
25	Vavunia

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Example: Water Resources in Sri Lanka

Each water unit comprises of four sectors;

- water quantity
- population
- agriculture
- food

All twenty five units, each with the above four sectors, are integrated to build the overall model for the whole country

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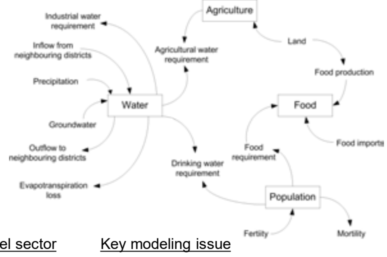
Example: Water Resources in Sri Lanka



Basic model structure

Model sector	Key modeling issue
Water quantity	inflow, outflow, demand, use
Population	Growth of population, fertility, mortality, migration
Agricultural	Cultivated land, land development, agricultural productions
Food	Food production, food import and export, availability, consumption

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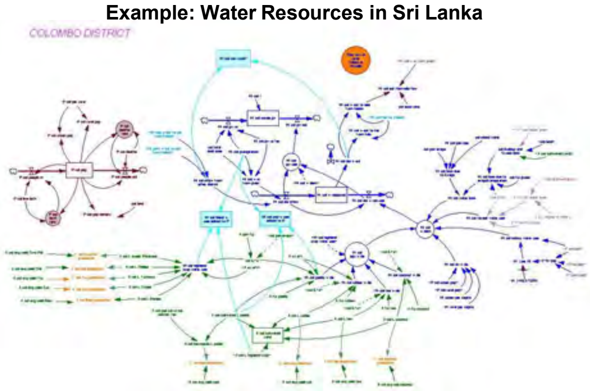
Example: Water Resources in Sri Lanka



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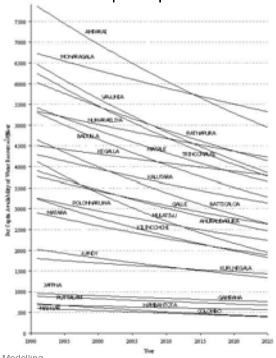
Example: Water Resources in Sri Lanka

District level per capita water availability



Water Resources System Planning and Management Modeling

Planning and managing water resources systems involve impact prediction through modeling

Note: models will have limitations in representing real systems

Model structure, input data, objectives and other model assumptions related to how real system functions or will behave under alternative plans and management practices may be uncertain

Water Resources System Planning and Management Modeling

Water resources systems are very complex

We do not understand sufficiently the multiple independent physical, biochemical, ecological, social, legal and political processes that govern behaviour of water resources systems

Models of real-world systems are always simplified representations

Models can represent in a fairly structured and ordered manner the important interdependencies and interactions among various control structures and users of a water resources system

Water Resources System Planning and Management Modeling

Models permit evaluation of the consequences of alternative engineering structures, of various operating and allocation policies and different assumptions regarding future supplies, demands, technology, costs and social and legal requirements.

Model components

Models (mathematical) contain algebraic equations.

The equations include;

Parameters –known variables

Decision variables – unknown variables

Models are developed for identifying base values for decision variables

(*include design and operating policy of water resources systems*)

Model components

Models describe, in mathematical terms, the system being analyzed and the conditions that the system has to satisfy.

These conditions are called **constraints**

Solving a model:

Finding values of unknown decision variables

Modeling Methods: Optimization and Simulation

Simulation

address “what if” question

Or a trial-and-error procedure

Optimization

A more organized mathematical approach

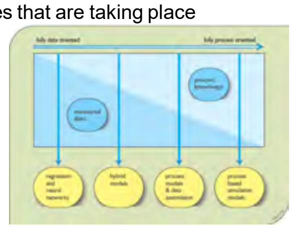
Automatically gives the best solution

Simulation Models

Can be statistical or Process oriented !

Pure statistical models are based solely on data (field measurements)

Pure process oriented models are based on knowledge of the fundamental processes that are taking place



Ref: Loucks, D.P. and Van Beek, E (2005) Water Resources Systems Planning and Management, UNESCO Publishing

Simulation Models (Process Oriented); Examples

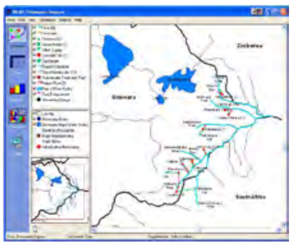
HEC-ResSim

Reservoir System Simulation Model developed by
US Army Corps of Engineers
Institute of Water Resources
Hydrologic Engineering Centre
USA

It is a computer program comprised of a graphical user interface (GUI) and a computational engine to simulate reservoir operations and river routing

WEAP - Water Evaluation And Planning System
Stockholm Environment Institute

WEAP is a microcomputer tool for integrated water resources planning
It provides a *comprehensive*, *flexible* and *user-friendly* framework for policy analysis

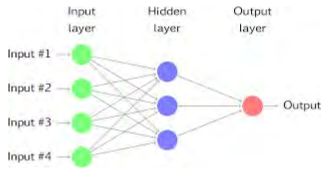


Simulation Models (Statistical); Examples

Artificial Neural Networks (ANN)

ANNs represents simplified models of brain

It is just a more complex type of regression or statistical (black-box) model



Optimization Models

Optimization Models;

- Can be Deterministic or Probabilistic or a mixture
- Can be Static or Dynamic with respect to time
- Can be Linear or Non-linear

Regardless of the type , they all include an objective function (which is used to evaluate multiple possible solutions)

Optimization Models

Optimization models can be classified into different types depending on the algorithm to be used to solve the model

- Lagrange multipliers
- Linear Programming
- Non-linear Programming
- Dynamic Programming
- Quadratic Programming
- Geometric Programming
- etc.,

Water Demand Management

Effective management of water resources has become very important due to limited water supplies and increasing water demands at present

Demand management is defined as the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource, namely water

It consists of five categories; (1)engineering, (2)economics, (3)enforcement, (4)encouragement, and (5) education

Benefits of Water Demand Management

- Reduces water demand with no deterioration in life style
- Reduces capital requirements for expansion of water supply and lowers operating costs
- Reduces generation of pollutants, and therefore the requirements for new or expanded wastewater treatment systems
- Facilities expansion of the coverage of available fund
- Enhances development and adoption of new technologies
- Leads to financially sustainable water systems

Water Demand Management Measures

Water Demand Management relies upon a range of measures (tools and techniques)

- Economic
- Socio-political, and
- Structural and operational

Water Demand Management Measures

Economic Measures

- Incentives (eg., rebates, tax credits)
- Disincentives (eg., real cost, penalties, fines)

Socio-political Measures

- Policies and Laws
- Economic policies, government regulations, standards on appliances (eg., promote water saving devices, encourage water savings in industries)
- Effective public/stakeholder education and awareness measures
- Wise use of water, direct restriction on use

Structural and Operational Measures

These are used to achieve better control over water demand

- Metering, retrofitting, rationing, recycling
- Reduction of non-revenue water (NRW), leakage detection and repair
- Use of water efficient devices
- Water use restrictions during periods of water shortage

Approaches for Water Demand Management

- Increase system efficiency
- Increase end use efficiency
- Promoting distributed sources of supply
- Substitute resource use
- Improve the market on resource usage

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Approaches for Water Demand Management

Increase system efficiency

- No change in usage, but change in system operation
- Leak detection and repair, pressure reduction

Increase end use efficiency

- Less resource use by consumers by using water advertising, education and use of water efficient devices
- More efficient watering of public open spaces
- Water efficiency in the planning, design and construction of homes and buildings

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Approaches for Water Demand Management

Promoting distributed sources of supply

- Provide service via local resource not being used
- Encourage rainwater use and grey-water reuse

Substitute resource use

- Provide same service without resource use
- Waterless sanitation, low water-use garden plants, plants adapted to local rainfall

Improve the market on resource usage

- Inform consumers about full cost of resource
- Full cost pricing, universal metering, information on impact excessive water use

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Lesson 9: Special Issues in Water Resources Management

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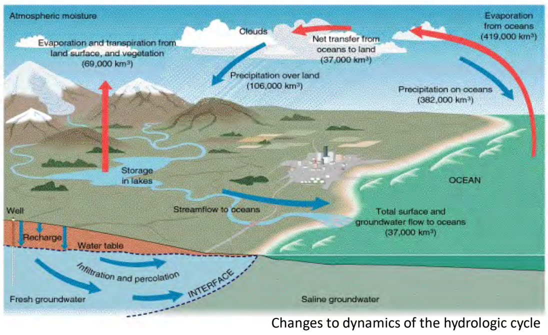
Hydrologic cycle



Changes to dynamics of the hydrologic cycle
Spatial and temporal distribution
Affects water quality and quantity

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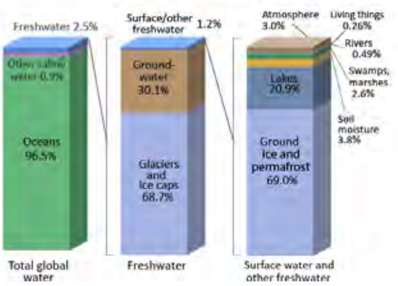
Fresh water resources on the earth

Where is Earth's Water?



https://water.usgs.gov/edu/earthwherewater.html

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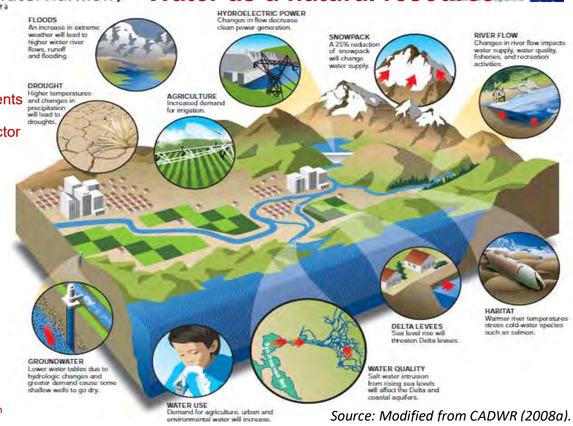
Water as a natural resource

Components of water sector



Source: Modified from CADWR (2008a).

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Issues in water sector

Issues are usually cropped up centered on following factors:

- achieving equitable distribution of water of required quality and quantity among the users
- allocating water to different sectors water supply, irrigation or to power generation. In many parts of the world such problems of allocation have to be faced not only nationally, but also across frontiers
- disasters and negative environmental impacts
- long-term sustainability of water resources and of the water supply facilities - storage depletion, sea water intrusion, and gradual contamination

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Issues in water sector

Underlying causes for creating issues:

As a result of ever escalating and competing demands, compounded by pollution and climate change-driven impacts, available freshwater resources are becoming increasingly stressed.

This is further compounded by poor management practices and the unsustainable extraction of water. Consequently, many parts of the world, particularly urban areas, are facing water shortages.

human-induced development panorama affects the existing water resources reducing the supply, while at the same time more inhabitants are demanding more water.

Water quantity issues

Increasing demands with

- Population growth
- Food production- Drinking water
- Industrial water demand
- More water for environmental conservation
- Increased pollution leading to unusable water
- Increased living standards - Improved hygiene conditions, domestic water use

Water and food security

- Agriculture is the largest user of water worldwide; and in many low-income countries, agriculture employs the largest share of people.
- Most viable agricultural land is already being used, and the significant growth in output required to feed the world's growing population will take place mostly on irrigated land.

Water and energy security

- Significant amounts of water are needed in almost all energy generation processes, from generating hydropower, to cooling thermal power plants, to driving steam turbines in concentrated solar plants.
- Population growth and rapidly-expanding economies place additional demands on water and energy, and several regions around the world are already experiencing significant water and energy shortages.

Water quantity issues

Water scarcity

Physical water scarcity and Economic water scarcity

It is important to highlight the distinction between these two forms of scarcity:

water can be physically available, but the resources are not available to improve it and distribute it to those who need it.

Physical water scarcity

This term typically applies to dry, arid regions where fresh water naturally occurs in low quantities. This is being greatly exacerbated by anthropogenic activities that take surface and ground water faster than the environment can replenish it.

Regions most affected by this type of water scarcity are Mexico, Northern and Southern Africa, the Middle East, India, and Northern China.

Economic water scarcity

Economic water scarcity applies to areas or cultures that lack the fiscal resources and/or human capacity to invest in water sources and meet the local demand.

Water is often only available to those who can pay for it or those in political power; leaving millions of the world's poorest without access. Regions most affected by this type of scarcity are portions of Central and South America, Central Africa, India, and South East Asia.

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Water quality issues

- Even after accounting for physical water availability or access, water quality could further reduce the amount of usable water available to a developing country for human consumption, sanitation, agriculture and industrial purposes, in addition to various ecosystem services.
- The level of water quality depends on its intended purpose: Water that could be unfit for human consumption could be still usable in industrial or agriculture applications.

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Water quality issues

- Water quality is affected both by natural processes and ecosystem characteristics but also the result of human activities, including industry, domestic and agricultural uses of water
- Challenges to water quality stem not only from the physical contaminants themselves but also from the sheer volume of contaminants that can overwhelm an area's infrastructure or resources to treat and remove the contaminants.

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Water quality issues

- Human cultural and cultural norms, in addition to governance structures, can also contribute to scenarios that further reduce the quality of available water.
- The absence or low enforcement of the following policy and market mechanisms in developing countries

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Water quantity issues

Spatial and temporal variability of available fresh creates :

- natural scarcity of water in certain areas
- floods, the siltation of river systems,
- lack water of good quality in rivers and water bodies

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Water issues in developing countries

https://en.wikipedia.org

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Water issues in developing countries

- 1.1 billion people in developing countries have inadequate access to clean water.
- 2.6 billion lack access to sanitation
- 1.8 million children die each year from diarrhea
- millions of women spend hours a day collecting water.

Barriers to addressing water problems in developing nations are focused mainly around issues of poverty, education, and poor governance.

Water issues in developing countries

Water quality in developing countries is often hampered by lack of or limited enforcement of:

- emission standards
- water quality standards
- chemical controls
- non-point source controls (e.g. agricultural runoff)
- incentives for pollution control/water treatment
- follow-up and legal enforcement
- integration with other related concerns (wastewater and solid waste management)
- environmental agency capacity (due to resources or lack of political will)
- understanding/awareness of issues and laws[1]

Climate change impacts

The impacts and risks associated with climate changes are already happening in many systems and sectors essential for human livelihood, including water resources, food security, energy security, coastal zones and health

An estimated 200 million people could be displaced as a result of climate impacts climate-related disasters by 2050 (IPCC 2007)

Climate change impacts on water sector

- **Extreme events**

Extreme events, floods and droughts, coastal storms will be more frequent

The devastating effects of extreme events, temperature increases and sea level rise have consequences for all, particularly the poor, and will only worsen in the future.

- **Sea level rise**

Inundation of low lying areas, coastal marshes and wetlands, exacerbate flooding and increase the salinity in rivers, bays and aquifers.

Impacts on water sector

More frequent hydrologic extreme events (Floods and droughts)

Sea level rise

Warm temperatures

create vast adverse impacts on water sector.

Societal impacts:

Increased disaster risks, damages to property and services due to frequent flood and drought

Adverse effects on agriculture & food production, energy, health, water supply and sanitation, ecosystems, etc..

- Increase of investment needs

particularly affect the poor!

Frequent floods and droughts

Climate change brings frequent extreme events, changes to rainfall pattern

- More flood inundation and more damages
  - Population living in flood prone areas
  - More infrastructure development
  - Increase mud flows, debris flows
- More droughts /prolonged low rainfall periods
  - Low stream flows
  - Water scarcity

Impacts on agriculture

Frequent floods

Inundation of cultivations, damages to the irrigation headworks and distribution systems, soil erosion, high sediment and pollutant concentrations in water

Frequent droughts/low precipitation

Crop failure, restriction on water uses, increased conflicts over water rights

Increased temperature

Low yields, high evaporation, crop failure

degradation of water quality

Increased sea level rise

saltwater entrainment, saline soil

Impacts on water supply

Frequent floods

Inundation of water intakes, treatment facilities,
damages to the distribution systems,
high sediment and pollutant concentrations in raw water

Frequent droughts/low precipitation

restriction on water uses,
increased conflicts over water rights

Increased temperature

increase demands for landscape, irrigation, human consumption, cooling
degradation of water quality
Higher losses

Increased sea level rise

saltwater entrainment, mixing of pollutants with fresh water due to inundation

Impacts on hydro energy

Frequent floods

Damages to infrastructure,
high sediment and pollutant concentrations

Frequent droughts/low precipitation

Low plant factor, restriction on water uses, increased conflicts over water rights

Impacts on wastewater treatment

Frequent floods

Inundation of ww treatment facilities,
Higher water levels d/s create backwater effect
high sediment and pollutant concentrations in combined systems

Frequent droughts/low precipitation

Lower dissolved oxygen content leading to tighter discharge consent standards

Increased temperature

Potential for odour generation in warmer conditions
positive effect on biological treatment processes

Increased sea level rise

Higher water levels d/s create backwater effect

Impact of land use on water issues

- Increased deforestation/ urbanization
  - More soil erosion
  - Reduced infiltration of water into the aquifers, leading to low base flows
  - Increased impervious areas
  - Increased landslides,
  - Flash floods leading to inundation

Impacts on storm water drainage

Frequent floods

Debris flow
high sediment and pollutant concentrations
Sewer clogging & overflows,
Higher d/s water levels create backwater effect

Frequent droughts/low precipitation

High pollutant concentration and odour generation

Flood management

- Flood mitigation
- Increased distributed storage
- Flood detentions and retention
- Increased infiltration LIDs
- Flood proofing

Drought management

- Increase storage
- Ecosystem conservation/catchment management
- Water regulations
- Modernized irrigation systems
- Drought resistant crop varieties

Water conflict management

- Water policy
- Hydroploitics
- Capacity building
- Trans-boundary River Management
  - With 263 international rivers in the world, supporting their cooperative management is an important contribution for fostering gains from water resources use and thus contributing to poverty alleviation.

Issues on the adequacy of existing water infrastructure

Statistical parameters of hydro-meteorological data series are not stationary. Historical hydro-meteorological data become not useful to make projection. Modern tools considering climate change projection would be necessary

Design criteria on stormwater inflows different return periods to be redefined

Upgrade existing water infrastructure and management practices due to uncertainty of projected hydrological changes

Improve resilience in water sector

- Improve distributed surface/subsurface water storage , recharge soil moisture
  Distributed storages
  Store seasonal high runoff , increase recharging groundwater, wetlands, to surface storage (from small to larger reservoirs) where possible
- Water quality management
  - stringent wastewater and waste disposal regulations
  - Ground water pollution control and remediation
- Catchment management practices
- Demand management, Recycling and reuse

Lesson 11: Introduction to Integrated Water Resources Management

Dr. S. Sivakumar
University of Jaffna, Sri Lanka
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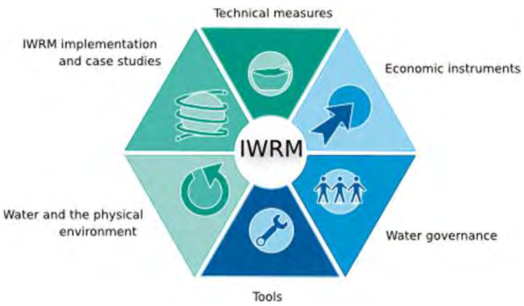
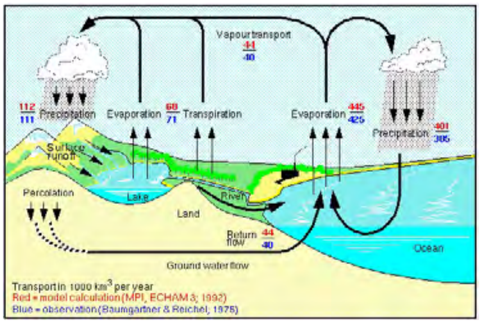
Integrated water resources management



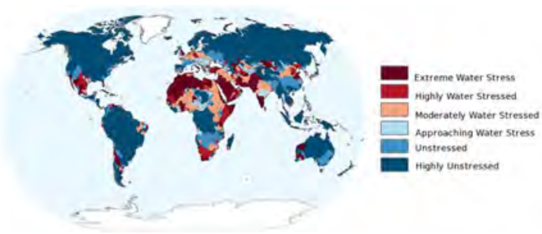
Course Outline

- Introduction to IWRM
- Water Supply, Waste Management, Sanitation and Health
- Ground water management
- Water Resource and River Basin Planning and Management
- Economic Dimensions of Water Use
- Demand Management
- Hydro-politics and conflict management
- Water Policy and Governance

Water Cycle



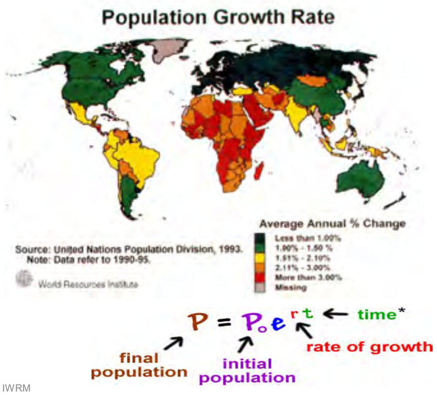
Stress on Water Resource Global Prospects



Stress on Water Resource Global Prospects

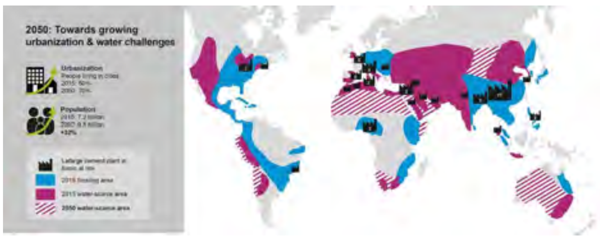
- Exponential population growth
- Increased Water Demand for Food and Drinking
- Increased economic activities
- Pressure on fragile ecosystems
- Water rights
- Water management, use and discharge (pollution)
- Climate change

All these issues transversally cross all levels of human activities. The situation is even more complex, as there is a recognised water governance crisis.



A Challenge to Water Management

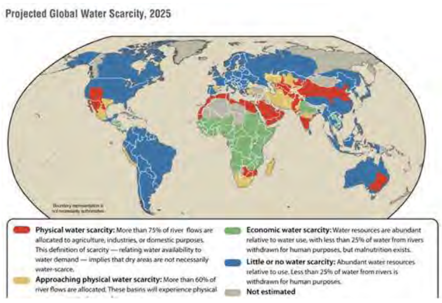
A Challenge to Water Management



A Challenge to Water Management

A Challenge to Water Management

A Challenge to Water Management



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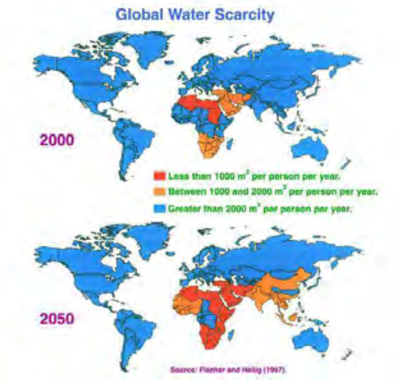

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Stressed Global Water Resource

- More than 2-billion people suffer from water shortages in over 40 countries.
- 1.1-billion people do not have access to safe drinking water.
- Four out of ten people in the world do not have access to improved sanitation (very basic facilities).
- Two-million tonnes of human waste is discharged into water courses every day.
- In the year 2025, more than 3-billion people will face water scarcity.

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Local, Regional, National, Regional, Global

Ancient — Community

1200 A.D. — Basic management of water quantity

1900 — Sectoral management of water quantity and quality; institutional fragmentation; spatial fragmentation; local co-ordination

1990s — Integrated multifunctional use; river basin as unit; institutionalised cooperation

Future — Multi-level Comprehensive Governance

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Concepts of Five Paradigms

- 1- Pre-modern (before 1950)
  - Local secure provision Domestic and livelihood water are inviolable social resources
- 2- Industrial modernity (1950s)
  - Hydraulic mission; Nature can be controlled
- 3- Late modernity (late 1970s and 1980s)
  - Nature cannot be controlled; Water in the environment was essential for *environmental services*
- 4- Economic efficiency (from 1990)
  - Water is an economic resource
- 5- IWRM (from late 1990s)

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Dublin Principles

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and environment
- Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels
- Women play a central part in the provision, Management and safeguarding of water
- Water has an economic value and should be recognized as an economic (and social) good

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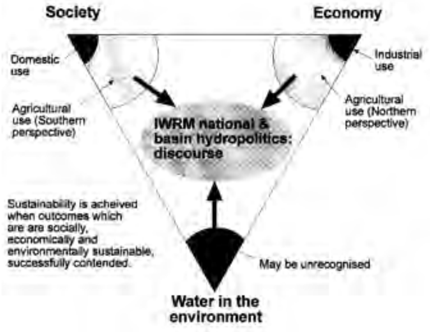
Integrated Water Resources Management

- IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems

Political Nature of IWRM

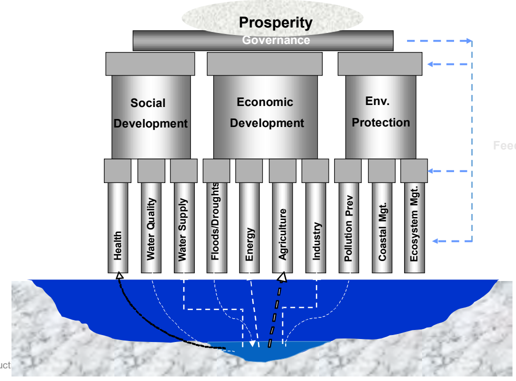


IWRM - Paradigm Shift

It departs from traditional approaches in three ways

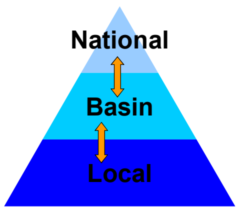
- Is cross-cutting and departs from the traditional *sectoral* approach.
- *Spatial* focus is the river basin.
- Departure from narrow professional and political boundaries and perspectives and broadened to incorporate participatory decision-making of *all* stakeholders (*Inclusion vs. exclusion*)

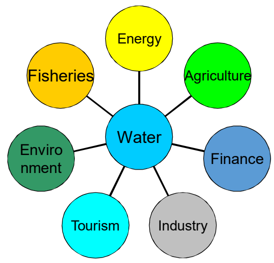
The Water Resources Development Process: Sectoral (or Use) Approach



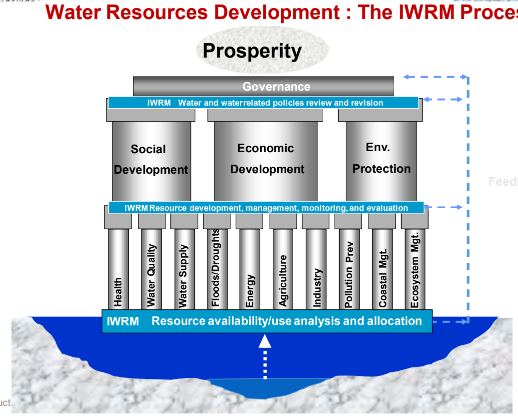
The Basics of Integration

More coordinated decision-making across sectors…



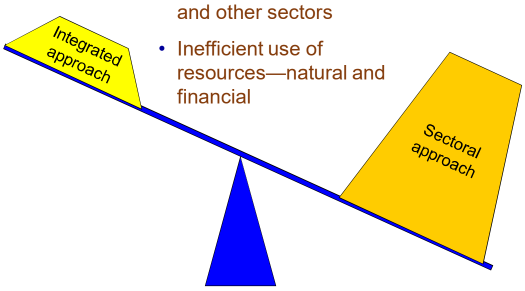


Water Resources Development : The IWRM Process



Risks of Fully Sectoral Approach

- Overlooking negative impacts on environment and other sectors
- Inefficient use of resources—natural and financial



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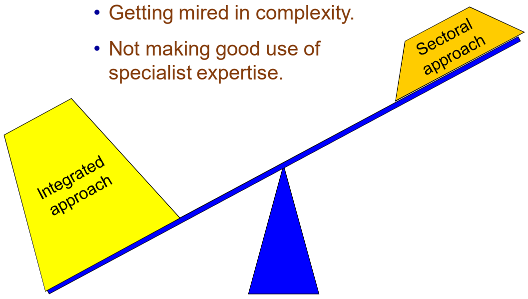
Risks of Fully Integrated Approach

- Getting mired in complexity.
- Not making good use of specialist expertise.



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Global Events in Promoting IWRM

▶Adopted at International Conference on Water and Environment (ICWE), Dublin 1992,

▶Contributed to Agenda 21/Rio Declaration (chapter. 18 on freshwater resources) at United Nations Conference on Environment and Development (UNCED) or Earth Summit, Rio de Janeiro 1992

▶UN CSD ("Rio + 5, 10, 20)

▶World Water Forums (at 3 years intervals)

▶Stockholm water week (annually)

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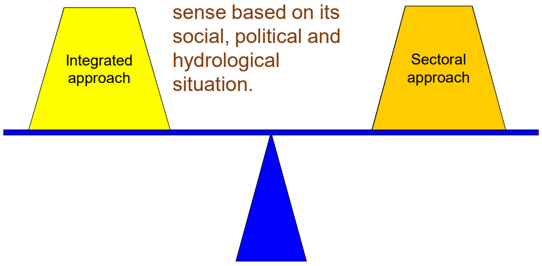
Finding a Balance

Each country needs to decide where integration makes sense based on its social, political and hydrological situation.



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Global Water Partnership

✓ To promote the concept and implementation of Integrated Water Resources Management (IWRM) to help resolve current and future water crises.

✓ Transform ground reality, through broad based stakeholder partnerships, to influence policy.

✓ Function as neutral change agent in facilitating policy formulation.

✓ Provide a focal point to overcome "fragmented" efforts leading to unsustainable management and development.

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IWRM - A Management Process for Water Governance

▶A shift from water development to governance

▶Manage the water resource for long-term, sustainable uses for future generations

▶Governance implies the capacity to both generate and implement appropriate policies

▶Established consensus and participation

▶Requires capacity building

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GWP Regional Partnerships – 13 Regions

CapNet

CapNet is an associated project of the UNDP

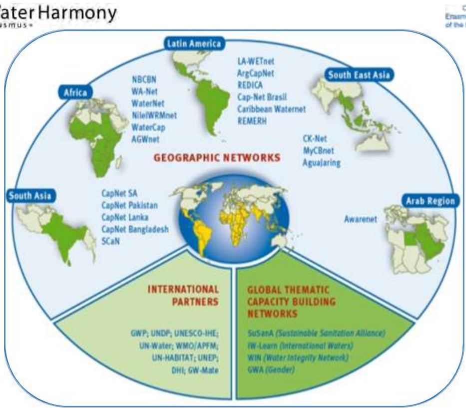
The Objective of CapNet is to enhance human resources development for Integrated Water Resources Management

through

strengthening or establishment of a number of regional IWRM networks able to deliver education and training support for improved management of water resources.

Capacity Building

- ✓Global Initiatives
- ✓CapNet
- ✓UNESCO-IHE
- ✓UN University
- ✓Waternet
- ✓SaciWATERs
- ✓Other Initiatives
  - ✓SIWI
  - ✓Australian Initiatives



Water Supply

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Introduction to Water Supply

Harsha Ratnaweera
Professor, Norwegian University of Life Sciences

Victor Gevod
Dr. Chem. Sci., Ukraine State University of Chemical Technology

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Learning targets

- Overview of the challenges and requirements related to water supply at present and in the future
- Knowledge about the historical development of modern water supply, and of the treatment processes applied nowadays
- Awareness of the expectations of the consumers and the conclusions derived from there
- Attracting attention for the importance of disinfection and the role of corrosion in distribution systems

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Outline

- Present status
- The challenges
- History of water treatment
- Requirement and goals
- Overview of processes and equipment
- Disinfection
- Corrosion control
- Distribution systems

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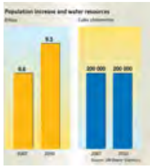
Present status

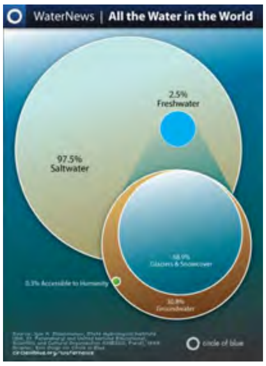
Water resources on earth

→ Freshwater is a scarce resource

Population growth on earth

→ Water shortages will become likely





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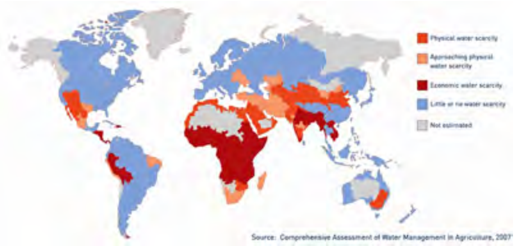
The challenges

2007: 1.2 billion people live in areas with water scarcity (physical scarcity)
In 2025: 1.9 billion will experience physical water scarcity; 67 % water stress
2007: 1.6 billion people cannot afford to have good water (economic scarcity)



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The challenges

Regarding the transmission of water-related diseases the lack of wastewater treatment is another big problem

History of water treatment

- Ancient People (20,000 B.C.) were hunters and gatherers of plant food.
- Surface water was used by them for drinking.

http://3.bp.blogspot.com/-33Pq5NIFr6M/VkSK3H79ANI/AAAAAAAABi4/vRxdO4ZyfQk/s1600/homo-sapiens-fire%2B%2528ewao.com%2529.jpg

- Ancient Greeks and Indians (4,000 B.C.) treated drinking water to improve its taste and odor by charcoal filtration, sunlight exposure, straining, and boiling.

https://thumbs.dreamstime.com/b/filtro-de-agua-de-piedra-de-la-gravedad-del-agua-arequipa-perú-42597337.jpg

- Ancient Egyptians (1,500 B.C.) used an alum salt to cause sedimentation of suspended particles in the water.

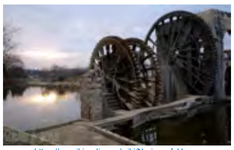
http://www.buffalowater.org/Quality/Treatment/WaterTreatmentHistory

History of water treatment

From 2,000 B.C. until the Middle Age the following happened:

- Population on Earth began to grow.
- The first major cities appeared.
- People started to build special facilities for transporting water to the consumers.
- Some civilizations even developed sewer systems.

https://www.tourmyindia.com/images/taragarh-fort4.jpg



https://en.wikipedia.org/wiki/Norias_of_Hama

https://en.wikipedia.org/wiki/Aqueduct_of_Segovia#/media/File:Aqueduct_of_Segovia_08.jpg

History of water treatment

At the end of the XVIII century mankind found itself with a dangerous sanitation problem:

- At that time the development of big cities had reached the point where epidemics of classic water-borne diseases became the biggest risk to the population.
- Due to urbanization the sources of drinking water became exposed to contamination from human and animal feces as well as industrial wastes.
- Population had begun to address sanitation problems by using water to transport personal wastes to the nearest watercourses.

http://blog.daum.net/_blog/BlogTypeView.do?blogid=0VzBy&articleno=1189&categoryId=13&regdt=20120514160205

History of water treatment

To overcome these problems, new concepts were proposed:

- To use water from sources that had never been exposed to human wastes.
- To use appropriate means to “re-purify” natural waters that had been contaminated by human activities.
- To supply water with elevated pressure in networks.

DWTP at beginning of the 20th century in Russia

http://geppener.ru/московский-водопровод

→ Unfortunately, the first concept was not viable in practice due to wide-spread anthropogenic pollution of natural resources.

→ Problems of drinking water supply were eventually solved by constructing water treatment plants and improving the water distribution systems.

History of water treatment

At present, the idea of drinking water treatment and supply is as follows:

- Drinking water treatment plants (DWTP) shall ensure a reliable supply.
- Drinking water should be chemically and microbiologically safe and aesthetically acceptable for human consumption.
- For industrial applications the requirements are usually different.
- The sources of water for municipal and industrial supplies are wells, rivers, lakes and reservoirs.
- The treatment processes applied depend strongly on the particular raw water quality.

http://greatwateralliance.com/mjs_oct30

Requirements and goals

Main requirements:

- Health-related
  - → Must be free from any microorganisms and parasites, and from any substances which, in numbers or concentrations, constitute a potential danger to human health
- Aesthetic requirements
  - → Must be free from any objectionable appearance (colour, particles), odour or taste
- (Economic requirements)
  - → Must enable economical and sustainable systems (reduce corrosion)

Requirements and goals

Today, the quality of drinking water in Europe should comply with the requirements set in the Water Framework Directive (2000/60/EC), i. e. tap water should be:

1. Palatable, - no unpleasant taste
2. Safe, - does not contain pathogens or chemicals harmful to the consumer
3. Clear, - should be free from suspended solids and turbidity
4. Colourless and odourless, - should be aesthetic to drink
5. Reasonably soft - limited lime contents allow consumers to wash clothes, dishes and themselves without use of excessive quantities of detergents and soap
6. Non-corrosive - to protect pipes and prevent leaching of metals from tanks or pipes
7. Low organic content - a high organic content results in biological growth in pipes and storage tanks that often affects quality.

Requirements and goals

Goals:

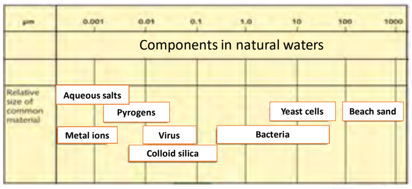
- Provision of hygienically safe drinking water (free from micro-organisms and chemical compounds harmful to human health)
- Fulfilment of user requirements (colour, pH, taste, odour)
- Compliance with legal requirements (National, EU and WHO)

Water treatment technologies at present:

→ Change of water quality by planned measures
→ Often means removal of selected substances
→ May also include addition of chemicals (e.g. coagulants)
→ Comprises both physical, chemical, and biological processes

Overview of processes and equipment

Typical contaminants of raw water and the scale of their sizes



The choice of the best suited water purification method depends primarily on the particle size of the impurities.

Depending on the size of particles in water and their relative density, the process of natural sedimentation occurs at different rates, as this table shows:

Diameter of Particle	Type of Particle	Settling time through 1 m. of water
10mm	Gravel	1 seconds
1mm	Sand	10 seconds
0.1mm	Fine Sand	2 minutes
10 micron	Protozoa, Algae, Clay	2 hours
1 micron	Bacteria, Algae	8 days
0.1 micron	Viruses, Colloids	2 years
10 nm	Viruses, Colloids	20 years
1 nm	Viruses, Colloids	200 years

Overview of processes and equipment

Processes applied for water purification

- Mechanical (Physical) → Screening, Filtration, Sedimentation
- Physico-chemical → Coagulation, Flocculation, Flotation, Adsorption, Ion-exchange, UV and Ultrasonic disinfection
- Biological → Precipitation and Oxidation by bacterial colonies on the surface of grains in filtration devices and bioreactors
- Chemical → Neutralization (Lime treatment) and Oxidation (Chlorine, Ozone, etc.)

Overview of processes and equipment

Equipment used at different steps of drinking water treatment

Kind of treatment	Unit processes	Required equipment
Pre-treatment	Coarse screening, Fine screening	Coarse and fine screens, sedimentation basins
Primary treatment	Coagulation, Flocculation, Sedimentation	Injectors, Mixers, Clarifiers
Secondary treatment	Rapid sand filtration, Slow sand filtration	Grain Filters
Advanced treatment	Adsorption on activated carbon, Fe and Mn removal, Hardness removal, Membrane processes	Grain filters, Aerators, Chemical reactors, Ion-exchange columns, Membrane modules
Disinfection	Chlorination, Ozonation, UV irradiation, etc.	Gas injectors, UV-sterilizes, US-sterilizes.
Distribution	Networks management	Storage basins, pumps, water networks

Overview of processes and equipment

Which factors influence the number of stages for water treatment?

Many plants have only two treatment stages. These are coagulation – flocculation – sedimentation and filtration followed by disinfection. Apart of these processes, the so-called advanced water treatment processes are:

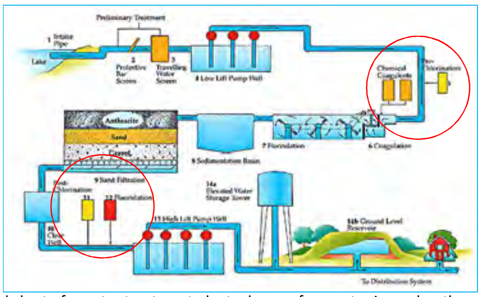
- Softening → (decrease of the water's hardness)
- Ion-exchange → (optimization of the water's ionic matrix)
- Adsorption → (selective removal of organic substances)
- Membrane filtration → (attaining special quality of treated water)

Ion exchange and membrane filtration are becoming increasingly important due to stricter regulations regarding the color of water and the concentrations of disinfection by-products.

Filtration through granular activated carbon prior to water disinfection becomes also more common.

Water Harmony

Overview of processes and equipment



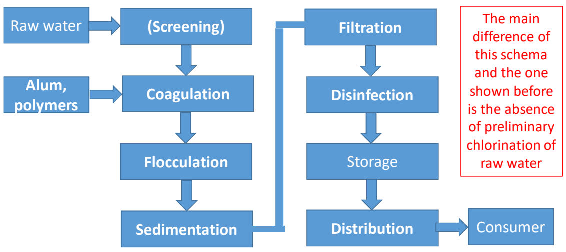
Typical chart of a water treatment plant when surface water is used as the source

http://antyradar.info/drinking-water-treatment/

Water Harmony

Overview of processes and equipment

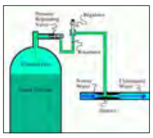
Block-scheme of a water treatment plant when the raw water is less contaminated



Water Harmony

Disinfection

Chemical methods: Chlorination and ozonation



https://plus.google.com/112794239029338180525/posts/Dovxz3TiSg8

- Chlorination is the most widely used method for chemical disinfection of drinking water.
  Chlorine residuals give a certain safety against bacterial re-growth in the distribution system.
  Its disadvantage is the formation of chlorinated by-products in the case of insufficient removal of organic matter from raw water.
- Treatment by ozone is the second widely used method for chemical disinfection of drinking water. Its disadvantage is the lack of residuals, which can lead to a rapid secondary microbiological contamination of water within the network.

Disinfection is the obligatory final stage of any process scheme in water treatment plants.

Water Harmony

Disinfection

Physical method: UV-radiation

https://www.indiamart.com/proddetail/uv-water-treatment-systems-4582156191.html

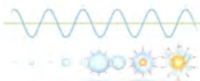
- Ultraviolet radiation is able to penetrate into bacterial cells and, by that, destroys their DNA.
- This kind of water treatment inactivates viruses, bacteria and their cysts, spores of fungi, etc.
- The disadvantages of the method are the absence of a prolonged action and the need for thorough initial water purification from suspended solids.
- At present, in countries that have introduced water treatment technologies with optional steps, ultraviolet disinfection is becoming increasingly widespread.

Water Harmony

Disinfection

Physical method: Ultrasonic cavitation

https://www.slideshare.net/RonColetta1/ecowater-chc-chemical-free-cooling-tower-water-treatment-system

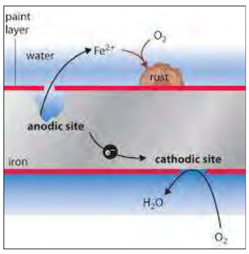


- The extreme pressures and temperatures created by hydrodynamic cavitation process physically destroy bacteria and other micro-organisms.
- This is an advantage because some micro-organisms can develop a certain resistance to traditional chemicals, requiring constant adjustment of treatment method.
- There are no such worries with hydro-dynamic cavitation process. Bacteria cannot adapt to having their cells ripped apart.

Water Harmony

Corrosion control

Corrosion processes in water



https://saylordotorg.github.io/text_general-chemistry-principles-patterns-and-applications-v1.0/s23-06-corrosion.html

- Water becomes corrosively active when it contains oxygen, as well as excessive concentrations of acids and mineral salts.
- These factors initiate the corrosion of water pipes, fittings of water-diverting valves, etc.
- Almost all technical devices and water supply systems are in principal subjects to corrosion damages.
- Water networks are not exception. The corrosion effects on steel pipes are especially negative.

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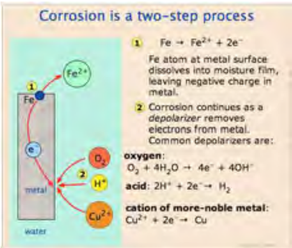
Corrosion control

Corrosion processes in water



https://anodesaus.com.au/news/corrosion-causes-corrosion/

- To prevent corrosion in steel pipes one has to minimize the electric current from the anodic points of the corrosion area to the cathodic points.
- A reduction of the corrosive activity in water can be attained by the removal of dissolved oxygen, by shifting the pH up to neutral or little alkaline values (removal of acidity excess), and by adjusting the mineral composition (demineralization of the water).

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Corrosion control

Correction of water acidity (pH adjustment)

- When rain falls the water is slightly acidic and, by that, naturally aggressive. The water can then dissolve calcite and other minerals in the groundwater aquifer and become neutralized. If this neutralization does not occur or if other contaminants are dissolved the water will be acidic.
- Acidic waters result in the corrosion of steel and copper pipes, heating cylinders and other equipment, leading to pinprick corrosion and holes.
- At pH values below 7 water is considered to be acidic, and corrosion accelerates at pH levels below 6.5. With pH levels below 6.0 water is considered to be extremely aggressive.
- Water acidity can be removed by adding lime or sodium hydroxide, or by filtration through a bed of any carbonate containing material (i.e. calcite, dolomite).

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Distribution systems

General requirements

Consumers will get high quality drinking water if the following requirements are fulfilled:

1. The water treatment plant guarantees a high quality of the water entering the water distribution system.
2. The water distribution net-work is built and operated in such a manner that the water does not undergo any secondary contamination.

https://atguv.com/atg-uv-applications/drinking-water/#gallery

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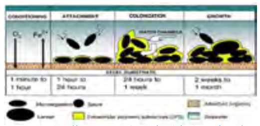
Distribution systems

Biological fouling and its control in distribution systems

- Biofouling refers to the undesirable formation of organic deposits on pipe surfaces. These deposits induce water quality changes, increase the rate of corrosion and microbiological contamination of the water to be supplied.
- Chlorination has been the predominant means of controlling biofilm formation in water distribution systems. The disadvantage of this method is the formation of chlorinated byproducts.
- Biological fouling in distribution systems can be avoided only by using advanced water treatment methods for the removal of organic substrates.



http://www.esru.strath.ac.uk/EandE/Web_sites/11-12/MORE/enviornmental/marine_growth.html

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Questions

- Which main factors are responsible for the water stress that is already visible in different parts of the world?
- What are the main differences between modern water supply systems and the first approaches developed in earlier times?
- How can present requirements and goals be characterized?
- How can water treatment processes be classified with respect to their principles?
- Which processes are available for water disinfection?
- Which water quality parameters are important for the corrosion of materials that are in contact with water?

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Water Sources and Pollution

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Learning targets

- Overview of important groups of water pollutants and their sources in surface waters
- Awareness of the effects of pollutants on the environment and on humans
- Knowledge about the types of pollution in groundwater and seawater

Outline

- Water pollution – Definition
- Types and sources of pollution in surface water
  - Pathogens
  - Oxygen demanding waste
  - Nutrients and salts
  - Thermal pollution
  - Heavy metals
  - Pesticides
  - Volatile organic chemicals (VOCs)
  - Emerging contaminants in water
- Groundwater and ocean pollution

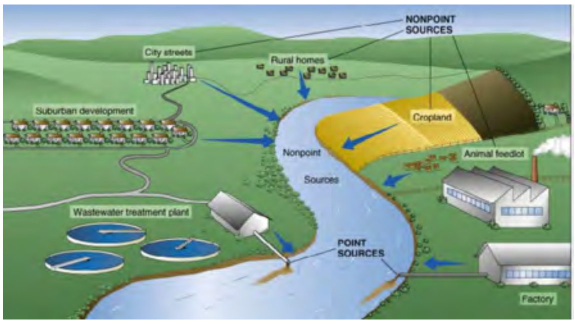
Water pollution – Definition

- Water pollution can be defined as an alteration of the physical, chemical, or biological characteristics of water through natural processes or human activities that negatively affects its legitimate use
- Sources of water pollution can be explained as point or non-point
- Point source water pollution
  - comes from a specific source, like a pipe
  - can be monitored and controlled by a permit system

  Examples: Industries or municipal treatment plants
- Non-point source pollution
  - cannot be traced to a direct discharge point
  - Pollutants diffuse into broad areas from which they enter (surface) water bodies, they may be associated with stormwater or runoff.

  Examples: Oil & grease from cars, fertilizers, animal waste, grass clippings

Water pollution – Definition



Source: Wright and Boorse, 2011.

Types and sources of pollution in surface water

Type of water pollutant	Sources of pollution
Pathogens	Human and animal waste
Oxygen-demanding wastes	Municipal wastewater and animal wastes
Nutrients	Animal wastes and inorganic wastes
Chemical pollutants	Industrial wastewater and pesticides from farms
Sediments	Soil erosion and mining erosion
Heavy metals	Industrial wastewater, mining sites, landfill leachate
Thermal pollutants	Industries and power plants

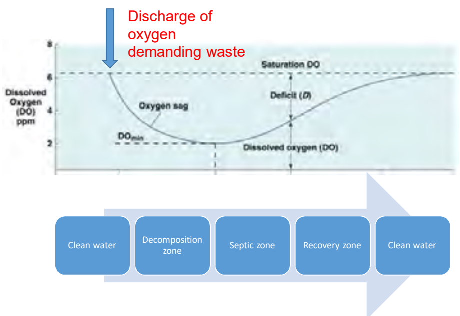
Pathogens

- Pathogens grow and multiply within the host, leading to water-borne diseases
- Poor sanitary conditions lead to accumulation of pathogens
  - Contact with human and animal excreta
  - Bathing, swimming in contaminated water or drinking of untreated water
- Examples for pathogens causing water-borne diseases are:
  - Bacteria – Chorela (*vibrio cholera*), Thyphoid fever (*salmonella typhi*)
  - Virus – Hepatitis (Hepatitis A virus), eye infection (Adenoviruses)
  - Protozoa – Diarrhea (Giardia lamblia)
  - Helminth – Ascariasis (Roundworm)

Oxygen demanding waste

- Typical examples for oxygen demanding wastes include municipal wastewater, food processing wastewater and certain inorganic wastes.
- The amount of dissolved oxygen (DO) in the water source is an indicator for the water quality.
  - COD and BOD are parameters the quantify the oxygen demand.
  - A DO of 5-8 mg/L is recommended for healthy fish populations.
- As bacteria decompose wastes, they utilize the DO in the water and reduce the DO level in the receiving water body in that way.
- As DO drops, fish and other aquatic life are threatened, furthermore, the recreational use of water bodies can be affected.

Oxygen demanding waste: The O_2 sag curve



Nutrients

- Enrichment of nutrients including nitrogen (N), phosphorus (P), calcium, and iron in the water bodies leads to water pollution
- Major sources of nitrogen include municipal wastewater, runoff from animal feedlots, and chemical fertilizers
- Enrichment of N and P leads to eutrophication and algae blooms
  - Algae require carbon, nitrogen and phosphorus for their growth
  - Death and decomposition of algae lead to DO depletion in water and add color, turbidity, tastes and odors to water, thus reducing its acceptability
- Effects of N in water bodies
  - depletion of dissolved oxygen in the receiving water body due to conversion of NH_3 to NO_2 and NO_3
  - N in the form of free ammonia is toxic to fish.

Nutrients

Examples for eutrophication in lakes

Nutrients

- The occurrence of NO_3 in water is a potential threat to public health
  - NO_3 is converted to NO_2 by bacteria in the alkaline digestive tract of infants
  - Hemoglobin in the blood is oxidized by NO_2 to methemoglobin
  - Methemoglobin cannot carry O_2 – blue baby syndrome
- Sources of phosphorus include human and animal waste, agricultural fertilizers and domestic sewage – mostly non-point sourced pollution as PO_4^{3-}.
- Phosphorus containing surfactants have now been replaced, though it was a serious issue earlier.
- Phosphorus induced eutrophication is still the largest water quality problem in lakes, reservoirs and ponds.

Salts

- Dissolved solids are accumulated in water bodies as it passes through soils and rocks
- Salts include cations such as Na^+, Ca^{2+}, Mg^{2+} and K^+, and anions such as Cl^-, SO_4^{2-} and HCO_3^-
- Their quantification is based on the total dissolved solids (TDS) concentration:
  - Fresh water < 1,500 mg/L
  - Brackish water = 1,500 – 5,000 mg/L
  - Saline water > 5, 000 mg/L
  - Seawater = 30,000 – 38,000 mg/L

Thermal pollution

- Steam-electric power plants require large amounts of cooling water
  - Nuclear plant warms about 150,000 m^3/hr of cooling water by 10°C
- Release of warm water to rivers or lakes adversely affect the aquatic life
  - For species such as trout and salmon, temperature rise is life threatening.
  - To a certain extent, temperature rise can improve fish growth.
  - Unanticipated addition of heat makes it difficult for the local ecology to adjust.
- Effect of elevated temperature on dissolved oxygen (DO) in water bodies
  - Increase in metabolic rates and increased DO demand by organisms
  - Available supply of DO in lakes and rivers is reduced due to faster DO utilization und lower DO solubility.

Heavy metals

- Metals with specific gravity greater than 4-5
  - Mercury (Hg), Lead (Pb), Cadmium (Cd) and Arsenic (As): toxic
  - Copper (Cu), Chromium (Cr), Nickel (Ni), Cobalt (Co), Iron (Fe) and Selenium (Se): required at low dosage but toxic at high dosage
- Effects of heavy metals on human health
  - Damage to nervous and kidney systems
  - Creation of mutations and induction of tumors
  - Affect excretory units called nephrons in kidneys; Cd, Pb, Hg are nephrotoxins that affect nephrons
- When heavy metal bearing residuals from water treatment are sent to landfills, the metals might be mobilized and present in the leachate

Pesticides

- Range of chemicals that kill undesirable target organisms
  - Insecticides, herbicides, rodenticides and fungicides
- Three main groups of synthetic organic insecticides
  - Organochlorines (chlorinated hydrocarbon), Organophosphates and Carbamates
- DDT (Dichlorodiphenyl trichloroethane)
  - In terms of human toxicity, DDT is relatively safe, but highly toxic to insects.
  - It is persistent and disruptive to food chains as it easily accumulates in fatty tissue.
  - Thus it is banned by several countries.
- DDT and DDE (Dichlorodiphenyl dichloroethene)
  - Interfere with enzymes that regulate the distribution of calcium in birds.
  - Affect egg shells, thus bird reproduction is severely affected.

Pesticides

Organochlorines vs. Organophosphates:

- Methoxychlor, chlordane, heptachlor, aldrin, dieldrin, endrin, and kepone are typical examples for organochlorines.
- Dieldrin and chlordane cause liver cancer.
- Aldrin and dieldrin cause birth defects in mice and hamsters.
- Kepone leads to neurological damage.
- Organochlorines have been replaced with organophosphates and carbamates.
- Organophosphates: parathion, malathion, diazinon are typical examples.
  - Not persistent and widely used
  - Less acutely toxic to humans than the organochlorines
  - Rapidly absorbed through skin, lungs and gastrointestinal tract
  - Hazardous when mixed in water at higher concentrations

Volatile organic chemicals (VOCs)

- Most commonly found contaminant in groundwater (GW)
  - 100-1000 times higher concentration in GW compared to surface water
- Often used as solvents in industrial processes
  - Suspected carcinogens or mutagens
- Typically removed from water by aeration
  - Vaporize and disperse in the atmosphere
  - Concentration of VOC in the atmosphere might reach a level of concern
- Toxic VOCs reported to be found in drinking water
  - Vinyl chloride, tetrachloroethylene, trichloroethylene, 1,2-dichloroethane, carbon tetrachloride

Volatile organic chemicals (VOCs)

- Vinyl chloride (chloroethylene)
  - Primarily used in the production of polyvinyl chloride resins
  - Human carcinogen
- Tetrachloroethylene
  - Used as a solvent and heat transfer medium
  - Causes tumors in animals, but inadequate evidence as carcinogen
- Trichloroethylene (TCE)
  - Cleaning agent for electronic parts and jet engines
  - Suspected carcinogen
- Carbon tetrachloride
  - Household cleaning agent
  - Used in fire extinguisher and solvents
  - Very toxic if ingested

Emerging contaminants in water

- Characterized by substance's environmental persistence, relative toxicity, deleterious impacts on human and other biota, occurrence frequency, and concentration
- Endocrine disrupting chemicals (EDC)
  - Number of chemicals including pesticides, detergents, combustion by-products, metals and pharmaceuticals
  - Organism's development and metabolism are dictated by an intricate system of chemical signalling and response controlled by the endocrine system.
  - EDCs interfere with natural functioning of this system by being or acting like a natural hormone, thus blocking or counteracting natural hormones.
  - They increase or decrease the production of natural hormones.
- EDCs are causing apparent human health effects
  - Reduced sperm counts in men, and breast and reproductive organ cancer

Emerging contaminants in water

- Hermaphroditism: the presence of both male and female reproductive organs in a single organism
  - Reported in frogs, salmon, oysters and turtle due to EDC
  - Sex reversal observed in 84% of female chinook salmon in Columbia River
- Estrogenic compound, 17β-estradiol (female sex hormone) has been shown to cause reproductive and developmental effects in fish
- Polybrominated biphenyl ethers (PBDEs)
  - Flame retardant additives
  - Bioaccumulate and exhibit toxicity in human and wildlife
- Perfluorocarboxylates (PFCAs)
  - Waste from the manufacture of fluorine containing surface treatment
  - Bioaccumulate and exhibit toxicity in human and wildlife

Groundwater pollution

- Pollutants such as fertilizers, pesticides, gasoline, and organic solvents can enter into groundwater aquifers from numerous sources.
- When groundwater becomes contaminated, it cannot cleanse itself of degradable wastes as quickly as flowing surface water does.
- Mechanisms for moving contamination through aquifers:
  - Dispersive transport - results from a combination of multiple mechanisms, such as molecular diffusion, eddy currents, and velocity gradients
  - Advective transport - mechanism by which a chemical is transported across the boundary of the system and through the system by the flow of the bulk medium.

Ocean pollution

- 80-90% of municipal sewage from most coastal areas of less-developed countries, and in some coastal areas of more-developed countries, is dumped into oceans without treatment.
- Crude and refined petroleum reach the ocean from a number of sources and become highly disruptive pollutants.
  - Tanker accidents and blowouts at offshore oil drilling rigs
- Volatile organic hydrocarbons in oil and other petroleum products kill many aquatic organisms immediately upon contact.
- The largest source of ocean oil pollution is urban and industrial runoff from land, much of it from leaks in pipelines and oil-handling facilities.

Questions

- What is the difference between point source and non-point source pollution?
- Give at least three pathogens which can cause water-borne diseases.
- Describe and explain the oxygen sag curve.
- Which are the main reasons for eutrophication?
- Give examples for emerging contaminants. Why are they of concern?
- Which types of pollutants are typical for groundwater and sea water?

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Water Chemistry

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Learning targets

- Knowledge about the basic structure of the water molecule
- Understanding of the terms reaction equilibrium and reactions kinetics
- Overview over some important reactions in aqueous solutions and their description

Outline

- Properties of water
- Hydrolysis reactions
- Law of mass action
- Reaction kinetics
- pH, acids, bases, and salts
- Solubility product
- Redox reactions

Properties of water

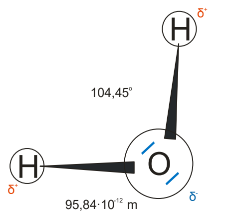
Elements:

- Hydrogen H (1)
- Oxygen O (8)

with isotopes (^{15}O), ^{16}O, ^{17}O, ^{18}O

Molecular orbitals of the electrons:

$1s^2$; $2s^2$; $2p^4$



Dipole structure of the water molecule

Properties of water

Main components found in natural waters:

- Dissolved gases
- Dissolved and suspended substances
- Bacteria and other microorganisms

Types of reactions with water molecules:

1. Electrolysis: $2\ H_2O \rightarrow 2\ H_2 + O_2$
2. Reaction with metal oxides: $CaO + H_2O \rightarrow Ca(OH)_2$
3. Reaction with nonmetal oxides: $SO_2 + H_2O \rightarrow H_2SO_3$
4. Reaction with active metals: $2\ Na + H_2O \rightarrow 2\ NaOH + H_2$
5. Formation of hydrates: $BaCl_2 + 2\ H_2O \leftrightarrow BaCl_2{\cdot}2H_2O$
6. Hydrolysis: $Al^{3+} + H_2O \leftrightarrow AlOH^{2+} + H^+$ resp. $CO_3^{2-} + H_2O \leftrightarrow HCO_3^- + OH$

Hydrolysis reactions

Hydrolysis of Al and Fe cations and polycations:

In water, the first hydrolysis step of Al^{3+} or/and Fe^{3+} cations, here depicted as Me^{3+}, results in:

$$Me^{3+} + HOH \rightarrow MeOH^{2+} + H^+$$

.... but finally $\{Me(OH)_3\}$ will be formed. The water becomes more acid, and positivelly charged colloidal particles $\{Me(OH)_3\}_n$ (some-times called as a colloidal sorbent), are able to adsorb impurities from the water.

At high and basic pH another reaction will occur:

$$Me(OH)_3 + OH^- \rightarrow Me(OH)_4^-$$

Hydrolysis reactions

By the end of 20th century some discoveries in the chemistry of aluminium were made, and so-called poly-aluminium cations were defined:

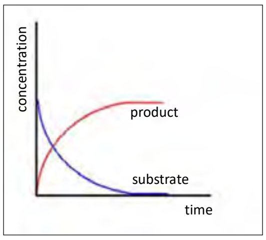
From $Al_8(OH)_{20}^{4+}$ into $AlO_4Al_{12}(OH)_{24}(H_2O)_{12}^{7+}$

The last species is briefly marked as $\{Al_{13}\}^{7+}$. It has a high valency and a very high efficiency as a coagulant, that can be related to the Schulze-Hardy rule (see lesson on coagulation).

Law of mass action

The figure shows changes of the substrate and product concentrations vs. time for a so-called **reversible reaction**.

Such a situation was considered and described by the two Norwegians Gulberg and Waage (1864) in their **law of mass action.**



Law of mass action

For a reaction

$$n \cdot A + m \cdot B \leftrightarrow x \cdot C + y \cdot D$$

the reaction rate from left to right is $v_L = k_L \cdot [A]^n \cdot [B]^m$

and from right to left it is: $v_R = k_R \cdot [C]^x \cdot [D]^y$

At an equilibrium state, always $v_L = v_R$, therefore the result for T = const is:

$$\frac{[C]^x \cdot [D]^y}{[A]^n \cdot [B]^m} = \text{const} = K$$

Law of mass action

The auto-dissociation of water is a good example for a reversible reaction:

$$H_2O \leftrightarrow H^+ + OH^-$$

resp. $$2\,H_2O \leftrightarrow H_3O^+ + OH^-$$

Application of the law of mass action gives:

$$K = \frac{[H^+] \cdot [OH^-]}{[H_2O]} = 1.8 \cdot 10^{-16} \text{ mol/L}$$

Reaction kinetics

Reaction kinetics describe the rate of chemical reactions. The mathematical expression is:

$$v = -\frac{dc}{dt} = \frac{dx}{dt}$$

where: c – the substrate concentration
x – the product concentration

Reaction kinetics

In water treatment processes, first order reactions are the most common ones:

$$v = -\frac{dc}{dt} = k \cdot c$$

$$-\int_{c_0}^{c} \frac{dc}{c} = k \cdot \int_0^t dt$$

$$\ln c = \ln c_0 - k \cdot t$$

As a result of integrating the kinetic equation in the range of time (***0, t***) for the concentration of the substrate (***c_0, c***), we obtain a final formula expressing a linear relationship between ***ln c*** and ***t***, where the gradient coefficient is ***–k***.

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Reaction kinetics

For the purpose of comparison, the reaction time to reach 50 % of the initial concentration $t_{1/2}$ is often used:

If $c = 0.5 \cdot c_o$ for $t_{1/2}$

then $\ln \frac{0.5 \cdot c_o}{c_o} = -k \cdot t_{1/2}$

hence $t_{1/2} = 0.693 / k$

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Reaction kinetics

The rate of reaction increases with increasing temperature. The simplest approach to describe this phenomenon is given by the Van't Hoff formula:

$$k_{T+\Delta T} = k_T \cdot a^{(\Delta T/10)}$$

As a result, each increase in temperature by 10 degrees speeds up the reaction rate by a factor of 2-4.

Therefore the temperature in a treatment plant (summer or winter) can also effect water treatment efficiency.

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pH, acids, bases, and salts

The molar concentration of water can be derived from its mass density and the molecular weight:

$$c(H_2O) = 1.000 \text{ g/L} / 18 \text{ g/mol} = 55.6 \text{ mol/L}$$

This can be used to calculate the ionic product of water from the law of mass action (see slide no 10):

$$[H^+] \cdot [OH^-] = K \cdot [H_2O]$$
$$= 1.8 \cdot 10^{-16} \text{ mol/L} \cdot 55.6 \text{ mol/L}$$
$$= 10^{-14} \text{ (mol/L)}^2 \quad \text{(at T = 298 K)}$$

Water Supply: Water Chemistry 15

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pH, acids, bases, and salts

Definitions: $pH = -\lg a(H^+)$ and $pOH = -\lg a(OH^-)$

with activities $a(H^+)$ and $a(OH^-)$ in mol/L

From $a(H^+) \cdot a(OH^-) = 10^{-14}$ (mol/L)^2 follows pH + pOH = 14

Question: What is the pH of pure water?

For water $[H^+] = [OH^-]$ hence $[H^+]^2 = 10^{-14}$ (mol/L)^2

and $[H^+] = 10^{-7}$ mol/L

Therefore $pH = -\lg 10^{-7} = -(-7) \lg 10 = 7$ (when conc. = activities)

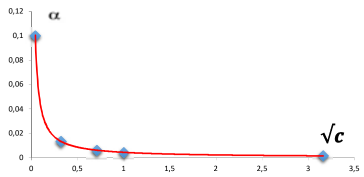
pOH = ?

Water Supply: Water Chemistry 16

WaterHarmony

pH, acids, bases, and salts

The degree of dissociation is the fraction of molecules that have dissociated. It is usually indicated by the Greek symbol **α**. The values of α have not been collected, but they can be calculated, because they depend on c, as shown below:



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pH, acids, bases, and salts

Cationic hydrolysis is very important for inorganic coagulants (Fe^{3+} or Al^{3+}) in water treatment plants (see slide no 6).

The simplest cationic hydrolysis reaction is the following one:

$$NH_4^+ + H_2O \leftrightarrow NH_4OH + H^+$$

Therefore K_h can be expressed as follows:

$$K_h = \frac{[NH_3] \cdot [H^+]}{[NH_4^+]} \cdot \frac{[OH^-]}{[OH^-]} = \frac{10^{-14}}{K_z} = \frac{[H^+]^2}{c_s}$$

hence $[H^+] = \sqrt{\frac{c_s \cdot 10^{-14}}{K_z}}$

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pH, acids, bases, and salts

Example: What is the pH of 0.1 M NH_4Cl, if $K_b = 1.8 \cdot 10^{-5}$ mol/L ?

$$[H^+] = \sqrt{\frac{10^{-1} \cdot 10^{-14}}{1{,}8 \cdot 10^{-5}}} =$$

$$= \sqrt{55{,}56 \cdot 10^{-12}} = 7{,}45 \cdot 10^{-6}$$

$$pH = 6 - \lg 7{,}45 = 6 - 0{,}87 = 5{,}13$$

Conclusion: The cationic hydrolysis of inorganic coagulants like $Fe_2(SO_4)_3$ or $AlCl_3$ leads to the input of acid in the water treated.

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Solubility product

The law of mass action (see slide no 10) can be used to calculate the solubility product of salts in water, e.g. of AgCl:

$$K = \frac{[Ag^+] \cdot [Cl^-]}{[AgCl]_{solid}} \quad \text{where } [AgCl]_{solid} = \text{const}$$

Thus $L = [AgCl]_{solid} \cdot K$

$= [Ag^+] \cdot [Cl^-]$

$=$ solubility product of AgCl in $(mol/L)^2$

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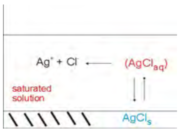
Solubility product

Example: Precipitation of AgCl

$AgCl_s \leftrightarrow Ag^+_{aq} + Cl^-_{aq}$

with $L \approx 10^{-10}$ $(mol/L)^2$



From the solubility product, the ion solubilities **x** can be calculated:

$[AgCl_{aq}] = [Ag^+] = [Cl^-] = \mathbf{x}$ and $L = \mathbf{x} \cdot \mathbf{x} = x^2$, hence $\mathbf{x} = \sqrt{L}$

This formula is valid for all precipitates formed of monovalent ions.

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Solubility product

When di- or tri-valent ions are involved, the calculation of the ion solubilities must be modified, e.g.

$Ag_2CrO_{4s} \leftrightarrow 2\ Ag^+ + CrO_4^{2-}$

$[Ag_2CrO_{4aq}] = [CrO_4^{2-}] = \mathbf{x}$, but $[Ag^+] = 2\ \mathbf{x}$

therefore $L = [Ag^+]^2 \cdot [CrO_4^{2-}] = (2\ \mathbf{x})^2 \cdot \mathbf{x} = 4\ \mathbf{x}^3$, and $\mathbf{x} = (L/4)^{1/3}$

Other examples: $Cu_3PO_4 \rightarrow L = (3\ \mathbf{x})^3 \cdot \mathbf{x} = 27\ \mathbf{x}^4$

$Ca_3(PO_4)_2 \rightarrow L = (3\ \mathbf{x})^3 \cdot (2\ \mathbf{x})^2 = 108\ \mathbf{x}^5$

The solubility is important for the removal of heavy metals, and for the formation of $Al(OH)_3$ and $Fe(OH)_3$ during coagulation.

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Solubility product

The ion solubility can be changed by adding another salt:

Example: The solubility of AgCl in water, with $L = 1 \cdot 10^{-10}$ $(mol/L)^2$, is

$\mathbf{x} = \sqrt{L} = 10^{-5}$ [mol/L]

What is the ion solubility of Ag in 0.1M NaCl?

Here $[Ag^+] \neq [Cl^-]$, but still $L = [Ag^+] \cdot [Cl^-]$

therefore $\mathbf{x'} = [AgCl] = [Ag^+] = L/[Cl^-] = 10^{-10}/10^{-1} = 10^{-9}$ [mol/L]

Thus, the solubility of Ag is reduced by a factor of 10^4 in this case!

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Solubility product

Solubility - selected data

Chemical formula	Solubility product **L**	Ion solubility mol/L	Ion solubility mg/L
$CaCO_3$	$4.7 \cdot 10^{-9}$	$[Ca^{2+}]=[CO_3^{2-}]=7 \cdot 10^{-5}$	0.0028 mg Ca^{2+}/L 0.0042 mg CO_3^{2-}/L
$PbCl_2$	$1.6 \cdot 10^{-5}$	$[Pb^{2+}]=1.6 \cdot 10^{-2}$	3.3 mg Pb^{2+}/L (**high**)
$AlPO_4$	$5.8 \cdot 10^{-19}$	$[Al^{3+}]=[PO_4^{3-}]=7.7 \cdot 10^{-10}$	$7.23 \cdot 10^{-8}$ mg PO_4^{3-}/L $2.0 \cdot 10^{-8}$ mg Al^{3+}/L
$Al(OH)_3$	$2.0 \cdot 10^{-33}$	$[Al^{3+}] \approx 3.0 \cdot 10^{-9}$	$\approx 8 \cdot 10^{-8}$ mg Al^{3+}/L
$Fe(OH)_3$	$6.0 \cdot 10^{-38}$	$[Fe^{3+}]= 0.2 \cdot 10^{-9}$	$\approx 1 \cdot 10^{-8}$ mg Fe^{3+}/L
$Ca_3(PO_4)_2$	$1.3 \cdot 10^{-32}$	$[Ca^{2+}]=4.9 \cdot 10^{-7}$ $[PO_4^{3-}]=3.3 \cdot 10^{-7}$	$\approx 2 \cdot 10^{-5}$ mg Ca^{2+}/L $\approx 3 \cdot 10^{-5}$ mg PO_4^{3-}/L
Fe_2S_3	$1.0 \cdot 10^{-88}$	$[Fe^{3+}]=2 \cdot 10^{-18}$ $[S^{2-}]=3 \cdot 10^{-18}$	$\approx 10^{-16}$ mg Fe^{3+}/L $\approx 10^{-16}$ mg S^{2-}/L(**low**)

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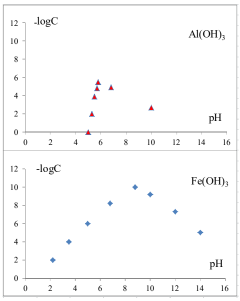
Solubility product

pH effect on solubility:

Solubility of metal hydroxides like $Al(OH)_3$ and/or $Fe(OH)_3$ strongly depends on pH of the water. These graphs illustrate the solubilities of $Al(OH)_3$ and $Fe(OH)_3$ as a function of pH.

Minimum solubility of $Al(OH)_3$ comes at pH ≈ 6 and minimum solubility of $Fe(OH)_3$ at pH ≈ 9. $Fe(OH)_3$ is less sensitive on pH (wide range of pH) compare to $Al(OH)_3$, where the range of pH is more narrow. This is important for coagulation with Al and Fe salts.



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Redox potential

Definition of the redox potential:

$$E = E_o' + (R \cdot T / z \cdot F) \cdot \ln K$$

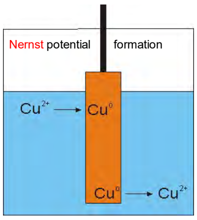
with z = valency ; F = Faraday's constant
and $K = a(Cu^{2+})/a(Cu)$

For standard conditions (T = 298 K) the equation looks as follows:

$$E = E_o' + 0.0295 \cdot \log K$$

With $E_o = E_o' - 0.0295 \cdot \log a(Cu)$ the final equation is:

$$E = E_o + 0.0295 \cdot \log a(Cu^{2+})$$



Principle of a first-kind electrode

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Redox potential

Values of standard potentials E_o (in V)

$Au^{3+} + 2e^- = Au^+$	1,29
$Cl_2 + 2e^- = 2\,Cl^-$	1,385
$Cr_2O_7^{2-} + 14\,H^+ + 6e^- = 2\,Cr^{3+} + 7\,H_2O$	1,36
$ClO_3^- + 6\,H^+ + 6e^- = Cl^- + 3\,H_2O$	1,45
$PbO_2 + 4\,H^+ + 2e^- = Pb^{2+} + 3\,H_2O$	1,456
$HClO + H^+ + 2e^- = Cl^- + H_2O$	1,49
$MnO_4^- + 8\,H^+ + 5e^- = Mn^{2+} + 4\,H_2O$	1,52
$Pb^{4+} + 2e^- = Pb^{2+}$	1,69
$H_2O_2 + 2\,H^+ + 2e^- = 2\,H_2O$	1,77
$Co^{3+} + e^- = Co^{2+}$	1,84
$O_3 + 2\,H^+ + 2e^- = H_2O + O_2$	2,07
$F_2 + 2e^- = 2F^-$	2,85
$Al^{3+} + 3e = Al$	-1.67
$Fe^{2+} + 2e = Fe$	-0.44

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Redox potential

Example: Oxidation by MnO_4^- (Permanganate titration)

$MnO_4^- + 8\,H^+ + 5e = Mn^{2+} + 4\,H_2O$ (in H_2SO_4 acid solution)

e.g. oxidation of Fe^{2+}:

$2\,KMnO_4 + 10\,Fe^{2+} + 3\,H_2SO_4 + 10\,H^+ \rightarrow 2\,MnSO_4 + 10\,Fe^{3+} + K_2SO_4 + 8\,H_2O$

with $Mn^{7+} + \underline{5e} \rightarrow Mn^{2+}$ **2x**

and $Fe^{2+} - \underline{e} \rightarrow Fe^{3+}$ **10x**

Another example: Oxidation of H_2O_2:

$2\,MnO_4^- + 5\,H_2O_2 + 6\,H^+ = 2\,Mn^{2+} + 5\,O_2 + 8\,H_2O$

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Questions

- Give examples for three types of reactions with water molecules.
- What are poly-aluminium cations, where are they found, and why are they important in water treatment?
- Describe briefly the idea of the law of mass action.
- What means the approach of first order kinetics, and how is temperature affecting reaction kinetics in general?
- How can the solubility of salts be affected by the addition of another salt?
- How is the redox potential defined?

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Stumm, W. and Morgan, J.J.: Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters. 3rd ed., Wiley, Hoboken 1995

Water intakes and transport systems

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Norwegian University of Life Sciences

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Learning targets

- Becoming familiar with estimations of water demand and its fluctuations
- Knowledge about the structure and main elements of water transport and water distribution systems and some basic design criteria
- Overview of approaches for leakage detection and network maintenance

Outline

- Water demand
- Intakes and main transmission lines
- Pumping stations
- Storage tanks
- Distribution networks and analysis
- Operation and maintenance

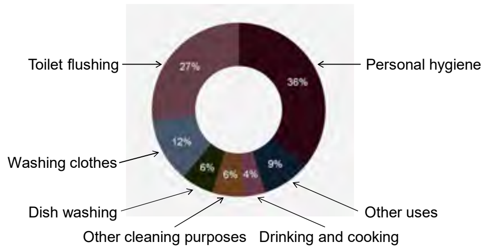
Water demand

Water consumption in European households (in L/p·d)

England 2013	147
Denmark 2013	107
Sweden 2013	158
Belgium 2004	102
Germany 2010	107
Finland 2013	140
Netherlands 2010	120
Norway	Officially [Statistics Norway] ca. 200 Reality 135 – 150

Water demand

Water usage in German households 2017 [BDEW, 2018]:

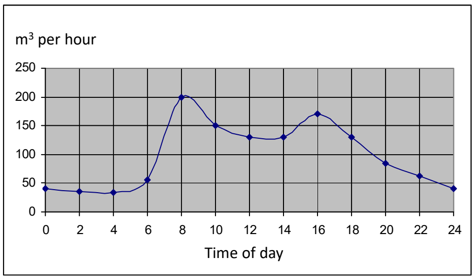


Water demand

Water demand in companies (examples) [Twort et al., 2017]

Company	Water demand per produced unit
Bakeries	2 m^3/ ton product
Breweries	7 m^3 / m^3 beer
Meat- and vegetables conservation	30 – 35 m^3 / ton product
Plastics factories	9 – 23 m^3 / ton product
Tanneries	83 m^3 / ton garment
Fish products, including packing	8.5 m^3 / ton product
Laundries	20 m^3 / ton laundry
Butcheries	5 m^3 / ton animals
Dairy, milk production	3 m^3 / m^3 milk
Soda factory	7 m^3 / m^3 soda
Small shops/offices	40 – 60 liters/employee/day
Hospitals	350 – 500 L / bed / day
Hotels	350 – 400 L / hotel bed

Water demand



Diurnal demand pattern, example

Water demand

Definition of peaking factors f and k:

- $f_{max} = Q_{max\ day} / Q_{mean\ day}$
- $f_{min} = Q_{min\ day} / Q_{mean\ day}$
- $k_{max} = Q_{max\ hours} / Q_{mean\ hour}$
- $k_{min} = Q_{min\ hour} / Q_{mean\ hour}$

Water demand

Calculation of peaking factors:

1) Daily maximum f_{max} = demand on the day of max. demand each year / mean daily demand. If demand on the day of max. demand is e.g. 6000 m³ and mean daily demand is 4000 m³, then f_{max} = 6000 / 4000 = 1,5.

2) Daily minimum f_{min} = demand on the day of min. demand each year / mean daily demand. If demand on the day of min. demand is e.g. 3000 m³ and mean daily demand is 4000 m³, then f_{min} = 3000 / 4000 = 0,75.

3) Hourly maximum k_{max} = demand during the hour of max. demand, daily / mean hourly demand. If demand during the hour of max. demand is e.g. 233 m³ and the mean hourly demand is 166 m³, then k_{max} = 233 / 166 = 1,4.

4) Hourly minimum k_{min} = demand during the hour of min. demand, daily / mean hourly demand.

Water demand

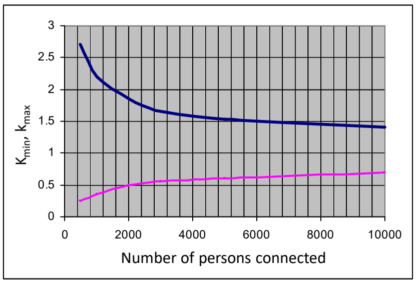
Design of water supply systems:

$$Q_{max} = (P \cdot q_{spec} \cdot f_{max} \cdot k_{max} + P \cdot q_{leak}) / 24 \cdot 60 \cdot 60 + Q_{ind} + Q_{fire}$$

Q_{max} = Maximum demand, annually (l/sec)
P = Number of persons
q_{spec} = Demand per capita (L/p·d)
Q_{leak} = Leakages per capita (L/p·d)
Q_{ind} = Demand of industry (L/s)
Q_{fire} = Fire demand (L/s)

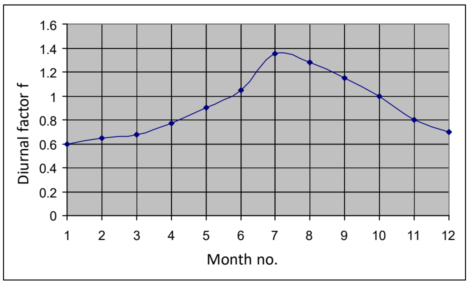
(In Norway the guidelines require Q_{fire} = 20 L/s for low development residential areas and 50 L/s otherwise.)

Water demand



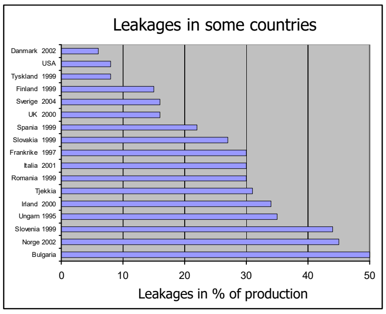
Variation of k_{max}, k_{min} with number of persons connected

Water demand

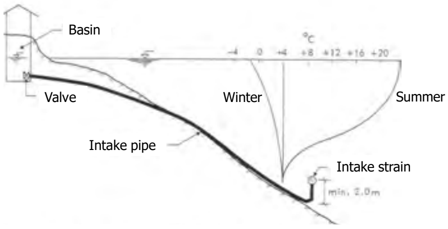


Diurnal variation of f as a function of month

Water demand



Intakes and main transmission lines

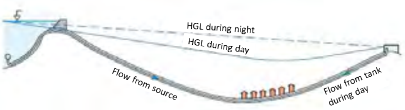


Intake arrangement, sketch

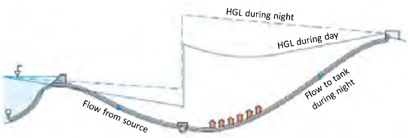
A deep intake in a lake will ensure a stable temperature all year round. Particles and sediments are kept out of the intake by placing it above the lake bottom. Intake pipes should have an even slope in order to avoid accumulation of air.

Intakes and main transmission lines

A.

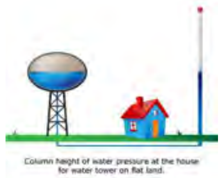


B.



HGL = hydraulic grade line, to be overcome by gravity or by pumping

Intakes and main transmission lines



Definition of the ***pressure head h***:
It expresses the height of a column of water that gives a certain pressure at the bottom of the column.

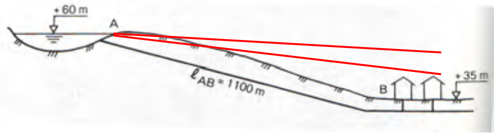
The pressure head in houses should be greater than 15 m and less than 85 m.

Intakes and main transmission lines

The potential energy at the source (A) may be used to

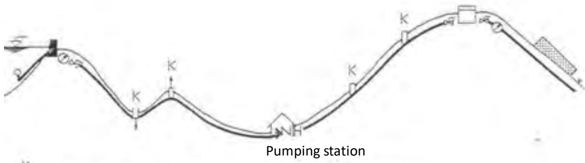
1) preserve a high pressure, and consequently, a lower waterflow in the pipe at (B), or
2) a higher waterflow and, consequently, a lower pressure at (B).

One cannot have high pressure and high waterflow at the same time.



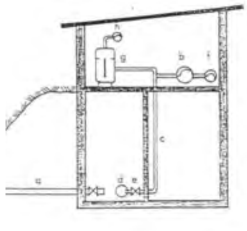
It is very energy demanding to reduce the pressure in a pressure reducing valve and then increase the pressure by pumping further downstream.

Intakes and main transmission lines



Typical equipment needed for transmission pipes

Pumping stations



a Intake pipe, e.g. from a lake
b Pump
c Suction side pipe from intake chamber
d Strain
e Flap valve will let water flow only in one direction
f Pressure side pipe
g Vacuum tank
h Vacuum pipe evacuates air that accumulates in the tank

Pumping station with a vacuum tank

Remember: A centrifugal pump cannot start when it is filled with air.

Pumping stations

Equipment typically found in a pumping station for drinking water:

- Pumps (usually of the centrifugal type)
- Backflow prevention valve. If there is a risk that the pump will empty when not operating, this valve need to be put on the suction side pipe.
- Measures to control the water hammer: Air vessel, adding a flywhell to the pump shaft, safety valve, frequency controlled pumps
- Flow meter
- Pressure sensors on both suction and pressure sides of the pump
- Shutoff valves (on both sides of all important equipment that needs to be taken out for repir)
- Emergency generator (in critical pumping stations)
- Monitoring and control (PLS)
- Security alarm etc.
- Bypass pipe

Pumping stations

Power requirement of a pump (for given units):

$$P = (q \times h) / 102\ \eta$$

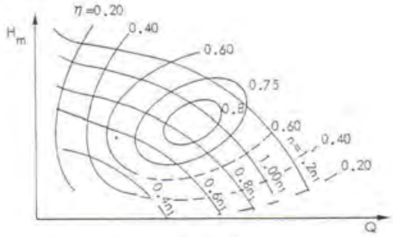
P = power requirement (kW)

q = flow through pump (L/s)

h = pressure head supplied by pump (m)

η = efficiency of the pump (e.g. 0.8)

Pumping stations

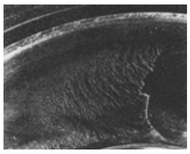


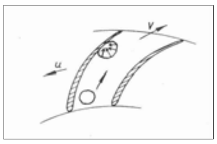
Pump characteristics and how it affects efficiency

Pumping stations

Cavitation in pipes:

If the pressure falls below the vapor pressure of the water, the water will start to “boil”, producing small vapor cavities. If the pressure then increases further downstream, the cavities will collapse suddenly. If this happens near a wall, the collapse will be asymmetrical and a jet will hit the wall. This produces a force that may damage the wall material with time.





Pumping stations

Cavitation in pumps:

In the pump and on the suction side of the pump, the pressure is often low and there is a risk of vapor cavities forming. When these vapor cavities reach the pressure side of the pump, the pressure increases very rapidly and the cavities collapse, i.e. imploed. This phenomenon may damage the pump.

In order to avoid this, the NPSHa-value on the pump suction end must be larger than the NPSHr-value of the pump.

The definitions are:

- NPSH available (NPSHa): Net Positive Suction Head available = absolute pressure at the suction port of the pump
- NPSH Required (NPSHr): Net Positive Suction Head required = minimum pressure required at the suction port of the pump to keep the pump from cavitating

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Pumping stations

Principle of how to compute NPSHa:

In order to avoid cavitation, the NPSHa-value must be larger than the NPSHr-value

- NPSHr is supplied by the pump manufacturer, and NPSHa you need to calculate for your specific setup
- NPSHa = HA + HZ - HF + HV – HVP

HA = atmospheric pressure (10 m of water head)
HZ = Static head on suction side (vertical distance between the upstream source and the pump level)
HF = Suction side friction head loss (m of water head)
HV = Velocity head (v^2/ 2 g)
HVP= Vapor pressure of water at the given temperature

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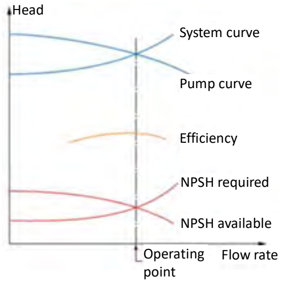
Pumping stations

Relationship between operating point, efficiency, and NPSH:



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Pumping stations

Example of how to compute NPSHa:

The water level in a tank is 2 m above the pump suction port, the atmospheric pressure is 10 m of water head, the friction head loss between the tank and the pump is 2 m of water head. The vapor pressure of water at 10 degrees celsius is 0,1 m of water head. The water velocity is 2 m/s.

The value from the NPSHr-curve of the manufacturer is 2,5 m for the chosen pump.

This gives an NPSHa-value of: 10 + 2 – 2 + 0,2 - 0,1 = 10,1 m.

Since the NPSHa-value is larger than the NPSHr-value, this pump will work well, given that all other requirements are met.

(Both the water vapor pressure and the velocity head may usually be neglected since they are very small).

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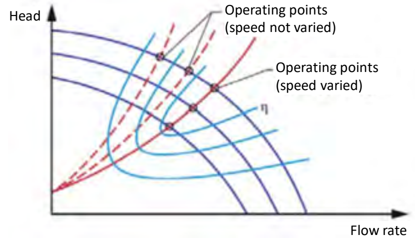
Pumping stations

Operating point of a variable-speed centrifugal pump:



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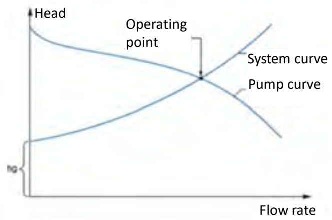
Pumping stations

Operating point of a pump:



h_g is the static head, h_f is the friction head loss and h_s are minor losses. The system curve is the sum of these three quantities and must equal the head supplied by the pump.

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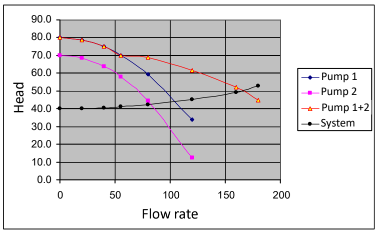
Pumping stations

→ Pumps operating in parallel: Addition of flow rates



→ Pumps operating in series: Addition of pressure heads from each pump in order to obtain the pump curve for the combined pumps

Pumping stations

Water hammer:

A water hammer may arise when the water velocity in a pipe changes rapidly. The maximum rise in the pressure head due to a water hammer is given by:

$$\Delta H = \frac{(V_1 - V_2) x C}{g}$$

where
- ΔH = change in pressure head due to water hammer
- V_1 = velocity before velocity change (m/s)
- V_2 = velocity after velocity change (m/s)
- C = speed of sound in the water/pipe system (m/s)
- g = acceleration of gravity 9,81 ms^{-2}

The speed of sound in the water/pipe system can be computed as:

$$C = \sqrt{\frac{1}{\rho\left(\frac{1}{Ev} + \frac{D}{S * E}\right)}}$$

where
- C = speed of sound in the water/pipe system (m/s)
- ρ = density of water (kg/m^3)
- Ev = modulus of elasticity for water (N/m^2)
- E = modulus of elasticity for pipe material (N/m^2)
- D = pipe diameter (m)
- S = pipe wall thickness (m)

Storage tanks

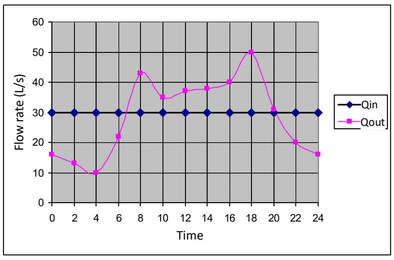
Storage tanks are often designed to hold these volumes:

1. Volume needed to accomodate diurnal water use variation
2. A safety reserve in case of e.g. a main pipe breaks
3. Reserve for firefighting water

Storage tanks provide additional benefits besides the storage function:

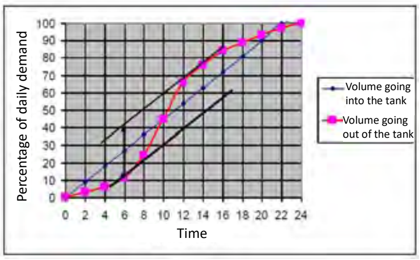
- They stabilize the pressure in the network.
- They dampen water hammer effects in the transmissionand distribution network.
- Particles in the water may sediment.
- The tank may function as a reactor for chlorination.

Storage tanks



Sketch showing the principle for accomodating diurnal water demand

Storage tanks



Accumulated water volume in and out of storage tank

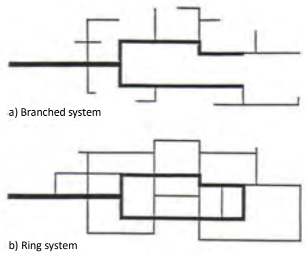
Distribution networks and analysis

Pipe materials used in water networks in Norwegian municipalities:

Material	Length (m)	Percentage
Asbestos cement	2.198.741	4,9 %
Iron/steel	14.359.458	32 %
PVC	15.907.698	35,5 %
PE	10.094.407	22,5 %
GRP	98.693	0,2 %
Other	1.078.673	2,4 %
Unkown	1.073.705	2,4 %

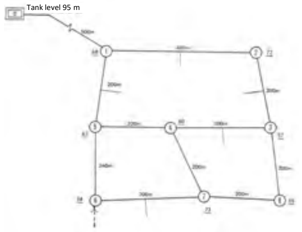
Distribution networks and analysis

Basic structures for network layout:



Distribution networks and analysis

The network is simplified to a set of nodes and links connecting the nodes. All demands happen in the nodes (an idealization):

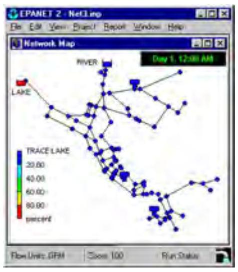


Pipe network with pipe lengths and elevations (underlined)

Distribution networks and analysis

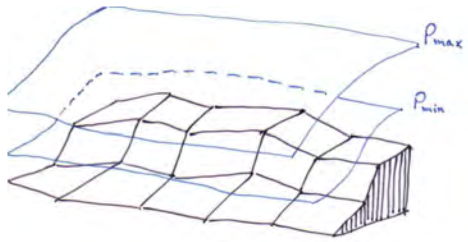
Kirchhoff laws are the basis for the solution algorithms:

- Flows into a node must equal flow out from the node (conservation of mass)
- The sum of all head losses around any closed loop in a network equals zero when clockwise flows are taken to give positive head losses and counterclock-wise flows are taken to give negative head losses (conservation of energy)



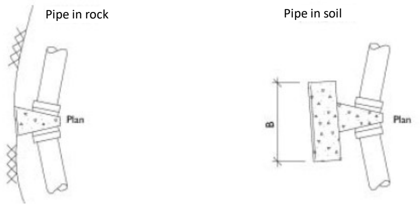
Distribution networks and analysis

Decision variables must be adjusted so that pressures are always within acceptable levels, for all design flow situations:



Distribution networks and analysis

When a pressurized pipe goes through a bend, large forces arise that must be controlled:



Distribution networks and analysis

Valves:

Air-release valve: In all high points, air pockets may accumulate in the network. These air pockets will cause additional head losses and consequently higher energy costs related to pumping, and the may exacerbate water hammer problems. In some situations, the rate of corrosion may also increase. Air-release valves should be installed everywhere air may accumulate. Air is automatically released through these valves.

Automatic air-release valve for expelling air that is released from the water:

- When air bubbles gather in the valve, the float is lowered and air is released.
- When air is expelled and the water rises, the float rises and the valve closes.

Distribution networks and analysis

Valves:

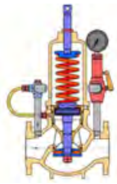
Drain valve: It must be possible to inspect the pipe with cameras or perform maintencance such as flushing, plug driving, scraping, rehabilitation etc. In these cases, the pipe must be emptied. Therefore, drain valves are needed in low points in the network. Drain valves should be put in manholes that can drain to a nearby river or a sewer.

Non-return valve: Non-return valves are needed when we only want water to flow in one direction. This is often the case in pumping stations where we don't want the pumped water to flow backwards when the pump is turned off. Another example is to put a backflow prevention valve on a pipe connected to a storage tank if we don't want water to exit from the tank through that pipe.

Distribution networks and analysis

Valves:

Pressure reducing valve: Too high pressures will lead to leakages and damages, both in houses and in the water distribution network. The pressure reducing valve reduces the pressure upstream of the valve to a constant specified (lower) pressure on the downstream side of the valve. These valves are also used to pass water from one pressure zone to another.

Distribution networks and analysis

Valves:

Safety valve / burst valve: A safety valve releases high pressures that may lead to damages. It opens at a specified maximum allowable pressure and ensures That the pressure does not exceed the specified one. It is often used in pumping stations and other places where damaging water hammer effects may arise.

Gate valve:

Butterfly valve:

Distribution networks and analysis

Fire hydrants (spring loaded and closable):

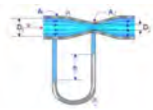
Capacity is usually set to Qmin = 35 L/s at a pressure in the pipe of 1 bar (0,1 MPa or 10 m of water head).


Distribution networks and analysis

Other elements:

Flange adapter

Manometer



Venturimeter for flow metering

Woltmann turbine water meter

Distribution networks and analysis

Valves:

Check valves that close if flow increases because of a pipe break

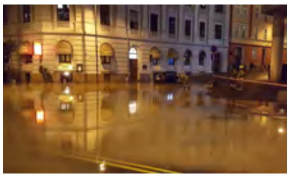
Check valve with weight loaded lever

Check valve with orifice flow meter

Distribution networks and analysis

Examples for broken water mains:

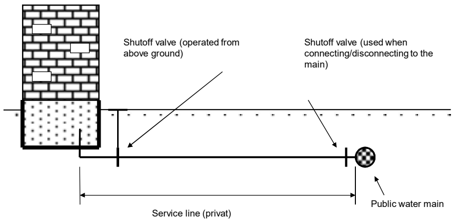
University of California-LA had damaging flash floods after a broken water main spilled millions of gallons of water onto campus.
Los Angeles, 29 July, 2014



Vika, Oslo closed off after a water main broke.
19 October, 2016

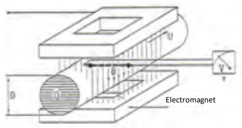
Operation and maintenance

Shutoff valves in service lines:



Operation and maintenance

Flow meters:

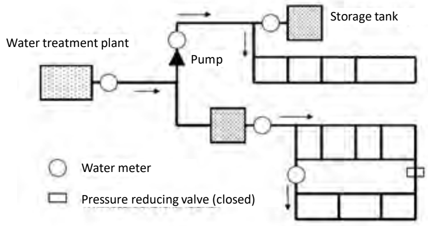


Flow meters with turbines and mechanical registration

Electromagnetic flow meters are more common today. They do not require a long straight pipe section upstream of the meter.

Operation and maintenance

Typical localization of flow meters:



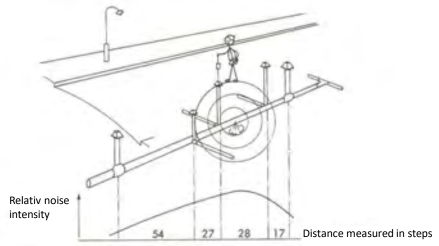
Operation and maintenance

Procedure for leakage reduction projects:

- Monitor the total amount of water produced during several days and compute probable leakage levels based on known demands
- Perform measurements in designated zones if there is a problem with leakages. Start with larger zones, then go to smaller zones until the leakage has been localized.
- Fine localization is done by ground listening, valve listening or leak noise correlator.
- Decide whether to uncover the leaking pipe and do a repair (is the leakage large enough to warrant the cost?)

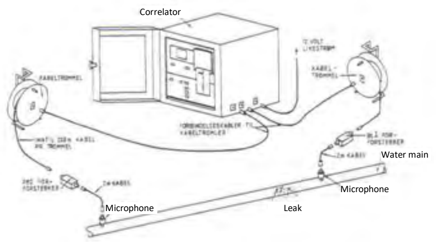
Operation and maintenance

Acoustic search for leakages – must usually be performed at night:



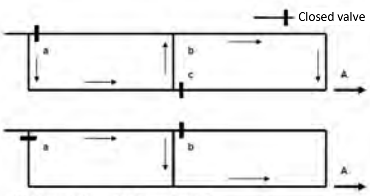
Operation and maintenance

Leakage detection based on the travel time of sound in each direction from the leakage point: Leak noise correlator



Operation and maintenance

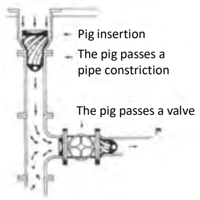
Plan for flushing a water network:



Water is first drained through a valve in manhole A. At first flushing, the valve in manhole a and manhole c is closed.
At second flushing, the valve in manhole a and manhole b is closed. After the two flushings, all pipes in this loop have been flushed.

Operation and maintenance

Removal of scaling in pipes: Driving various types of «pigs» through the pipes until the system is clean.

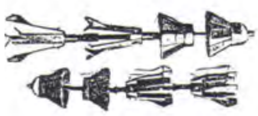


Repeated sessions with various pig hardnesses will help to clean sediments and growth and corrosion products from the pipe walls

Operation and maintenance

Removal of corrosion products in pipes: Corrosion products must be scraped away with dedicated steel scrapers that are pulled through the pipes with a winch.

A corroded drinking water main



Steel scrapers

Questions

- How is the household water demand varying with time of the day and month of the year, respectively?
- Which is the typical equipment needed for transmission pipes?
- What is the reason for cavitation, and what does NPSH mean?
- Which basic structures for network layout have been developed?
- What are the tasks of air-release valves, pressure reducing valves, and check valves?
- Why is leakage detection important, and how can it be done?

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Brandt, M.J., Johnson, K. M., J., Elphinston, A.J. and Ratnayaka, D.D.: Twort's Water Supply, 7th ed., Butterworth-Heinemann, Oxford 2017

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https://www.bdew.de/media/documents/20180815_Trinkwasserverwendung-HH-2017.pdf

Filtration

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Professor
Igor Sikorsky Kyiv Polytechnic Institute
National Technical University of Ukraine

Learning targets

- Overview of classification criteria for filter materials and filtration units
- Understanding of mechanisms for the retention of particles in deep-bed filters, including pressure loss development and breakthrough
- Knowledge about the construction of modern filters for technical and household applications

Outline

- Characterization and classification of filters
- Filter properties
- Filter operation
- Design of modern filter systems

Characterization and classification of filters

Typical hydraulic performances of layer and volume filtration processes can be classified by:

- **Filtration rate** in m/h
  This parameter describes the amount of water (m^3/h) that is passing through 1 m^2 of the filter surface
- **Flushing intensity in** L/s
  This is the amount of water (L/s) needed to wash m^2 of the filter surface.

Characterization and classification of filters

Filter materials can be classified depending on the quality of the purified water, productivity of the filter, and cost considerations:

- **Grain** – main types of material are quartz sand, anthracite, polystyrene, expanded clay, activated carbon, etc.
- **Reticulated foam** – foams of different size and openings, depending on the size of the impurities, like nets
- **Fabric** – cotton, linen, cloth, glass or nylon canvases
- **Alluvial** – water purification by a layer of wood flour, diatomite, asbestos flour incorporated in the frame of porous ceramic, net, fabric canvas
- **Cartridge** – synthetic porous elements with very small pores or specific filling
- **Fibrous** – a bunch of long elements

Characterization and classification of filters

Grain filters – the widest used filters because of their low costs and easiness in operation. The main types of this kind of filters:

- **Adhesive** – for the removal of particles
- **Sorption** – for the removal organics, e.g. tastes and odor
- **Ion-exchange** – for the exchange of anions and cations

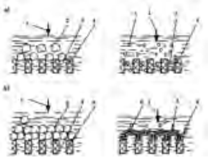
Filter properties

The properties of the grains used as filter material depend on:

- **Filtration rate**, m/h – slow (0,1 - 0,2), rapid (5,5 - 15), ultrafast (> 25)
- **Particle size of the filling** – small-grained (0,3 - 1 mm), medium-grained (0,5 - 0,8 mm), coarse-grained (1 - 2 mm)
- **Number of filtering layers** – one-layer, multi-layer
- **Flow quantity** – one-flow, two-flows
- **Pressure** – high pressure, atmospheric pressure
- **Direction of filtering flow** –vertical ascending and declining, horizontal (including radial)
- **Filling material** – heavier than water or floating

Filter operation

Mechanisms of separating particles of different sizes in filters:



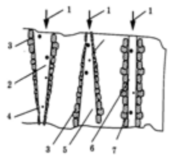
Scheme of transporting particles to the filter grains:

a) at the initial moment; b) at the final moment

1 – the direction of hydraulic flow; 2 – large particles; 3 – porous channel; 4 – porous channel walls; 5 – small particles; 6 – bridge

Filter operation

Mechanisms of separating particles of different sizes in filters:

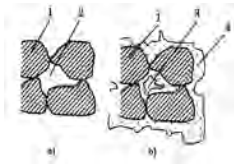


Scheme of porous channels in a packed filter:

1 – the direction of water flow; 2 – narrow channel; 3 – large grains; 4 – small grains; 5 – expanding channel; 6 – channel with constant diameter; 7 – relatively homogeneous grains

Filter operation

Mechanisms of separating particles of different sizes in filters:

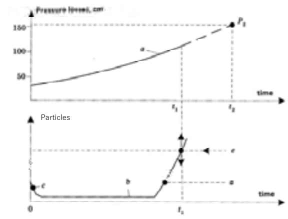


Scheme of volume loaded with particles in the pores of the filter material:

1 – grains; 2 – clear channel; 3 – loaded channel; 4 – particles

Filter operation

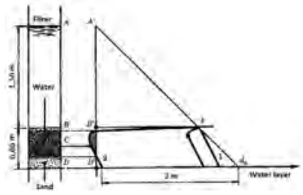
Course of a typical filter run:



Development of pressure loss and filtrate quality during filter operation

Filter operation

Course of a typical filter run:



Pressure distribution inside polydisperse (heterogeneous) filter material (with fine sand grains on the top):

1 – in clean sand; 2 – in loaded sand at a pressure loss of about 2 m

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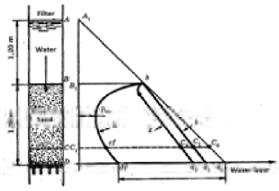
Filter operation

Course of a typical filter run:



Pressure distribution inside homogeneous) filter material (with same grain size on the top and the bottom):

1 – in clear sand; 2 – during loading; 3 – in loaded sand (pressure loss ~ 2 m)

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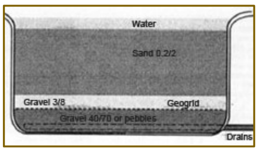
Slow sand filtration



- Slow sand filtration is oldest kind of water treatment.
- A well-designed and properly main-tained slow sand filter effectively removes turbidity and pathogenic micro-organisms through various biological, physical and chemical processes in a single treatment step.
- Slow sand filtration systems are characterized by a high reliability and rather low lifecycle costs. Neither construction nor operation and main-tenance of this filtration systems require more than basic skills.

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Slow sand filtration

Advantages:

- Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated raw water
- Simplicity of design and high self-help compatibility
- If constructed with gravity flow only, no electrical pumps required
- Local materials can be used for construction
- High reliability and ability to withstand fluctuations in water quality. No necessity for the application of chemicals
- Easy to install in rural, semi-urban and remote areas
- Long lifespan (Estimated more than 10 years)

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Slow sand filtration

Disadvantages:

- Minimal quality and constant flow of fresh water is required: (Turbidity < 20 NTU) and low algae concentration. Otherwise pretreatment is necessary.
- Cold temperatures lower the efficiency of the process due to decrease in biological activity. Loss of productivity during long filter skimming period
- Regular maintenance required. Some chemical compounds (e.g. fluorine) are not removed.
- Natural organic matter not totally removed at slow sand filtration leads to formation of chlorine byproducts if chlorine is applied for final disinfection.
- Requirement of large land area, large quantities of sand, and manual labor for cleaning

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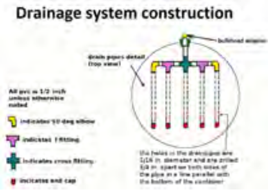
Design of modern filter systems

Technical-scale filters:



Source: https://www.pinterest.com/jacksontang/filter/

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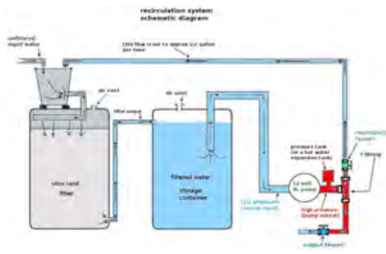
Design of modern filter systems

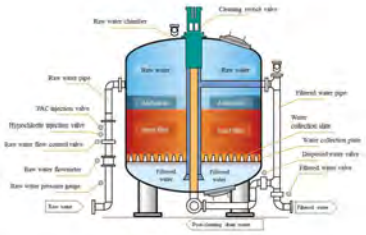
Technical-scale filters:



Source: https://www.pinterest.com/jacksontang/filter/

Design of modern filter systems

Technical-scale filters:



Source: https://www.pinterest.com/jacksontang/filter/

Design of modern filter systems

Household filters:

Scheme of cartridge filter for purification of water

Source: http://interesko.info/raznovidnosti-filtrov-mexanicheskoj-ochistki-vody/

Questions

- Give three examples for typical filter materials.
- What is the main difference between slow and rapid sand filters?
- How are filter media usually regenerated?
- Which hydraulic parameters are used in order to describe the filtration process?
- How do pressure loss and breakthrough, respectively, develop during a normal operation of a deep-bed filter?
- How does the pressure loss profile inside a deep-bed filter look like in the beginning and at the end of a filter run?

References

Montgomery, J.M.: Water Treatment - Principles and Design. 3rd ed., John Wiley & Sons, Hoboken 2012

Тугай А.М., Орлов В.О. Водопостачання: Підручник. – К. Знання, 2009. – 735 с. (ISBN 978-966-346-487-9)

Pictures:

https://www.pinterest.com/jacksontang/filter/

http://interesko.info/raznovidnosti-filtrov-mexanicheskoj-ochistki-vody/

Water Harmony

Coagulation

Harsha Ratnaweera
Professor
Norwegian University of Life Sciences

WATER HARMONY ERASMUS +

Water Harmony

Learning targets

- Basic understanding of the coagulation mechanisms and the role of the water matrix
- Overview of criteria for the selection of coagulants
- Knowledge about the realization of the coagulation process on a technical scale, taking a number of different boundary conditions into account

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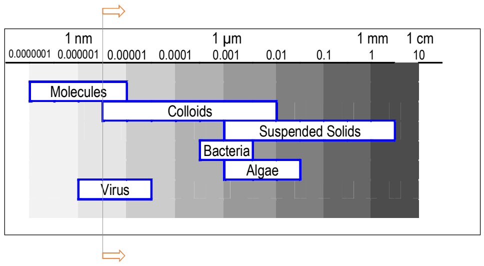
Water Harmony

Outline

- Objectives
- Need of coagulation in water supply
- General process stages
- Coagulation mechanisms
- Coagulants and coagulation chemistry
- Process configurations

Water Harmony

What can be removed by coagulation?



Water Harmony

Coagulation – main objectives

- Removal of particles (various pollutants)
- Removal of colour
- Removal of microorganisms

Water Harmony

Why is coagulation needed in water supply?

- Why remove colloids/particles in drinking water?
  - Turbidity in tap water
  - Sediments accumulating in the network
  - Microorganisms are colloids/particles
  - Particles may influence downstream treatment, in particular disinfection
- Why remove NOM?
  - NOM gives colour
  - NOM will reduce the effect of disinfection
  - NOM is a DBP precursor
    - *NOM = Natural Organic Matter*
    - *DBP = Disinfection By Products*

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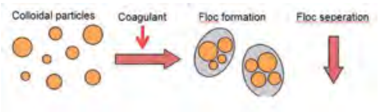
General process stages

- Coagulation
  - Addition of coagulants
  - Mixing
- Flocculation
  - Addition of flocculants
  - Mixing/flocculation
- Separation
  - Sedimentation
  - Flotation
  - Filtration



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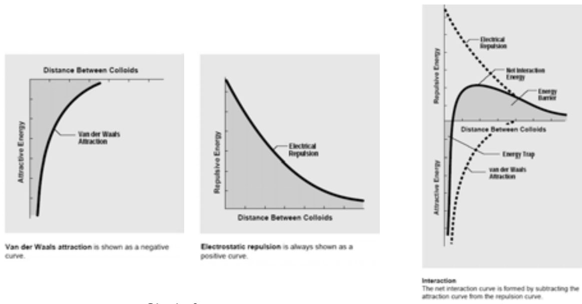
Attraction and repulsion between colloids



Single forces

Resulting force

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Terminology

– Coagulation ≠ Flocculation
– Chemical treatment = Coagulation
– Coagulants = Precipitants ≠ Flocculants
– Flocculants = Helping coagulants

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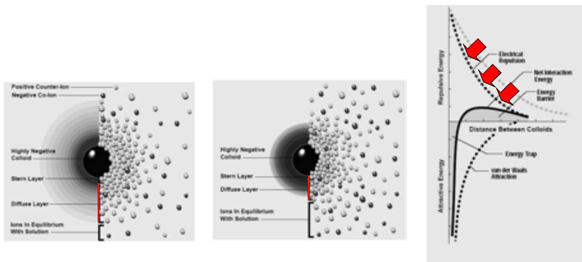
1. Double layer compression



Low high

ionic strength

Resulting force

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The four coagulation mechanisms

1. Compression of Double Layer
2. Adsorption-charge neutralization
3. Bridging
4. Sweep floc

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Schulze-Hardy rule

An empirical rule summarizing the general tendency of the critical coagulation concentration (M) to vary inversely with the sixth power of the counter ion charge number of added electrolyte, without specific absorption (or chemical reactions):

$$M^{I} : M^{II} : M^{III} = \left(\frac{1}{1}\right)^{6} : \left(\frac{1}{2}\right)^{6} : \left(\frac{1}{3}\right)^{6} = 100 : 1.6 : 0.3$$

This rule can be derived from the DLVO theory.

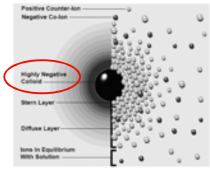
Effect of water matrix

Hard water is easier to coagulate!

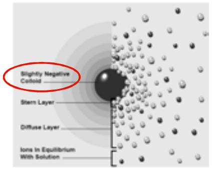
Reason:

The Ca^{2+} and Mg^{2+} ions affect the double layer more strongly because of their higher charge number compared with mono-valent ions.

2. Adsorption-charge neutralization

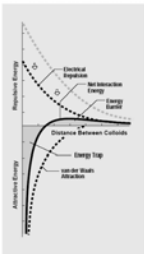


Before



after

addition of coagulant and adsorption of resulting polynuclear hydroxy complexes on colloid surface



Charge Reduction
Coagulant addition lowers the surface charge and drops the repulsive energy curve. More coagulant can be added to completely eliminate the energy barrier.

Resulting force

Positively charged ions / complexes

- Organic polymers: cationic
- Hydrolysis products: "+" charged species

Hydrolysis reaction (summary):

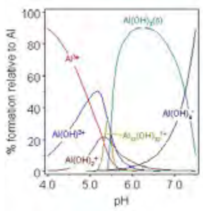
$Al^{3+} + 3\,H_2O \Leftrightarrow Al(OH)_3 + 3\,H^+$

Hydrolysis reaction (single steps):

$Al^{3+} + 3\,H_2O \Leftrightarrow Al(OH)^{2+} + 2\,H_2O + H^+$

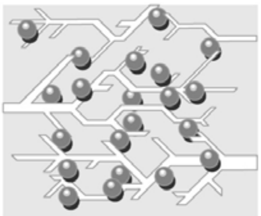
$\Leftrightarrow Al(OH)_2^{+} + H_2O + 2\,H^+$

$\Leftrightarrow Al(OH)_3 + 3\,H^+$



3. Bridging

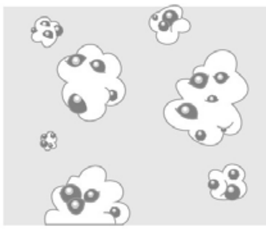
This mechanism is determining when polymers are applied.



Bridging
Each polymer chain attaches to many colloids.

4. Sweep floc

Sweep floc plays a major role when higher dosages of metal salts are used.



Sweep Floc
Colloids become enmeshed in the growing precipitate.

Coagulants and related mechanisms

Water type	Drinking water coagulation		Wastewater coagulation	
Mechanism and coagulant type	Inorganic coagulants	Organic coagulants	Inorganic coagulants	Organic coagulants
Double-layer compression	Occasionally	Not applicable	Used when seawater is available	Not applicable
Adsorption-charge neutralisation	Dominant	Occurs with cationic polymers	Occurs frequently	Occurs with cationic polymers
Inter-particle bridging	Not applicable	Dominant	Not applicable	Dominant
Colloidal entrapment (Sweep floc)	Occasionally	Not applicable	Dominant	Not applicable

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Selection of coagulants

Important factors:

- ➢ Raw water quality
- ➢ Downstream processes
- ➢ Required treatment efficiency
- ➢ Economical and practical conditions

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Selection of coagulants

- Traditional:
  - Al^{3+} (Aluminium sulphate, Aluminium chloride)
  - Fe^{3+} (Iron chloride, Iron chloride sulphate (= ferric salts))
  - Ca^{2+} (Calcium hydroxide)
  - Fe^{2+} (Iron sulphate (= ferrous salt))
- New (innovative):
  - Prepolymerized metals salts (PAX, PIX)
  - Metals salts with Silica / water glass
  - Metal salts with Ca^{2+}
  - Metal salts with organic flocculants
  - Chitosan
  - Ti^{4+} and Zr^{4+} salts

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Consequences of non-optimal dosing

- ➢ Under dosage and over dosage
- ➢ Higher coagulant costs
- ➢ Unnecessary increase in the amount of sludge (sludge management costs)
- ➢ Poor treatment
- ➢ Risk for higher residual aluminium concentration
- ➢ Too low pH for downstream processes

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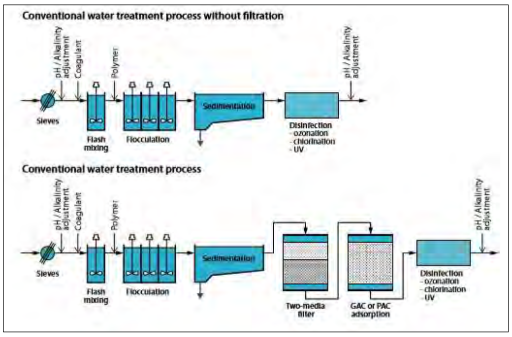
Process configurations: Flow sheet I



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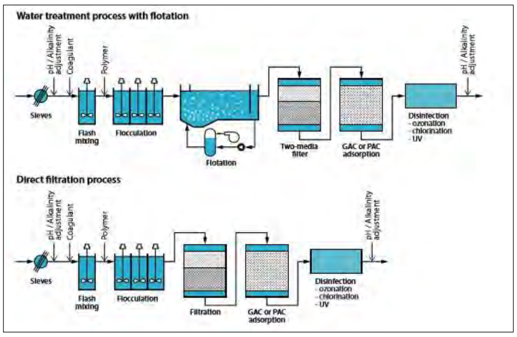
Process configurations: Flow sheet II



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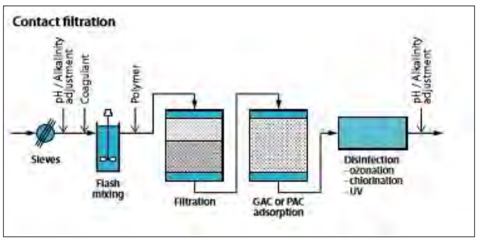
Process configurations: Flow sheet III



Questions

- Why is coagulation an important process in drinking water treatment?
- Which are the four main coagulation mechanisms, and how significant are they for different coagulants?
- What are consequences of non-optimal dosing?
- How does a typical treatment train for coagulation look like, when the raw water is characterized by a
  - a) high turbidity
  - b) low turbidity?

References

AWWA: Water Treatment Plant Design.
5th ed., McGraw-Hill, New York 2012

Bratby, John: Coagulation and Flocculation in Water and Wastewater Treatment.
3rd ed., IWA Publishing, London 2016

Montgomery, J.M.: Water Treatment - Principles and Design.
3rd ed., John Wiley & Sons, Hoboken 2012

Membrane Processes

Dr. Zakhar Maletskyi
Norwegian University of Life Sciences

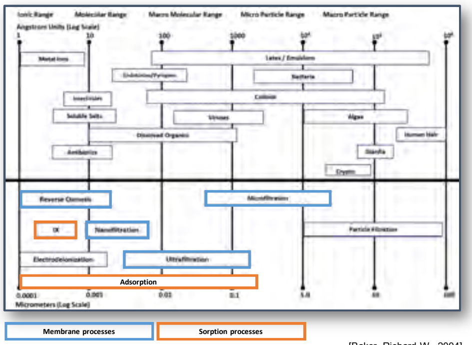
Learning targets

- Understanding of the principles and general boundary conditions of membrane separation processes
- Overview of different membrane elements
- Proficiency of describing the operation of a RO unit
- Insight into the problems of membrane fouling

Outline

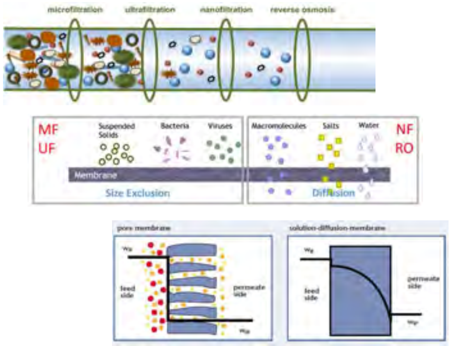
- Fundamentals of membrane processes
- Membranes and membrane elements
- Ultrafiltration (UF): Properties, configurations and applications
- UF: Technical-scale plants
- Nanofiltration (NF) and Reverse Osmosis (RO): Membrane properties and process parameters
- Limitations caused by membrane fouling

Size of compounds and separation processes



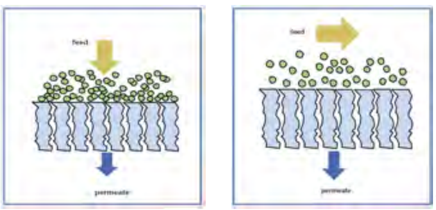
[Baker, Richard W., 2004]

Fundamentals of membrane processes



[Water Planet, Dow Water&Process Solutions, RWTH MT for WWT]

Fundamentals of membrane processes



[Dow Water&Process Solutions, RWTH MT for WWT]

Dead-end filtration

Not feasible for RO/NF:

A. Sparingly soluble salts precipitate and foul the membrane.
B. Filter cake build-up

Cross-flow filtration

Required for RO/NF:

A. Sweeps away membrane foulants
B. Minimizes concentration polarization
C. Generates a concentrate stream and a permeate stream

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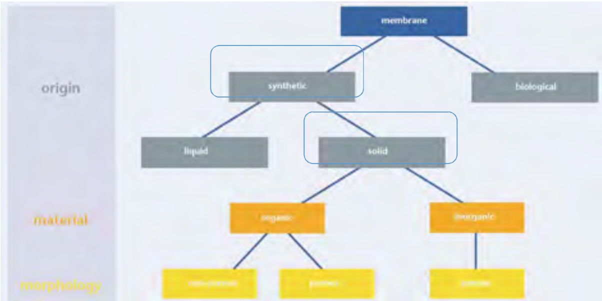
Membranes and membrane elements



[RWTH MT for WWT]

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Membranes and membrane elements


Hollow fibre


Tubular


Sheets


Plates

[Cembrane, Dow Chemical, Inge, 2018]

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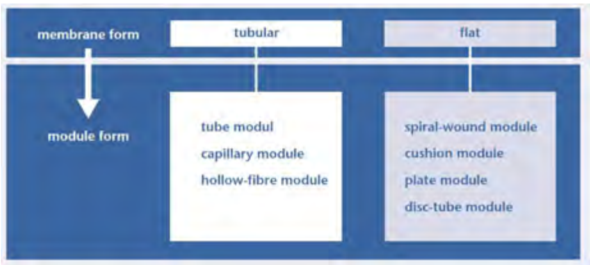
Membranes and membrane elements



[RWTH MT for WWT]

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Membranes and membrane elements


Fibre-frame


Fibre-housing


Tubular


Spiral wound


Flat sheet - frame


Plate-frame

[Cembrane, Dow Chemical, Inge, Microdyn-Nadir, X-Flow, 2018]

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Membranes and membrane elements

Operating pressure: Strongly dependent on membrane type!

Membrane Process	Typical Operating Pressure Range (bar)
Reverse Osmosis Seawater Brackish water	 55 - 70 10 - 40
Nanofiltration	3.5 - 15
Ultrafiltration	2 - 7
Microfiltration	0.1-3

[Dow Chemical, Filmtech membranes – Technical presentation]

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UF: Properties, configurations and applications

Applications of UF processes:

- ✓ **Surface Water** Treatment for industrial or municipal use
- ✓ Municipal **Wastewater** Treatment/Reuse
- ✓ **Industrial** Wastewater or Process Water treatment
- ✓ **Seawater** RO pretreatment

[Dow Chemical, UF membranes – Technical presentation]

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UF: Properties, configurations and applications

Hollow fibre and tubular membranes are most popular!

- **Pore Size**: UF vs MF
- **Fiber Material**: Strength, Chemical Stability, Hydrophilicity
- **Flow configuration:** Out-In vs In-Out

[Dow Chemical, UF membranes – Technical presentation]

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UF: Properties, configurations and applications

Comparison of UF vs. Microfiltration (MF):

- Due to smaller pore size, **UF provides better filtrate water quality** (e.g. SDI, TOC, turbidity,...)
- UF has **higher removal** of Microorganisms (especially virus).
- MF membranes typically operates in a depth filtration pattern with eventual pore blocking, compared to UF's cake filtration pattern (easily removed by BW).
- UF has a thin active layer and a high porosity sub-structure. An asymmetric membrane will have higher stable permeability and better backwash efficiency.

[Dow Chemical, Filmtech membranes – Technical presentation]

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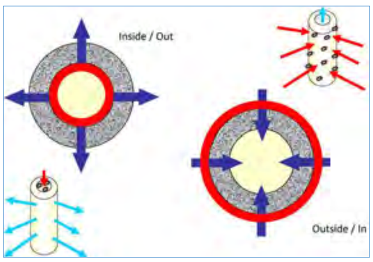
UF: Properties, configurations and applications

Two possible flow configurations:



[Dow Chemical, UF membranes - Technical presentation]

Advantages & disadvantages – what do you think?

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UF: Properties, configurations and applications

Comparison of O-I vs. I-O configuration:

- Out-In (O/I) configuration can cope with worse feed conditions. No fiber plugging risk.
- O/I provides larger membrane area (~2X).
- O/I can use Air Scour for higher cleaning efficiency.
- O/I requires lower Backwash flow (~50-60% vs I/O).
- O/I provides lower ΔP through the module.
- O/I fibers usually have only one open end, which makes fiber repair easier.

[Dow Chemical, UF membranes - Technical presentation]

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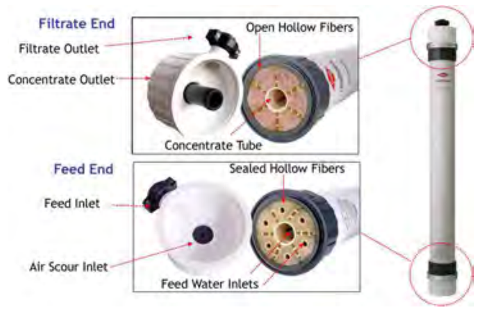
UF: Properties, configurations and applications

Construction of hollow fibre modules:



[Dow Chemical, UF membranes - Technical presentation]

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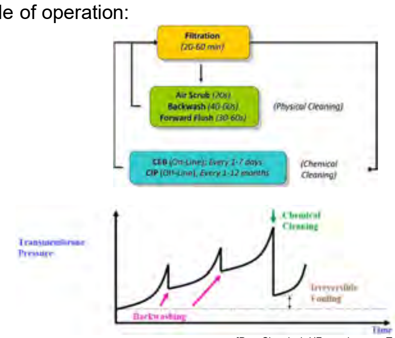
UF: Properties, configurations and applications

Mode of operation:



[Dow Chemical, UF membranes - Technical presentation]

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UF: Technical-scale plants

Pressurized system

Submerged system

[Cembrane, Dow Chemical, Inge, 2018]

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UF: Technical-scale plants

[Cembrane, Dow Chemical, Inge, 2018]

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UF: Technical-scale plants

Advantages and market drivers (compared with conventional technologies):

- **Lower footprint and weight**
- **Higher and more consistent filtrate quality** (Log-Removal credit regardless water source)
- **Rejects pathogens** resistant to chlorination
- **Lower chemical use** (polymer, coagulant, pH adjustment, chlorination,...)
- **Easier maintenance** (highly automated operation)
- **Easier expandability**
- **Integrated systems**
  - More stringent regulations around the world to provide better water treatment.
  - Increased industry experience & confidence in UF/MF.
  - Decline in costs (CAPEX & OPEX).
  - Possibility of on-line membrane integrity check.
  - Wider range of applications and providers.

[Dow Chemical, UF membranes - Technical presentation]

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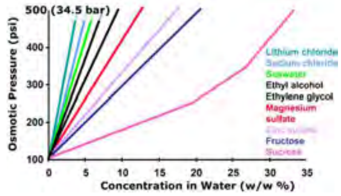
RO: Membrane properties and process parameters

The osmotic pressure must be accounted for:

Osmotic pressure
is the pressure which needs to be applied to a solution to prevent the inward flow of water across a semipermeable membrane



[Dow Chemical, Filmtech membranes - Technical presentation]

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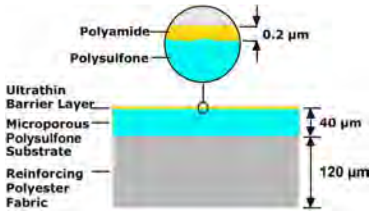
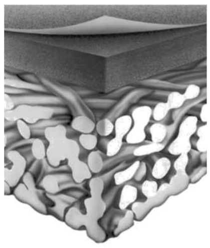
RO: Membrane properties and process parameters

Structure of a RO membrane:





[Dow Chemical, Filmtech membranes - Technical presentation]

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Dow Chemical, Filmtech membranes – technical presentation

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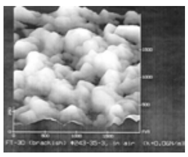
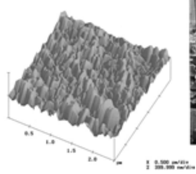
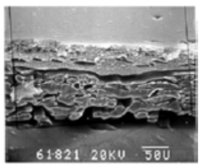
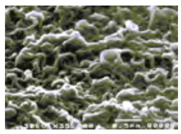
RO: Membrane properties and process parameters

Close-ups of RO membranes:









What kind of pores do you see?

[Dow Chemical, Filmtech membranes - Technical presentation]

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RO: Membrane properties and process parameters

Membrane selectivity:

	MW	Rejection (%)
Sodium fluoride (NaF)	42	99
Sodium cyanide (NaCN)	49	97
Sodium chloride (NaCl)	58	99.5
Silica (SiO_2)	60	99
Sodium bicarbonate ($NaHCO_3$)	84	99
Sodium nitrate ($NaNO_3$)	85	97
Magnesium chloride ($MgCl_2$)	95	99.5
Calcium chloride ($CaCl_2$)	111	99.5
Magnesium sulfate ($MgSO_4$)	120	99.7
Nickel sulfate ($NiSO_4$)	155	99.7
Copper sulfate ($CuSO_4$)	160	99.7

	MW	Rejection (%)
Formaldehyde	30	35
Methanol	32	25
Ethanol	46	70
Isopropanol	60	90
Urea	60	70
Lactic acid (pH 2)	90	94
Lactic acid (pH 5)	90	99
Glucose	180	98
Sucrose	342	99
Chlorinated pesticides	-	99

[Dow Chemical, Filmtech membranes - Technical presentation]

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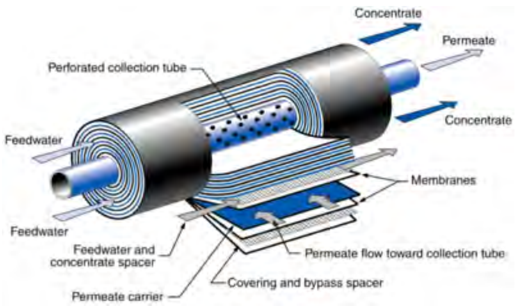
RO: Membrane properties and process parameters

Spiral-wound membrane element:



[NALCO: Reverse Osmosis]

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RO: Membrane properties and process parameters

Description of water and salt fluxes:

$$F_w = K_w (\Delta P - \Delta\pi)$$

F_w - solvent flux [gallons per square foot per day=gfd]
K_w - solvent mass transfer coefficient [gfd/psi] (A value)
ΔP - transmembrane pressure differential [psi]
$\Delta\pi$ - osmotic pressure differential [psi]

$$F_s = K_s (\Delta C)$$

F_s - solute flux [pounds per square foot per day, lbfd]
K_s - solute mass transfer coefficient [gfd] (B value)
ΔC - transmembrane concentration differential [lb/gal]

[Dow Chemical, Filmtech membranes - Technical presentation]

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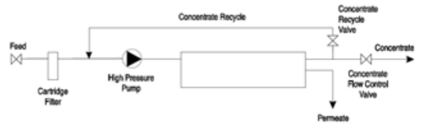
RO: Membrane properties and process parameters

Main process parameters:



$$\text{Recovery (\%)} = \frac{\text{Permeate flow}}{\text{Feed flow}} \times 100$$

$$\text{Salt Passage (\%)} = \frac{\text{Permeate Salt Concentration}}{\text{Feed Salt Concentration}} \times 100$$

$$\text{Salt Rejection (\%)} = 100 - \text{Salt Passage}$$

Illustration: https://youtu.be/BeXHKpuHVZg [Technical Training Professionals, 2018]

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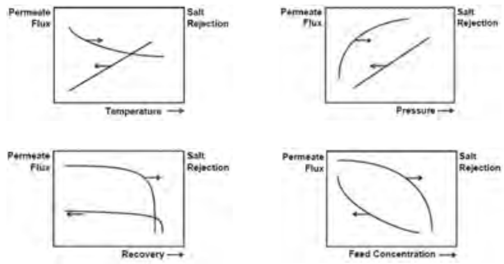
RO: Membrane properties and process parameters

Module operation: Effect of different parameters



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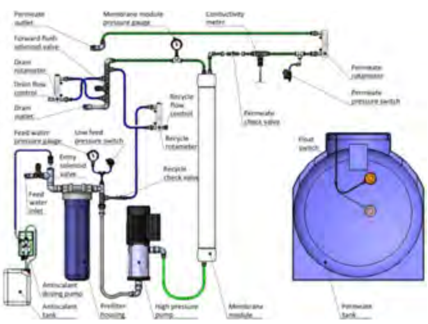
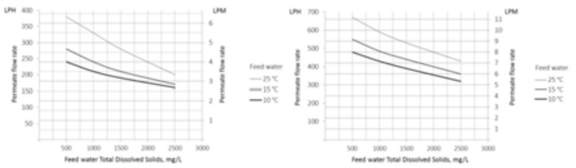
RO: Commercial / household unit



[Ecosoft MO6000/MO10000 User Manual]

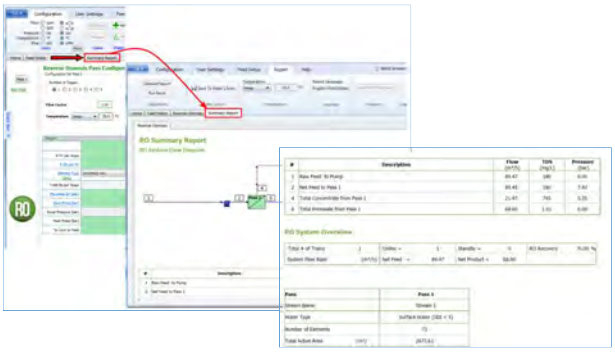
RO: Commercial / household unit

Unit capacity, m³/d	6	10
Recycle flow rate, LPM	13-15	8.2-11.2
Drain flow rate, LPM	1.2-1.7	2.2-3.0
Permeate flow rate, LPM	3.5-4.5	6.5-9.0
Pressure in the membrane module, MPa	0.1-1.0	0.8-1.0



[Ecosoft MO6000/MO10000 User Manual]

RO modeling software: WAVE for Filmtec membranes



Limitations caused by membrane fouling

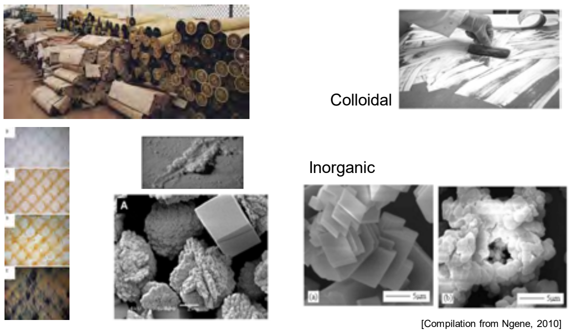
Characteristics of fouling processes:

- Affects membrane performance
- Commonly caused by raw water characteristics and inappropriate pre-treatment
- **Colloidal and particle fouling** – caused by solids from the pretreatment entering the first stage elements
- **Biofouling** – occurs due to high biological growth potential in feed water, improper operation and procedures, and dead legs in the systems
- **Organic fouling** – caused by natural organic matter in the feed water, polluted raw water, polyelectrolytes from coagulation/flocculation pre-treatment
- **Inorganic fouling** – scaling of salts due to concentration polarization

Counter measures:

→ Proper pre-treatment, dosing of reagents, chemical cleaning

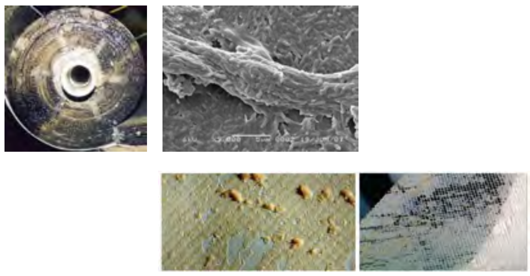
Limitations caused by membrane fouling



[Compilation from Ngene, 2010]

Limitations caused by membrane fouling

Effects of biofouling:



[Compilation from Ngene, 2010]

RO: Technical-scale plant

Visit to the Ashkelon Desalination Plant:

https://youtu.be/BiiT2v_nEIM [IDE Technologies Co, 2013]

Questions

- What is the basic principle of membrane separation?
- Which general structure do membranes have, in which forms are they manufactured, and how do modules look like?
- How are UF units usually operated, and what are they applied for?
- What is the meaning of “osmotic pressure”?
- Which parameters are used in order to describe the RO process?
- What are causes and consequences of membrane fouling?

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Adsorption

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Learning targets

- Knowledge about the theoretical background of the adsorption process (interactions between adsorbent and adsorbate, adsorption equilibrium and kinetics)
- Overview over different adsorbents and their respective properties and applications
- Understanding of basic process configurations and the development of mass transfer zones in fixed beds

Outline

- Theoretical introduction to adsorption
  - Factors influencing adsorption
  - Steps of the adsorption process (adsorption kinetics)
  - Adsorption isotherms
- Adsorbents
  - Activated carbon (PAC and GAC)
  - Activated alumina
  - Molecular sieves
- Applications
- Process configurations and carbon regeneration

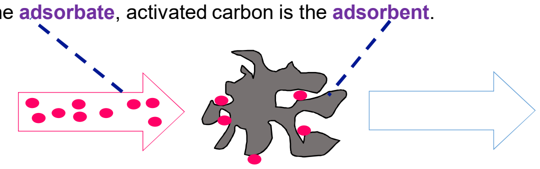
Theoretical introduction to adsorption

Adsorption process

Dissolved substances (**adsorbates**) accumulate on the surface of a solid material (**adsorbent**).

Example:

Color can be removed from water using activated carbon. Color is the **adsorbate**, activated carbon is the **adsorbent**.



Theoretical introduction to adsorption

Types of Adsorption:

Properties	Physisorption	Chemisorption
Bonding	Van der Waals interactions (e.g. London dispersion, dipole-dipole).	Chemical bonding involving orbital overlap and charge transfer.
Enthalpy	20-40 kJ mol^{-1}	80-240 kJ mol^{-1}
Saturation	Multi-layer	Mono-layer
Surface Specificity	No	Yes
Nature	Reversible	Mostly Irreversible

Theoretical introduction to adsorption

Factors influencing adsorption:

- Surface area of adsorbent

  The extent of adsorption is proportional to the specific surface area of the adsorbent.
- Solubility of the adsorbate

  The greater the solubility, and the stronger the solute-solvent bond, the smaller is the extent of adsorption.
- Hydrogen ion concentration (pH) of the solution

Theoretical introduction to adsorption

Factors influencing adsorption:

- Temperature

  Heavy metal removal is usually better at higher temperature.

- Nature of the adsorbate

  The physiochemical nature (e.g. surface functional groups)

- Mixture of adsorbates

  The compounds may mutually enhance adsorption, may act relatively independently, or may interfere with each another.

Theoretical introduction to adsorption

Types of interactions between adsorbent and adsorbate (adsorption forces):

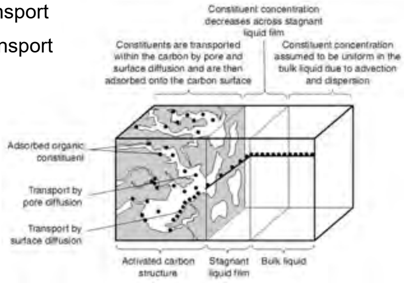
- Coulomb-unlike charges
- Dipole-dipole interactions
- London or van der Waals forces
- Hydrogen bonding
- Point charge and a dipole
- Point charge neutral species
- Covalent bonding with reaction

London or van der Waals forces are often predominant.

Theoretical introduction to adsorption

Steps of the adsorption process (adsorption kinetics):

- Bulk solution transport
- Film diffusion transport
- Pore transport
- Adsorption



Theoretical introduction to adsorption

Adsorption equilibrium:

If the adsorbent and the adsorbate are in contact long enough, an equilibrium will be established between the amount of adsorbate adsorbed and the amount of adsorbate in solution.

This equilibrium relationship is described by an isotherm.

Adsorption isotherm:

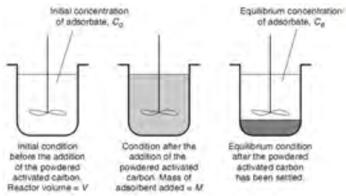
The mass of adsorbate per unit mass of adsorbent at equilibrium and at a given temperature

Theoretical introduction to adsorption

Determination of isotherms:

Calculation of adsorbed material from a mass balance:

$$q_e = \frac{(C_o - C_e)V}{m}$$



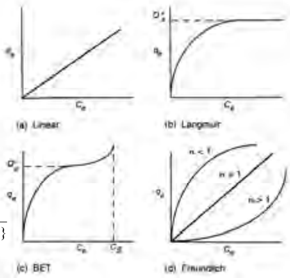
where
q_e = mass of material adsorbed (at equilibrium) per mass of adsorbent, mg adsorbate/g adsorbent
C_0 = initial concentration of adsorbate, mg/L
C_e = equilibrium concentration in solution when amount adsorbed equals q_e, mg/L
V = volume of liquid in the reactor, L
m = mass of adsorbent, g

Theoretical introduction to adsorption

Adsorption isotherms (examples):

$$q_e = k_{lin} C_e$$

$$q_e = \frac{K \cdot Q_a^0 \cdot C_e}{1 + K \cdot C_e}$$



$$q_e = \frac{K_B \cdot C_e \cdot Q_a^0}{(C_S - C_e)\{1 + (K_B - 1)(C_e / C_S)\}}$$

$$q_e = K_F C_e^{1/n}$$

Theoretical introduction to adsorption

Adsorption isotherms: Langmuir model

This model assumes monolayer coverage and constant binding energy between surface and adsorbate.

The model equation is:

$$q_e = \frac{K \cdot Q_a^0 \cdot C_e}{1 + K \cdot C_e}$$

Q_a^0 represents the maximum adsorption capacity (monolayer coverage) (g solute/g adsorbent).

C_e has units of mg/L

K has units of L/mg

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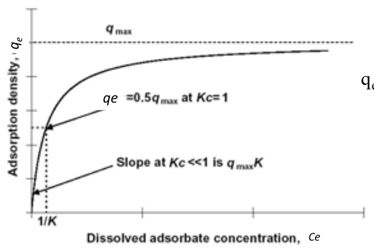
Theoretical introduction to adsorption

Adsorption isotherms: Shape of the Langmuir isotherm



$$q_e = \frac{K \cdot Q_a^0 \cdot C_e}{1 + K \cdot C_e}$$

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Theoretical introduction to adsorption

Adsorption isotherms: BET isotherm[*)]

This is a more general, multi-layer model. It assumes that a Langmuir isotherm applies to each layer and no transmigration occurs between the layers. It also assumes that there is equal energy of adsorption for each layer except for the first layer.

The model equation is:

$$q_e = \frac{K_B \cdot C_e \cdot Q_a^0}{(C_S - C_e)\{1 + (K_B - 1)(C_e / C_S)\}}$$

C_S = saturation (solubility limit) concentration of the solute (mg/liter)

K_B = a parameter related to the binding intensity for all layers

Note: When $C_e << C_S$, $K_B >> 1$ and $K = K_B/C_S$ then the BET isotherm approaches the Langmuir isotherm.

*) Brunauer, Emmett and Teller

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Theoretical introduction to adsorption

Adsorption isotherms: Freundlich isotherm

For the special case that the surface energies are heterogeneous (particularly good for mixed adsorbates) in which the energy term, "K_F", varies as a function of surface coverage, the Freundlich model is appropriate.

The model equation is:

$$q_e = K_F C_e^{1/n}$$

K_F and n are system specific constants.

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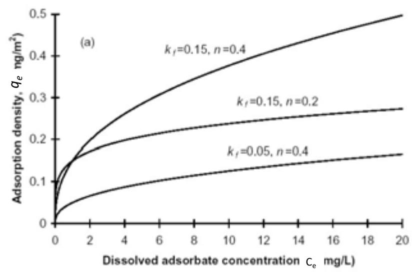
Theoretical introduction to adsorption

Adsorption isotherms: Shape of the Freundlich isotherm



$$q_e = K_F C_e^{1/n}$$

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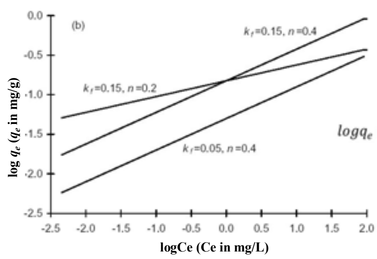
Theoretical introduction to adsorption

Adsorption isotherms: Shape of the Freundlich isotherm (log-scale)



$$\log q_e = \log K_f + n \log Ce$$

Theoretical introduction to adsorption

Example 1

Each jar receives activated carbon and 100 mL of a 600 mg/L solution of **xylene** and is then shaken for 48 h.

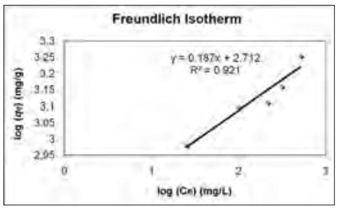
The following equilibrium concentrations are found:

Jar	1	2	3	4	5
Carbon (mg)	60	40	30	20	5
C_e (mg/L)	25	99	212	310	510

Theoretical introduction to adsorption

Example 1

The solid phase concentrations are calculated from a mass balance and plotted vs. the liquid concentrations. The Freundlich equation is then fitted to the data:



Theoretical introduction to adsorption

Example 2

Adsorption of benzene onto activated carbon has been reported to obey the following Freundlich isotherm equation, where *c* is in mg/L and *q* is in mg/g:

$$q_{benz} = 50.1\, c_{benz}^{0.533}$$

A solution at 25°C containing 0.50 mg/L benzene is to be treated in a batch process to reduce the concentration to less than 0.01 mg/L. The adsorbent is activated carbon with a specific surface area of 650 m^2/g.

Compute the required activated carbon dose.

Theoretical introduction to adsorption

Example 2

Solution:

The solid-phase concentration of benzene in equilibrium with c_{eq} of 0.010 mg/L can be determined from the isotherm expression:

$$q_{benz} = 50.1\, c_{benz}^{0.533} = 4.30 \text{ mg/g}$$

A mass balance on the contaminant can then be rewritten and solved for the activated carbon dose

$$q_e = \frac{(C_o - C_e)V}{m} \Rightarrow c_{tot,benz} = c_{benz} + q_{benz} c_{AC} \quad \text{where } c_{AC} = m/V$$

$$0.50 = 0.010 + (4.30 \text{ mg/g})\, c_{AC}$$

$$c_{AC} = 0.114 \text{ g/L} = 114 \text{ mg/L}$$

Theoretical introduction to adsorption

Example 3

If 114 mg/L adsorbent is used to treat a 0.500 mg/L solution of toluene, what will the equilibrium concentration and solid-phase concentration be? The isotherm equation for toluene is:

$$q_{tol} = 76.6\, c_{tol}^{0.365}$$

Solution:

The mass balance on toluene is:

$$c_{tot,tol} = c_{tol} + q_{tol} c_{AC} \qquad 0.50 = c_{tol} + \left(76.6\, c_{tol}^{0.365}\right)(0.114 \text{ g/L})$$

$$c_{tol} = 3.93\text{x}10^{-4} \text{ mg/L}$$

Adsorbents: Basic types

- Activated Carbon (AC)

  Removal of all of the adsorbates mentioned above (to varying degrees) by the far most popular adsorbent
- Activated Alumina
- Molecular Sieves (zeolite)

  Clays with adsorptive properties

Adsorbents: Properties

Properties of Activated Carbon

Bulk Density	22-34 lb/ft^3
Heat Capacity	0.27-0.36 BTU/lb°F
Pore Volume	0.56-1.20 cm^3/g
Surface Area	600-1600 m^2/g
Average Pore Diameter	15-25 Å
Regeneration Temperature (Steaming)	100-140 °C
Maximum Allowable Temperature	150 °C

Adsorbents: Properties

Properties of Activated Alumina

Bulk Density	
Granules	38-42 lb/ft^3
Pellets	54-58 lb/ft^3
Specific Heat	0.21-0.25 BTU/lb°F
Pore Volume	0.29-0.37 cm^3/g
Surface Area	210-360 m^2/g
Average Pore Diameter	18-48 Å
Regeneration Temperature (Steaming)	200-250 °C
Maximum Allowable Temperature	500 °C

Adsorbents: Properties

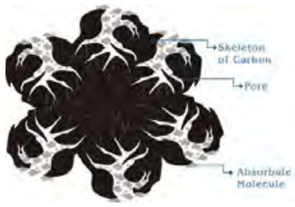
Properties of Molecular Sieves

	Anhydrous Sodium Aluminosilicate	Anhydrous Calcium Aluminosilicate	Anhydrous Aluminosilicate
Type	4A	5A	13X
Density in bulk (lb/ft^3)	44	44	38
Specific Heat (BTU/lb°F)	0.19	0.19	-
Effective diameter of pores (Å)	4	5	13
Regeneration Temperature (°C)	200-300	200-300	200-300
Maximum Allowable Temperature (°C)	600	600	600

Adsorbents: Preparation of activated carbon

AC can be prepared from any carbonaceous material e.g.

- Wood
- Lignite
- Coal
- Nutshells
- Bones



[Kan-Carbon, 2018]

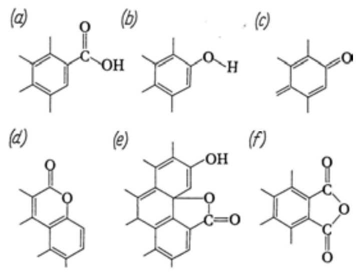
Adsorbents: Preparation of activated carbon

Production process: Two steps

- **Pyrolysis:**
  The carboneous material has to be pyrolyzed (heated in a low oxygen environment). This forms a "char".
- **Activation:**
  The char is then activated by heating to 800-1000 °C in the presence of steam, oxygen or $C0_2$ to form gaseous products.

Adsorbents: Properties of activated carbon

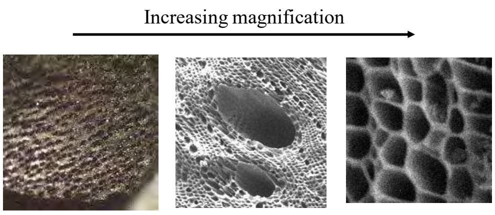
AC has oxygen-containing groups on its surface:



[Mattson and Mark, 1971]

Adsorbents: Properties of activated carbon

AC has a heterogeneous pore structure:

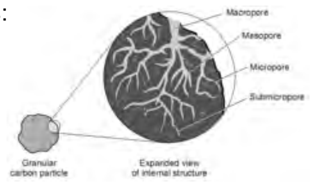


Photos of Activated Carbon [Zhang, 2015]

Adsorbents: Properties of activated carbon

Definition of AC pore sizes:

- Micropores: d < 2 nm
- Mesopores: d = 2-20 nm
- Macropores: d > 20 nm



Distribution:

Pore size	% pore volume	% surface area
Micro	30 - 60	> 95
Meso	< 10	< 5
Macro	25 - 30	negligible

Adsorbents: Types of activated carbon

PAC: Powdered activated carbon

- Fine powder, d < 0.05 mm
- Surface area as much as 100 acres/lb (≈ 1000 m^2/g)
- Pore sizes (radii) down to 10^{-9} m

GAC: Granular activated carbon

- Diameter: 0.5 - 4 mm
- Surface area equal or a bit less than PAC

Adsorbents: Types of activated carbon

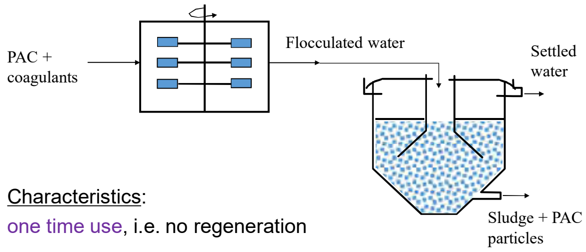
Comparison of GAC and PAC [Zhang, 2015]:

Parameter	Unit	Type of activated carbon[a]	
		GAC	PAC
Total surface area	m^2/g	700–1300	800–1800
Bulk density	kg/m^3	400–500	360–740
Particle density, wetted in water	kg/L	1.0–1.5	1.3–1.4
Particle size range	mm (μm)	0.1–2.36	(5–50)
Effective size	mm	0.6–0.9	na
Uniformity coefficient	UC	≤1.9	na
Mean pore radius	Å	16–30	20–40
Iodine number		600–1100	800–1200
Abrasion number	minimum	75–85	70–80
Ash	%	≤8	≤6
Moisture as packed	%	2–8	3–10

Adsorbents: Types of activated carbon

How to use PAC (typically for taste and odor removal):

Mixing with raw water + removal by sedimentation or filtration



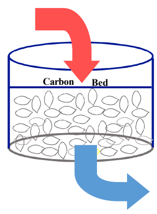
Characteristics:

one time use, i.e. no regeneration

Adsorbents: Types of activated carbon

How to use GAC (typically for treatment of groundwater and riverbank filtrate in order to remove taste, odor, and micropollutants):

- Use of a fixed-bed column
- Downward flow through the column
- After exhaustion of the carbon capacity regeneration in a furnace by oxidizing the adsorbed organic matter



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Applications

- Removal of refractory organic compounds
- Removal of inorganic compounds such as nitrogen, sulfides, and heavy metals
- Chemical reduction of oxidants
- Removal of taste and odor compounds

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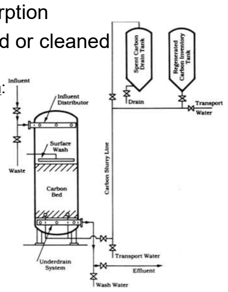
Process configurations

Column flow system: Fixed-bed

- Provides filtration as well as adsorption
- Has to be periodically backwashed or cleaned

Principle:

Practical design:



[Gao, 2016]

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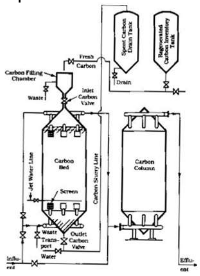
Process configurations

Column flow system: Fluidized-bed

- Continuous supply of fresh + removal of spent carbon
- Not effective as a filter

Principle:

Practical design:



[Gao, 2016]

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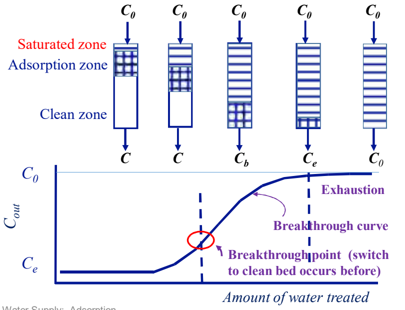
Process configurations

Fixed-bed system: Breakthrough development



The time to breakthrough is decreased by:

- ✓ Increased particle size of carbon
- ✓ Higher concentration in the influent
- ✓ Increased pH of the water
- ✓ Increased flow rate
- ✓ Lower bed depth

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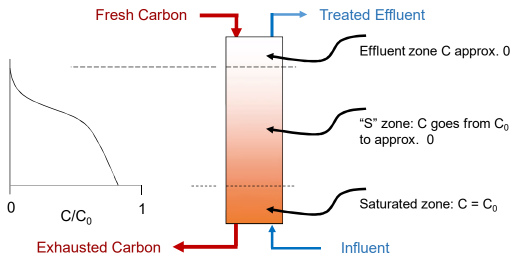
Process configurations

Fluidized-bed system: Mass transfer zone



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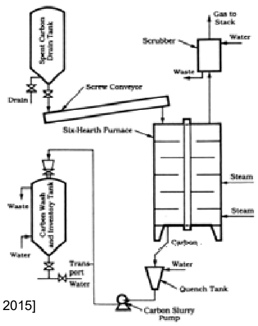
Carbon Regeneration

- Spent carbon is usually regenerated at 500 ºC under low oxygen conditions in the presence of steam.
- Activated carbon loss is about 5-15% for each regeneration.
- Adsorbed organics are volatilized and oxidized during the regeneration process.



[Zhang, 2015]

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Questions

- Which raw materials are used for activated carbon production, and what are the main production steps?
- Describe briefly how an adsorption isotherm is determined experimentally. Which models are available for the description of isotherm data?
- Which steps are distinguished when describing adsorption kinetics?
- Explain the development of a breakthrough curve in a fixed-bed column and some factors that have an effect on it.
- What are important aspects when applying GAC and PAC, respectively?

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Zhang, Z.J.: Water and Wastewater Treatment, 4th ed., China Construction Industry Press, Beijing, 2015 (in Chinese)

Ion Exchange

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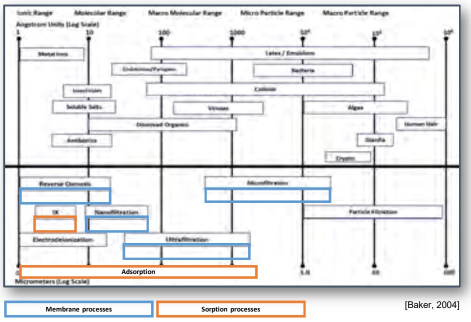
Learning targets

- Basic understanding of the principles of ion exchange and the determining parameters
- Overview of the main applications of ion exchange resins
- Knowledge about the technologies and systems for ion exchange, and the related operational aspects

Outline

- Process objectives and applications
- Structure of resins and basic principles
- Properties of ion exchange resins
- Process conditions and breakthrough
- Process combinations
- Operation of IEX columns
- Ion exchange equipment

Size of compounds and separation processes



[Baker, 2004]

First documented case of ion exchange (IEX)

Gustave Doré

Exodus 15:23

When they came to Marah, they could not drink the waters of Marah, for they were bitter; therefore it was named Marah.

Exodus 15:24

So the people grumbled at Moses, saying, "What shall we drink?"

Exodus 15:25

Then he cried out to the LORD, and the LORD showed him a tree; and he threw it into the waters, and the waters became sweet. There He made for them a statute and regulation, and there He tested them.

Application of ion exchange processes

Cation Exchangers:
- Softening
- Dealkalization

Anion Exchangers:
- NOM removal
- Nitrate removal
- Boron removal
- Perchlorate removal
- Metal complex removal (anionic) – Cr, U, Ra

Cation + Anion Exchangers:
- Demineralization
- Condensate polishing
- Nuclear applications
- Ultra pure water

[WQA, 2010]

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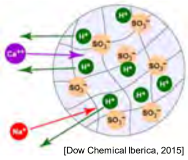
Structure of resins and basic principles

Solid materials able to **sorb charged ions** from an electrolyte solution and **release an equivalent amount** of other ions of equal charge to the solution

Technical terms:

- Charged matrix – **Functional groups** → poly-ion (e.g. SO_3^-)
- **Counterions** (e.g. H^+, Ca^{2+}, Na^+)
- **Solvent** (e.g. water) → swelling
- **Pores** – real channels or openings between polymer chains



[Dow Chemical Iberica, 2015]

Exchange reactions (examples):

$$\overline{X-Na^+} + K^+ \Leftrightarrow \overline{X-K^+} + Na^+$$

$$\overline{R-Ca^{2+}} + 2Na^+ \Leftrightarrow \overline{R-(Na^+)_2} + Ca^{2+}$$

$$\overline{R-(Cl^-)} + SO_4^{2-} \Leftrightarrow \overline{R-SO_4^{2-}} + 2Cl^-$$

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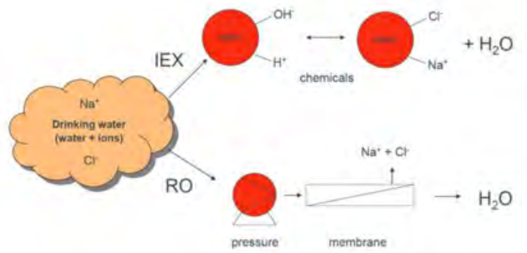
Structure of resins and basic principles

Comparison of IEX and Reverse Osmosis (RO):



[Dow Chemical Iberica, 2015]

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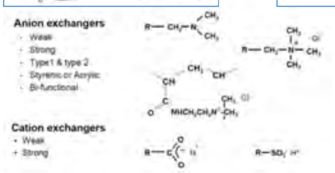
Structure of resins and basic principles

Chemistry of functional groups:

[Dow Chemical Iberica, 2015]



Charge → Capacity

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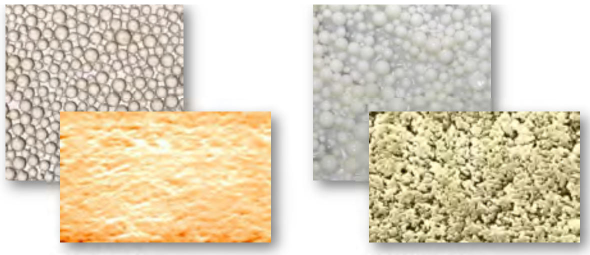
Structure of resins and basic principles

Porosity of ion exchange resins:



Gel-type resin

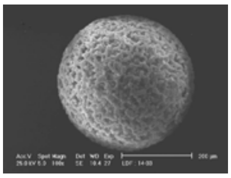
Macroporous resin

[Dow Chemical Iberica, 2015]

WaterHarmony

Structure of resins and basic principles

Porosity of ion exchange resins:



Macroporous resin (close-up)

Gel resins

- Irreversible uptake of large organic anions → organic fouling → reduction of capacity
- Side exchange phenomena

Macroporous resins

- Inert additive during synthesis that is removed afterwards
- Large pores: 200-2000 Å

WaterHarmony

Structure of resins and basic principles

Particles sizes:

Monodisperse resin

Polydisperse resin

[Dow Chemical Iberica, 2015]

Advantages with monosphere resins:

- Uniform development of exhaustion and regeneration
- Mixtures of different resins can be separated
- Fixed bed can be arranged

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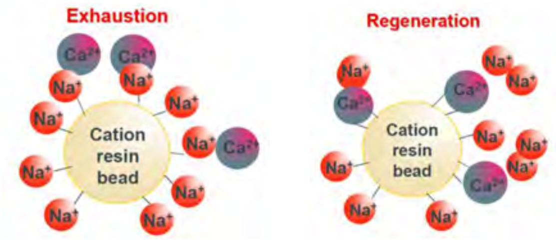
Structure of resins and basic principles

Exhaustion and regeneration:



[Dow Chemical Iberica, 2015]

See also: GE Life Sciences, 2018; https://youtu.be/q3fMqgT1do8?t=27s

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Properties of ion exchange resins

Stability of ion exchange resins:

- Mechanical – osmotic shock (-50%...+100% of volume)
- Thermal stability
  - Strong acid cation exchangers 120 °C
  - Weak acid cation exchangers 75 °C
  - Weak basic exchangers 180 °C
  - Anion exchange Type-II 40 °C
  - → Storage conditions
- Chemical stability
  - Oxidants
  - Acids

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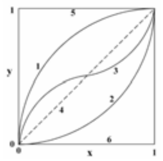
Properties of ion exchange resins

Ion exchange equilibria:

$$z_A\,\overline{R-B^{z_B}} + z_B\,A^{z_A} \Leftrightarrow z_B\,\overline{R-A^{z_A}} + z_A\,B^{z_B}$$

$$x_i = \frac{z_i\,c_i}{\sum_j z_j\,c_j} = \frac{z_i\,c_i}{c_0} \qquad y_i = \frac{z_i\,\bar{c}_i}{\sum_j z_j\,\bar{c}_j} = \frac{z_i\,\bar{c}_i}{\bar{c}_{max}}$$



1 – first component is preferred before the second component
2 – reverse case to (1)
3 – there are areas of preference and non-preference
4 – none of the two components is preferred
5, 6 – irreversible isotherms

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Properties of ion exchange resins

Selectivity of ion exchangers - general rules:

- Ions of higher valence are preferred
- Ions with smaller solvation shell are preferred
- Ions that undergo particular interactions with functional groups are preferred
- More polar ions are preferred
- Ions that are not forming complexes with co-ions are preferred

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Properties of ion exchange resins

Selectivity of ion exchangers - series of selectivity:

a) Strongly acidic exchangers:

$Ti^{4+} > Cr^{3+} > Al^{3+} > Ba^{2+} > Pb^{2+} > Fe^{2+} > Ca^{2+} > Ni^{2+} > Cd^{2+} > Cu^{2+} > Zn^{2+} > Mg^{2+} > Ag^{+} > Cu^{+} > K^{+} > NH_4^{+} > Na^{+} > H^{+}$

b) Weakly acidic exchangers

$H^{+} >> Cu^{2+} < Pb^{2+} > Fe^{2+} > Ni^{2+} > Cd^{2+} > Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$

c) Strongly basic exchangers (types 1 and 2):

$SO_4^{2-} < NO_3^{-} > PO_43^{-}$ > Oxalat > NO_2^{-} > Cl^{-} > Formiat > Citrat > Tartrat > Phenolat > F^{-} > Acetat > HCO_3^{-} > $HSiO_3^{-}$ > CN^{-} > HBO_3^{-} > OH^{-}

d) Weakly basic exchangers

$OH^{-} >> [Fe(OH)_6]^{4-(3-)} > [Cu(OH)_4]^{3-} > [Ni(OH)_4]^{3-} > CrO_4^{2-} > SO_4^{2-} > NO_3^{-} > HPO_4^{2-} > NO_2^{-} > SCN^{-} > Cl^{-}$ > Formiat > Kommplexonate > Citrat > Tartrat > Oxalat > F^{-}

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Properties of ion exchange resins

Selectivity of ion exchangers – separation factors:

Table 3.1: Separataion factors from the exchange of monovalent cations for hydrogen ions for the strongly acidic cation exchanger Duolite C 100

Cation	Degree of crosslinking, % DVB			
	4	8	12	16
H^+	1.0	1.0	1.0	1.0
Li^+	0.9	0.85	0.81	0.74
Na^+	1.3	1.5	1.7	1.9
NH_4^+	1.6	1.95	2.3	2.5
K^+	1.75	2.5	3.05	3.35
Rb^+	1.9	2.6	3.1	3.4
Cs^+	2.0	2.7	3.2	3.45
Cu^+	3.2	5.3	9.5	14.5
Ag^+	6.0	7.6	12.0	17.0

[Purolite Ion Exchange Manual]

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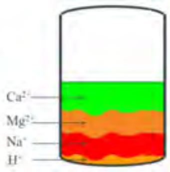
Properties of ion exchange resins

Selective separation:

Resin selectivity creates chromatographic exhaustion:

- loosely held ions travel quickly
- tightly held ions travel slowly
- moving ionic wave fronts are established



[Dow Chemical Iberica, 2015]

- Selectivity Increases with Charge
  - $Al^{3+} > Ca^{2+} > Na^{+}$
  - $SO_4^{2-} > Cl^{-}$
- Selectivity Increases with Atomic Number
  - $Ca^{2+} > Mg^{2+}$
  - $Br^{-} > Cl^{-} > F^{-}$

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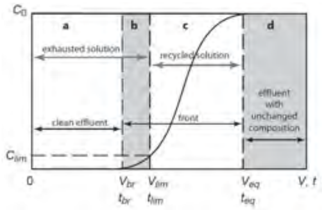
Process conditions and breakthrough

Development of the breakthrough curve [Zagorodni 2006]:



Technical terms:

- Maximum capacity
- Effective capacity – depends on pH, concentration etc.
- Useful capacity – below equilibrium
- Breakthrough capacity

Important design parameter: **Useful capacity in meq/L**, depending on process conditions including regeneration. This information is usually provided by the resin manufacturer.

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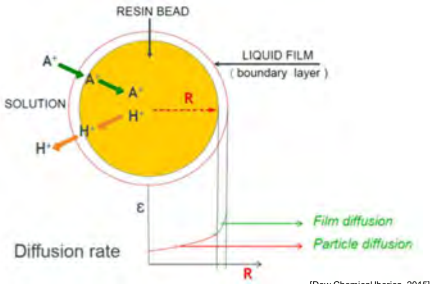
Properties of ion exchange resins

Ion exchange kinetics:



[Dow Chemical Iberica, 2015]

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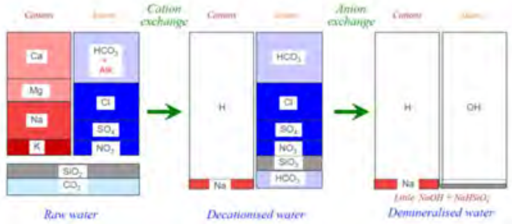
Process combinations

Demineralisation = removal of **cations** and **anions**

- Cation exchange: all cations replaced by H^{+}
- Anion exchange: all anions replaced by OH^{-}



[Dow Chemical Iberica, 2015]

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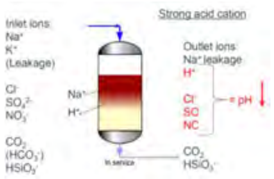
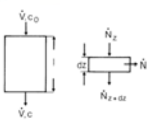
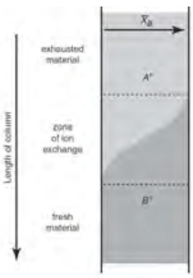
Process conditions and breakthrough

Packed bed process:



Mass balance approach:





[Zagorodni 2006]

WaterHarmony Erasmus+

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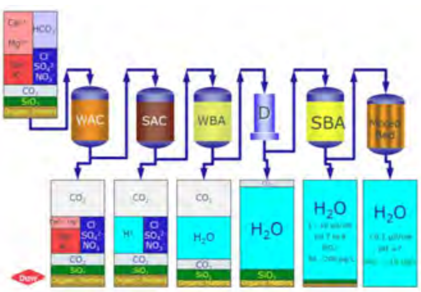
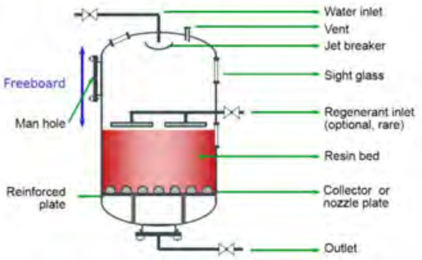
Process combinations



[Dow Chemical Iberica, 2015]

Operation of IEX columns

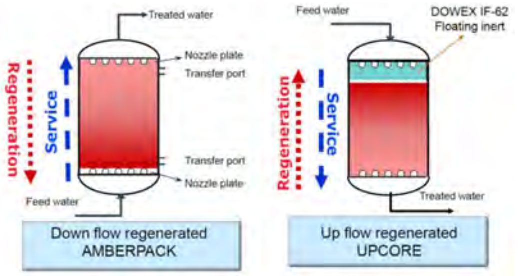
Main components and connections:



[Dow Chemical Iberica, 2015]

Operation of IEX columns

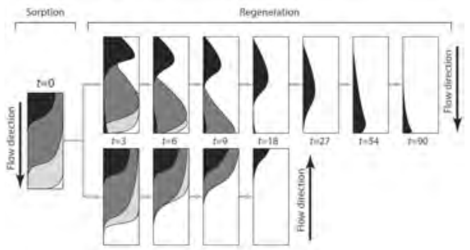
Counter-current regeneration:



[Dow Chemical Iberica, 2015]

Operation of IEX columns

Co-current vs. counter-current regeneration:

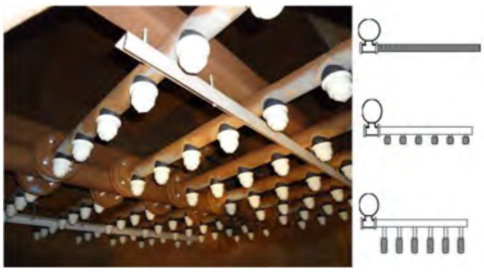


Concentration profiles in resin columns [Zagorodni, 2006]

Ion exchange equipment

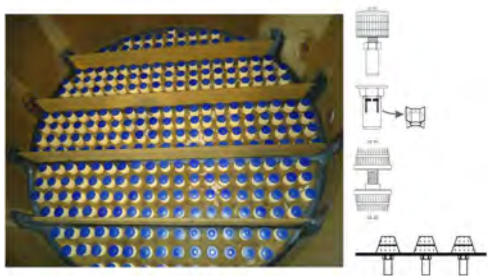
[Hydro, 2015]

Ion exchange equipment



[Dow Chemical Iberica, 2015]

Ion exchange equipment



[Dow Chemical Iberica, 2015]

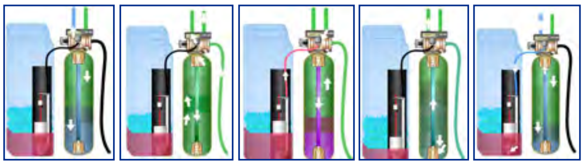
Ion exchange equipment

[Ecosoft and Ecowater, 2018]

Ion exchange equipment

[Ecosoft, Ecowater and Clack Corp., 2018]

Ion exchange equipment



[Ecowater, 2018]

Questions

- How does the basic structure of an ion exchange resin look like?
- Which factors play a role regarding the uptake of ions by a resin and the eventual breakthrough in column operation?
- What is the meaning of “selectivity”?
- Which combination of resins is necessary in order to reach a complete demineralization of the influent water?
- What are other typical applications of ion exchange in water treatment?

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Disinfection

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Learning targets

- The physical and chemical bases of disinfection in water treatment are reviewed.
- Chemical equations, equipment and technological schemes for the processes of chlorination, ozonation, and ultraviolet irradiation are showed.
- It is aimed at becoming familiar with these terms:
  - Disinfection – principles and methods
  - Pollutants
  - Chlorination
  - Ozonation
  - Ultraviolet irradiation

Outline

- Introduction
- Chlorination
- Ozonation
- Contact devices for ozonation
- UV irradiation for disinfection
- UV irradiation in combination with ozone
- Post-chlorination

Introduction

Aquatic pathogens: Microorganisms that are capable of causing human diseases (often fatal):

Bacteria	Viruses	Protozoa
Campylobacter jejuni, Campylobacter Coli	Adenoviruses	Entamoeba histolytica
Salmonella (non typhi) Shigella spp	Enteroviruses Hepatitis A	Giardia intestinalis Cryptosporidium parvum
Escherichia Coli (E.Coli) (pathogens) Vibrio cholerae Yersinia enterolitica Pseudomonas aeruginosa Aeromonas spp	Enteroviruses hepatitis A, hepatitis E Norwalk virus Rotavirus Small round viruses	Dracunculus medinensis

Introduction

- Surface waters usually contain organic compounds and pathogens, leading to the need of disinfection.
- Chlorination is the mostly used method of disinfection. However, chlorination of water containing organic substances forms organic chlorine compounds that are dangerous to humans.
- Contact of the mucous membranes of the esophagus, stomach and intestines with these carcinogens can cause cancer of the digestive system.

Introduction

- Therefore, the task is to minimize the impact of pathogens and toxic compounds on humans and the environment.
- The main methods of disinfecting water, which are used for inactivating pathogens, are:
  - Chlorination
  - Ozonation
  - Ultraviolet water treatment
- All these methods are accompanied by oxidative processes.

Introduction

Oxidative processes can be classified as follows:

- **natural**, which include the treatment of water in nature under the influence of air oxygen, as well as under the influence of solar radiation
- **artificial,** when the treatment is done by effective oxidants (O_3, H_2O_2, $KMnO_4$, ClO_2, Cl_2, $HClO^-$, ClO etc.)
- **special**, such as thermo-oxidative, photocatalyst, electro-chemical, and radiation methods

Chlorination

Chlorine and its compounds possess a high bactericidal effect. It is explained by the action of chlorine and its compounds on cell protoplasm enzymes. This leads to a more or less rapid death of the microorganisms.

Examples for reaction times:

Germ inactivation for chlorinated water*

Germ	Time
E. coli O157:H7 Bacterium	Less than 1 minute
Hepatitis A Virus	About 16 minutes
Giardia Protozoan	About 45 minutes
Cryptosporidium Protozoan	About 15,300 minutes (10.6 days)

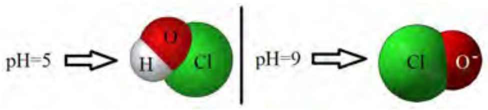
* Laboratory testing results using chlorine demand free water with 1ppm (1mg/L) 7.5, 77 °F (25 °C) and in the absence of cyanuric acid.

Chlorination

- The action of chlorine is varying depending on pH.
- Dosing of chlorine into the water formes hypochlorous (hydrogen (I) oxychlorate) and hydrochloric acid:

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

- Increasing the pH of water leads to the formation of hypochlorite ions ClO^-:



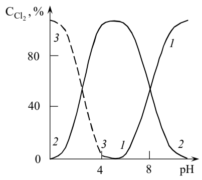
Chlorination

- Chlorine acts as an oxidant under acidic conditions, in which there is no dissociation of hypochlorous acid.
- At pH > 4, molecular chlorine is almost absent. Dissociation of HOCl into H^+ and ClO^- is beginning.
- With increasing pH the ClO^- ion may form radicals:

$$ClO^- + H_2O \rightarrow Cl^- + 2\ OH^*$$

- Standard potentials:

$$E^0_{Cl_2/2Cl^-} = 1{,}359\,V; \quad E^0_{HClO+H^+/Cl^-+H_2O} = 1{,}47\,V; \quad E^0_{ClO^-+H_2O/Cl^-+OH^-} = 0{,}906\,V;$$



Species of active chlorine in aqueous solutions, depending on pH: 1 - ClO^-; 2 – HClO, 3 - Cl_2

Chlorination

- In the presence of ammonium compounds in water, hypo-chlorous acid forms, as well as chloramine NH_2Cl and dichloramine $NHCl_2$. Chlorine in the form of chloramine is called bound "active" chlorine.
- The formation of halogenated compounds is associated with the fact that about 90% of active chlorine takes part in oxidation reactions:

$$R\text{-}CHO + HOCl \rightarrow R\text{-}COOH + HCl$$

- About 10% of chlorine takes part in substitution reactions:

$$R\text{-}CH_2\text{-}CH{=}CH\text{-}R_2 + HOCl \rightarrow R\text{-}CHCl\text{-}CH{=}CH\text{-}R_2 + H_2O$$

Chlorination

- Sources of the "active" chlorine are hypochlorites, chlorites, and chlorine dioxide.
- Sodium hypochlorite (oxychlorate) is formed by passing chlorine gas through an alkaline solution:

$$Cl_2 + 2\ NaOH \rightarrow NaClO + NaCl + H_2O$$

- Calcium hypochlorite is prepared by the chlorination of calcium hydroxide at a temperature of 25–30°C:

$$2\ Ca(OH)_2 + 2\ Cl_2 \rightarrow Ca(ClO)_2 + CaCl_2 + 2\ H_2O$$

- Calcium chlorite (bleach) is obtained from calcium hydroxide and chlorine:

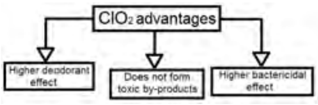
$$Ca(OH)_2 + Cl_2 \rightarrow CaOCl_2 + H_2O$$

Chlorination

- A strong oxidizing agent is sodium chlorite $NaClO_2$, which decomposes with the release of chlorine dioxide ClO_2:

$$2\ NaClO_2 + Cl_2 \rightarrow 2\ ClO_2 + 2\ NaCl$$

$$5\ NaClO_2 + 4\ HCl \rightarrow 5\ NaCl + 4\ ClO_2 + 2\ H_2O$$



- In an alkaline environment, ClO_2 decomposes at a high speed according to the reaction:

$$2\ ClO_2 + 2\ NaOH \rightarrow NaClO_2 + NaClO_3 + H_2O$$

Chlorination

Residual chlorine:

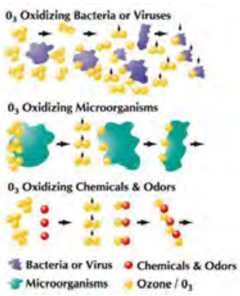
Residual chlorine is to be present in drinking water. It is very volatile, and small concentrations can quickly evaporate from the water. However, free chlorine represents a serious danger to human health at high concentrations.

Standards of residual chlorine in drinking water:

Residual chlorine	The concentration of residual chlorine, mg/L	Time required for chlorine to contact with water, min, not less than
1. Free	0.3-0.5	30
2. Bound	0.8-1.2	60

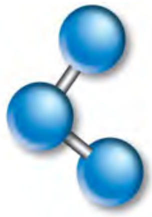
Ozonation

- A total virulent and bactericidal effect is achieved when using ozone.
- Ozone oxidation can effectively decolorize both drinking water and waste water.
- It improves the taste, eliminates odors and flavors, and guarantees a thorough disinfection of the water.



Ozonation

- In nature, ozone gas is found in the upper atmosphere.
- At a temperature of -111.9°C, ozone is transformed into the unstable liquid. The melting point is -197.2 ± 0.2°C.
- The density (at 0°C and a pressure of 0.1 MPa) is 2.154 g/L.
- The heat of formation is 143.64 kJ/mol.
- The solubility coefficient in water at 0°C is 0.394 kg/m³.
- The redox potential is 2.07V.



Ozone O_3 – relative molecular mass = 48 g/mol

Ozonation

The decomposition of ozone in air:

$$O_3 + M \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} O_2 + O^{\bullet} + M$$

- k1 = 7,8·1011 [-2340/(RT)], $l \cdot mol^{-1} \cdot s^{-1}$
- k-1 = 1,24·10-10 [-1090/ (RT)], $l \cdot mol^{-1} \cdot s^{-1}$
- M – random particle

$$O + O_3 \xrightarrow{k2} 2\ O_2$$

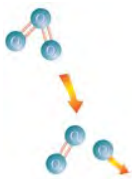
- k2 = 2,9·109 [-3700/(RT)], $l \cdot mol^{-1} \cdot s^{-1}$

Ozonation

The decomposition of ozone in water:

In water, the ozone decomposition reaction mechanism is rather complicated, since the degradation rate is influenced by many factors:

- the conditions for the transition from the gaseous ozone into the liquid phase,
- the ratio between the partial pressure of the gas
- its solubility in aqueous solution
- the kinetics of oxidation



Ozonation

The oxidation by ozone:

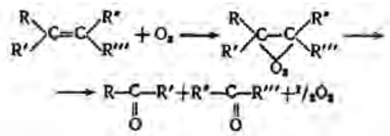
The action of ozone in an oxidation process can occur in **three different ways**:

- direct oxidation with one oxygen atom
- the accession of the whole molecule of ozone to the oxidizing agents to form ozonides
- increased catalytic oxidizing action of oxygen present in the ozonized air

Ozonation

Direct oxidation:

Ozonolysis is a process for fixing the ozone double or triple carbon bond with its subsequent cleavage and formation of ozonides which, as ozone, are unstable compounds and degrade rapidly:



Ozonation

Ozone oxidizes both inorganic and organic substances dissolved in water. Consider a few examples:

- Metal compounds are oxidized by ozone to compounds of higher valence. For example, the reactions with iron and manganese occur as follows:

$$2\,FeSO_4 + H_2SO_4 + O_3 \rightarrow Fe_2(SO_4)_3 + H_2O + O_2$$

$$MnSO_4 + O_3 + 2\,H_2O \rightarrow H_2MnO_3 + O_2 + H_2SO_4$$

$$2\,H_2MnO_3 + 3O_3 \rightarrow 2\,HMnO_4 + 3\,O_2 + H_2O$$

Ozonation

- The oxidation of hydrogen sulfide is:

$$H_2S + O_3 \rightarrow H_2O + SO_2$$

$$3\,H_2S + 4\,O_3 \rightarrow 3\,H_2SO_4$$

- Thiocyanate ion and cyanide ions react with ozone according to this scheme:

$$SCN^- + 2\,O_3 + 2\,OH^- \rightarrow CN^- + SO_3^{2-} + 2\,O_2 + H_2O$$

$$CN^- + SO_3^{2-} + 2\,O_3 \rightarrow CNO^- + SO_4^{2-} + 2\,O_2$$

The oxidation process is recommended to be conducted in a neutral or weakly acidic medium at a temperature of 5–25 °C.

Ozonation

- Ammonia is oxidized with ozone in an alkaline environment to nitric acid and water:

$$NH_3 + 4\,O_3 \rightarrow NO_3^- + 4\,O_2 + H_2O + H^+$$

With pH increasing from 7 to 9, the reaction rate increases by a factor of 10-20. Therefore, from an economic point of view, it is advantageous to use ozone for the oxidation of ammonia when alkaline water is present and there is no need for a special alkalization.

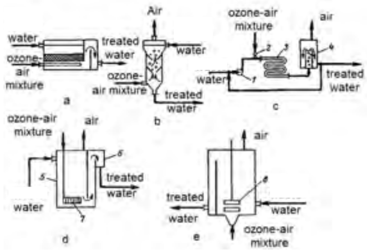
- Urea in aqueous solutions can be oxidized to nitric acid, O_2, CO_2 and water. A feature of the reaction is that it starts after a certain period of time after the dosage of ozone.

Ozonation

- Ozone shows a high oxidation potential for phenols. The mechanism of phenol oxidation by ozone is the same in acidic or alkaline solutions, although the reaction rates under these conditions are significantly different.

With increasing pH the phenol decay rate increases. The primary intermediate reaction product is catechol, then quinone is formed. Finally, after a series of transformations, carboxylic acid is produced.

Contact devices for ozonation



a - with a nozzle; b - a bubble column with plates; c - a coil reactor; d - a bubble column with a porous plate; e - column with a mechanical turbine type stirrer; 1 - Pump; 2 - injector-mixer; 3 - coil; 4 - air separator; 5 - contact chamber; 6 - collection chamber; 7 - a diffuser; 8 - turbine

Contact devices for ozonation

Since ozone is a strong toxic agent (superior, for example, to hydrocyanic acid), residual ozone in the off-gas of ozonation plants must be decomposed.

Residual ozone can be destroyed by:

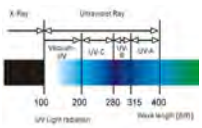
- adsorption
- pyrolysis
- catalytic reduction

The catalyzed destruction leads to rapid decomposition of ozone into oxygen and atomic oxygen in the presence of a catalyst (platinum mesh) at 60-120°C. The contact time is less than 1 second.

UV irradiation for disinfection

Classification:

UV-radiation covers a wavelength range from 100 to 400 nm. Rays with a wavelength of 100-200 nm are called vacuum or hard ultraviolet. Their energy can suffice for the destruction of organic molecules. Rays with a wavelength of 200-400 nm that are generated by special mercury or xenon lamps, are widely used for the disinfection of air and water.

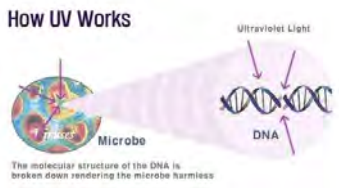


UV installation for water disinfection

UV irradiation for disinfection

Effect on microorganisms:

Only a part of the spectrum of UV-radiation in the wavelength range 205-315 nm with maximum effectiveness at 260±10 nm has a disinfection effect.



UV irradiation for disinfection

Irradiation dose:

- The effectiveness of water disinfection (the portion of micro-organisms killed by UV irradiation) is proportional to the light intensity (mW/cm^2) and the contact time (s).
- The product of these two quantities is called irradiation dose (mJ/cm^2). It is a measure of the bactericidal power transferred to the microorganisms.
- The **minimum dose** of UV irradiation for the disinfection of drinking water is **16 mJ/cm^2**. It provides a reduction of patho-genic bacteria in the water by at least 5 orders of magnitude (logs), and of indicator bacteria by 2-6 logs. The dose also reduces the amount of viruses by 2-3 logs.

UV irradiation for disinfection

Advantages of UV disinfection:

- The most important advantage of UV water treatment is the absence of a change of its physical and chemical characteristics even at doses much higher than practically necessary.
- Other advantages are:
  - versatile effects and high effectiveness on the inactivation of various microorganisms in water
  - ecological, safe for human life and health
  - low operating costs
  - low capital cost
  - ease of maintenance facilities

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UV irradiation for disinfection

Disadvantages of UV disinfection:

- A serious drawback of UV disinfection is the absence of an aftereffect, i.e. purified water can become contaminated again in subsequent stages of processing or transport.
- UV irradiation kills microorganisms in water, but the cell walls of bacteria, fungi and viruses remain in the water. When used as a drinking water it is desirable to remove them by means of fine filtration.
- A combination of UV irradiation and ozonation is an efficient way to overcome some of the shortcomings.

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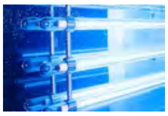
UV irradiation in combination with ozone

- Oxidative water treatment processes can be significantly enhanced when used in conjunction with ultrasound or ultraviolet irradiation (UV). UV can accelerate oxidation reactions by a factor of 10^2-10^4.
- The oxidation process can be divided into **two stages**:
  - photochemical excitation of molecules by UV irradiation
  - oxidation by ozone



Mercury lamps with different pressure

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UV irradiation in combination with ozone

Photochemical phenomena in the system water-oxygen-ozone-organic substances:

In such systems, hydroxyl and hydroxyde-peroxyde radicals are formed. When mercury lamps with low or high-pressure are used as a radiation source, the ozone decomposition process leads to O• (‘D), which is a singlet, and therefore reacts with water at high speed, forming HO• radicals by the following mechanism:

$$O^{\bullet}\ (‘D) + H_2O \rightarrow 2\ HO^{\bullet}$$

These radicals are very strong oxidants that react unspecifically with most organic substances.

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Post-chlorination

- During ozonation and/or UV water treatment, highly reactive radicals are the basis of high efficiencies.
- However, these radicals react readily with a variety of impurities in the water and on the walls of pipes and devices, which leads to their rapid disappearance. Therefore, regrowth of micro-organisms in treated water (secondary pollution) is possible.
- In order to counteract regrowth, post-chlorination is applied in many places after ozonation and UV treatment.
- Post-chlorination makes it also possible to transport treated water to consumers over long distances without a decrease of its hygienic quality.

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Questions

- How are oxidative processes classified?
- In which way is chlorine acting as a disinfectant?
- Describe the hydrolysis and dissociation of chlorine in water.
- What is the meaning of bound chlorine?
- How can chlorine dioxide be produced?
- Which factors affect the decomposition of ozone in water?
- Which parts belong to contact devices for ozonation?
- Describe the parameter “dose” used to characterize UV disinfection, and give some advantages and disadvantages of the process.

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Biological processes

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Learning targets

- Understanding of biological transformation principles for organic and inorganic compounds to be removed from raw water
- Knowledge about the boundary conditions and the main design and operational parameters of biological processes
- Overview of typical process applications

Outline

- Removal of organic matter
  - Riverbank filtration
  - Slow sand filtration
  - Ozonation and biofiltration
  - Biological activated carbon process
- Oxidation of ammonium
- Reduction of nitrate
- Iron and manganese removal
- Final remarks

Removal of organic matter

Basic principle

Oxidation of organic substrate by (sessile) heterotrophic bacteria:

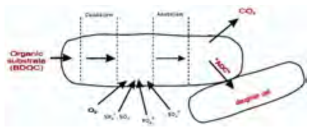
Substrate + O_2 → Biomass + CO_2 + H_2O

Characteristic parameters

- BDOC = biodegradable dissolved organic carbon
- AOC = assimilable organic carbon

Main pathways

- formation of new biomass (assimilation)
- mineralization for generation of energy
- yield in drinking water treatment processes usually < 10%



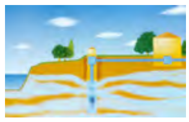
Metabolic rate of a heterotrophic bacteria cell, after Uhl and Overath [2004]

Removal of organic matter

Riverbank filtration

Principle

- Infiltration of river water into the upper aquifer
- Mixing with groundwater and flow to extraction wells
- Travel time: some days to several weeks



Courtesy: *DVGW, 1995*

Application

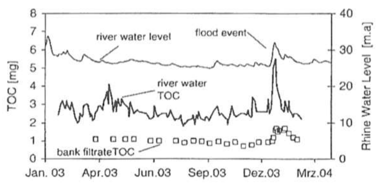
Pre-treatment of surface water (rivers, lakes) in aeras with suitable aquifers

Effects:
- Removal of particles and colloids by filtration
- Elimination of micro-organisms (often by several logs)
- **Removal of organic compounds by degradation processes**
- Elimination of metals by sorption and precipitation
- Equalization of peak concentrations

Removal of organic matter

Riverbank filtration

Data from Duesseldorf (Germany): Removal of organic compounds by 50 – 60%



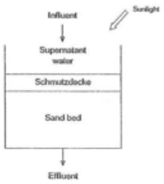
TOC (Total Organic Carbon) concentrations in the river Rhine and in bank filtrate during one year [Eckert and Irmscher, 2006]

Removal of organic matter

Slow sand filtration

Principle

- Filtration of raw water through an open sand bed by gravity
- Formation of a layer of particles, micro-organisms and algae (Schmutzdecke) on top of the sand bed
- Regeneration by removal/washing of upper sand layer



Application

Pre-treatment of surface water (or biofiltration of ozonated water, see below)

Effects:
- ► Removal of particles and colloids by filtration
- ► Elimination of micro-organisms in the Schmutzdecke
- ► **Removal of organic compounds by degradation processes**

Removal of organic matter

Slow sand filtration

Typical design parameters

- Hydraulic loading restricted to 0.05 – 0.5 m/h
- Filter depth 0.5 – 2 m; cross sectional area up to 10.000 m^2
- Grain size 0.25 – 1 mm
- Depth of supernatant 0.3 – 1 m
- Frequency of regeneration between some weeks and several months
- Ripening period several days

Data from practical operations (example)

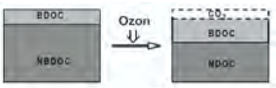
Removal of DOC (Dissolved Organic Carbon) by (15 ± 5)% [Collins et al., 1992], depending on the biodegradable organic fraction (BDOC) in the influent water

Removal of organic matter

Ozonation and biofiltration

Idea

- Increase of the biodegradable fraction of organics (BDOC) by pre-ozonation without substantial mineralization to CO_2 and H_2O [Uhl & Overath, 2004]



- Aerobic degradation of the organic substrate by heterotrophic micro-organisms attached to filter grains in slow or rapid sand filters

Instead of sand, granular activated carbon (GAC) is often used for biofiltration purposes. Then GAC acts both as a biofilm carrier in the upper layer and as a sorbent for organics in the lower part of the packed column.

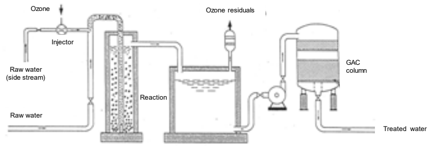
Combined with ozonation this is called “biological activated carbon process”.

Removal of organic matter

Biological activated carbon process

Principle

- Addition of 0.5 – 1 mg ozone per mg DOC, then reaction time 20 – 30 min
- Filtration through GAC at a hydraulic loading of 5 – 10 m/h
- Filter regeneration by backwashing, if needed (depending on head loss)
- GAC reactivation after several weeks to up to 6 months

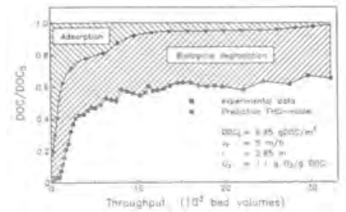


Treatment of riverbank filtrate in Duesseldorf (Germany) by biological activated carbon [SWD, 2011]

Removal of organic matter

Biological activated carbon process

Differentiation between removal mechanisms in a study with humic material:



Removal of dissolved organic carbon (DOC) by adsorption and biodegradation in a GAC column [Hubele, 1985]

Oxidation of ammonium

Principle

Oxidation of ammonium (nitrification) by sessile chemo-lithotrophic bacteria:

$$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + H_2O + 2\ H^+$$

Important parameters

- pH = 7 – 8
- Temperature ≥ 5°C
- Oxygen availability (≈ 3.6 mg O_2 per mg NH_4^+)

Practical realization

Operation of rapid sand filters or dual media filters (sand + GAC) as carriers for nitrifying bacteria

Observation that start-up phase with new filter material may take several weeks

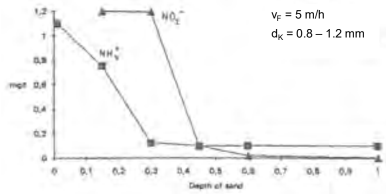
Backwashing with caution in order not to loose all of the biomass

Oxidation of ammonium

Application

Ammonium removal from surface water (maximum permissible value 0.5 mg/L)

Data from Paris (France): Treatment of bank filtrate from the river Loire



Nitrification taking place in the upper sand layer of a rapid sand filter [Nauleau and Jouhier, 1991]

Reduction of nitrate

Principle

Reduction of nitrate (denitrification) by sessile heterotrophic bacteria:

$$5\ C_2H_5OH + 12\ NO_3^- \rightarrow 6\ N_2 + 10\ HCO_3^- + 2\ OH^- + 9\ H_2O$$

Important parameters

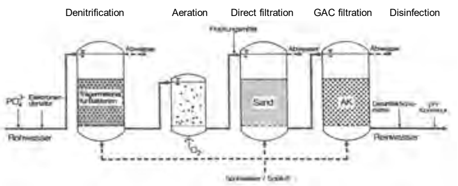
- pH = 6.5 – 8
- Organic substrate (electron donor) availability, also for removal of oxygen
  - Addition of acetic acid: practical demand 0.79 g / g NO_3^-
  - Addition of ethanol: practical demand 0.45 g / g NO_3^-
- Dosage of phosphate (demand ≈ 5 – 6 mg PO_4^{3-} / g NO_3^-)
- If necessary, addition of other micro-nutrients, e.g. Fe

Nitrate reduction can also be achieved by autotrophic bacteria. In that case, hydrogen (H_2) is used an electron donor: $5\ H_2 + 2\ H^+ + 2\ NO_3^- \rightarrow N_2 + 6\ H_2O$

Reduction of nitrate

Practical realization

Combination of a biofilm reactor with appropriate post-treatment stages for (a) aeration and removal of nitrogen gas, (b) removal of biomass and residual substrate, and (c) disinfection



Scheme of nitrate removal by denitrification, after Rohmann and Sontheimer [1985]

Reduction of nitrate

Application

Nitrate removal from groundwater (maximum permissible value 50 mg/l)

Experiences from Germany

- Altogether 12 technical plants (8 with heterotrophic and 4 with autotrophic denitrification) built since 1988
- Bioreactor principles: fixed-bed, fluidized-bed, rotating contactor
- Nominal capacities: 25 – 2000 m^3/h
- Volumetric degradation rates (heterotrophic plants): 2 – 5.5 kg NO_3^- / (m^3 · d)
- No problems with initial nitrate concentrations > 100 mg/l; removal efficiency determined solely by amount of substrate added
- Control of nitrite easier with ethanol as a substrate instead of acetic acid
- Frequent backwashing of the bioreactor for removal of excess biomass
- Start-up phase up to 4 weeks, then stable operation despite of backwashing

Iron and manganese removal

Above-ground plants

Operating principle for iron removal

Utilization of chemo-lithotrophic bacteria for the oxidation of Fe(II) to Fe(III):

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

Oxygen needed as an electron acceptor:

$$2\ H^+ + ½\ O_2 + 2\ e^- \rightarrow H_2O$$

Overall reaction: $2\ Fe^{2+} + ½\ O_2 + 5\ H_2O \rightarrow 2\ Fe(OH)_3 + 4\ H^+$

Carbon source for bacteria: CO_2, i.e. no organic substrate required

Important parameters

- Addition of oxygen rather under-stoichiometric, i.e. less than 0.14 mg / mg Fe
- pH slightly basic
- Sufficient buffer capacity because of release of H^+ ions

Iron and manganese removal

Above-ground plants

Application

Iron removal from oxygen-poor groundwater (threshold value 0.2 mg/l)

Practical realization

Aeration of the raw water in order to increase its oxygen content

Operation of rapid sand filters as carriers for iron oxidizing bacteria at hydraulic loadings of 20 – 30 m/h

Precipitation of Fe(III) as $Fe(OH)_3$ at the surface of the bacteria

Regular backwashing for removal of precipitates at time-lags of several days

Start-up phase with new filter material may take some weeks

Data from practical operations (example)

Filter loadings of 3 – 5 kg Fe / m^2 possible [Mouchet, 1992]

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Iron and manganese removal

Above-ground plants

Operating principle for manganese removal

Utilization of chemo-lithotrophic bacteria for the oxidation of Mn(II) to Mn(IV):

$$Mn^{2+} \rightarrow Mn^{4+} + 2\,e^-$$

Oxygen needed as an electron acceptor:

$$2\,H^+ + \tfrac{1}{2}\,O_2 + 2\,e^- \rightarrow H_2O$$

Overall reaction: $Mn^{2+} + \tfrac{1}{2}\,O_2 + H_2O \rightarrow MnO_2 + 2\,H^+$

Carbon source for bacteria: CO_2, i.e. no organic substrate required

Important parameters

- Addition of oxygen rather over-stoichiometric, i.e. more than 0.29 mg / mg Mn
- pH rather basic
- No interference by CH_4, NH_4^+ ions and Fe^{2+} ions, respectively

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Iron and manganese removal

Above-ground plants

Application

Manganese removal from oxygen-poor groundwater (threshold value 0.05 mg/L)

Practical realization

Aeration of the raw water in order to increase its oxygen content (Redox potential > 250 mV)
pH adjustment to pH > 6.5 if needed
Operation of rapid sand filters as carriers for manganese oxidizing bacteria at hydraulic loadings of 8 – 13 m/h
Precipitation of Mn(IV) as MnO_2 outside of the bacteria
Regular backwashing for removal of precipitates at time-lags of several days
Start-up phase with new filter material may take several weeks

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Iron and manganese removal

Sub-surface treatment

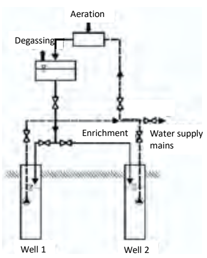
Operating principle

Water is abstracted from a well, aerated and injected back into the aquifer.

After a certain period of time water is pumped from the well and used directly for supply. Iron and manganese are oxidized and precipitated in the aquifer.

When the oxygen pool in the aquifer around the well is exhausted, aerated water must be injected again.

The ratio between water for supply and water for injection can vary between 2 and 12.



Principle of sub-surface treatment for iron and manganese removal

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Iron and manganese removal

Sub-surface treatment

Application

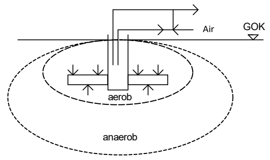
Iron and manganese removal in areas with an appropriate aquifer, in particular for small water supplies

Practical realization

Operation of at least 2 vertical wells (or one horizontal well, see figure)

Establishment of an oxidation zone around the well with oxidizing bacteria attached to the grains of the aquifer

Start-up phase may take several months, especially for manganese oxidation.



Oxidation zone around a horizontal well for sub-surface iron and manganese removal

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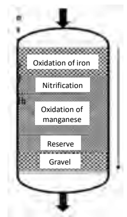
Final remarks

Design and operation of biological processes

- primarily based on empirical values
- utilization of ubiquitous bacteria
- formation of different oxidation zones when both ammonium, iron and manganese present
- operation usually quite stable
- if c(Mn) > 0.1 c(Fe), then two-stage process (two filters) recommended

Treated water quality (target values)

- Organic matter: BDOC as low as possible
- Ammonium < 0.1 mg/l; Nitrate < 25 mg/L
- Iron < 0.02 mg/L; Manganese < 0.01 mg/L



Oxidation zones in a rapid sand filter fed with ammonium, iron and manganese rich water

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Questions

- Why is the removal of BDOC an important task in water treatment?
- Which are the four process principles applied for BDOC removal in practice?
- What kind of process configuration is required for nitrate removal when drinking water is to be treated?
- How are iron and manganese removed in above-ground installations?
- What are the advantages with sub-surface treatment for the removal of iron and manganese?

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Removal of particular pollutants

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Dr. Chem. Sci., Ukraine State University of Chemical Technology

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Learning targets

- Providing insight into the principles of processes for the removal of particles and inorganic substances from water
- Awareness that some focuses may change in the future
- Knowledge about different approaches to monitor the quality of water

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Outline

- Removal of particles and microorganisms
- Removal of inorganic substances
- Future focuses
- Monitoring of water quality

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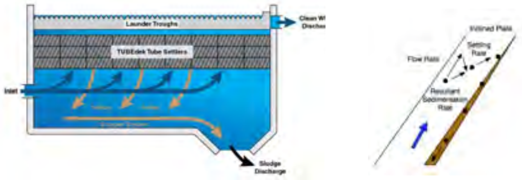
Removal of particles and microorganisms

Clarifier design: Upgrading of traditional rectangular clarifiers by lamella or tube installations



http://2hwatertechnologies.co.uk/treatments/lamella-settlement

The main advantage of lamella clarifiers is the large effective settling area due to the use of inclined plates, which improves the operating conditions in a number of ways. First of all the unit is more compact, because the inclined plates allow the clarifier to be operated with overflow rates 2-4 times higher than those of traditional settling basins.

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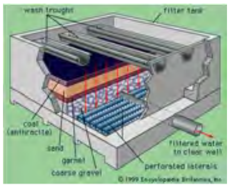
Removal of particles and microorganisms

Design and operation of rapid sand filters



https://www.britannica.com/technology/water-supply-system/images-videos#

For rapid sand filtration the water flow through the sand bed is about two orders of magnitude higher than for slow sand filtration. The rates are about 10 -20 m/h and 0.1-0.2 m/h, respectively.

- Rapid sand filters have graded sand within the bed. The grain size distribution is to optimize the passage of water while minimizing the breakthrough of particles.
- Rapid sand filters are cleaned in place by forcing water flowing backward through the sand. The wash water flow rate is such that the sand is expanded and the filtered particles are removed from the bed. After backwashing the sand settles back into place.
- The larger grains settle first resulting in fine sand layer on the top and coarse sand layer on the bottom. Rapid sand filters are the most common type of filters used in water treatment today.

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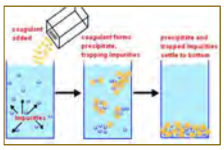
Removal of particles and microorganisms

Treatment of colloid dispersions in water



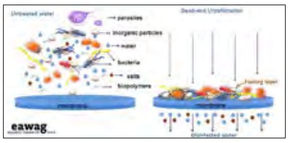
- Fine dispersed solids, such as clays, metal oxides as well as humic substances, proteins and microorganisms, form **colloidal systems**.
- There the particles have sizes on the order of $10^{-8} – 10^{-5}$ m.
- Dimensions of these particles and forces of mutual repulsion prevents them from being filtered easily or settled rapidly. Colloids in water are usually negatively charged, so they repel each other preventing aggregation and sedimentation. Sedimentation or filtration can be attained by adding of a special reagent, the coagulant, in order to create flocs.

http://builtconstructions.in/onlinemagazine/Bangalore/Pages/Waste-Water-Treatment-906.aspx

Removal of particles and microorganisms

Mechanical removal of microorganisms

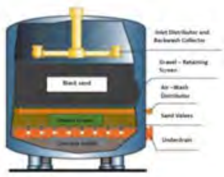
- Slow filtration of water through a sand bed or another suitable grain material leads to the removal of the overwhelming majority of bacteria from filtered water by the upper layer of the filter bed (Schmutzdecke). The effectiveness of this method can reach 99 %, therefore it is an efficient pre-treatment process also with respect to microorganisms.
- Filtration of water through micro-porous membranes leads to the removal of all bacteria from filtered water. The efficiency of this method is 100 % as long as the membrane is not damaged.



https://www.sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/membrane-filtration

Removal of inorganic substances

Iron and manganese removal



Cross-section of a filter unit for iron and manganese removal

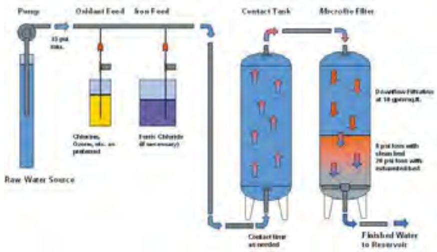
http://www.hitachizosen.co.jp/english/release/2015/12/001953.html

- Fe^{2+} and Mn^{2+} soluble in water are exposed to the air. This leads to the formation of insoluble oxides of Fe^{3+} and Mn^{4+}. The rate of oxidation depend on pH, alkalinity, organic content and presence of oxidizing agents in water.
- The oxidation process occurs according to the reaction:

  $Fe^{2+} + Mn^{2+} + (½\,x+1)\,O_2 \rightarrow FeO_x + MnO_2$
- The reaction products are withdrawn from the water by filtration through an appropriate granular bed (e.g. quarts sand, green sand or black sand).

Removal of inorganic substances

Removal of arsenic



Technological scheme for removal of arsenic by oxidation and direct filtration

http://aquashakti.co/products/arsenic-removal-filter/

Removal of inorganic substances

Fluoride removal

https://www.slideshare.net/NayanaD123/defluoridation-by-bioadsorbents

- Excess fluoride can be removed from potable water by filtration through activated carbon, calcium phosphate, synthetic calcium phosphate, activated alumina, or bone char (animal done powder).
- Examples of reactions:

  $Ca_3(PO_4)_2 + 6\,NaF \rightarrow 3\,CaF_2 + 2\,Na_3PO_4$

  $Ca(OH)_2 + 2\,NaF \rightarrow CaF_2 + 2\,NaOH$

  $Al(OH)_3 + 3\,NaF \rightarrow AlF_3 + 3\,NaOH$
- The lime – soda process of water softening also allows to remove excess fluoride from water.

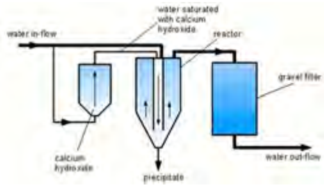
Removal of inorganic substances

Carbonate hardness removal

Calcium and magnesium ions are (partially) precipitated by adding lime:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\,CaCO_3 + 2\,H_2O$$

$$Mg(HCO_3)_2 + 2\,Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 + H_2O + CO_2$$



Scheme of water softening

https://www.slideshare.net/reddyas/12-water-softening

Removal of inorganic substances

Total hardness removal

Calcium and magnesium ions are completely precipitated according to these equations:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\,CaCO_3 + 2\,H_2O$$

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 + H_2O + CO_2$$

$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2\,NaCl$$

$$MgCl_2 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCl_2$$

Scheme of total hardness removal (lime-soda process)

https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=2062922688

Future focuses

- Application of sustainable solutions (less energy, less residuals, natural products and methods)
- Removal of new toxic compounds (POPs = Persistent Organic Pollutants; PPCPs = Pharmaceuticals and Personal Care Products)
- Characterization and removal of microplastics
- Combination of advanced water treatment processes
- A risk based approach rather than satisfying static demands

Monitoring of water quality

- Daily, weekly or monthly monitoring
- Use of grab samples
- Often outlet samples only



Monitoring of water quality

Why is monitoring necessary?

→ Increasing treatment requirements
- health reasons
- environmental reasons
- legal reasons

→ Extreme treatment requirements
- micro-pollutants, nutrients
- footprint – cost of land
- process economy

→ Operational requirements
- unmanned operation – lack of resources / costs

Monitoring of water quality

Type of real-time measurements:

→ with chemicals
- Automated lab analysis (Flow Injection Analysis (FIA) & Sequential Flow Injection (SIA))

→ Sensors without chemicals
- Ion selective electrodes
- Photometric analyses
  - UV absorption (colour, DO)
  - UV-Vis absorption (COD, TOC, BOD)

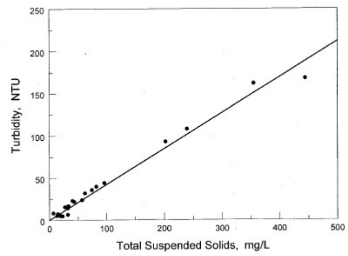
→ Virtual sensors (soft sensors)

Monitoring of water quality

Overview of real-time sensors for certain pollutants
- Suspended Solids
- Inorganic species
- Heavy metals
- Physico-chemical parameters
- Microbiological contaminant indicators, such as E. Coli
- Pesticides
- Endocrine Disrupting Compounds (EDCs)
- Radioactive materials
- Pharmaceuticals

Monitoring of water quality

Principle of virtual sensors:



Example: TSS = f (Turbidity)

Questions

- Describe briefly the performance of processes applied for the removal of particles and colloids.
- What is the principle behind iron and manganese removal?
- How can hardness in water be removed chemically?
- Which future trends are likely to become important for water treatment systems?
- What are the differences between real-time and virtual sensors in water quality monitoring?

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Montgomery, J.M.: Water Treatment - Principles and Design.
3rd ed., John Wiley & Sons, Hoboken 2012

Combined processes

Joachim Fettig
Professor, University of Applied Sciences OWL
Harsha Ratnaweera
Professor, Norwegian University of Life Sciences

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Learning targets

- Insight into the necessity to optimally combine several unit processes in order to meet all of the treatment requirements
- Overview of typical treatment trains for raw waters from different sources

Outline

- Introductory remarks
- Groundwater
- Water from lakes and reservoirs
- River water
- Wastewater for potable reuse
- Conclusions

Introductory remarks

The objectives of water treatment processes can be grouped into four main classes:

- Removal of particles and colloids
- Removal/inactivation of microorganisms
- Removal of dissolved inorganic components
- Removal of organic species

In some treatment facilities only one task has to be fulfilled, e.g. removal of iron from groundwater.

In many waterworks, however, several tasks must be performed in order to meet all of the requirements. Then different unit processes need to be combined and harmonized with each other.

Groundwater

Example: Bersenbrueck Waterworks (Germany)

Tasks:

- Removal of iron and manganese
- Removal of carbonic acid

Problem:

Iron and manganese cannot be removed in the same rapid sand filter because of low pH and an unfavourable Fe : Mn ratio

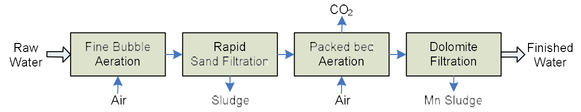
Solution:

1. Application of two filtration stages with preceding aeration and stripping of CO_2
2. Use of dolomite as an alkaline filter material in the second filter

Groundwater

Example: Bersenbrueck Waterworks (Germany)

Processes:



Nominal capacity: 380 m³/h

Finished water quality:

pH = 7.9	Total hardness = 1.26 mmole/L	Alkalinity = 1.5 mmole/L
Iron = 0.01 mg/L	Manganese = 0.025 mg/L	
Conductivity = 344 µS/cm	Turbidity < 0.20 NTU	TOC < 1 mg/L

Groundwater

Example: Bersenbrueck Waterworks (Germany)

Oxidizing tank – Filter I – Packed-bed aerator – Filter II [Wasserverband Bersenbrueck, 2018]

Water from lakes and reservoirs

Example: Sipplingen Waterworks at Lake Constance (Germany)

Tasks:

- Removal of suspended and colloidal solids
- Disinfection

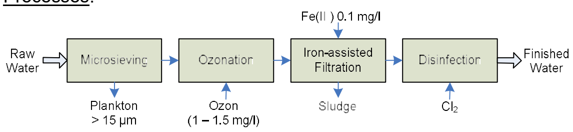
Solution:

1. Application of micro-strainers and rapid sand filters for turbidity removal
2. Ozonation for pre-oxidation and micro-flocculation
3. Addition of ferric chloride prior to the filtration stage
4. Final disinfection with chlorine

Water from lakes and reservoirs

Example: Sipplingen Waterworks at Lake Constance (Germany)

Processes:



Nominal capacity: 20,000 m^3/h

Operating conditions:

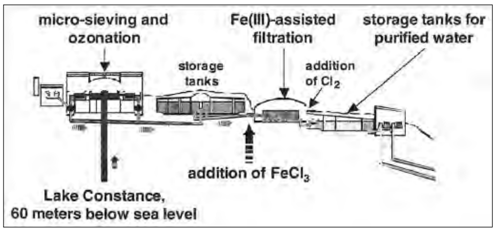
- Ozon generation from pure oxygen, reaction time after ozonation ca. 2 hrs
- Two-layer filtration in 27 filter units, filtration rate 8 m/h, operating time ca. 10 d

Finished water quality:

Turbidity < 0.05 NTU; TOC = 1 mg/L; Conductivity = 336 µS/cm; Total hardness = 1.6 mmole/L

Water from lakes and reservoirs

Example: Sipplingen Waterworks at Lake Constance (Germany)



Scheme of Sipplingen Waterworks [Jekel, 2004]

Water from lakes and reservoirs

Example: Waterworks at Aabach Dam (Germany)

Tasks:

- Removal of suspended and colloidal solids
- Removal of iron and manganese
- Increase of hardness
- Disinfection

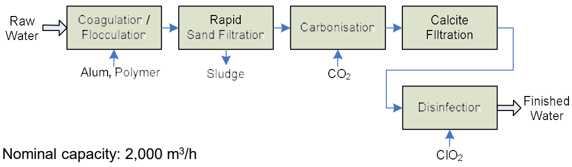
Solution:

1. Application of coagulation/direct filtration for turbidity removal
2. Carbonisation by the addition of CO_2
3. De-acidification by calcite filtration
4. Final disinfection with chlorine dioxide

Water from lakes and reservoirs

Example: Waterworks at Aabach Dam (Germany)

Processes:



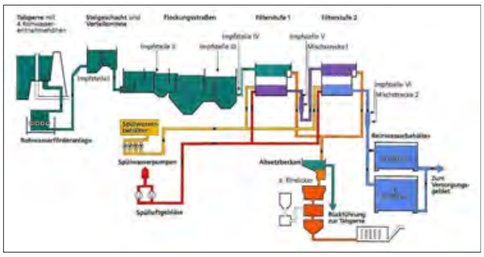
Nominal capacity: 2,000 m^3/h

Finished water quality:

pH = 7.95	Total hardness = 1.58 mmole/L	Alkalinity = 2.57 mmole/L
Iron < 0.01 mg/L	Manganese < 0.005 mg/L	Aluminium = 0.02 mg/L
Conductivity = 342 µS/cm	Turbidity = 0.09 NTU	TOC = 2.2 mg/L

Water from lakes and reservoirs

Example: Waterworks at Aabach Dam (Germany)



Scheme of the Waterworks at Aabach Dam [Aabachtalsperrenverband, 2018]

Water from lakes and reservoirs

Example: Roetgen Waterworks at Dreilaegerbach Dam (Germany)

Tasks:

- Removal of suspended and colloidal solids
- Removal of iron and manganese
- Increase of hardness
- Disinfection

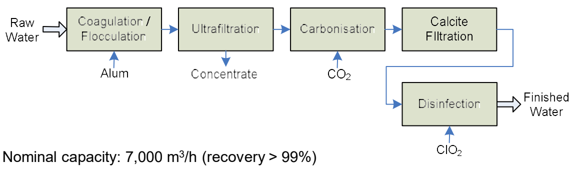
Solution:

1. Application of coagulation/ultrafiltration for turbidity removal
2. Carbonisation by the addition of CO_2
3. De-acidification by calcite filtration
4. Final disinfection with chlorine dioxide

Water from lakes and reservoirs

Example: Roetgen Waterworks at Dreilaegerbach Dam (Germany)

Processes:



Nominal capacity: 7,000 m³/h (recovery > 99%)

Finished water quality:

pH = 8.7	Total hardness = 0.64 mmole/L	Alkalinity = 0.75 mmole/L
Iron < 0.005 mg/L	Manganese = 0.002 mg/L	Aluminium = 0.015 mg/L
Conductivity = 202 µS/cm	Turbidity < 0.05 NTU	TOC = 1.7 mg/L

Water from lakes and reservoirs

Example: Roetgen Waterworks at Dreilaegerbach Dam (Germany)


UF modules for treatment of drinking water (left) and backwash water (right) [WAG, 2008]

River water

Example: Dohne Waterworks at the river Ruhr (Germany)

Tasks:

- Removal of microorganisms
- Removal of suspended and colloidal solids
- Removal of dissolved organic substances
- Disinfection

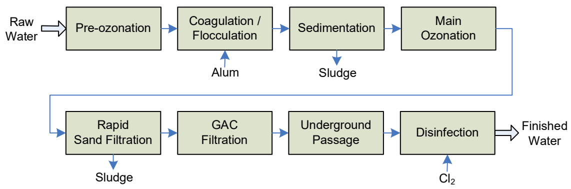
Solution: The „Mulheim Process“ that includes an underground passage

1. Application of two-stage ozonation
2. Coagulation/Flocculation + Sedimentation
3. Rapid sand filtration; biologically enhanced GAC filtration
4. Artificial groundwater recharge

River water

Example: Dohne Waterworks at the river Ruhr (Germany)

Processes:

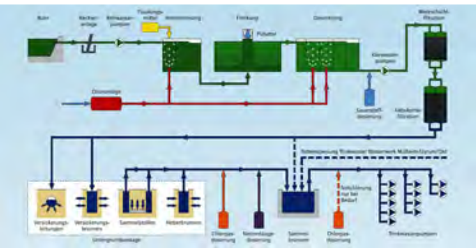


Nominal capacity: 2,500 m³/h

Finished water quality: similar to Styrum Waterworks, see below

River water

Example: Dohne Waterworks at the river Ruhr (Germany)



Scheme of Dohne Waterworks [Rheinisch-Westfälische Wasserwerksgesellschaft, 2018a]

River water

Example: Styrum-East Waterworks at the river Ruhr (Germany)

Tasks:

- Removal of microorganisms
- Removal of suspended and colloidal solids
- Removal of dissolved organic substances
- Disinfection

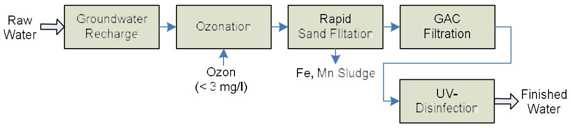
Solution: Modified „Mulheim Process" with preceding underground passage, i.e.

1. Artificial groundwater recharge
2. Ozonation
3. Rapid-sand filtration; biologically enhanced GAC filtration

River water

Example: Styrum-East Waterworks at the river Ruhr (Germany)

Processes:



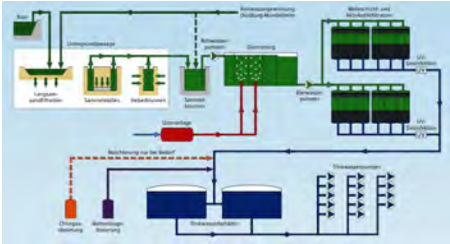
Nominal capacity: 6,000 m^3/h

Finished water quality:

pH = 7.8	Total hardness = 1.40 mmole/L	Alkalinity = 2.29 mmole/L
Iron < 0.005 mg/L	Manganese < 0.005 mg/L	
Conductivity = 521 µS/cm	Turbidity < 0.10 NTU	TOC = 0.6 mg/L

River water

Example: Styrum-East Waterworks at the river Ruhr (Germany)



Scheme of Styrum Waterworks [Rheinisch-Westfälische Wasserwerksgesellschaft, 2018b]

River water

Example: Langenau Waterworks at the river Danube (Germany)

Tasks:

- Removal of microorganisms
- Removal of suspended and colloidal solids
- Removal of dissolved organic substances
- Disinfection

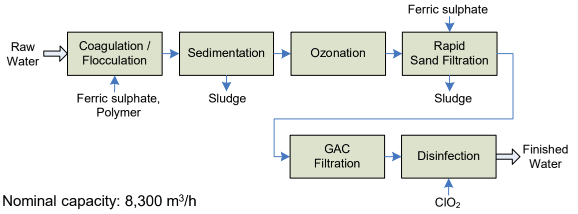
Solution:

1. Coagulation/flocculation + Sedimentation
2. Ozonation
3. Rapid sand (direct) filtration; biologically enhanced GAC filtration
4. Final disinfection with chlorine dioxide

River water

Example: Langenau Waterworks at the river Danube (Germany)

Processes:



Nominal capacity: 8,300 m^3/h

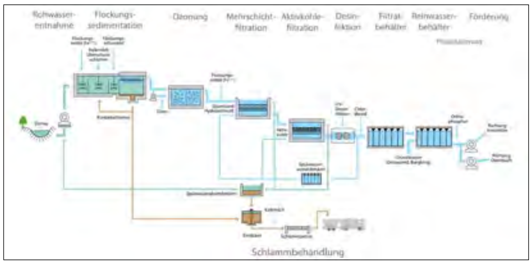
Finished water quality:

Turbidity < 0.05 NTU; TOC = 0.9 mg/L; Conductivity = 497 µS/cm; Total hardness = 2.26 mmole/L

Water Harmony

River water

Example: Langenau Waterworks at the river Danube (Germany)



Scheme of Langenau Waterworks [Landeswasserversorgung, 2018]

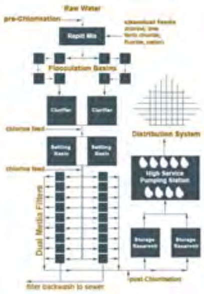
Water Harmony

River water

In some European countries, **pre-chlorination** is not applied anymore, while in Eastern Europe and in several other countries, e.g. the US, this is still a common practice.

A main disadvantage of pre-chlorination is the increased formation of chlorinated organic substances (AOX).

Example: Waterworks of the City of Saginaw/Michigan (US)



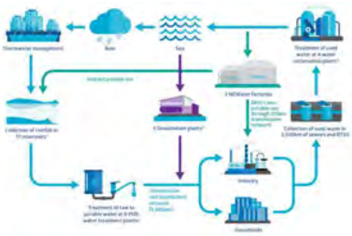
http://www.saginaw-mi.com/departments/wastewaterandwatertreatmentservices/watertreatment/watertreatmentprocess.php

Water Harmony

Wastewater for indirect potable reuse

Example: NEWater approach in Singapore

Concept:



Water management in Singapore including indirect potable reuse [Public Utilities Board Singapore, 2018]

Water Harmony

Wastewater for indirect potable reuse

Example: NEWater approach in Singapore

Tasks:

- Removal of microorganisms
- Removal of suspended and colloidal solids
- Removal of dissolved inorganic and organic substances
- Disinfection

Solution:

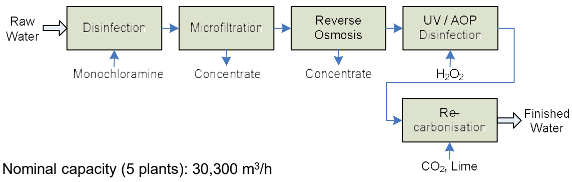
1. Disinfection with monochloramine
2. Microfiltration + Reverse osmosis
3. Final disinfection with UV/AOP
4. Recarbonisation with CO_2 and lime

Water Harmony

Wastewater for indirect potable reuse

Example: NEWater approach in Singapore

Processes:



Nominal capacity (5 plants): 30,300 m^3/h

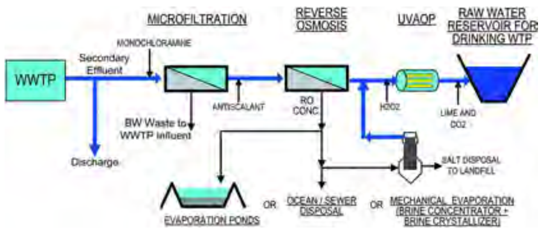
Finished water quality:

pH = 7 - 8.5	Total hardness < 0.20 mmole/L	Alkalinity < 0.20 mmole/L
Conductivity < 200 µS/cm	Turbidity < 0.1 NTU	TOC < 0.1 mg/L

Water Harmony

Wastewater for indirect potable reuse

Example: NEWater approach in Singapore



Scheme of the NEWater plants in Singapore [Public Utilities Board Singapore, 2018]

Conclusions

There are **no general rules** how combined processes should be designed and optimized, since the particular raw water always plays an important role. However, the examples described in this lesson show some **trends**:

1. While coagulation/sedimentation + rapid sand filtration still is the prevailing technique for particle removal, it can be supplemented by a micro-strainer or replaced by an underground passage or ultrafiltration.
2. Ozonation is a powerful tool for minimizing hygienic risks. It must always be combined with biological stabilization of the water, most often by biologically enhanced activated carbon adsorption.
3. Final treatment using chlorine or chlorine dioxide still is predominating, but disinfection by UV or UV/AOP are upcoming techniques.
4. Reverse osmosis, a well-established desalination process, is also applied as a barrier against harmful dissolved compounds in wastewater for reuse.

Questions

- Which specific conditions can require the application of combined processes for groundwater treatment?
- Which process combinations are typical for raw waters from lakes and reservoirs?
- What kind of process configuration is often applied for raw waters from rivers?
- What are the particular problems with wastewater reuse schemes, and how do they affect the selection and/or combination of treatment processes?

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Technological Trends

Joachim Fettig
Professor, University of Applied Sciences OWL
Harsha Ratnaweera
Professor, Norwegian University of Life Sciences

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Learning targets

- Overview of current technological developments in different areas, both with respect to the optimization of processes and the application of new materials
- Becoming familiar with new challenges and solutions in drinking water treatment

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Outline

- Process optimization in general
- Ultrafiltration with ceramic membranes
- DBP control by enhanced coagulation
- Control of organic micro-pollutants
- UV disinfection improvements
- Control of emerging inorganic pollutants
  - Removal of arsenic
  - Removal of nickel
  - Removal of uranium
- Partial softening by nanofiltration
- Seawater desalination by reverse osmosis
- Finals remarks

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Global drivers for technological trends

[Royan, 2012; updated 2016]

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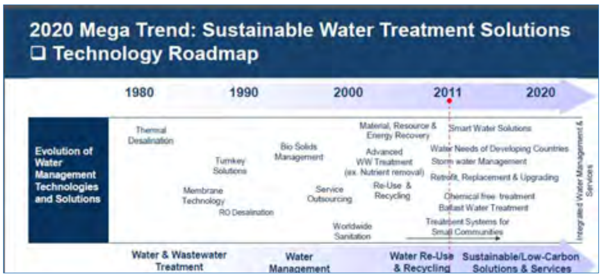
Global drivers for technological trends



[Royan, 2012]

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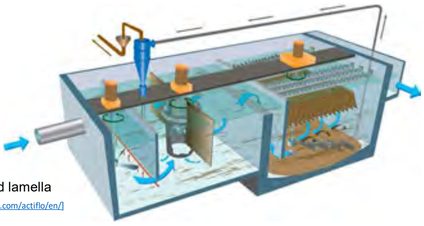
Global drivers for technological trends

[WIM, 2015]

Process optimisation in general: Coagulation

Ballasted coagulation (addition of micro-sand, magnetic particles, etc.) increases the separation efficiency and speed, as well as reduces the plant's foot-print. A combination with lamella sedimentation increases the efficiency further.



© Actiflo with micro-sand and lamella
[http://technomaps.veoliawatertechnologies.com/actiflo/en/]

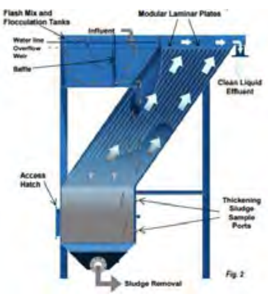
Process optimisation in general: Flotation

Flotation is quite efficient in utilising the space. Special constructions may further increase the space savings.

[http://www.degremont-technologies.com/cms_medias/pdf/AQUADAF_US_Infilco.pdf]

Process optimisation in general: Flotation

- Flotation units integrated with lamella plates can increase the efficiency and capacity



[http://www.mwwatermark.com/en_US/slant-plate-dissolved-air-flotation-clarifier/]

Ultrafiltration with ceramic membranes

Present situation

- Ultrafiltration well established during the past 20 years as a process for **removing particles and colloids**, and even natural organic matter (NOM)
- Large treatment plants with production rates of **several 100.000 m³/d** found in many countries today
- Application of **organic membranes** common because of their mechanical robustness and their low price

Limitation

- Sensitivity of the membranes with respect to **oxidizing chemicals**
- After some years decreased flow rates (flux) because of **irreversible fouling** processes and **aging/compacting** of the membranes

Ultrafiltration with ceramic membranes

Alternative

- Application of **ceramic membranes** made of aluminium oxide, titanium dioxide, zirconium dioxide or carbon composites originally developed for industrial separation processes,
- First large-scale plants in Sweden, Luxembourg, Japan and Singapore

Advantages

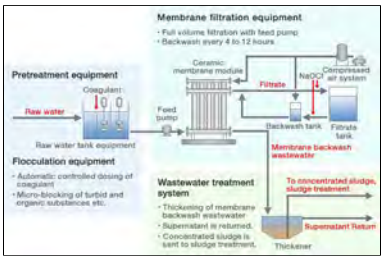
- High **mechanical strength** → increased backwash pressure (up to 5 bars)
- High **chemical robustness** → withstand ozone, e.g. for fouling control
- Long operating lifetime (> 15 years)

Main disadvantage

- Prices 3-4 times higher than for organic membranes → **higher capex**

Ultrafiltration with ceramic membranes

Example: Process scheme developed by Metawater Co (Japan)



[Metawater, 2018]

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DBP control by enhanced coagulation

Present situation

- **Natural organic matter** (NOM) found in all surface and ground waters
- **Increase** in the amount of NOM observed over the past 10–20 years in several raw water supplies
- Relevance for drinking water:
  - a) colour, taste and odor problems
  - b) increased disinfectant doses resulting in **increased production** of **harmful disinfection by-products** (DBPs, e.g. THMs)
  - c) promoted biological growth and deposits in the distribution system
  - d) increased levels of complexed heavy metals and adsorbed organic pollutants

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DBP control by enhanced coagulation

Treatment

- Most common and economically feasible: **Coagulation and flocculation** followed by sedimentation/flotation and sand filtration
- Treatment efficiency dependent on the **type of NOM**
- Observation: The hydrophobic fraction and high molar mass compounds of NOM are better removable than the hydrophilic fraction and low molar mass compounds
- Requirements (i.e. in the US defined in the Disinfectants and Disinfection Byproduct Rule as of 2006): **Enhanced and/or optimized coagulation** for better removal of NOM
- Further goals: Maximum pathogen removal, low turbidities and particle counts, and minimum residual Al or Fe

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DBP control by enhanced coagulation

Approach

- Better process control so the treatment efficiency is improved and remains constant
  - Optimal coagulant dosage control
  - Online surveillance of NOM after coagulation

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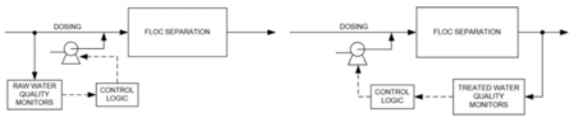
DBP control by enhanced coagulation

Example

- Online monitoring of inlet quality to define the optimal coagulant dosage
- Feed-back control / Adjustment of coagulant dosing to obtain best NOM removal



Feed-forward control Feed-backward control

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Control of organic micro-pollutants

Present situation

- Organic micro-pollutants from industries, personal care products and pharmaceuticals increasingly found in surface waters
- Nature-orientated treatment like riverbank filtration not efficient to remove all of these pollutants
- Groundwater sometimes contaminated with pesticides

Solution

Processes which can remove micro-pollutants must be included in conventional treatment trains, in particular

→ chemical oxidation, first of all **ozonation**

→ adsorption on (granular) **activated carbon**

also in combination (see lesson 13, biological activated carbon systems)

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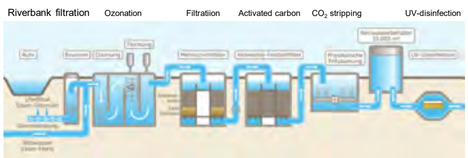
Control of organic micro-pollutants

Example: Upgrading of Essen-Ueberruhr waterworks (Germany) in 2016

- Raw water: Riverbank filtrate from river Ruhr
- Capacity: 288.000 m³/d resp. 75 Mio. m³/a, serving about 1 Mio. people
- Upgraded by an ozonation and a granular activated carbon (1.500 m³) stage



[Stadtwerke Essen, 2018]

UV disinfection – increased lifetime

- Present status

UV disinfection is a well-known method for inactivation of micro-organisms. The short lifetime of the lamps (2 years) is a cost-driver.

- Solution

By use of LED technology the lamp lifetime can be increased to >11 years.

- Possible problem

Disinfection by-products: no THMs, but more exotic ones (still unkown) could be generated.

Control of emerging inorganic pollutants

Removal of arsenic

Problem

- Occurance of arsenic of natural origin in groundwater resources all over the world, in some areas at concentrations of several 100 µg/L
- WHO guideline value: 10 µg/L
- Developed countries: Centralised treatment for arsenic removal needed

Technical solutions

I. If necessary oxidation of arsenite As(III) to arsenate As(V), then **precipitation** of As(V) **with Fe(III) salts** and direct filtration

Advantage: Reliable operation possible, high efficiency

Disadvantage: Further treatment and disposal of filter backwash wastewater loaded with arsenic bound to $Fe(OH)_3$ flocs required

Control of emerging inorganic pollutants

Removal of arsenic

Technical solutions

II. If necessary oxidation of arsenite As(III) to arsenate As(V), then **adsorption** of As(V) onto **granular ferric hydroxide** (GFH) in fixed-bed columns

Advantages:
- Reliable and very easy operation
- High efficiency
- High capacity (treatment of several 10.000 bed volumes before breakthrough)

Disadvantage: Disposal of exhausted GFH on (non-hazardous) landfills (≈ 5–25 g/m³ treated water)

GFH has also been applied successfully for removing phosphate (e.g. for the restoration of lakes) and for antimony removal from drinking water

Control of emerging inorganic pollutants

Removal of arsenic

Example

GFH-plant in Little Freer, Texas (US), in operation since 2013

Product: Bayoxide E33 ferric oxide

Plant: 3 columns with one operating in parallel and the other two in series; total flow rate = 200 m³/h

Raw water concentration = 34 µg/L
Treated water concentration < 10 µg/L

Throughput before replacement of adsorbent ≈ 50.000 bed volumes

GFH plant [WWD, 2014]

Control of emerging inorganic pollutants

Removal of nickel

Problem

- Occurance of nickel Ni^{2+} of natural origin in groundwater resources in Europe, at concentrations of several 10 µg/L
- WHO guideline value: 70 µg/L
- Maximum allowable concentration in the EU: 20 µg/L

Technical solution

Application of **selective ion exchange resins** (chelate cation exchanger) originally developed for industrial wastewater treatment, in fixed-bed columns

Advantages: Reliable operation, high capacity → long service life
External regeneration of exhausted ion exchange resins

Control of emerging inorganic pollutants

Removal of nickel

Example

Small waterworks in Germany, upgraded for nickel removal in 2012

Product: Chelate cation exchanger, conditioned with calcium ions

Plant: 4 columns operating in parallel; total flow rate = 100 m³/h

Hydraulic loading rate = 22 m/h

Raw water concentration = 45 µg/L
Treated water concentration < 5 µg/L

Specific costs = 0.043 €/m³

Nickel removal plant [Walter, et al., 2015]

Control of emerging inorganic pollutants

Removal of uranium

Problem

- Occurance of uranium of natural origin as U(VI), e.g. $UO_2(CO_3)_2^{2-}$, in ground-water resources all over the world, at concentrations of several 10 µg/L
- WHO guideline value: 30 µg/L because of toxicity, not because of radiation
- Maximum allowable concentration in Germany: 10 µg/L

Technical solution

Application of **selective ion exchange resins** (strong basic anion exchanger) in fixed-bed columns, effluent concentrations < 0.1 µg/L

Advantages: Reliable operation, high capacity → long service life
External regeneration of exhausted ion exchange resins

Control of emerging inorganic pollutants

Removal of uranium

Example

Waterworks Hirschaid in Germany, upgraded for uranium removal in 2007

Product: Uranex ion exchanger

Plant: 1 column;
maximum flow rate = 58 m³/h

Hydraulic loading rate up to 40 m/h

Raw water concentration = 37 µg/L
Treated water concentration < 1 µg/L

Service life of the resin ≥ 1.5 a

Ion exchanger for uranium removal in Hirschaid [Veolia Water, 2018]

Partial softening by nanofiltration

Present situation

- High hardness in groundwater in different parts of the world, i.e. the sum of dissolved calcium and magnesium is higher than 2.5 mmol/L (corresponding to 250 mg/L of calcium carbonate)
- No maximum allowable values for hardness in drinking water but some **drawbacks for consumers**, e.g. precipitation of calcite in hot water systems and high demand of detergents
- Technical solution: Centralised softening of hard raw water by lime softening, ion exchange, or **nanofiltration** (membranes with cut-off < 400-500 Daltons)

Removal of calcium and magnesium ions by nanofiltration

General description of membrane processes → see lesson 10

Operating conditions: Cross-flow, thus disposal of concentrate necessary

Partial softening by nanofiltration

Operating parameters:

- Recovery = **75-80%** (single-stage process), up to **85%** (two-stage process)
- Operating pressure = **2-12 bar**
- Flux rate = **15-50 (L/(m²·h))** {Average in Germany: 24 (L/(m²·h)) at 10-12 °C}
- Rejection of magnesium sulphate usually **≥ 90%**, therefore also sidestream treatment for partial softening common
- Prevention of scaling (in particular with respect to barium and strontium) by dosing of anti-scalants
- Post-treatment: Removal of carbon dioxide by aeration or calcite filters
- Operating lifetime of the membranes = **3-5 years**
- Specific energy consumption usually **< 0.5 kWh/m³** {Average in Germany: 0,32 kWh/m³ }

Partial softening by nanofiltration

Example: Upgrading of Karlstein waterworks (Germany) in 2009

Raw water: Shallow groundwater, hardness = 3.6-3.9 mmol/L

Product: TORAY Polyamide Composite membrane

Maximum flow rate = 85 m³/h

Operating pressure = 9 bar

Recovery > 80%

Treated water hardness < 1.8 mmol/L

Post-treatment: CO_2-removal by aeration

Nanofiltration plant for partial softening in Karlstein [Toray Membrane Europe, 2009]

Seawater desalination by osmosis

Present situation

Reverse Osmosis (RO) has been used over several decades for seawater desalination. However, the energy costs are a big challenge to the widespread use of this technology.

Solutions

- Mixing of seawater with water reclaimed from wastewater reuse processes to dilute salt in the seawater before RO. Thus pumping costs are reduced since the diluted seawater can be pumped through the filtering process at lower pressure (>30% reduction of power usage, Hitachi®)
- Forward Osmosis induces a net flow of water through the membrane from seawater to the permeate. The reverse osmosis process uses hydraulic pressure, while forward osmosis uses the osmotic pressure gradient as the driving force for separation.
- Various research and applications show a remarkable reduction of energy using "recuperators". The energy consumption could be below 2 kWh/m³ compared with 20 kWh/m³ in the 1970's. The theoretical minimum is 1 kWh/m³ (American Membrane Technology Association).

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Final remarks

General trends regarding the design and operation of treatment processes:

- Intensified **process surveillance and automation**
- Increased application of **process simulation tools** and **on-line control** instruments
- **Reduction** of the amount of **chemicals** added during treatment
- Introduction of **Technical Safety Management** structures to water abstraction, treatment, and distribution
- Implementation of **Water Safety Plans**
- Strengthening of the **multiple-barrier principle**
- **Improving efficiency of seawater** desalination by energy recuperators, forward osmosis etc.

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Questions

- Summarize briefly five important drivers for technological developments in drinking water treatment.
- Which improvements have recently been achieved in designing and operating the coagulation and flocculation process?
- What kind of modifications and new applications have been found for membrane processes (UF, NF and RO), respectively?
- Which new solutions are available for the separation of organic micro-pollutants and the inactivation of micro-organisms?
- Which techniques have been developed for removing arsenic, nickel and uranium as emerging inorganic pollutants?

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Residuals Management

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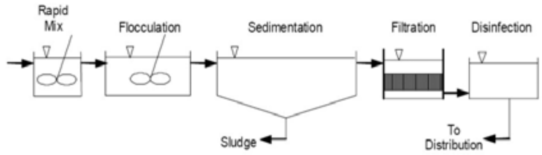
Learning targets

- Knowledge about the origin of solid residuals, and methods to estimate their amounts
- Understanding of the properties of different types of sludge
- Overview of sludge treatment, disposal and reuse methods

Outline

- Background
- Production of residuals:
  - Quantities of sludge wastewater, and of dry sludge
  - Qualities of sludge wastewater, and of dry sludge
- Sludge treatment methods
- Sludge disposal and reuse

Background



Conventional treatment train for drinking water

- In drinking water treatment plants (DWTP), usually a certain amount of sludge wastewater is produced.
- Only a few DWTP have treatment facilities for this sludge wastewater.
- Residuals from the DWTP will pollute the receiving water if it is discharged directly.

Production of residuals

Quantity of sludge wastewater:

Rough estimates

- The amount of sludge wastewater generally accounts for 3-6 % of the water yield.
- Among this total amount, the amount of sludge discharged from sedimentation tanks accounts for 0.5-3 %, with a solid content of about 0.1-2 %.
- The volume of filter backwash water accounts for 1 % of the water yield, the solid content is about 0.03-0.05 vol%.

Production of residuals

Quantity of sludge wastewater:

Accurate calculations, based on the operating parameters of the DWTP

- According to the number of sludge discharges per day, the duration and the amount of each sludge discharge, and the grid number of the sedimentation tank, the amount of sludge wastewater from sedimentation can be calculated.
- According to the number of filter backwashes per day, the flushing duration, flushing intensity, single filter area and filter cell number, the amount of filter backwash wastewater can be calculated.

Production of residuals

Quantity of dry sludge, important for the size of the sludge dewatering equipment

a. The recommended formula of the Japanese waterways association is as follows:

$$S = Q(T \cdot E_1 + C \cdot E_2) \cdot 10^{-6}$$

where S - Amount of dry sludge, t/d
Q - Water supply capacity of plant, m^3/d
T - Turbidity of raw water, NTU
E_1 - Relationship between turbidity of raw water and SS (mg/l)
C - Dosing rate of aluminum salt coagulant, mg Al_2O_3 / L
E_2 - Conversion of aluminum salt (Al_2O_3) coagulant into dry sludge, normally using 1.53

Production of residuals

b. The calculation formula of dry sludge quantity proposed by the British Water Research Center is:

$$S = SS + 0.2 \cdot C + 1.53 \cdot A + 1.9 \cdot F \quad (mg/l)$$

where SS - Suspended solids in raw water, mg/L
C - Color in raw water, CU
A - Dosing rate of aluminum salt coagulant, mg Al_2O_3 / L
F - Dosing rate of ferric salt coagulant, mg Fe / L

Production of residuals

c. Cornwell recommends the following two formulas for the sludge produced when aluminum or ferric salts are used as a coagulant:

$$S = 8.34 \cdot Q\,(0.26 \cdot Al + SS + A)$$

$$S = 8.34 \cdot Q\,(1.9 \cdot Fe + SS + A)$$

where S - Amount of dry sludge, b/d (1 b/d = 0.4536 kg/d)
Q - Water supply capacity of water plant, mgd (1 mgd = $3.785 \cdot 10^3$ m^3/d)
C - Color in the raw water, CU
Al - Dosing rate of aluminum salt coagulant, mg $Al_2(SO_4)_3$ / L
Fe - Dosing rate of ferric salt coagulant, mg Fe / L
SS - Total suspended solids in raw water, mg/L
A - Dosing rate of other additives for water treatment, mg/L

Production of residuals

Quality of sludge wastewater, important for its treatment options

Characteristics:

- Often the inorganic components are the main fraction, thus the amount of organics is limited.
- In general, sludge wastewater may contain 80 mg/L BOD, the corresponding organic matter content is then about 500 mg/L.

Production of residuals

Quality of sludge, important for subsequent treatment

Sludge types:

a. Sludge that contains an iron or aluminum coagulant:

The metal hydroxide formed by the coagulant changes with the quality of the raw water. The biological activity of the sludge is not strong, and the pH value is close to neutral. The solid content is 0-5 % when presenting flow state, 8-12 % if it is a sponge, and 18-25% if it is a dense sludge.

b. The retention of solids, ferric and manganese in the filter back flushing water:

The back flushing drainage has a high water content. The solid content is about 0.02-0.05 %; the turbidity is relatively stable, and the discharge of sewage is small. The characteristics are basically the same as those of the sludge.

Sludge treatment methods

Treatment of sludge wastewater generally includes equilibration, concentration, pretreatment, dewatering and finally sludge disposal.

<u>Equilibration</u>

The sludge from sedimentation basins and filters is discharged intermittently, therefore, an equilibration tank must be set up for providing an uniform load for subsequent equipment.

For sludge from sedimentation basins and filters normally more than two regulating pond are needed, in order to adapt to the requirements of cleaning and maintenance.

Sludge treatment methods

Treatment methods for backwash water from filters

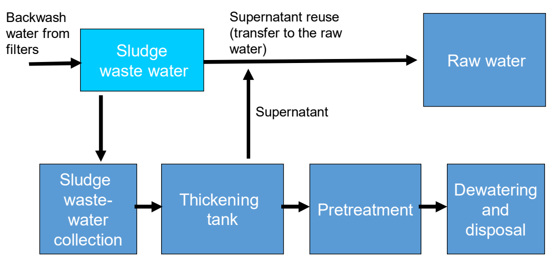
a. Direct discharge, if the content of sludge in sludge water is low
b. Direct reuse as raw water
c. Pre-thickening, then reuse of the supernatant, and discharge of the sludge into the sludge treatment system
d. Sharing the same settling tank with sludge from sedimentation basins, but this will make the sludge diluted, so it will not be easy to concentrate it in the following processes.

Sludge treatment methods

Treatment methods for sludge from sedimentation basins

a. Concentration tank: increase of the solid content to about 3 %, and reuse of the supernatant
b. Thickening method: gravity thickening, air floatation thickening, and so on
c. Sludge pretreatment: methods such as conditioning, heating, etc.
d. Sludge dewatering: use of a filter frame, a centrifugal dewatering machine, a belt filter press, etc.

Sludge treatment methods



Conventional treatment process for sludge wastewater

Sludge disposal and reuse

Sludge disposal

a. Sludge disposal costs are high, and the environmental impact is large.
b. Disposal options

   landfilling, ocean dumping, use as an agricultural resource
c. Sludge used in agriculture: sludge from DWTP contains clay, humus and other suspended matter, while there are little nutrients. However, it can improve the cohesion of soil and the soil structure, which is beneficial to the cultivation of the soil.
d. In China, the sludge mainly goes to landfills.

Sludge disposal and reuse

Sludge reuse

Technologies for sludge reuse:

a. In sludge treatment processes, the comprehensive utilization of various by-products and recovery of some of the sludge is a general goal
b. Recycling of aluminum: sludge can contain some 10 % Al, and recovery is possible via acid treatment
c. Recycling of ferric salts: also possible via acid recovery
d. Comprehensive utilization of sludge: Sludge from water treatment has good adhesion properties and is suited for brick making, cement, and so on.

Questions

- Which are the main sources for solid residuals from drinking water treatment?
- How is filter backwash water usually treated?
- How is the standard procedure with sludge from sedimentation basins?
- What kind of disposal options are available for the solid residuals?
- Which valuables are present in sludge from drinking water treatment where a recovery process might be considered?

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Utility Management

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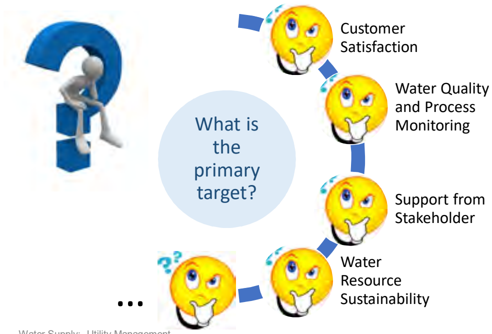
Learning targets

- Becoming sensitive for the importance of proper utility management
- Getting an overview over the main elements of the effective utility management (EUM) approach
- Knowledge about practical tools available for the implementation of EUM

Outline

– Management of a Treatment Plant
– Effective Utility Management (EUM)
– Surveillance and Control
– Water Quality and Process Monitoring
– Models and Simulation Programs
– Reporting

Management of a Treatment Plant



Effective Utility Management (EUM)

Definition of EUM:

A comprehensive water sector utility performance assessment and management framework, endorsed by the U.S. Environmental Protection Agency and ten national water sector associations dedicated to improving products and services, increasing community support for water services, and ensuring a strong and viable utility into the future.

[Watereum.org, 2008]

Main Components of EUM

Ten Attributes of Effectively Managed Water Utilities

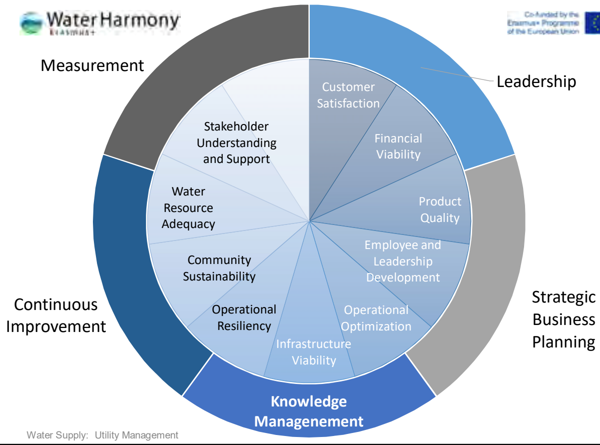
Keys to Management Success

Where-to-Begin Self-Assessment Tool

Main Components of EUM

10 Attributes of Effectively Managed Water Utilities:

1. Product Quality
2. Customer Satisfaction
3. Employee and Leadership Development
4. Operational Optimization
5. Financial Viability



Main Components of EUM

10 Attributes of Effectively Managed Water Utilities:

6. Infrastructure Viability
7. Operational Resiliency
8. Community Sustainability
9. Water Resource Adequacy
10. Stakeholder Understanding and Support

Main Components of EUM

Where-to-begin: Self-Assessment Tool

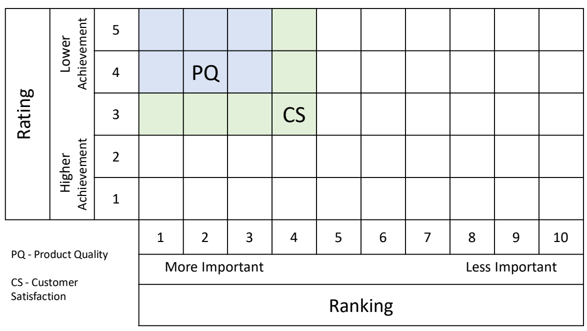
- Assessment of Current Conditions
- Ranking of Importance of Each Attributes
- Determination of Importance and Level of Achievement
- Selection of the Most Important Attributes

Main Components of EUM

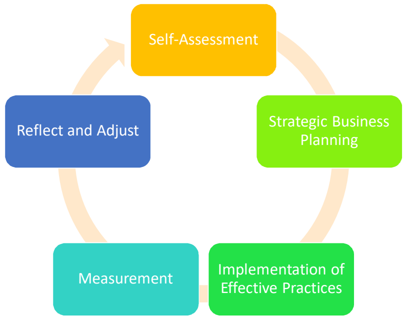
Keys to Management Success:

1. Leadership
2. Strategic Business Planning
3. Knowledge Management
4. Measurement
5. Continual Improvement Management

EUM: Selection of the Most Important Attributes



The EUM Cycle



Practical Tools that Implement EUM

- **Lean** – set of methods that are aimed at identifying and deleting "waste" in processes

  "Waste" is non-value-added activity that refers to any inefficiency in resource use and deployment

- **Six Sigma** statistical methods offer "how to" techniques to make implementation happen and deliver results

[Resource Guide, 2012]

Identifying Lean Wastes with DOWNTIME

- **D**efects
- **O**verproduction
- **W**aiting
- **N**on-utilized or under-utilized resources/talent
- **T**ransportation
- **I**nventory
- **M**otion
- **E**xcess Processing

Key Lean principles

- Focus on the customer
- Reduce the complexity of processes
- Use metrics and visual controls to provide rapid feedback to improve real-time decision-making
- Involve employees in continual improvement and problem-solving activities
- Use a whole-systems perspective that seeks to optimize processes across multiple goals

[Resource Guide, 2012]

Methods Relevant to Water-Sector Utilities

Method	Goal and Focus of Improvement	Examples
Standard Work	Document the best way to perform a task/operation to make it easy to work efficiently and effectively	Step-by-step and visual documentation of processes for operating facility equipment, emergency response processes, compliance monitoring, job performance standards
5S (or 5S+Safety)	Improve the organization, cleanliness, safety, and efficiency of work areas	Maintenance and repair truck layout, organization of chemical supplies, desk organization
Lean Event (e.g., Kaizen Event)	Eliminate inefficiency and non-value added activity (waste) in repeatable processes in a short time period	Reducing time to respond to service delivery calls or back-ups; improving billing, contracting, or hiring processes

Methods Relevant to Water-Sector Utilities

Method	Goal and Focus of Improvement	Examples
Total Productive Maintenance (TPM)	Integrate effective maintenance practices into all employees' work to minimize breakdowns, accidents, and other losses	Wastewater treatment plant operator practices, such as drying operations in the solids handling area; monitoring, inspecting, and adjusting pumps, motors, generators, air compressors, and other plant equipment
Six Sigma	Eliminate variation or defects in processes or address complex problems using statistical analysis	Optimizing plant digester operations, identifying root causes of effluent variations or sanitary sewer overflows, optimizing the use of chemical disinfectants

Methods Relevant to Surveillance and Control

Surveillance and Control for Water Quality and Process Monitoring [Resource Guide, 2012]:

- Histogram
- Layering
- Lean Event Charter
- Plan-Do-Check-Act Project Worksheet
- Control chart
- SIPOC Process Definition Sheet
- Fishbone diagram
- ABC-analysis
- Brain storm

Methods Relevant to Surveillance and Control

Models and Simulation Programs for Water Treatment Processes (Examples):

- STOAT
- WEAP
- SimEau

Questions

- What are typical attributes of effectively managed water utilities?
- Which steps are belonging to the self-assessment tool?
- What are the five elements of the EUM cycle?
- What does "DOWNTIME" mean?

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Economics in water treatment

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WATER HARMONY ERASMUS •

Learning targets

- Becoming familiar with cost factors in water supply systems
- Knowledge about calculation tools for investment and operation and maintenance, respectively
- Overview of the general structure of water tariffs and wastewater charges

Outline

– Losses in water supply systems
– Investment costs
– Example: Rehabilitation project in Ukraine
– Operation and maintenance (O&M) costs
– Water tariffs and wastewater charges

Losses in water supply systems

With the degradation of the technical condition of water supply systems, their efficiency is noticeably reduced, while unreasonable losses of water and leaks are increasing.

The largest leaks and unaccounted-for water losses in Eastern Ukraine were found 2008 in:

- Lugansk (60.7 % - temporarily occupied territory)
- Donetsk (49 % - temporarily occupied territory)
- Zakarpattya (44.4 %)
- Sevastopol (43.9 % - temporarily occupied territory)
- Dnipropetrovsk (42.9 %) regions

It was caused, as in the previous years, by critical conditions of the water distribution systems, the relevant equipment, fittings etc.
[National Commission, 2015].

Losses in water supply systems

In addition to water losses, there are other, equally important, categories of losses at water supply companies. They include

- environmental losses including damage caused to the health of citizens by poor quality water;
- losses associated with accidents on the roads as a result of leakages and break-downs of water supply systems;
- energy expenditures which are equal to 40-60% of water supply companies' production costs, according to analytical findings;
- losses occurring as a result of thefts, i.e. unauthorized connection to water supply networks;
- damage from flooding, as a result of water leaks from pipelines;
- losses of the state funds, arising from provision of subsidies to cover mismanagement and non-payments;
- losses of industrial and commercial enterprises, high rates which must compensate reduced rates for citizens;
- reduction of stability and reliability of water supply system as a whole.

Losses in water supply systems

As a summary, losses may include, except generally recognized direct losses, the following:

- over-expenditures
- loss of benefits
- delay of payment funds in time
- unused potential, i.e. loss of resources, facilities, rates of development, level of financial stability
- wear and tear of water supply companies (part of the equipment that worked out its term)

Investment costs

Legend:
76% – Water supply system
13% – Water treatment plants
6% – Water intake facilities
4% – Pump stations
1% – Storage tanks

Example of fixed costs of water supply companies in Ukraine [Minregion, 2014]

Investment costs

The principal formula of the NPV (net present value) calculation is written as [Koreniuk and Fedulova, 2014]:

- with annual costs under the project:

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

- with one-time capital investments:

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - C_t$$

where B_t – profit (non-inflicted loss) in year t
r – discount factor
C_t – investment costs in year t (estimated project cost)
T – duration of reference period

Investment costs

The calculation of the return on investments is as follows:

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{C_t}$$

$$BCR = \frac{\sum_{t=0}^{n} \frac{(B_t + B_{et})}{(1+r)^t}}{\sum_{t=0}^{n} \frac{(C_t + C_{et})}{(1+r)^t}}$$

where B_{et} – ecological component of profit (non-inflicted loss) in year t (may be neglected in calculations)
C_{et} – ecological component of investment costs in year t (may be neglected in calculations)

Example: Rehabilitation project in Ukraine

Introduction:

Implementation of the investment project “Development and improvement of operation of centralized water supply, water disposal, and effluent treatment systems” of the Utility Company (UC) “Dniprovodokanal” in the Dnipropetrovsk region of Ukraine. Participants of the project were UC “Dniprovodokanal” (Ukraine) and VEMA S.A. (Switzerland).

30.11.2004 – Starting date of realization of all project activities.
31.12.2012 – Deadline of realization of all project activities.

Example: Rehabilitation project in Ukraine

Basic pre-project power consumption of UC “Dniprovodokanal” (water supply and sewage pump stations, water treatment plants) [Dniprovodokanal, 2006]

Year	Basic power consumption, 1000 kW·h
1998	193,527.9
1999	196,429.6
2000	186,329.0
2001	183,505.1
2002	186,292.8
2003	185,737.3
2004	182,888.4

Example: Rehabilitation project in Ukraine

Objects participated in the project within the boundaries of Dnipropetrovsk city [Dniprovodokanal, 2006]

Quantity of water intake structures, pc.	2
Quantity of water supply pump stations, pc.	9
Quantity of local booster pump stations, pc.	43
Length of mains systems, km	452.5
Length of municipal water distribution networks, km	1529.1
Quantity of wastewater treatment plants, pc.	4
Length of sewage collectors, km	182
Quantity of sewage pump stations, pc.	50
Length of sewage networks without collectors, km	1023.3

Example: Rehabilitation project in Ukraine

Schedule of the project [Dniprovodokanal, 2006]

No	Project stages	Period
1	Development of Project design documentation	2004 -2012
2	Modernization of pumping equipment	2004 -2012
3	Replacement of pumping equipment	2004 -2012
4	Optimization of technological process of water pumping, that is, changing of regimes of pump stations' operation	2004 -2012
5	Replacement of valves	2004 -2012
6	Replacement of water supply and sewage networks	2004 -2012
7	Installation of a new group of metering devices	2004 -2012
8	Installation of frequency regulators	2004 -2012
9	Modernization of aeration systems at treatment facilities (aerotanks)	2004 -2012

Example: Rehabilitation project in Ukraine

Additional financial costs for modernization, Mio UAH [Dniprovodokanal, 2006]

Period	Cost of modernization, Mio UAH						
	Modernization of pumping equipment (trimming of impeller)	Replacement of pumping equipment	Replacement of valves	Replacement of water supply and sewage networks	Installation of a new group of metering devices	Installation of frequency regulators	Modernization of aeration systems at treatment facilities (aerotanks)
30/11/2004 - 31/12/2012	1.04	41.7	3.2	55.42	0.26	18.19	9.83

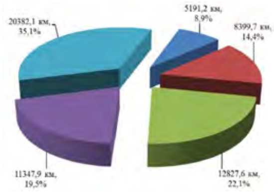
Example: Rehabilitation project in Ukraine

Indicative volumes of financial support of the program "Drinking water of Dnipropetrovsk for 2006 – 2020 years", in 1000 UAH [Regulations, 2006]

Activities	Period of implementation, years	Indicative volume of funding							
		Total volume	By years						
			2006	2007	2008	2009	2010	First stage, total	Next stage, total
1. Protection and rational use of sources of drinking water supply and protection of water bodies from pollution by wastewaters, including:	2006 - 2010	121000	1315	1655	865	780	780	5395	115605
Water supply		23040	370	630	830	630	580	3040	20000
Water disposal		97960	945	1025	35	150	200	2355	95605
2. Regulatory support	2006 - 2010	1140	180	50	20	160	50	460	680
3. Development and reconstruction of water supply and water disposal system, including:	2006 - 2010	325770	25894	26244	27044	26194	23334	128710	197060
Construction and reconstruction of water supply facilities and networks		226700	15804	15804	15504	15404	15544	78060	148640
Construction and reconstruction of water disposal facilities and networks		99070	10090	10440	11540	10790	7790	50650	48420
4. Education, training, provision of public awareness	2006 - 2010	1500	100	100	100	100	100	500	1000
Total		455880	28379	28939	28459	27774	24894	138445	317455

Operation and maintenance (O&M) costs

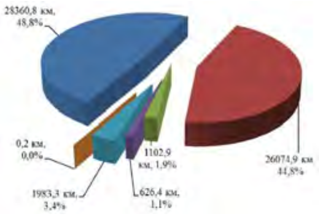
In Ukraine, only 9% of water supply networks are not in critical condition. Their life cycle does not exceed 25 years, as informed by the National Commission for State Regulation of Energy and Public Utilities.



Legend:
- 8.9 % – less than 25 years
- 14.4 % – 26-50 years
- 22.1 % – 50-75 years
- 19.5 % – 76-90 years
- 35.1 % – over 90 years

Structure of water supply networks (47 companies) by years of service [NCSREPU, 2014]

Operation and maintenance (O&M) costs



Legend:
- 48.8 % - Steel
- 44.8 % - Cast iron
- 1.9 % - Reinforced concrete
- 1.1 % - Asbestos cement
- 3.4 % - Plastic
- 0.0 % (0.2 km) - Others

Structure of water supply networks (47 companies) by material of pipes [NCSREPU, 2014]

Operation and maintenance (O&M) costs

Flow of production assets at the companies, which characterizes the degree of equipment upgrade, is investigated using the indicators below.

1. Coefficient of renewal of fixed assets:

$$C_r = FAps / FAep \cdot 100$$

where

FAps – sum of new fixed assets at cost, put into service in the reporting period;

FAep – sum of fixed assets at cost as at the end of the reporting period.

2. Coefficient of fixed asset retirement:

$$C_{ret} = FAret / FAbp \cdot 100$$

where

FAret – sum of fixed assets retired in the reporting period because of aging and wear and tear;

FAbp – sum of fixed assets as at the beginning of the reporting period.

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Water tariffs and wastewater charges

During the recent years the rates for centralized water supply and water disposal were approved for citizens at a loss. Therefore, they fail to cover the losses of water services' company for provision of their services. Rates for services on water supply/water disposal should be economically justified. In connection with it, the Cabinet of Ministers in 2015 approved the Resolution which terminates the practice of use of the uniform rate for centralized water supply/ water disposal.

Rates for centralized water supply/water disposal services (using systems arranged in houses) with structures [NCSREPU, 2014]

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Donetsk region		
1	Production Utility Company "Kramatorsk Water Services Company"	9.00	4.75	No. 3218 as of 29.12.2015 (registered with the Ministry of Justice on 25.01.2016 with No. 128/28258) amendments to No. 2868 as of 26.11.2015	16.02.2016
2	UC "VBAKHMUT-VODA"	13.42	8.45	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	26.08.2016

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Water tariffs and wastewater charges

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Dnipropetrovsk region		
1	UC "Dniprovodokanal" of Dnipropetrovsk Municipal Council	7.25	5.20	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
2	Production Utility Company "Miskvodokanal" of Dniprodzerzhinsk Municipal Council	6.13	6.29	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
3	UC "Zhovti Vody Water Services' Company" of Dnipropetrovsk Regional Council	10.59	10.64	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	26.08.2016
4	UC "Nikopol PD WSU"	6.29	10.40	No. 1285 as of 21.07.2016 (amendments to No. 2868 as of 26.11.2015)	26.08.2016
5	UC of Dnipropetrovsk Municipal Council "Aulskyi Watercourse"	3.65	4.02	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
6	UC "Novomoskovsk Water Services' Company"	10.54	8.03	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
7	UC "Kryvbasvodokanal"	5.50	6.05	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
8	UC "Pavlograd Production Directorate of Water and Sewage Utilities (PD WSU)" at Pavlograd Municipal Council	14.26	8.14	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
9	Municipal Utility Company "Ordzhonikidze Production Directorate of Water and Sewage Utilities"	8.54	8.88	No. 2868 as of 26.11.2015 (registered with the Ministry of Justice on 11.01.2016 with No. 24/28154)	29.01.2016

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Water tariffs and wastewater charges

No	Licensee name	Rates (incl. VAT), UAH/m³ (as at 30.08.2016)		No., date of resolution	Effective date of the resolution
		Water supply	Water disposal		
1	2	3	4	5	6
			Kyiv region		
1	UC "Irpinvodokanal"	5.80	9.29	No. 1142 as of 16.06.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
2	UC WSU "Boryspilvodokanal"	10.08	7.45	No. 811 as of 19.05.2016 (registered with the Ministry of Justice on 16.06.2016 with No. 866/28996) amendments to No. 2868 as of 26.11.2015	05.07.2016
3	UC "Brovary-teplovodoenergiya"	7.00	6.97	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
4	UC "Fastivvodokanal"	12.70	18.82	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
5	"BILOTSERKIVVODA" LLC	8.65	11.93	No. 1239 as of 07.07.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016
6	UC "Vyshnivskvodokanal» of Vyshneve Municipal Council, Kyiv-Sviatoshyn district, Kyiv region	7.29	5.07	No. 1142 as of 16.06.2016 (amendments to No. 2868 as of 26.11.2015)	02.08.2016

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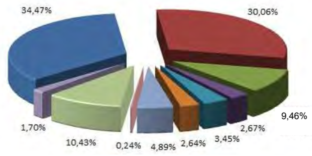
Water tariffs and wastewater charges



Legend:
34.47 % - Labor costs with deductions
30.06 % - Electric power costs
9.46 % - Costs for water acquisition/ wastewater treatment by other companies
2.67 % - Fuel and lubricants' costs
2.64 % - Reagent costs
3.45 % - Repair (materials) costs
4.89 % - Depreciation
0.24 % - Financial costs
10.43 % - Other costs (taxes, dues, banking charges, occupational safety, communication services, booster pump services, other services of third parties)
1.70 % - Profit

Weighted average structure of tariffs for centralized water supply in Ukraine since 01.05.2015, according to estimates of the National Commission for State Regulation of Energy and Public Utilities [NCSREPU, 2014]

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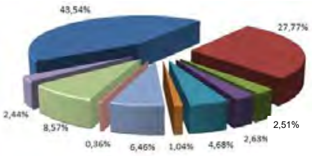
Water tariffs and wastewater charges



Legend:
43.54 % - Labor costs with deductions
27.77 % - Electric power costs
2.51 % - Costs for water acquisition/ wastewater treatment by other companies
2.63 % - Fuel and lubricants' costs
1.04 % - Reagent costs
4.68 % - Repair (materials) costs
6.46 % - Depreciation
0.36 % - Financial costs
8.57 % - Other costs (taxes, dues, banking charges, occupational safety, communication services, booster pump services, other services of third parties)
2.44 % - Profit

Weighted average structure of charges for centralized water disposal in Ukraine since 01.05.2015, according to estimates of the National Commission for State Regulation of Energy and Public Utilities [NCSREPU, 2014]

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Questions

- Which type of losses can be encountered in water supply systems?
- What is the meaning of "net present value" and "return on investment" in investment costs calculations?
- What was the main focus of the large rehabilitation project in Ukraine?
- Which parameters are used in order to characterize the degree of equipment upgrade?
- What are the main operational cost contributions to water tariffs in Ukraine?

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Impact of Climate Change

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Learning targets

- Understanding of the basic terms climate and climate system
- Knowledge about different observations that support the assumption of man-made climate change
- Overview over the impact of climate change on water supply, and possible adaptation strategies

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Outline

– Climate
– Climate system
– Climate change
– Climate change impacts
– Adaptation to climate change impacts

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Climate

Climate is a measure of the average pattern of variation in meteo-rological variables in a given region over long periods of time.

Meteorological variables are first of all:

- Temperature
- Humidity
- Atmospheric pressure
- Wind
- Precipitation
- Atmospheric particle count

Climate is different from weather. Weather describes the short-term conditions of meteorological variables in a given region.

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Climate

The climate of a location is affected by:

- Latitude
- Terrain
- Altitude
- Nearby water bodies and their currents.

Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation.

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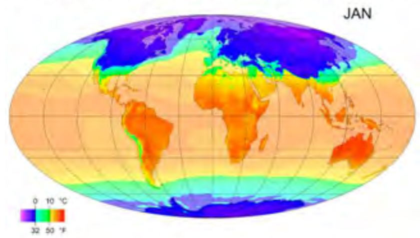
Climate

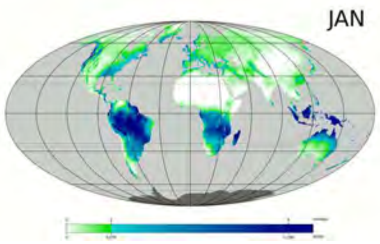
This is an example of how climate varies with location and season:



Monthly average surface temperatures from 1961–1990
Source: http://en.wikipedia.org/wiki/Climate

Climate

This graph shows the variation of precipitation on earth:



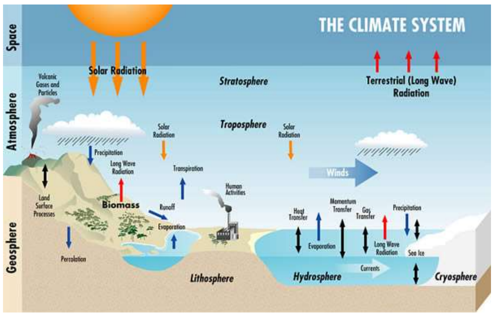
Precipitation by month, Source: http://en.wikipedia.org/wiki/Climate

Climate

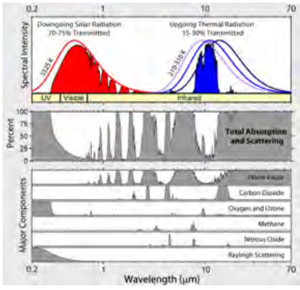
The regional climate is generated by the **climate system**, which has five components:

- Atmosphere with Troposphere 0 to 12 km
  Stratosphere 12 to 50 km
  Mesosphere 50 to 80 km
  Thermosphere 80 to 700 km
  Exosphere 700 to 10,000 km
- Hydrosphere
- Cryosphere - earth surface where water is in solid form
- Lithosphere - earth crust and the uppermost mantle
- Biosphere

Climate system

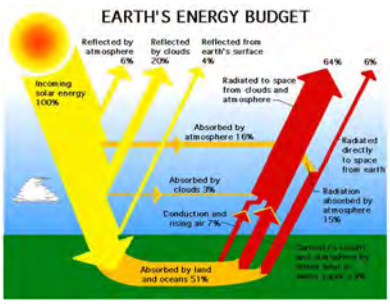


Climate system



Radiation transmitted by the atmosphere

Climate system



Source: http://science-edu.larc.nasa.gov/EDDOCS/whatis.html

Climate change

Definition according to the United Nations Framework Convention on Climate Change:

"A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

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Climate change

Evidence of global temperature increases since 1900:

- Recorded temperature changes
- The observed rise in sea level of 4-8 inches
- The shrinkage of mountain glaciers
- Reduction of northern hemisphere snow cover
- Increasing sub-surface ground temperatures

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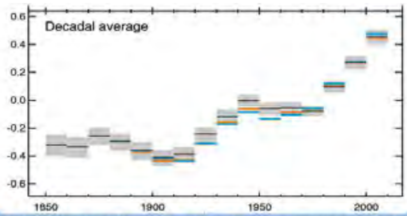
Climate change



Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

Observed globally averaged combined land and ocean temperature anomaly (IPCC 2013)

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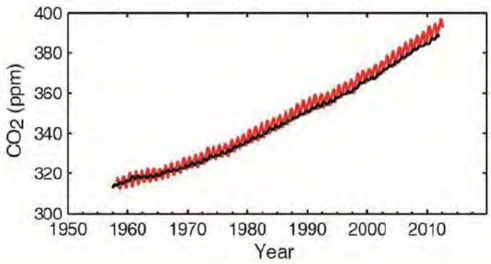
Climate change



Anthropogenic CO_2 increase in the atmosphere (IPCC 2013)

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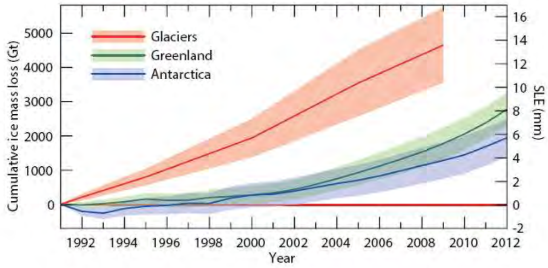
Climate change



Glacier mass loss (IPCC 2013)

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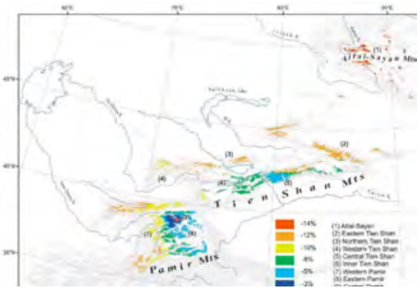
Climate change



Losses of glacier area in Asia (IPCC 2013)

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Climate change

Glaciers in the Himalaya

- store about 12,000 km^3 of fresh-water
- are receding and thinning
- support perennial rivers such as the Indus, Ganga and Brahma-putra which, in turn, are the lifeline of millions of people (IPCC)

Composite satellite image of the Gangotri Glacier terminus has retracted since 1780 (Courtesy of NASA EROS Data Center, 9 September 2001, IPCC 2007)

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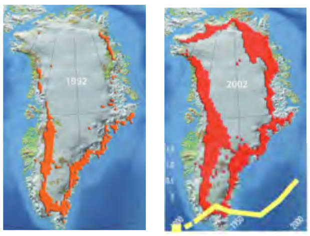
Climate change

Greenland ice sheet:

- The red areas on these two images show the expansion of seasonal melting of the Greenland ice sheet from 1992 to 2002 (GEO4).
- The Yellow line shows the temperature increased by 1ºC from 1900 to 2000.



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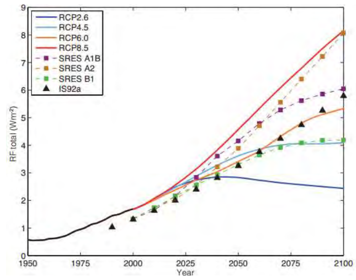
Climate change

RCP scenarios
- IPCC AR5 (2013)

Forcing by CO_2 has increased

- 1.24 Wm^{-2} (1993)
- 1.4 Wm^{-2} (2001)
- 1.7 Wm^{-2} (2013)



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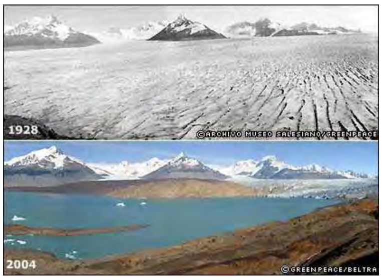
Climate change

UPSALA Glacier (Argentina):



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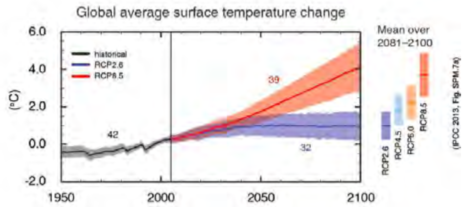
Climate change

Projections – GMST anomaly:



Without more mitigation, global mean surface temperature might increase by 3.7° to 4.8°C over the 21[st] century.

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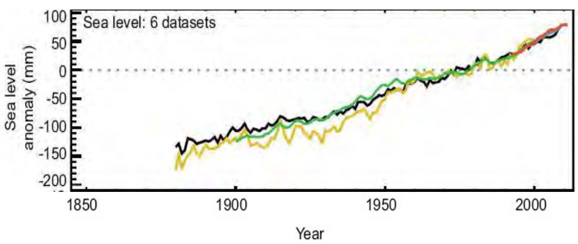
Climate change



Mean sea level rise (IPCC 2013)

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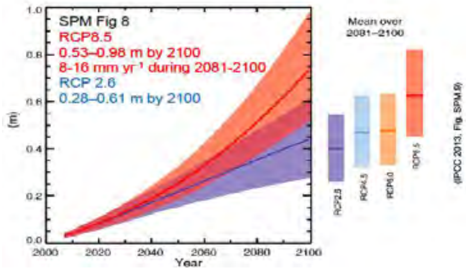
Climate change

Projections – GMSL rise:



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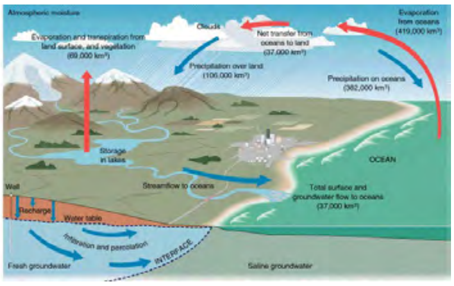
Climate change impacts

The impacts and risks associated with these changes are real and are already happening in many systems and sectors essential for human livelihood, including water resources, food security, energy security, coastal zones and health.

An estimated 200 million people could be displaced as a result of climate impacts climate-related disasters by 2050 (IPCC 2007).

Water Harmony

Climate change impacts



Impacts on water resources: Hydrologic cycle

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Climate change impacts

Climate-water nexus:

Components of the urban water sector are impacted by the climate change

Source: Modified from CADWR (2012)

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Climate change impacts

Extreme events:

- Extreme events, floods and droughts, and coastal storms will be more frequent.
- The devastating effects of extreme events, temperature increases and sea level rise have consequences for all, particularly the poor, and will only worsen in the future.

Sea level rise associated with temperature increase:

- Inundation of low lying areas, coastal marshes and wetlands, exacerbate flooding and increase of the salinity in rivers, bays and aquifers.

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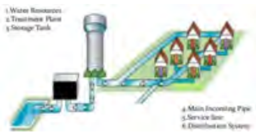
Climate change impacts

Water supply systems consist of

- Water sources
- Water supply infrastructure
  - Water intakes
  - Water treatment plants & processes
  - Water storage
  - Water distribution - pumping



Water supply systems need to ensure the supply of sufficient quantities of water with accepted quality to the users.

Water Harmony

Climate change impacts

Climate change impacts have adverse impacts on the

- Quantity and quality of water supply sources
  - Streamflow
  - Lakes or reservoir storage
  - groundwater - shallow wells, deep groundwater extraction through boreholes
  - Imported water
- Water supply infrastructure
  - Structures, treatment plants & processes, water distribution systems

Climate change impacts

Water Quantity:

Frequent extremes of precipitations leads to

- high discharges in rivers/ higher water levels in reservoir affecting intake infrastructures
- increased flooding incidences in facilities
- Increased damages to the distribution systems

Climate change impacts

Water quantity:

Reduced flows due to frequent droughts will result in

- less inflows to reservoirs thus affecting supply systems
- warmer water temperatures may aggravate demands for various in-stream and non-consumptive water uses
- increase water-related conflicts, and restriction of new water users

Climate change impacts

Water quantity:

Increased temperatures will result in

- higher evapotranspiration rates that will increase demands for landscape irrigation and additional human consumption
- demands for cooling water in arid and semi-arid regions
- greater summer peak demand

Climate change impacts

Water quality:

Increased sea level rise results in

- salt water entrainment to coastal surface water sources

- mixing of pollutants with fresh water due to inundation of fresh and polluted water/land together
- reduced velocity of inflows, causing sediment depositions /stream bed aggradation with more release of pollutants

Climate change impacts

Water quality:

Increased air temperatures can lead to

- biological and chemical degradation of water quality, by increased solubility and concentrations of contaminants in fresh water
- enhanced growth of algae, microbes, parasites, and invasive species

Climate change impacts

Water quality:

Frequent extremes of precipitations leads to increased flooding to mix fresh water with polluted water/ contaminated sites

Climate change impacts

Water quality:

Frequent extremes of precipitations lead to high sediment discharges, and pollutants accompanied by increased runoff

- preventing adequate water quality of streamflow for water-supply extraction
- entrainment of increased total dissolved solids / heavy metal/toxic substances from agricultural and urban wastes.

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Climate change impacts

Water supply infrastructure:

Frequent extremes of precipitations lead to

- high discharges in rivers/ higher water levels in reservoirs affecting intake infrastructure
- increased flooding incidences in facilities
- increased damages to the distribution systems
- high sediment concentrations

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Climate change impacts

Water supply infrastructure:

Reduced precipitation will contribute to

- more frequent and intense droughts that may affect reservoir and groundwater storage, as well as rainwater capture systems.
- result in less groundwater recharge and lower summer stream flows to increase pollutant concentrations
- increased pumping costs due to deeper groundwater levels

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Climate change impacts

Water supply infrastructure:

Poor raw water quality will require

- special treatment processes
- higher treatment costs
- higher maintenance costs of pipes

High concentrations of sediment and debris will lead to

- higher maintenance costs
- larger sludge volumes

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Adaptation to climate change impacts

Climate change mitigation and adaptation

There are two main responses to climate change, viz:

- climate change mitigation is cutting the emissions that cause climate change
- climate change adaptation is preparing for the impacts of climate change

IPCC has defined climate adaptation as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities”.

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Adaptation to climate change impacts

Adaptation is a local issue that depends on geographical, climatic, bio-physical and socio-economic characteristics

Adaptation options are many, including:

- Structural options to ensure water quantity and quality
  - Dikes (embankments, levee), sewer networks, drainage
  - Retention ponds for artificial recharge, dams
  - Desalination technologies
  - Coastal wall, flood proofing
  - Green Buildings

Adaptation to climate change impacts

- Non-Structural options to ensure quantity and quality:

- National and sectoral policies
- Demand management, water pricing
- Efficient water use, reuse
- Watershed management
- Insurance
- Awareness campaign

Adaptation to climate change impacts

Adaptation of water supply systems for climate resilience

- Proper water supply management by
  - reducing water loss through leakages
  - reducing water usage - proper billing and reducing water theft
- Assess the flood levels and make the water intakes/ treatment facilities flood proof/ relocate
  - Make structures to be safe against extreme events (floods, coastal storms)
- Risk of failure of operation, contamination
  - Plan for emergency options, Water Safety Plans (WSP)

Adaptation to climate change impacts

Adaptation of water supply systems for climate resilience

- Improve water resources managements
  - catchment management practices, soil erosion control
  - distributed surface/subsurface water storage
  - pollutant abating practices, e.g. LIDs, wetlands
  - improve infiltration, e.g. LIDs
- Upgrade existing water infrastructure and management practices due to uncertainty of projected hydrological changes

(Statistical parameters of hydro-meteorological data series are not stationary. Historical hydro-meteorological data become not useful to make projections. Modern tools considering climate change will be necessary. In addition, design criteria on stormwater inflows for different return periods need to be redefined.)

Adaptation to climate change impacts

Examples for Low Impact Developments (LIDs)

Questions

- What is the difference between climate and weather?
- Which are the five components of the climate system?
- Give three observations which prove that climate change is very likely.
- How could climate change negatively affect water supply, both with respect to water quantity and water quality?
- Give some examples how water supply systems could be made resilient for climate change.

References

CADWR 2012: Climate Change and Cities - First Assessment Report of the Urban Climate, ed. by Rosenzweig, C., Solecki, W.D., Hammer, S.A. and Mehrotra, S., Cambridge University Press, Cambridge 2012.

IPCC 2007: Climate Change 2007 – The Physical Science Basis. Contribution of the Working Group I to the 4th Assessment Report of the IPCC. https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

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UN 1992: United Nations Framework Convention on Climate Change (Rio Convention, entered into force on 21 March 1994) https://unfccc.int/resource/docs/convkp/conveng.pdf

Wastewater Treatment & Engineering

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What is wastewater

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Content

- Definition of wastewater
- Origin of wastewater
- Domestic wastewater
  - quantity of domestic wastewater
  - quality of domestic wastewater
  - classification of domestic wastewater
- Industrial wastewater
  - Concept
  - Source, type, typical pollutant of industrial wastewater
  - Water pollution and characteristic of industrial wastewater
- Storm water

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Definition of wastewater

- ➢Any water that has been adversely affected in quality by anthropogenic influence
- ➢originate from a combination of domestic, industrial, commercial or agricultural activities, surface runoff or storm water, and from sewer inflow or infiltration.

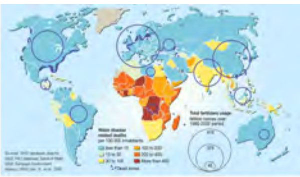

Fig.1 water disease related deaths per 100 000 inhabitants

Fig.2 Eutrophication equivalents (N) per hectare and year

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Origin of wastewater

- 1st classification method

Agricultural source	Domestic source	Industrial source
• Point sources • Poultry waste • Piggery waste • Silage liquor • Dairy farming waste • Slaughtering waste • Vegetable waste • Firewater • Non-point sources • Sediment runoff • Nutrient runoff (Commercial fertilizer)	• Washing/laundry • Shower • Kitchen • Toilet • Septic tank • School • Hospitals • Hotels/restaurant • Office • Small business activities, etc.	• Abattoir • Fertilizer • Pulp and paper • Textile • Tanneries • Dye processing • Food processing • Pharmaceutical • Petrochemical • Metallurgical • Plastics industries, etc.

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Origin of wastewater

Fig.3 example of a typical point source discharge

- 2nd classification method
  - Point source
    - – Definition: any discernible confined and discrete conveyance including but not limited to a pipe, ditch, channel, or conduit from which pollutants are or may be discharged.
      - eg. municipal landfills, leaking gasoline storage tanks, leaking septic tanks, accidental spills and industrial waste disposal sites
  - Non-point source
    - – Definition: comes from many diffuse sources
    - – ie. runoff and seepage from agricultural lands

Fig.4 example of non-point source discharge

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Source of wastewater

Fig.5 relation of wastewater discharge and drinking water intake

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Domestic wastewater

- Quantity of domestic wastewater calculation
  - **Wastewater Quantity Estimation**

$$Q=Nq$$

Q ——daily wastewater flow, m^3/d

N ——population to be served, capita

q ——Per capita sewage contributed per day, $m^3/d \cdot cap$

- Usually 60%~ 80% of the water consumption

Fluctuations in wastewater Flow

(i) $Q_{max}= 2\ Q_{average}$

(ii) $Q_{min} = 2/3\ Q_{average}$

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Domestic wastewater

- Domestic wastewater flow rate:
  - Where water supply and wastewater flow data are lacking. a liter per capita per day (lpcd) allowance not exceeding those in the following table

Table 1 estimate of wastewater discharge flow rate

Description	liters per capita per day (lpcd)
Non–SMSA cities and towns with projected total 10–yr population of 5,000 or less .	225–265
Other cities and towns	245–300

http://docs.legis.wisconsin.gov/code/admin_code/nr/100/110.pdf

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Water usage in households

A typical wastewater flow rate from a residential home in the United States might average 265 L per capita per day .

http://www.home-water-works.org/calculator

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Water usage of miscellaneous facilities

- *Table 2: Typical Wastewater Flow Rates for Miscellaneous Facilities*

Type of establishment	liters/cap.d	Type of establishment	liters/cap.d
airports	19	Cottages and small dwellings with seasonal occupancy	284
Bathhouses and swimming pools	38	Country clubs (per resident member)	380
camps		Country clubs	95
campground with central comfort station	132	dwellings	
with flush toilets, no showers	95	boarding housed	190
day camps (no meal served)	57	rooming housed	151
luxury camps	380	Hospitals (per bed)	946

Illinois EPA, 1997

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Domestic wastewater

- Quantity distribution of domestic wastewater

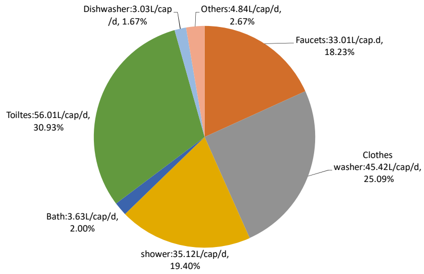

Fig.6 Average indoor residential water discharge for 12 North American cities.

Source: Data from AWWA 1999.

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Domestic wastewater

- Wastewater production

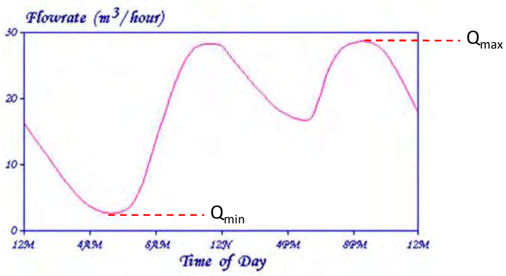

Fig.7 Typical hourly variation in domestic WW flowrates

Domestic wastewater

- Quality of domestic wastewater:
  - Quality depends on the pollutant content

Fig.8 Water as a liquid waste and as a medium for solid wastes in the domestic situation

Domestic wastewater

- Components in domestic wastewater:
  - *Table 3: components in domestic wastewater*

Components in domestic WW		Comments
Organic matter	Human waste	faeces, urine, blood
	Food waste	usually from kitchen waste macerators
Oils and fats		usually from tipping down drains
Metals		found in foods, via human wastes
Solvents		tipping down drains, cleaning
Chemicals		via human wastes; via cleaners, soaps etc, washing, bathing and cooking
Paints		households

Domestic wastewater

- Components in domestic WW

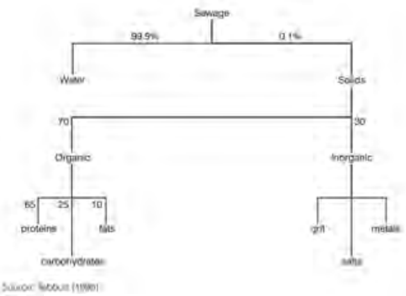

Fig.9 components in domestic wastewater

Domestic wastewater

- Typical domestic WW compositions
  - *Table 4: typical domestic wastewater compositions*

Pollutant	Concentration, mg/l Weak	Average	Strong
Total solids	350	800	1200
Total suspended solids	100	240	350
Total dissolved solids	250	500	850
Settleable solids (ml/l)	5	10	20
Volatile suspended solids	80	180	280
Volatile dissolved solids	100	260	300
Ammonia nitrogen	10	20	35
Total nitrogen	20	35	80
Phosphorus	5	10	15
Alkalinity as $CaCO_3$	50	100	250
Oil & grease	50	100	150
5-Day biochemical oxygen demand	120	225	400
Chemical oxygen demand	175	325	575
Total organic carbon	65	125	220

Table 5 Specific pollution loads per person

pollutant	g/d·C
BOD_5	20~50
SS	40~60
TN	5~11
TP	0.7~1.4
COD	40~100

Source: “Code for design of outdoor wastewater engineering” GB50014-2006 (2016) P.R.China

Domestic wastewater

- Classification of domestic wastewater
- What is **greywater**?
  - Low load
  - Generated from **wash hand basins, showers and bath** (not from a kitchen sink or toilet)
  - Can be recycled on-site for uses such as Water Closet (WC) flushing, landscape irrigation and constructed wetlands
- what constitutes greywater
  - UK: showers, bath tubs, wash basins,
  - excludes washing machines, kitchen sinks, toilet flushing
  - Israel: showers, bath tubs, wash basins, washing machines, kitchen sinks
  - Yemen: kitchen sink, hand wash basins, bath room showers, washing machine

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Domestic wastewater

- Classification of WW
- What is **blackwater**?
  - High load
  - From **WC flushing, kitchen sinks, (dish washers)**
  - High risk of contamination by bacteria, viruses and pathogens
  - Should not be reused in the home
  - Components: faeces, urine, toilet paper, flushing water

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Domestic wastewater—grey water-quantity

- in the western countries the high percentages of in-house greywater are produced from bathrooms and wash machines while the low percentages are produced from kitchens and hand wash basins

- *Table 8 Household greywater quantities in the literatures*

Location	kitchen sink	Hand wash basin	bathroom shower	washing machine	Greywater Percentage
Sydney	29		41	30	80
US	27.8		41.7	30.5	72
	11	55		34	
	11	7	48	34	68
Oman	34	7	51	8	82
Sana'a	37	32	18	13	87

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Domestic wastewater—grey water-quantity

- *Table 6 Average quantity of grey water*

Country/ region	Rural area	Big city
Jordan	14 L/c·d	59 L/c·d (Amman)
European communities	66 L/c·d	274L/c·d
Yemen		35L/c·d (Sana'a)
Australia	704L/d for family of two adults and four children	

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Domestic wastewater—grey water-quality

- Affecting factors:
  - Number of household occupants
  - Ages of household occupants
  - Health status
  - Lifestyle
  - Tap water sources
  - Water usage patterns
  - Household products used
    - Soaps
    - Shampoos
    - Detergents
    - Mouthwash
    - Toothpaste
    - Hair dyes
    - Shaving cream
    - Body oils

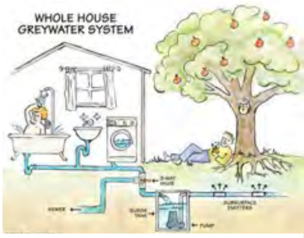

Fig.10 greywater production in daily life

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Domestic wastewater—grey water-quantity

- Grey water represents over 60% of the total wastewater stream
- *Table 7: approximate generation percentage of wastewater and greywater*

Wastewater type	Total Wastewater		Total Greywater	
	% Total	(L/day)	% Total	(L/day)
Toilet	32	186	-	-
Hand Basin	5	28	8	28
Bath/shower	33	193	54	193
Kitchen	7	44	-	-
Laundry	23	135	38	135
Total	100	586	100	356

[16] DWE. 2008. NSW Guidelines for Greywater Reuse in Sewered, Single Houshold Residential Premises. Department of Water & Energy, NSW government. www.dwe.nsw.gov.au.

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Domestic wastewater—grey water-quality

- *Table 9 Household greywater quality in the Arab counties*

Parameters	Unit	Qebia (Palestine)	Karak (Jordan)	Kuwait (Kuwait)	Sana'a (Yemen)	WHO/FAO guidelines
pH		6.60-6.86	5.93-7.82	7.5	6.0	6.5-8.4[b]
TSS	Mg/L	36-396	23-358	204	510.80	20[c]
Turbidity	FAU	-	-	120	618.60	-
NO_3^-	Mg/L	0-1.3	-	5	98.12	9.5–518.5[b]
NH_4-N	Mg/L	25-45	-	4.8	11.28	-
PO_4^-	Mg/L	-	-		16.10	-
BOD_5	Mg/L	941-997	110-1240	40	518	20[c]
COD	Mg/L	1391-2405	92-3330	-	2000	-
F.C	N/100 ml	10^4-$37x10^4$	-		19×10^6	200[a]

a WHO 1989 guidelines for public parks and crops likely to be eaten uncooked
b FAO guideline for water quality for irrigation
c WHO/AFESD Consultation, limit for vegetables likely to be eaten uncooked

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Domestic wastewater—grey water-quality

- *Table 10 Household greywater quality in some western countries*

Parameters	Unit	USA	Sweden	Australia	Range
pH		6.8	-	7.3	6.6-8.7
TSS	Mg/L	-	-	-	45-330
Turbidity	FAU	-	-	113	22->200
NO_3^-	Mg/L	-	-	-	<0.1-0.8
NH_4-N	Mg/L	-	-	-	<1-25.4
PO_4^-	Mg/L	7.8	-		-
BOD_5	Mg/L	164	196	159	90-290
COD	Mg/L	366	-	-	-
F.C	N/100 ml	$8.8x10^5$-$13x10^6$	-	-	-

Sources: Jefferson, B., et al. 2000. Technologies for domestic wastewater recycling. Urban Water 1 (4): 285-292.
Jeppesen, B., et al. (1994) Urban Water Research Association of, A. 1994. *Domestic greywater reuse: overseas practice and its applicability to Australia:* Published for the Urban Water Research Association of Australia by the Melbourne Water Corporation.

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Domestic wastewater—black water-quality

- Blackwater samples were collected from 44 similar small houses consisting of 141 persons—92 adults and 49 children (Vibyasen South,Sweden)
  - *Table 11: Flows and concentration of ordinary wastewater parameters*

		Greywater (GW)			Blackwater (BW)		
		Average	Range		Average	Range	
			Min	Max		Min	Max
Q	m^3/h	0.54	0.16	1.02	0.17	0.16	0.18
P_{tot}	mg/L	7.53	4.6	11	42.7	21	58
N_{tot}	mg/L	9.68	8.0	11	150	130	180
BOD_7	mg/L	418	350	500	1037	410	1400
COD_{Cr}	mg/L	588	495	682	2260	806	3138
TS	mg/L	630	570	700	3180	920	4320
VS	mg/L	330	300	360	2560	420	3660
pH	–	7.50	6.06	8.38	8.94	8.87	9.08

Sources: Helena Palmquist, Jorgen Hanæus. Hazardous substances in separately collected grey- and blackwater from ordinary Swedish households. Science of Total Environment, 348 (2005) 151– 163

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Domestic wastewater—black water-quality

- Each person on average excretes about 4 kg N and 0.4 kg P in urine, and 0.55 kg N and 0.18 kg P in faeces per year.
- In Sweden it has been estimated that the nutrient value of urine from the total population was equivalent to 15–20 % of chemical fertilizer use in 1993

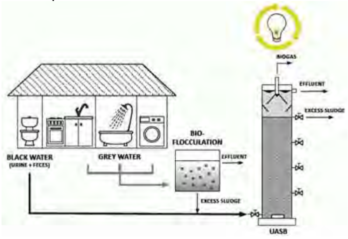

Fig.11 wastewater discharge and treatment in household

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Industrial wastewater

- Concepts
  - Generated from various industrial activities
  - Causing serious environmental pollution
  - Generally difficult to be treated
  - Multi-component

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Industrial wastewater

- Sources of industrial wastewater
  - Mining industry
  - Mechanical industry
  - Chemical industry
  - Food industry
  - Manufacturing industry
  - Others

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Industrial wastewater

- Industrial water use

Water withdrawals for industry:

- World: 22% of total water use

- High-income countries: 59% of total water use.

- Low-and middle- income countries: 10% of total water use.

Source: Extracted from the Executive summary of the WWDR. World Bank, 2001. . Washington DC.

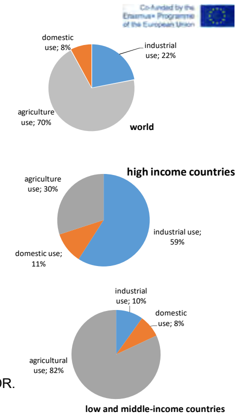


Fig.12 percentage of different water usage

Industrial wastewater

- Industrial water use

Sources : Ondeo IS , 2012 .

Industrial wastewater

- Classification of industrial wastewater
  - Organic industrial wastewater
    - Manufacturing pharmaceuticals, cosmetics, organic dye-stuffs, glue and adhesives, soaps, synthetic detergents, herbicides
    - Tanneries and leather factories
    - Textile factories
    - Cellulose and paper manufacturing plants
    - Oil refining industry
    - Brewery and fermentation factories
    - Metal processing industry

Industrial wastewater

- types of industrial wastewater and typical pollutants
  - *Table 12: Types of industrial wastewater and typical pollutants*

sector	pollutant
Iron and steel	BOD, COD, oil, metals, acids, phenols, cyanide
Textiles and leather	BOD, solids, sulfates, chromium
Pulp and paper	BOD, COD, solids, chlorinated organic compounds
Petrochemicals and refineries	BOD, COD, mineral oils, phenols, chromium
Chemicals	COD, organic chemicals, heavy metals, SS, cyanide
Non-ferrous metals	Fluorine, SS
Microelectronics	COD, organic chemicals
Mining	SS, metals, acids, salts

Industrial wastewater

- Water pollutants from industry

- Industrial pollutants were discharged in a large amount every year

- Most of the pollutants in wastewater is toxic

- This wastewater usually suffered from an untreated process in developing countries

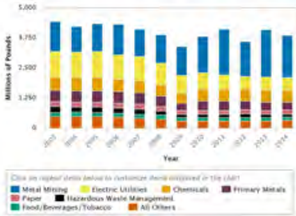


Fig.13 total disposal or other releases by sector, 2003-2014

Data from US Environmental Protection Agency (EPA)

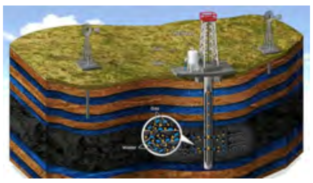
Industrial wastewater

- Classification of industrial wastewater
  - Inorganic industrial wastewater
    - Coal and steel industry
    - Nonmetallic minerals industry
    - Surface processing of metals(iron picking works, electroplating plants)

Industrial wastewater

- Water pollutants from industry

I. Mining industry
- Ore washing wastewater and groundwater
- Soluble ions, suspended solids
- Floation agent



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Industrial wastewater

- Water pollutants from industry
  - II. Smelting industry
    - Cooling water and dusting wastewater
    - Heavy metal ions, suspended solids
    - Acidic

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Industrial wastewater

- Water pollutants from industry
  - III. Mechanical industry
    - Electroplating wastewater
    - Lubricating oil, resin
    - Chromium, zicn, cyanide

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Industrial wastewater

- Water pollutants from industry
  - IV. Petroleum industry
    - Soluble salts, oil
    - Sulphur, alkali
    - Phenol, acetone, arene

Fig.14 water usage of offshore oil platform

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Industrial wastewater

- Water pollutants from industry
  - V. Chemical industry
    - Soluble salts, acid, alkali, suspended solids, sulfide.
    - Dye, coatings, wastewater from synthetic rubber etc.
    - Heavy polluted

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Industrial wastewater

- Water pollutants from industry
  - VI. Pulp and paper industry
    - Cellulose, lignin, volatile organic acids
    - Bad odour
    - Heavy polluted

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Industrial wastewater

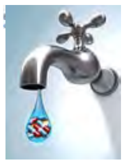
- Water pollutants from industry
  - VII. Textile printing and dyeing industry
    - Natural matters, fat, starch
    - Cellulose, lignin, dye, detergent
    - Sulfide, salts, alkali

Industrial wastewater

- Water pollutants from industry
  - VIII. Food industry
    - Washing water
    - Organic matters, suspended solids

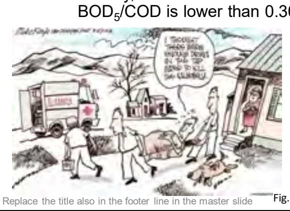
Industrial wastewater

- Wastewater characteristic
  - Major pollution composition
    - Acidic wastewater, alkaline wastewater, cadmium-containing wastewater, phosphorus-containing wastewater, COD-rich wastewater, etc.
  - Chemical characteristic
    - Biodegradable or persistent organic pollutants
    - Inorganic pollutants, e.g. sulfide, nitrate, cadmium



Industrial wastewater

- Characteristics of industrial wastewater
  - Wastewater from the pharmaceutical industries
    - Varies a great deal
    - Different kinds of effluent with widely varying qualities flow from the different production areas
    - Usually, COD 5000~15000 mg/L, BOD is relative low, the ratio of BOD_5/COD is lower than 0.30, bad color, high (or low) pH value



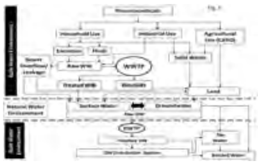


Fig.15 transportation and conversion of pharmaceuticals in water

Industrial wastewater

- Characteristics of industrial wastewater
  - Wastewater produced by tannery plants
    - In a tannery with chrome and bark tanning, the wastewater resulting from the different processes are as follows: soaking and washing 22.5%, liming 17.5%, rinsing 5.5%, plumping and bating 19%, chrome tanning 2%, bark tanning 2%, washing and drumming 31.5%
    - The wastewater flow is very uneven, the peak flow can be 2.5 fold of the average hourly flow rate
    - Fairly acid pH
    - High chloride content (up to 5g Cl/L)
    - High COD concentration (1500~2500mg/L)
    - High amount of settable substances (10~20g/L)
    - High emulsified fat, tends to form foam
    - Dichromate content can reach a peak value of 2000mg/L

Industrial wastewater

- Characteristics of industrial wastewater
  - Wastewater produced by brewery industry
    - Wastewater come from:
    - (1) washing water
    - (2) rinsing water
    - (3) fermentation process

Industrial wastewater

- Characteristics of industrial wastewater
  - Wastewater produced by brewery industry
    - No toxic contaminants
    - Easy biodegradable
    - Good carbon source for N and P removal
    - Concentration of the mixed wastewater: COD 1500~5000mg/L, BOD_5 1000~3000mg/L, TP 5~30 mg/L, PO_4^{3-}-P 2~5mg/L, settable solid 3~30mg/L

Industrial wastewater

- Characteristics of industrial wastewater—brewery WW

Table 13 Composition of wastewater produced by different processes

Type of wastewater	pH	Dry residue (mg/L)	SS (mg/L)	BOD5 (mg/L)
Barrel cleaning	7.1	980	250	21
Bottle cleaning				
a) Washing solution	11.5	71700	310	870
b) Rinsing water	7.2	940	95	16
Filter cloth washing				
a) Mash filter	6.7	1070	1846	325
b) Cooler sludge filter	6.7	1290	456	694
Fermentation				
a)Fermenting without yeast	5.3	2060	3944	3550
b) Fermenting with yeast	5.0	------	------	70250
c) Storage without yeast	6.8	1010	164	502
d) Storage with yeast	5.2	------	10900	84500
e) Beer filter	5.9	1940	37835	2000

Industrial wastewater

- Characteristics of industrial wastewater
  - *Table 14 Wastewater produced by petroleum refineries*

Pollution	Approximate Quantities
Cooling systems	3.5-5 m³ of wastewater generated per ton of crude
Polluted wastewater	BOD 150-250 mg/l COD 300-600 mg/l phenol 20-200 mg/l oil 100-300 mg/l (desalter water) oil 5000 mg/l in tank bottom benzene 1-100 mg/l heavy metals 0.1-100 mg/l

all this figures depend on the process configuration but we give here a general guide

Resource: Pollution Prevention and Abatement Handbook World Bank Group

Industrial wastewater

- Characteristics of industrial wastewater
  - Wastewater produced by cooling towers
    - high temperature
    - high dissolved solids
    - High concentration of biocides residues
    - High concentration of anti-fouling agents

Storm water

- Characteristics of storm water
  - Storm water includes any surface runoff and flows resulting from precipitation, drainage or other sources
  - Component:
    - suspended sediments, metals, petroleum hydrocarbons, Polycyclic Aromatic Hydrocarbons (PAHs), coliform, etc.

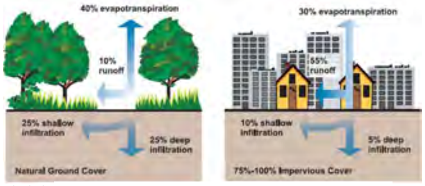


Fig.16 transportation of rainwater in different region

Storm water

- Factors Influencing the quantity and quality
  - Intensity, duration, and areal extent of storms
  - time intervals between successive
  - Land contours, land uses, population densities
  - incidence and nature of industries
  - size and layout of sewer systems

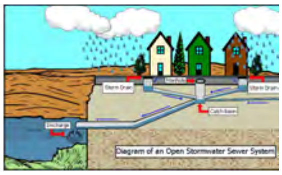


Fig.17 discharge of rain water

Storm water

- Storm water quality highly variable, and some of this variability can be explained by land use and source area (much variability also due to rain characteristics).
  - Water color was high (over 200) in runoff from land with dense vegetations
  - Water color was not correlated with turbidity
  - row crop runoff had the highest TSS concentrations

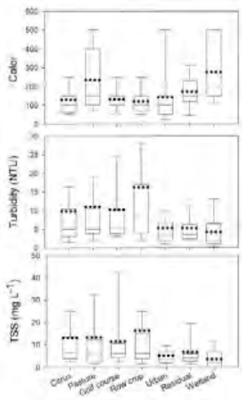


Fig.18 Whisker box plots of color, turbidity and TSS concentration of storm water from Major land use

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Storm water

- Dairy land runoff has the highest nutrient concentration
- Row crop runoff has the second highest nutrient concentration
- The runoff from urban, wetland and residual are slightest polluted

▪ *Table 15: Mean and median nutrient concentrations in storm water runoff from eight land use types sampled*

Land Use	No. of Samples	Total P (mg L-1)		Total N (mg L-1)		Organic N (mg L-1)		Inorganic N (mg L-1)		NH_3-N (mg L-1)		NO_x-N (mg L-1)	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Citrus	127	0.29	0.16	1.37	1.23	1.11	1.05	0.26	0.13	0.13	0.06	0.14	0.04
Pasture	53	0.29	0.22	1.46	1.09	1.32	0.94	0.15	0.08	0.11	0.06	0.03	0.01
Urban	115	0.22	0.09	1.07	0.82	0.92	0.72	0.13	0.05	0.06	0.03	0.07	0.01
Golf Course	28	0.24	0.19	1.62	1.51	1.27	1.22	0.32	0.22	0.20	0.10	0.12	0.07
Wetland	30	0.02	0.01	1.18	0.94	1.10	0.99	0.14	0.02	0.14	0.02	0.00	0.00
Row crop	20	0.63	0.45	1.88	1.31	1.14	0.97	0.77	0.33	0.20	0.04	0.57	0.27
Residual	21	0.26	0.20	1.09	0.87	0.87	0.81	0.21	0.14	0.09	0.05	0.11	0.05
Dairy	8	12.54	8.86	38.9	24.6	9.98	7.39	28.9	11.5	28.5	11.0	0.39	0.03

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Thank you for your listening!

Any Questions?

Acknowledgements

This lecture presentation are the outcome of joint efforts by many colleagues in particular: **Prof. Lihua Cheng**, **Dr. Yan`an Cai** and **Dr. Zhixuan Yin**.

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Status and needs

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Basic theory on the wastewater treatment

a. Physical purification

- Dilution
- Convection： Movement of pollutants in the direction of water flow
- Blend
- Precipitate
- volatilization

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CONTENT

- National, regional and international status of wastewater treatment
- Challenges with wastewater: environmental, health and aesthetic aspects
- Legal aspects: national, regional and international practices

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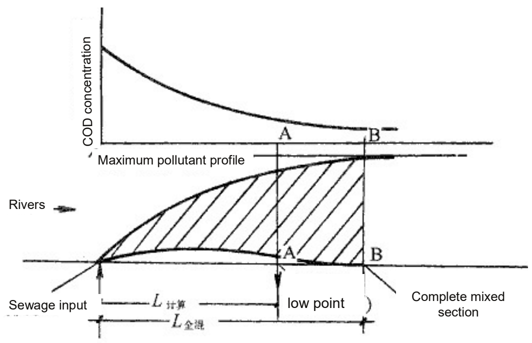

Physical purification process of water

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1. National, regional and international status of wastewater treatment

- Basic theory on the wastewater treatment
- Basic process on the wastewater treatment

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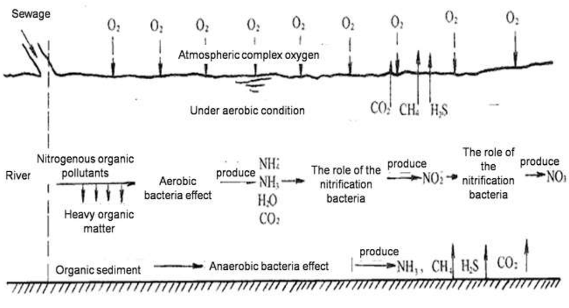
b. Chemical cleaning

- Oxidation reduction
- Acid base reaction
- Adsorption and condensation

c. Biological degradation

- Aerobic
- Anaerobic
- Anoxic



Biological degradation

Oxygen consumption kinetics of organic compounds

$$\begin{cases} \dfrac{dL}{dt} = -K_1 L \\ t = 0, L = L_0 \end{cases}$$

$$\int_{L_0}^{L_t} \frac{dL}{L} = \int_0^t -K_1 dt \qquad [\ln L]_{L_0}^{L_t} = -[K_1 t]_0^t \qquad \ln \frac{L_t}{L_0} = -K_1 t$$

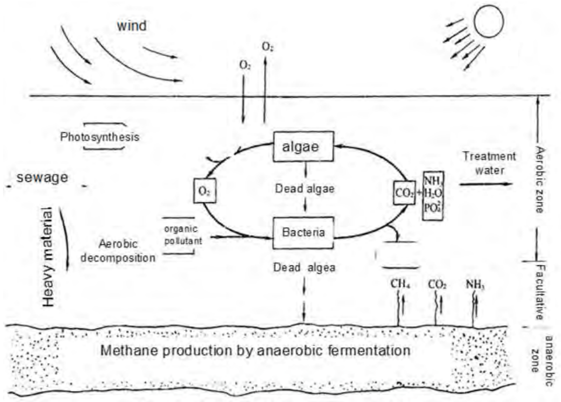
$$L_t = L_0 \cdot \exp(-K_1 t)$$

$$L_t = L_0 \cdot 10^{-k_1 t}$$

L-------Organic matter concentration

$$k_1 = 0.434 K_1$$

k_1------Oxygen consumption rate constant



Degradation of organic matter

Kinetics of the change of dissolved oxygen

$$\begin{cases} \dfrac{dD}{dt} = k_2 D \\ t = 0, D = D_0 \end{cases}$$

D-------Oxygen deficiency $D=C_0-C_x$

k_2------Oxygen recovery rate constant

Phelps equation

$$\begin{cases} \dfrac{dD}{dt} = k_1 L - k_2 D \\ t = 0, D = 0, L = L_0 \end{cases}$$

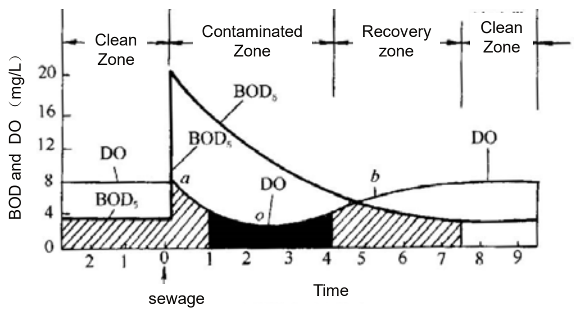
Time to reach the point of oxygen

$$t_c = \frac{\lg\left\{\dfrac{k_2}{k_1}\left[1 - \dfrac{D_0(k_2 - k_1)}{k_1 L_0}\right]\right\}}{k_2 - k_1}$$

d. Phelps equation

Two hypotheses:

- The degradation rate of organic matter is only related to the concentration of organic matter.
- Only aerobic microorganisms are involved, by atmospheric oxygen

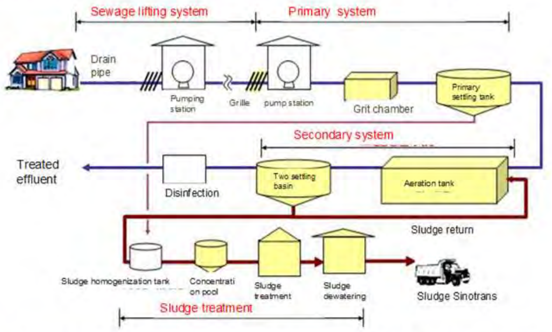


Basic process on the municipal wastewater treatment

2. Challenges with wastewater: environmental, health and aesthetic aspects

- Inorganic pollutant
- Organic pollutant

The basic method and system design of urban sewage treatment



Schematic diagram of urban sewage and sludge conventional treatment system

Inorganic pollution

- Acid and alkali pollution: industrial wastewater, acid rain
- Nitrogen and phosphorus pollution: eutrophicaiton
- Sulfate and sulfide pollution
- Chloride contamination
- Heavy metal pollution

Efficiency of treatment stages

Process	method	Main process	Treatment efficiency（%）	
			SS	BOD5
Primary	Precipitation method	Precipitation (natural precipitation)	40～55	20～30
Secondary	Biological membrane method	Primary sedimentation, biological membrane method, two precipitation	60～90	65～90
	Activated sludge process	Initial sedimentation, biological reaction tank, two precipitation	70～90	65～95

- **The harm of eutrophication**
  - Water quality becomes muddy
  - Reduction of dissolved oxygen
  - Algal toxins
  - Increase color, smell
  - Generation of precursor
  - Increase the cost of water supply plant
  - Destruction of aquatic ecology

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Water shortage in Wuxi city in 2007 Because of Taihu eutrophicaiton

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3. Legal aspects: national, regional and international practices

- China
- Germany
- Norway
- Poland
- Sri Lanka
- Ukraine

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Polar bear with green fur

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China

Wastewater pollutant discharge standards are based on the quality standards of water environment.

"Surface water environmental quality standards（GB3838-2002）"， It divides the waters into five categories.

Class I, mainly applied to the source of water，National Nature Reserve
Class II, mainly used in surface water source protection area
Class III, mainly applicable to the two level of protection of surface water，fishery waters and swimming areas.
Class IV, mainly applicable to general industrial water and recreational water.
Class V, mainly applicable to agricultural water district and the general landscape requirements of water

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Organic pollution

- Oil pollution
- Phenol pollution
- Surface active agent pollution

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Surface water environmental quality standards (mg/L)

Serial number		Class I	Class II	ClassIII	Class IV	Class V
1	water temperature ℃	Anthropogenic environmental water temperature changes should be limited to: Week average maximum temperature rise ≤1， Week average maximum temperature reduce ≤2				
2	pH	6~9				
3	DO ≥		6	5	3	2
4	Permanganate index ≤	2	4	6	10	15
5	COD ≤	15	15	20	30	40
6	BOD5 ≤	3	3	4	6	10
7	NH3-N ≤	0.15	0.5	1	1.5	2
8	TP (P meter) ≤	0.02 (lake，reservoir0.01)	0.1 (lake，reservoir0.025)	0.2 (lake，reservoir0.05)	0.3 (lake，reservoir0.1)	0.4 (lake，reservoir0.2)
9	TN (N meter) ≤	0.2	0.5	1	1.5	2
10	Cu ≤	0.01	1	1	1	1
11	Zn ≤	0.05	1	1	2	2
12	Fluoride (F^- meter) ≤	1	1	1	1.5	1.5
13	Se ≤	0.01	0.01	0.05	0.05	0.1
14	As ≤	0.05	0.05	0.05	0.1	0.1
15	Hg ≤	0.00005	0.00005	0.0001	0.001	0.001
16	Cd ≤	0.001	0.005	0.005	0.005	0.01
17	Cr ≤	0.01	0.05	0.05	0.05	0.1
18	Pb ≤	0.01	0.01	0.05	0.05	0.1
19	Cyanide ≤	0.005	0.05	0.2	0.2	0.2
20	Volatitle phenol ≤	0.002	0.002	0.005	0.01	0.1
21	Petroleum class ≤	0.05	0.05	0.05	0.5	1
22	anionic surface-active	0.2	0.2	0.2	0.3	0.3
23	Sulfide ≤	0.05	0.1	0.05	0.5	1
24	Fecal coliforms ≤	200	2000	10000	20000	40000

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Water pollutant discharge standards are also classified into national standards and local standards in China.

- National standards
- Local standards

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Germany

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Related national municipalwastewater discharge standards

（1）**Pollutant discharge standard of urban sewage treatment plant** GB18918-2002)
（2）**Classification of urban sewage recycling and utilization** GB/T18919-2002
（3）**The city service water quality and city wastewater reclamation** GB/T18920-2002
（4）**Urban sewage regeneration and utilization of landscape water quality** GB/T18921-2002
（5）**Municipal wastewater reclamation and reuse of groundwater recharge** GB/T19772-2005
（6）**Urban sewage recycling and utilization of industrial water quality** GB/T19923-2005
（7）**Water quality standard for landscape and recreation** GB12941-91
（8）**Water quality standard of reclaimed water reuse for landscape water body** CJ/T95-2000
（9）**Water quality control standard of reclaimed water used as cooling water** GB50335-2002
（10）**Recommended water quality standards for reclaimed water used as cooling water** CECS61：94

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Norway

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Related local wastewater discharge standards Shandong Province

（1）Comprehensive discharge standard of water pollutants in the peninsula of Shandong Province（DB37/676-2007）2008-04-30

（2）Standard for comprehensive discharge of water pollutants in Haihe River Basin of Shandong Province (DB37/675-2007)2008-04-30

（3）Shandong province water pollutants discharge standard of Xiaoqing River Basin (DB37/656－2006)2008-04-30

（4）Comprehensive discharge standard of water pollutants along the line of the south to North Water Transfer in Shandong Province (DB37/ 599－2006)2008-04-30

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Poland

Sri Lanka

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Ukraine

Status and needs

WATER CHEMISTRY

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CONTENT*

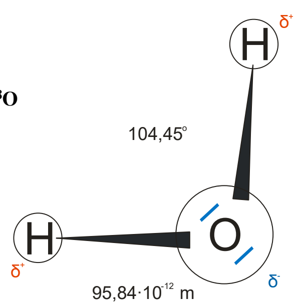
Water Chemistry 2

Fig. 1. Water molecule

oxygen (8)

isotopes (^{15}O), ^{16}O, ^{17}O, ^{18}O

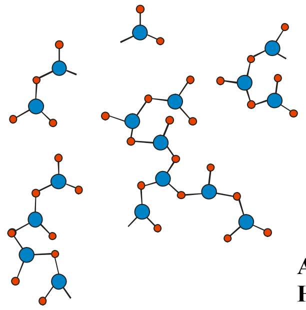
electrons: $1s^2$; $2s^2$ $2p^4$



water dipole structure*

Water Chemistry 3

Fig. 2. Association* of H_2O molecules



Association* of H_2O molecules

Water Chemistry 4

Chemical Properties of Water (some selected)

1. electrolysis: $2H_2O \rightarrow 2H_2 + O_2$
2. reaction with Metal Oxides: $CaO + H_2O \rightarrow Ca(OH)_2$
3. reaction with Nonmetal Oxides*: $SO_2 + H_2O \rightarrow H_2SO_3$
4. reaction with Active Metals: $2Na + H_2O \rightarrow 2NaOH + H_2$
5. formation of Hydrates: $BaCl_2 + 2H_2O \leftrightarrow BaCl_2{\cdot}2H_2O$
6. hydrolysis**: a) $CO_3^{2-} + H_2O \leftrightarrow HCO_3^- + OH^-$
   b) $C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$
   c) $Al^{3+} + H_2O \leftrightarrow AlOH^{2+} + H^+$

Water Chemistry 5

HYDROLYSIS of Al and Fe cations and polycations

In wastewater and wastewater a first step of **Al^{3+} or/and Fe^{3+} cations**

hydrolysis is following: **Al^{3+} (Fe^{3+})** + HOH = **$Al(Fe)OH^{2+}$** + H^+

.... and finally **$\{Al(Fe)(OH)_3\}$** might be formed

The wastewater becomes more **acid** and **positivelly*** charged **colloidal particles $\{Al(Fe)(OH)_3\}_n$** (sometimes called as colloidal sorbent) **are able to adsorb impurities from the treated water/wastewater**.

At high and basic pH some other reaction may occur:

$$Al(Fe)(OH)_3 + OH^- = Al(Fe)(OH)_4^-$$

Water Chemistry 6

The end of 20th century brought some discoveries in a chemistry of **aluminum**

and so-called **poly-aluminum cations** were defined:

from $Al_8(OH)_{20}^{4+}$ into $AlO_4Al_{12}(OH)_{24}(H_2O)_{12}^{7+}$

The last one use to be briefly marked as $\{Al_{13}\}^{7+}$. It has a high valency and then its small content in chemicals used for water/wastewater treatment increases their purification efficiency even more than1000-times – - see Hardy –Schultz rule*.

Many nuclear reactors use water as a moderator, a substance that slows down neutrons.

Water pollutants:

a) oxygen-demanding wastes (both plants and animals)
b) disease causing agents (pathogenic microorganisms; cholera)
c) radioactive material (leakage from nuclear power plants)
d) heat = high temperature = thermal pollution (coolant; oxygen)
e) plants nutrients (excess of „trophic" N and P)
f) synthetic organic chemicals (detergents, pesticides, food additives)
g) inorganic chemicals and minerals (sulphates exchanging to H_2S)

Water impurities

a. dissolved and suspended materials, gases
b. bacteria and other microorganisms

Purification and other treatment of Water

1) distillation (-a and -b) and...
boiling at least for 15 min. (b. and...part of a.)
2) sedimentation (coagulation), filtration (sand)
and disinfection (chlorine or aeration)
3) hard water and its softening
4) *med.* fluoridation of water against the dental caries

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2) sedimentation (coagulation), filtration (sand)
and disinfection (chlorine or aeration)
3) hard water and its softening
4) *med.* fluoridation of water against the dental caries

In the body, WATER acts as:

a) a component of cell and/or tissue fluid

b) a solvent

c) a transporting agent that facilitates the digestibility, decomposition and excretion of substances

If the water intake is greater than water output, a condition known as *endema* results.

If water intake is less than output *dehydration* occurs

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Chemical kinetics searches **the rate** and **mechanism** of chemical reactions.

The rate of the reaction use to be mathematically expressed as:

$$v = -\frac{dc}{dt} = \frac{dx}{dt}$$

where: c – the substrate concentracion*
x – the product concentration*

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In nature the most common are the first order reactions:

$$v = -\frac{dc}{dt} = k \cdot c$$

$$-\int_{c_0}^{c} \frac{dc}{c} = k \cdot \int_0^t dt$$

$$\ln c = \ln c_0 - k \cdot t$$

As a result of Integration* of the kinetics equation in the range of time (***0,t***) at the concentration of the substrate (***c_0,c***) we obtained a final formula expressing linear relationship between ***lnc*** and ***t***, where the direction coefficient is ***–k***.

An example of the 1-st order reaction is a hydrolysis process like:

$$CH_3COOC_2H_5 + HOH \rightarrow CH_3COOH + C_2H_5OH$$

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In practice the half of a first order reaction time $t_{1/2}$ use to be often used.

$t_{1/2}$ is defined as a time needed to react of half of the primary concentration of the product

If c at $t_{1/2}$ is $0.5 \cdot c_o$

then $\ln\frac{0.5c_o}{c_o} = -k \cdot t_{1/2}$ and $\ln(0.5) = -k \cdot t_{1/2}$

hence finally $\frac{0.693}{k} = t_{\frac{1}{2}}$ makes possible of many simple calculations like below:

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Example 1:

The half of a first order reaction time $t_{1/2}$ is 371.04 hours. How many hours are needed to react for 75% of the primary concentration of the product?

for the **1st order reaction:** $t_{\frac{1}{2}} = \frac{0.693}{k}$ then $k = \frac{0.693}{t_{\frac{1}{2}}} = \frac{0.693}{15.46} = 1.08\ \text{hours}^{-1}$

therefore $t = \frac{1}{k} \cdot 2.303 \cdot \lg\frac{c_o}{c} = \frac{1}{0.045} \cdot 2.303 \cdot \lg\frac{100}{25} =$ **739.2 hours**

==

and **not** as from simple relationship like:

50% - 371.04 hours

75% - x and x = ~~556.56 hours~~*

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Rate of reaction increases when a **temperature** increasing.

The simplest aproach to this phenomenon gives a **formula of Van't Hoff** :

$$k_{T+\Delta T} = k_T \cdot a^{(\Delta T/10)}$$

expressed that each increase of **10 degrees** in temperature speeds up

a reaction rate by **2 - 4 times**,

what means that any lab reaction carried at **200° C** can be finished during **1 minute** instead of **72 minutes** in **20°C** for instance*

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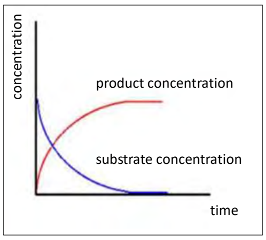
Fig. 3. Reversible reaction



Graph 2 shows changes of the substrate and product concentrations in time so-called **reversible reaction**.

Such a situation was considered and described by two great* Norwegians **Gulberg and Waage** in their **law of mass action.**

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Law of mass action (Guldberg and Waage 1864)

chemical kinetics shows that: **$V = -\Delta c/\Delta t = k \cdot c^p$**

where *c* means molar conc. of the reactant(s)

for such a reaction: $nA + mB \leftrightarrow xC + yD$

$^*V_L = k_L \cdot [A]^n \cdot [B]^m$ (where $n+m=p$ and $[\ldots]=c$) $^{**}V_R = k_R \cdot [C]^x \cdot [D]^y$

at an equilibrium state **always***** $V_L = V_R$ and finally at T=const

$$\frac{[C]^x \cdot [D]^y}{[A]^n \cdot [B]^m} = \text{const} = K$$

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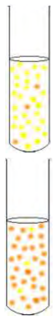
Fig. 4. Chromates and dichromates



$2\,CrO_4^{2-}(aq) + 2\,H^+(aq) \leftrightarrow Cr_2O_7^{2-}(aq) + H_2O$

$$const = \frac{K}{[H_2O]} = K' = \frac{[Cr_2O_7^{2-}]}{[CrO_4^{2-}]^2 \cdot [H^+]^2}$$

In a solution called a chromate solution*, there is also a little bit of dichromate, but the predominant color will be yellow.

In a solution called a dichromate solution*, there is also a little bit of chromate, but the predominant color will be orange.

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$H_2O \leftrightarrow H^+ + OH^-$ or $(2H_2O \leftrightarrow H_3O^+ + OH^-)^*$

and according to **Guldberg and Waage Law**

$$K = \frac{[H^+] \cdot [OH^-]}{[H_2O]} = 1.8 \cdot 10^{-16}$$

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Let's calculate the concentration of **„water in water"** (expected to be constant)

if $d_{H_2O} = 1\ g \cdot cm^{-3}$ then $1000\ cm^3$ of $H_2O \equiv 1000\ g$ of H_2O

(**a**)1000 cm^3 - (**b**)1M (solution*) - (**c**) (contain) 18g H_2O (1 mol of water)

(**d**)**1000 cm^3** - (**e**) **x** - (**f**) **1000g H_2O**

always: **a·b·f = d·e·c** , therefore here

$$x = \frac{1000cm^3 \cdot 1M \cdot 1000g}{1000cm^3 \cdot 18g} = \frac{10^2}{1.8}M = [H_2O]^{**}$$

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$$K = \frac{[H^+] \cdot [OH^-]}{[H_2O]} = 1.8 \cdot 10^{-16}$$

therefore $[H^+] \cdot [OH^-] = \frac{10^2}{1.8} \cdot 1.8 \cdot 10^{-16}$

hence finally for any ***ionic product***:

$[H^+] \cdot [OH^-] = 10^{-14}$ **(at T=298K)**

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let $pH = -lg[H^+]$ and $pOH = -lg[OH^-]$

$[H^+][OH^-] = 10^{-14}$ then after $[\cdot(-lg)]$ of a left and right side

finally we have a logharitmic version: **pH + pOH = 14**

Let's calculate ***pH of water.***

for water always $[H^+]=[OH^-]$; hence $[H^+]^2 = 10^{-14}$

and then $[H^+]=10^{-7}$

therefore $pH = -lg10^{-7} = -(-7)lg10 = 7$; **pOH=?***

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Example 2. Calculate *pH of 0.125 M HCl.*

notice, for strong acid like HCl

$[HCl]^* = [Cl^-] = [H^+] = 0.125 = 1.25 \cdot 10^{-1}$

$pH = -\lg(1.25 \cdot 10^{-1}) = -(\lg 1.25 + \lg 10^{-1}) = 1 - \lg(1.25) =$

$= 1 - 0.097 = 0.903 \approx$ **0.9**

Example 3. Calculate $[OH^-]$ *in the solution of pH = 12.72.*

$pOH = 14 - pH = 14 - 12.72 = 1.28$

$[OH^-] = 10^{-1.28} = 10^{-2} \cdot 10^{0.72} =$

$= 5.25 \cdot 10^{-2} = 0.0525^*$

this is 0.0525 molar water solutions of OH^- anions

Dissociation Degree

The dissociation degree is a fraction of number molecules that have dissociated. It is usually indicated by the Greek symbol **α**.
The values of α have not been collected, but they can be calculated, because they depend on c*.

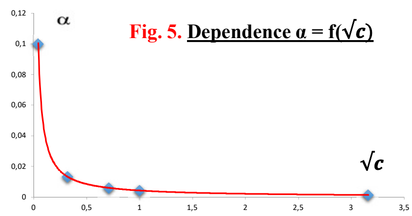


Fig. 5. **Dependence $\alpha = f(\sqrt{c})$**

Example 4. $1.782 \cdot 10^{22}$ molecules of a weak acid HA were introduced to 1 dm^3 of the solution and pH = 3 was measured. Calculate **α** of the acid.

a) if pH = 3 then $[H^+] = 10^{-3} = 0.001$

b) 1 mol H^+ ≡ $6.023 \cdot 10^{23}$ molecules
10^{-3} mol ≡ x

----

and then $x = 6.023 \cdot 10^{20}$ molecules/ions of H^+ ≡
≡ a number of the dissociated HA

c) therefore $\alpha = \frac{6.023 \cdot 10^{20}}{1.782 \cdot 10^{22}} = 3.38 \cdot 10^{-2} = 0.0338 \equiv 3.38\%$

Ostwald's Law

$CH_3COOH \leftrightarrow CH_3COO^- + H^+$ $\quad K = \frac{[CH_3COO^-] \cdot [H^+]}{[CH_3COOH]}$

if $[CH_3COO^-] = [H^+] = c_a \cdot \alpha$ and $[CH_3COOH] = c_a(1 - \alpha)$

then $K = \frac{c_a \cdot \alpha \cdot c_a \cdot \alpha}{c_a(1-\alpha)}$ and $K = \frac{c_\alpha \cdot \alpha^2}{(1-\alpha)}$

for $1 \gg \alpha$ $\quad (1 - \alpha) \approx 1$ and $K = c_a \cdot \alpha^2$

exactly when $\alpha < 0{,}05$, or when $\frac{c}{K} > 400$

----

most cases $\alpha = \sqrt{\frac{K}{c_\alpha}}$ therefore „$\alpha = f(c_a)$" *

Example 5. Calculate pH of 0.24 M NH_3. ($K_b = 1.78 \cdot 10^{-5}$)

$\frac{c}{K} = \frac{0.24}{1.78 \cdot 10^{-5}} = \frac{24 \cdot 10^{-2}}{1.78 \cdot 10^{-5}} = 13.48 \cdot 10^3 = 13480$

(FORTUNATELY!?)* 13480 > 400 therefore

$K = c \cdot \alpha^2$ and $\alpha = \sqrt{\frac{K}{c}} = \sqrt{\frac{1.78 \cdot 10^{-5}}{0.24}}$

$\alpha = \sqrt{\frac{17.8 \cdot 10^{-6}}{0.24}} = \sqrt{(74.2 \cdot 10^{-6})} = 8.6 \cdot 10^{-3}$

$[OH^-] = \alpha \cdot c = 8.6 \cdot 10^{-3} \cdot 0.24 = 2.07 \cdot 10^{-3}$

$pOH = -\lg(2.07 \cdot 10^{-3}) = 3 - 0.32 = 2.68$, $pH = 14 - 2.68 =$ **11.32****

pH of salt

anionic hydrolysis runs: $CH_3COO^- + H_2O \leftrightarrow CH_3COOH + OH^-$

$$K = \frac{[CH_3COOH]\cdot[OH^-]}{[CH_3COO^-]\cdot[H_2O]} \quad \text{and} \quad K_h = \frac{[CH_3COOH]\,[OH^-]}{[CH_3COO^-]}$$

$$\frac{[CH_3COOH]\cdot[OH^-]}{[CH_3COO^-]} \cdot \frac{[H^+]}{[H^+]} = \frac{10^{-14}}{K_a} = \frac{[OH^-]^2}{c_s}$$

$$[OH^-] = \sqrt{\frac{c_s \cdot 10^{-14}}{K_a}}$$

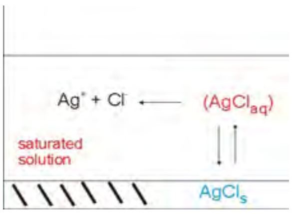
Example 6: Calculate pH of 0.1M **CH_3COOK**, if $K_a = 1.8\cdot10^{-5}$.

$$[OH^-] = \sqrt{\frac{10^{-1}\cdot10^{-14}}{1.8\cdot10^{-5}}} = 7.45\cdot10^{-6}$$

pOH = 6 - lg7.45 = 6 - 0.87 = 5.13

therefore pH = 14 - 5.13 = **8.87***

Fig. 6. Precipitation of AgCl



precipitate

(Definition) **SOLUBILITY** is ***molarity*** (molar conc.) of the saturated solution*.

For poorly soluble substances (salts) use to be a small value and for **AgCl** the solubility is app. 0.00001 (10^{-5} mol·dm^{-3}), **what will be proved soon...**

According to **Guldberg and Waage Law**

$$K = \frac{[Ag^+]\cdot[Cl^-]}{[AgCl\ solid]} \quad \text{where} \quad [AgCl\ solid] = const$$

and K·[AgCl solid] = L

hence $L = [Ag^+]\cdot[Cl^-]$

If d = 5.56 g·cm^{-3} of solid AgCl, let's calculate a molar conc. of poorly soluble (solid) salt in a solid salt like AgCl (Ag-108; Cl-35.5).

(a) 1000 cm^3 – (b) 1 M („solution") – (c) 143.5g AgCl (always!)
(d) 1000 cm^3 - (e) x M - (f) 5560g AgCl (always!)

Like to pH of water calculations, remember that „always":

a·b·f=d·e·c *

therefore, x = (1000·1·5560)/(1000·143.5) = const ≈ 39

Conclusion: **$[AgCl_s]$ ≈** (always) **39** [mol·dm^{-3}] and is… **const!!**

let consider the easiest case: $L=[Ag^+]\cdot[Cl^-]$

$AgCl_s \leftrightarrow Ag^+_{aq} + Cl^-_{aq}$

1mol = 1mol + 1mol

Let the solubility (remaining: means molar conc. of the saturated solution) is „x", therefore

$[AgCl_{aq}] = [Ag^+] = [Cl^-] = x$

and $L = x\cdot x = x^2$, hence $x = \sqrt{L}$

AgBr ; AgJ ; AgCN ; $CaCO_3$; $AlPO_4$ etc.*

$Ag_2CrO_{4s} \leftrightarrow 2Ag^+ + CrO_4^{2-}$

1mol = 2mol + 1 mol, and then

$[Ag_2CrO_{4aq}] = [CrO_4^{2-}] = x$, but $[Ag^+] = 2x$

therefore $L = [Ag^+]^2 \cdot [CrO_4^{2-}] = (2x)^2 \cdot x = 4x^3$

$PbCl_2$

Ag_3PO_4: $L = (3x)^3 \cdot x = 27x^4$

$Ca_3(PO_4)_2$: $L = (3x)^3 \cdot (2x)^2 = 108x^5$

Fe_2S_3 : $L = (2x)^2 \cdot (3x)^3 = 108x^5$

Tab. 1. Solubility - selected data

Chemical formula	Solubility Product L	Ion solubility *Mol/L*	Ion solubility *mg/L*
$CaCO_3$	$4.7 \cdot 10^{-9}$	$[Ca^{2+}]=[CO_3^{2-}]=7 \cdot 10^{-5}$	0.0028 mg Ca^{2+}/L 0.0042 mg CO_3^{2-}/L
$PbCl_2$	$1.6 \cdot 10^{-5}$	$[Pb^{2+}]=1.6 \cdot 10^{-2}$	3.3 mg Pb^{2+}/L **(high)**
$AlPO_4$	$5.8 \cdot 10^{-19}$	$[Al^{3+}]=[PO_4^{3-}]=7.7 \cdot 10^{-10}$	$7.23 \cdot 10^{-8}$ mg PO_4^{3-}/L $2.0 \cdot 10^{-8}$ mg Al^{3+}/L
$Al(OH)_3$	$2.0 \cdot 10^{-33}$	$[Al^{3+}] \approx 3.0 \cdot 10^{-9}$	$\approx 8 \cdot 10^{-8}$ mg Al^{3+}/L
$Fe(OH)_3$	$6.0 \cdot 10^{-38}$	$[Fe^{3+}]= 0.2 \cdot 10^{-9}$	$\approx 1 \cdot 10^{-8}$ mg Fe^{3+}/L
$Ca_3(PO_4)_2$	$1.3 \cdot 10^{-32}$	$[Ca^{2+}]=4.9 \cdot 10^{-7}$ $[PO_4^{3-}]=3.3 \cdot 10^{-7}$	$\approx 2 \cdot 10^{-5}$ mg Ca^{2+}/L $\approx 3 \cdot 10^{-5}$ mg PO_4^{3-}/L
Fe_2S_3	$1.0 \cdot 10^{-88}$	$[Fe^{3+}]=2 \cdot 10^{-18}$ $[S^{2-}]=3 \cdot 10^{-18}$	$\approx 10^{-16}$ mg Fe^{3+}/L $\approx 10^{-16}$ mg S^{2-}/L **(low)**

Example 7: Will be any precipitate (like stone or „sand") formed when 50 cm^3 0.001M $C_2O_4^{2-}$ (oxalate) comes to the human kidney containing 100 cm^3 0.001M Ca^{2+} (L for CaC_2O_4 = **$2.1 \cdot 10^{-9}$**)?

In the kidney:

$[C_2O_4^{2-}] = 0.001 \cdot (50/150) = 3{,}33 \cdot 10^{-4}$

$[Ca^{2+}] = 0.001 \cdot (100/150) = 6.66 \cdot 10^{-4}$

$[C_2O_4^{2-}] \cdot [Ca^{2+}] = 3.33 \cdot 10^{-4} \cdot 6.66 \cdot 10^{-4} = 22.18 \cdot 10^{-8} = 2.2 \cdot 10^{-7}$

$2.2 \cdot 10^{-7}$ > (100-times) **$2.1 \cdot 10^{-9}$**

therefore "unfortunately" the **stone will be formed** in the kidney

Example 8: Calculate the solubility of AgCl ($L=1 \cdot 10^{-10}$):
a) in water, b) in 0,1M HCl.

a) $L=[Ag^+] \cdot [Cl^-]=x^2$, hence **(„regular")** $x = [AgCl] =$
$= [Ag^+] = [Cl^-] = \sqrt{L} = \sqrt{10^{-10}} = 10^{-5}$ $[mol \cdot dm^{-3}]$

b) in HCl solution **$[Ag^+] \neq [Cl^-]$**

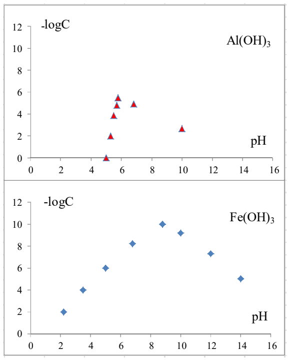
$L = [Ag^+] \cdot [Cl^-]$, and hence **(„irregular")** $x' = [AgCl] =$
$= [Ag^+] = L/[Cl^-] = 10^{-10}/10^{-1} = 10^{-9}$ $[mol \cdot dm^{-3}]$

Finally: x in water (regular) **:** x' in 0,1M HCl („irregular") =

$= 10^{-5}/10^{-9} = 10^4 =$ 10000-fold worse! than...**in water!***

Fig. 7. pH effect on solubility

Solubility of metal hydroxides like $Al(OH)_3$ and/or $Fe(OH)_3$ strongly depends on pH of ...water or wastewater. That's why graphs illustrating solubility of $Al(OH)_3$ or/and $Fe(OH)_3$ as dependence on pH are so important for treatment of water and wastewater. Minimum of $Al(OH)_3$ solubility comes at pH≈6 and solubility minimum for $Fe(OH)_3$ comes at pH≈9. $Fe(OH)_3$ is less sensitive on pH (wide range of pH) compare to $Al(OH)_3$, where the range of pH is more narrow.



Alfred Werner Nobel's experiment

heating up such a system gradually at keeping control of $[Cl^-]$

{hexaamminecobalt(III) chloride}

$[Co(NH_3)_6]Cl_3 \rightarrow [Co(NH_3)_5H_2O]Cl_3 \rightarrow$

$\rightarrow ...[Co(H_2O)_6]Cl_3 \rightarrow$

$\rightarrow ...[Co(H_2O)_5Cl]Cl_2$

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Important Assumptions are:

Na^+, K^+, Ca^{2+}, Mg^{2+} exist in water solution

but „Fe^{2+}, Fe^{3+}, Co^{3+}, Cu^{2+}"
do not exists (are not available in water solution)*

because the aquacomplexes like:

$Co(H_2O)_6^{3+}$, $Fe(H_2O)_6^{2+}$, $Fe(H_2O)_6^{3+}$

$Cu(H_2O)_4^{2+}$ exist and they

are the only available in water solution

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Tab. 2. **Configuration of electrons at the coordination number 6**

Atom (Element)	Ion (Cation)	Complex Ion
Cobalt Co (27)	Co^{3+}	$Co(NH_3)_6^{3+}$
		Krypton structure
$1s^2$	$1s^2$	$1s^2$
$2s^2\ 2p^6$	$2s^2\ 2p^6$	$2s^2\ 2p^6$
$3s^2\ 3p^6\ 3d^7$	$3s^2\ 3p^6\ 3d^6$	$3s^2\ 3p^6\ 3d^{10}$
$4s^2$	and	$4s^2\ 4p^6$
no octet here	no octet here either	

$\Delta = (d^{10} - d^6) + 4S^2 + 4p^6 = 4 + 8 = 12 = 6$ pairs of electrons = 6 NH_3

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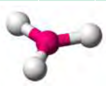
Fig. 8. **Shapes of complexes**

Coordination number	Angle	Shape
2	180°	linear

Ligand-----Metal Ion-----Ligand

Coordination number	Angle	Shape
4	109° 28´	tetrahedron

Coordination number	Angle	Shape
3	120°	trigonal planar



Coordination number	Angle	Shape
6	90°	Octahedron

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Coordination Number

a) 4 : Cu, Zn, Ag, Cd, Sn, Hg, Pb

b) 6: very easy coordinating and forming the lasting complexes both simples and chelates

Ligands

a) containing oxygen (less selective): H_2O, OH^-, O^{2-}, CO_3^{2-}, SO_4^{2-}, $RCOO^-$, NO^- etc.

b) containing N and/or S (more selective and more common): NH_3, NH_2^-, H_2S, S^{2-}, $S_2O_3^{2-}$, SCN^-, RS^-

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Typical complexes (also aqua complexes):

$[Cu(H_2O)_4]^{2+}$; $[Cu(NH_3)_4]^{2+}$; $[Zn(NH_3)_4]^{2+}$; $[Ag(NH_3)_2]^+$

$[Fe(H_2O)_6]^{2+}$; $[Fe(CN)_6]^{4-}$; $[Fe(CN)_6]^{3-}$; $[Ag(S_2O_3)_2]^{3-}$

$[Al(OH)_4(H_2O)_2]^-$; $[Pb(OH)_3]^-$

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Labile complexes (like aqua complexes) are easy exchanging onto **stable** complexes:

$[Ni(H_2O)_4]^{2+} + 4CN^- \rightarrow [Ni(CN)_4]^{2-} + 4H_2O$

Some selected complexing reactions

$Au + 4HCl + 3HNO_3 \rightarrow HAuCl_4 + 3NO_2 + 3H_2O$

$[CuCl_2(H_2O)_2] + Cl^- \rightarrow [CuCl_3(H_2O)]^- + H_2O$

$Zn(OH)_2 + 2OH^- \rightarrow [Zn(OH)_4]^{2-}$

$HgS + S^{2-} \rightarrow [HgS_2]^{2-}$; $As_2S_3 + 3S^{2-} \rightarrow 2[AsS_3]^{3-}$

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Significance of complexing in nature

1. Transportation of cations (Fe^{3+} for instance) from soil to a plant by so-called chelates.
2. Carrying Ni^{2+}, Co^{2+}, czy Ca^{2+} in the organisms by amino acids as ligands.
3. Dissolving of some poorly soluble precipitates:

   a) $Cu(OH)_2\downarrow + 4NH_3{\cdot}H_2O \rightarrow [Cu(NH_3)_4](OH)_2$

   b) vitamin C as a ligand protects silting (clogging) of the organism (human body for instance) and also is able to transform some precipitates into „assimilable" forms.

4. Bioligands improve assimilability of some fertilizers as $Ca_3(PO_4)_2$ for instance. Chelates (so-called multi-pincers chelates particularly) like chlorophyll, hemoglobin or vitamin C make the system acid and then are increasing a solubility of many precipitates.
5. Nature prefers labile systems. Cis-isomers use to complex strongly, that's why in nature trans-maleic acid is common, opposite to cis-maleic one.
6. Chelatotheraphy is a significant medical branch:

   a) cis-platinium inhibits a development of some cancer tissue

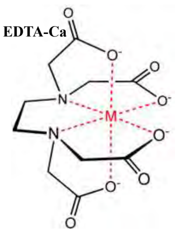
   b) excess of Cu^{2+} in food, so-called Wilsona disease use to be treated with a commonly known bioligand EDTA,

   c) BAL (2,3-ditio-1-propanol) is an antidote at poisoning with haevy metals

Fig. 9. EDTA structure

multi-pincers chelate

EDTA-Ca



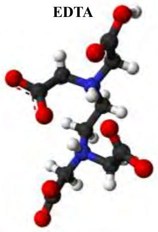
EDTA complexing reactions*:

1EDTA + 1Na^+ = $(EDTA\text{-}Na)^+$

1EDTA + 1Ca^{2+} = $(ADTA\text{-}Ca)^{2+}$

1EDTA + 1Fe^{3+} = $(EDTA\text{-}Fe)^{3+}$

EDTA



Any chemical reaction as neutralization for instance

$H_2SO_4 + 2NaOH = Na_2SO_4 + H_2O$

$Na_2CO_3 + 2HNO_3 = 2NaNO_3 + H_2O + CO_2$

By Ben Mills , https://commons.wikimedia.org/w/index.php?curid=3557118

forming of hardness: (rock) $CaCO_3\downarrow$ + (rain) $CO_2 + H_2O \rightarrow Ca(HCO_3)_{2(aq)}$

Carbonate Hardness (T_c)* + Permanent Hardness (T_p) = Total Hardness (T_t)

$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O$

$Mg^{2+} + 2HCO_3^- \rightarrow Mg(OH)_2\downarrow + 2CO_2\uparrow$

1°N is an equivalent of 10 mg CaO** per 1L of water

Water hardness removal

$Ca^{2+} + CO_3^{2-}$ {from Na_2CO_3} $\rightleftharpoons CaCO_3\downarrow$
$Mg^{2+} + 2OH^-$ {from $Ca(OH)_2$} $\rightleftharpoons Mg(OH)_2\downarrow$

Na - Kt - Na + Ca^{2+} {from $Ca(HCO_3)_2$}* $\rightleftharpoons$ (→) Kt = Ca + $2Na^+$
Na - Kt - Na + Mg^{2+} {from $MgCl_2$} $\rightleftharpoons$ (→) Kt = Mg + $2Na^+$

Kt = Ca + $2Na^+$ $\rightleftharpoons$ (→) Na - Kt - Na + Ca^{2+} regeneration
Kt = Mg + $2Na^+$ $\rightleftharpoons$ (→) Na - Kt - Na + Mg^{2+} regeneration

(Analytical) Example 9: The water hardness is 18°N. How many cm^3 of 0.02M EDTA is needed for complexing all Ca^{2+} and Mg^{2+} cations being responsible for that hardness in 1 dm^3 of that water. [Ca-40]

1°N – 10 mg of CaO in 1dm^3 (as a definition says)
18°N - x and x = 180 mg CaO per 1 dm^3

1 mol of EDTA ≡ (complexing) ≡ 1 mol Ca^{2+} ≡ 1 mol CaO

1000 cm^3 - 1 M EDTA - 56 000 mg CaO
y - 0.02 M - 180 mg CaO

$$y = \frac{1000\cdot 1\cdot 180}{0.02\cdot 5\ 000} = 161\ cm^3$$

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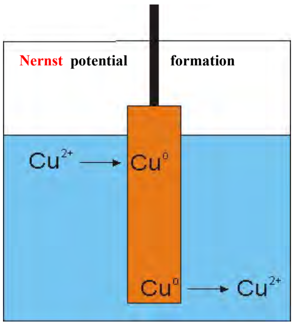
Fig.10. First-kind electrode



$E = E_o' + \frac{R \cdot T}{z \cdot F} \ln K$, but $K = \frac{[Cu^{2+}]}{[Cu]}$,

or exactly * $K = \frac{a_{Cu^{2+}}}{a_{Cu}}$

so in standard conditions for **Cu** **

and at T = 298 K (Europe):

$\frac{R \cdot T}{z \cdot F} \ln K = 0{,}0295 \cdot \log K$

therefore $E = E_o + 0{,}0295 \cdot \log a_{Cu^{2+}}$

where $E_o = E_o' - \log a_{Cu}$

notice: $E = E_o$ when $a_{Cu^{2+}} = 1$ (!) ***

Water Chemistry 55

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MnO_4^- redox reactions*: $MnO_4^- + 8H^+ + 5e = Mn^{2+} + 4H_2O$ (H_2SO_4 acid)

Oxidation by MnO_4^- (MnO_4^- titration)

$2KMnO_4 + 5H_2C_2O_4 + 3H_2SO_4 = 2MnSO_4 + 10CO_2 + K_2SO_4 + 8H_2O$

$Mn^{7+} + \underline{5e} = Mn^{2+}$ 2

$2C^{3+} - \underline{2e} = 2C^{4+}$ 5

$MnO_4^- + 5Fe^{2+} + 8H^+ = Mn^{2+} + 5Fe^{3+} + 4H_2O$

$2MnO_4^- + 5H_2O_2 + 6H^+ = 2Mn^{2+} + 5O_2 + 8H_2O$

Water Chemistry 58

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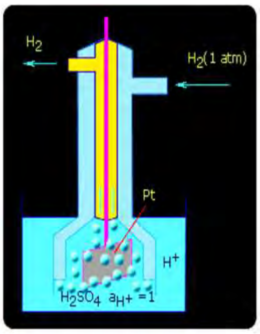

Fig. 11. Standard Hydrogen electrode

For such an electrode

a standard potential is **0***

Water Chemistry 56

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Example 10. 1,003 g H_2O_2 **of primary solution was diluted to** 250 cm³. For titrating 25 cm³ of the diluted solution was used* 17,4 cm³ 0,02 m $KMnO_4$. Calculate % concentration of the primary H_2O_2 solution.

$2MnO_4^- + 5H_2O_2 + 6H^+ = 2Mn^{2+} + 5O_2 + 8H_2O$

2·1000 cm³ – 1 M - 5·34 g H_2O_2

17,85 cm³ – 0,02 M - x and then x = 0,0303 g H_2O_2 (in 25 cm³)

1,003 g of the solution - 10·0,0303 g H_2O_2 (in 250 cm³)

therefore 100 g of the solution - y

----

then y = 30,2 % H_2O_2

Water Chemistry 59

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Tab. 3. Values of standard potentials

$Au^{3+} + 2e^- = Au^+$	1,29
$Cl_2 + 2e^- = 2Cl^-$	1,385
$Cr_2O_7^{2-} + 14H^+ + 6e^- = 2Cr^{3+} + 7H_2O$	1,36
$BrO_3^- + 6H^+ + 6e^- = Br^- + 3H_2O$	1,44
$ClO_3^- + 6H^+ + 6e^- = Cl^- + 3H_2O$	1,45
$PbO_2 + 4H^+ + 2e^- = Pb^{2+} + 3H_2O$	1,456
$HClO + H^+ + 2e^- = Cl^- + H_2O$	1,49
$MnO_4^- + 8H^+ + 5e^- = Mn^{2+} + 4H_2O$	1,52
$Ce^{4+} + e^- = Ce^{3+}$	1,61
$Pb^{4+} + 2e^- = Pb^{2+}$	1,69
$H_2O_2 + 2H^+ + 2e^- = 2H_2O$	1,77
$Co^{3+} + e^- = Co^{2+}$	1,84
$O_3 + 2H^+ + 2e^- = H_2O + O_2$	2,07
$F_2 + 2e^- = 2F^-$	2,85

Water Chemistry 57

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Redox reactions running in wastewater (another lecture)*

Aerobic conditions

organic matter + O_2 + **aerobic bacteria** → $CO_2 + H_2O$

Anoxic conditions

organic matter + NO_3^- + **denitrification bacteria** → $CO_2 + N_2$

Anaerobic conditions

organic matter + **fermentation bacteria** → $CO_2 + SO_4^{2-}$ + acetic anions + hydrogen + organic acids + alcohols + **sulphate reducing bacteria** → $CO_2 + H_2S$**

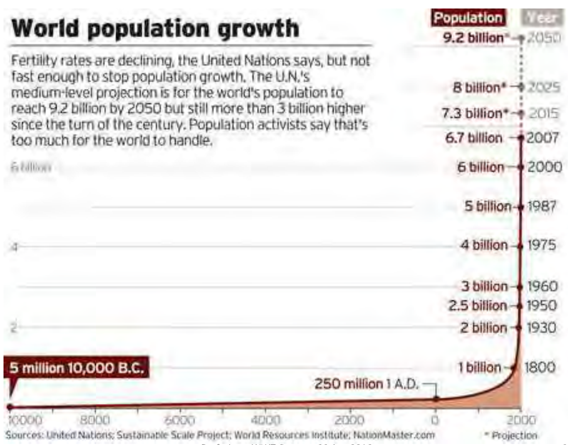
Water Chemistry 60

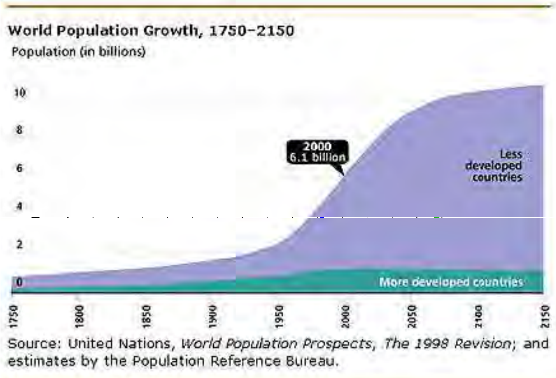
Introduction to Wastewater Management

Gemunu Herath
Department of Civil Engineering
University of Peradeniya

Why wastewater is an emegring issue today

- From 1900-2000 global water demands rose six-fold, more than twice the rate of population growth .
- World water consumption doubling every 20 years, more than twice the population growth.
- Most these waters once used is thrownout as wastewater.
- With expected future population growth trends unless we start managing these wastewaters, incresed future water stress is inevatible.





- Future Population

Under this Scenario Urbanization is INEVITABLE

De-Urbanization ………… Do you Advocate??

~~No~~

Not Feasible & Not Desirable

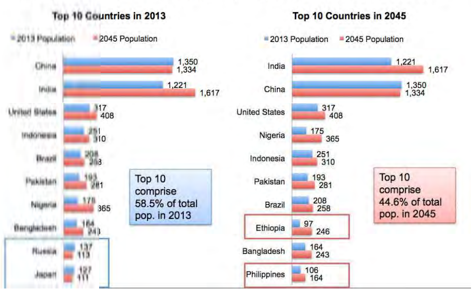
WHY

City = an attractive magnet

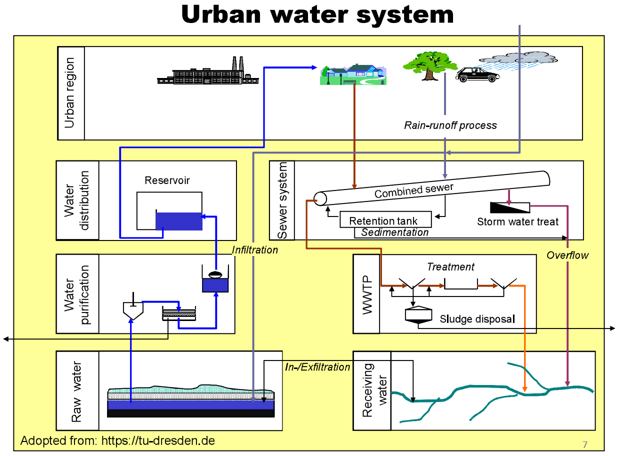
Prospective on Urban Environmental Development
Industrial Countries : Environmental conscious
Developing Countries : Confrontation between economic development Vs Environmental protection

Top 10 Countries

- Fragmentation – an increasing long tail of population



Urban water system



Adopted from: https://tu-dresden.de

Aim of Wastewater Treatment

The overall objectives of wastewater treatment are to;

- Enable wastewater to be disposed safely, without endangering the public health and the water environment
- Reduce nuisance conditions to public, environment
- To recover energy, nutrients, water and other valubles from wastewater.

What is Wastewater

- Wastewater is the remaining product of fresh water after being used by a community or,
- It is any water that has been adversely affected in quality by anthropogenic (human) or natural influence.
- Wastewater contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources.

Wastewater Types

- Depending on their origin, wastewater can be classed as
  - Community or domestic wastewater (sanitary waste coming from houses, officers, schools etc.),
  - Commercial wastewater (coming from shops),
  - Industrial wastewater (coming from factories),
  - agricultural wastewater (coming from agri. lands such as paddy fields, vegetable plots etc.) or
  - surface runoff (storm water).

Sewage or Community or Domestic Wastewater

Includes

- **Blackwater** is a the wastewater containing fecal matter and urine.
- **Graywater or Sullage** is the wastewater produced form other domestic activities such as washing processes

Graywater differs from blackwater as it does not contain human body waste (feces and urine).

- On average 80 to 90% water use at home become wastewater.
- About 50–70% of domestic wastewater is gray-water

Wastewater Composition

In wastewater:

- 99.9% by mass is water
- The rest 0.1% consists of;
  - 70% organic solids (Protiens, Crabohydrates, Fats etc..)
  - 30% inorganic solids (Sediments, Salts and Metals)
- This 0.1% Solids shall determine the properties of the wastewater
  - Physical Properties
  - Chemical Properties and
  - Bactreological Properties

Physical Parameters:

– Color, Odor, Solids, Temperature etc.

Chemical Parameters:

– Organic – Proteins, CHO, Fats & Oils, Pesticides, Phenols, Priority pollutants, Volatile organic compounds, Surfactants (compounds that lower the surface tension – ex. detergents, emulsifiers) and grease

– Inorganic –Alkalinity, Chlorides, Heavy metals, N, pH, P, Priority pollutants and S

– Gases – H_2S, CH_4, O_2

Biological Parameters :

– Bacteriological contents (Animals, Plants, Bacteria, Viruses)

- Many of these parameters are interrelated for example; Temperature affects biological activity in WW and amount of gases dissolved

TABLE 3-16
Typical composition of untreated domestic wastewater

Contaminants	Unit	Concentration		
		Weak	Medium	Strong
Solids, total (TS)	mg/L	350	720	1200
Dissolved, total (TDS)	mg/L	250	500	850
Fixed	mg/L	145	300	525
Volatile	mg/L	105	200	325
Suspended solids (SS)	mg/L	100	220	350
Fixed	mg/L	20	55	75
Volatile	mg/L	80	165	275
Settleable solids	mL/L	5	10	20
Biochemical oxygen demand, mg/L: 5-day, 20°C (BOD_5, 20°C)	mg/L	110	220	400
Total organic carbon (TOC)	mg/L	80	160	290
Chemical oxygen demand (COD)	mg/L	250	500	1000
Nitrogen (total as N)	mg/L	20	40	85
Organic	mg/L	8	15	35
Free ammonia	mg/L	12	25	50
Nitrites	mg/L	0	0	0
Nitrates	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	8	15
Organic	mg/L	1	3	5
Inorganic	mg/L	3	5	10
Chlorides[a]	mg/L	30	50	100
Sulfate[a]	mg/L	20	30	50
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliform[b]	no/100 mL	10^6–10^7	10^7–10^8	10^8–10^9
Volatile organic compounds (VOCs)	μg/L	<100	100–400	>400

[a] Values should be increased by amount present in domestic water supply.
[b] See Table 3-18 for typical values for other microorganisms.
Note: 1.8(°C) + 32 = °F.

Adapted from Metcalf and Eddy (1991) *Wastewater Engineering. Treatment Disposal Reuse*, G. Tchobanoglous and F.L. Burton

Important contaminants in Wastewater

- SS, Biodegradable organics, Pathogens, Nutrients, Priority Pollutants, Refractory organics, Heavy metals, dissolved inorganic

Biodegradable organics –

- composed of CHO, Proteins, Fats and oils
- measured in terms of BOD and COD
- if discharged untreated,
  – depletion of natural oxygen resources
  – development of septic conditions

Organic Matter

- about 75% of SS, 40% filterable solids are organic
- derived from animal, plant materials and synthetic organic compounds
- normally composed of C, H and O, in some cases N
- S, P and Fe may present

Common organic materials;

- carbohydrates, lignin, fats, proteins and
- their decomposition products,
- various natural and synthetic organic chemicals from the process industries.

Principal organic groups;

- proteins 40-60%, Sugars 25-50%, fats and oils 10% and
- synthetic organic molecules, surfactants, organic PP, VOC, pesticides in minor amounts

Proteins

- contain C as well as H and O, high % of N (16%)
- many cases S, P and Fe are present
- Protein and Urea are main sources of N in WW
- with large quantities of proteins, decomposition will produce extremely foul odours

CHO

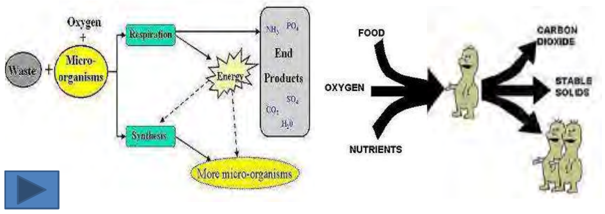
- widely distributed, sugars, starch, cellulose, fibre
- all found in WW, contains C, H and O
- common CHO contain 6 or multiples of 6 C atoms
- H and O are 2:1
- Some CHO, sugars are soluble, starch insoluble, sugars tend to decompose, by fermentation to produce alcohol and CO_2
- enzymes of certain bacteria and yeasts

Organic Pollution

- Microorganisms that thrive in water feed on biodegradable substances.
- When large amounts of biodegradable organic waste is mixed with water, many microorganism thrive on them
- During this process microorganism utilize available oxygen in water. The is called oxygen depletion.
- Common oxygen-depleting substances include natural materials, such as plant matter (e.g. leaves and grass) as well as man-made waste and chemicals.
- When oxygen levels in water are depleted, it makes difficult for the aquatic life to survive.

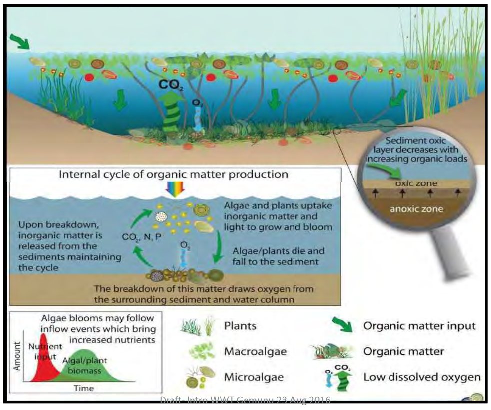
Aerobic Digestion

- This is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the organic waste.
- Organic waste in the presence of oxygen broken down to new bacteria cells, CO_2, H_2O and other stable solids



Oxygen Depletion in Lakes

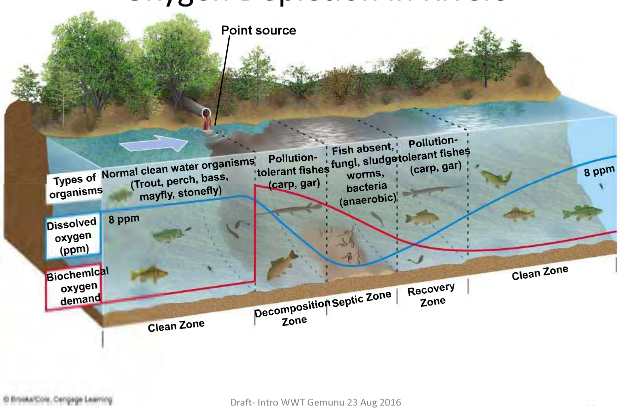
Process of Oxygen Depletion

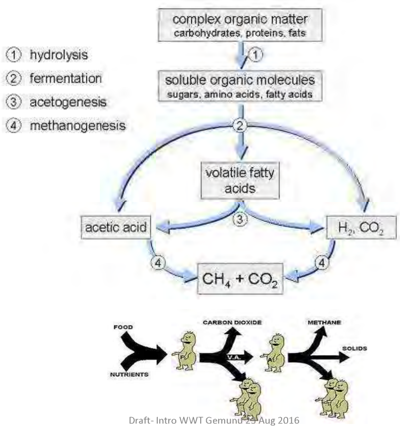


Anaerobic Digestion

- This a biochemical reaction carried out in a number of steps by several types of micro-organisms that require little or no oxygen to live.
- During this process, a gas principally composed of methane (CH_4) and carbon dioxide (CO_2), **known as biogas**, is produced.
- The amount of gas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition (and gas production).
- Bad order is created through the generation of H_2S.

Oxygen Depletion in Rivers





Monitoring Through

- Dissolved Oxygen Level in Water
- Biochemical Oxidation Demand
- Chemical Oxidation Demand
- Total Carbon Content

Solid Matter

- Measured in terms of;
  - Suspended solids (settleable or colloidal)
  - Dissolved Solids
  - Total Solids

Suspended Solids

- Sources; Domestic WW, Storm Water and Industrial WW
- Environmental Problems;
  - Reduction in penetration of light,
  - Settle to bottom covering spawning grounds, reduce DO
  - Reduction in stream bed, increased flooding risk
  - Visible pollution

Important Contaminants

Inorganic salts

- Sources; Industrial WW
- Environmental Problems;
  - Creation of hard waters, deposition of scale
  - Nitrogen and Phosphorous induce **eutrophication**
  - Acidic salts create Corrosion, Reduction of aquatic life and Soil Stalinization

Eutrophication

- This is a process where water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae and nuisance weed plants).
- This enhanced plant growth, often called an algal bloom, reduces sunlight penetration causing lower level algae to die.
- This dead algae settle to the bottom and its decomposition will cause dissolved oxygen levels to go down. This is unsuitable for other aquatic life and can cause them to die
- Further floating algae settle at water body banks due to wind causing weed growth. This reduces the capacity with the ultimatum being the disappearance of the water body.
- Main reason for this process is the addition of excessive amounts of nutrients – Nitrogen and Phosporous
- Sources: agricultural runoff, deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; WW discharges

Important Contaminants

Floating Solids and Liquids

- Sources; Domestic and Industrial WW
- Environmental Problems;
  - Aesthetic effect
  - Interference with natural aeration
  - Destruction of shoreline vegetation and consequent erosion
  - Causes nuisance in water treatment

Color

- Sources; Industrial WW
- Environmental Problems;
  - Visible pollution, reduce transmission of light
  - Difficulty to eliminate

Important Contaminants

Pathogenic Organisms

Transmission of communicable diseases

- cholera, typhoid, hepatitis,
- dysentery,
- worms etc.

Anticipated Environmental Impacts

Suspended Solids (SS) – Can lead to the development of sludge deposits creating anaerobic zones, reduce sunlight penetration, aesthetic problems

Biodegradable organics (BOD or COD) – biological stabilization can lead deplete oxygen in water bodies leading to septic conditions

Pathogens – Transmission of communicable diseases such as cholera, typhoid, hepatitis, dysentery, worms etc.

Nutrients (N,P) – lead to the excessive growth of aquatic plants such as algae leading to accelerate Eutrophication, pollute groundwater

Priority Pollutants – organic or inorganic compounds that may lead to suspected health impacts

Heavy Metals – can cause toxic conditions due to bio accumulation

Dissolved inorganic – cause harness, scaling, increase soil salinization

Estimating Design Flow-rates

- In the field accurate measurement of actual wastewater flow-rates is almost impossible.
- In general WW flow rates are determined or estimated with the available water use data or through past records of similar situations.
- Among the methods, most accurate can be the use of actual municipal water use data.
- Municipal water use can be divided as;
  - Domestic water use including commercial and institutional use
  - Industrial water use
  - Public water use and
  - Unaccounted water use

Wastewater Flow-data

- This is the determination of the quantity or volume of wastewater generated in terms of flow-rates.
- In general WW flow rates are expressed as the total amount of wastewater generated in a day.
- This volume need to be treated everyday.
- In an area major components of wastewater flows include;
  - Domestic wastewater; wastewater discharged from residences, commercial, institutional and similar facilities
  - Industrial wastewater; wastewater predominantly comes from industrial activities
  - Infiltration inflow; water that enters the sewer system through leaking
  - Storm water; runoff resulting from rainfall

Forecasting Design rates

Wastewater Flow Variations/ Wastewater Strength Variations

Short-term variations

- Typically wastewater generations tend to follow a diurnal variation.
  - Minimum flow occur during the early morning hours
  - Peak flow generally occurs in the late morning hours in typical residential areas and during mid day in commercial areas
  - Waste load
  - Short-term variations include hourly variations, daily variations, weekly variations and some times monthly variations

Seasonal Variations

- As a result of seasonal weather/climatic patterns
- Seasonal activity pattern (harvesting, festive, holiday, school season etc.)

Industrial Variations

- This is difficult to predict as it is based on the type of industry, type of process, level of activity/production etc.

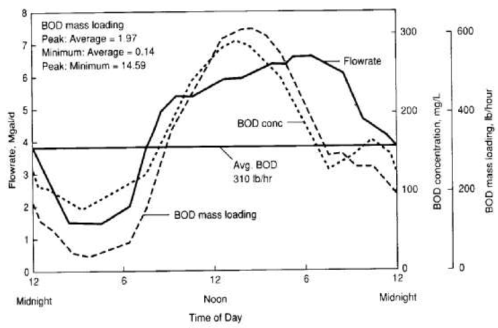


Illustration of diurnal wastewater flow, BOD, and mass-loading variability. *Note*: Mgal/d × 0.043813 = m^3/s.

Important Design Flow rates

- Maximum daily flow/peak flow; The maximum flowrate that occurs over a 24 hour period based on annual operating data. Usage; hydraulic retention time of primary unit operations

  Typical peak factor – 1.5 to 3.0 X Daily Average Flow
- Average daily flow; The average flowrate occurring over a 24hour period based on annual flowrate data. Usage; Sixing treatment units, pump designs, chemical and sludge volume estimations
- Minimum daily flow; The minimum flowrate that occurs over a 24 hour period based on annual operating data. Usage; sizing conveyance pipes, channels

  Typical peak factor – 0.1 to 0.4 X Daily Average Flow
- Peak hourly flow; The peak hourly flowrate that occurs over a 24 hour period based on annual operating data. Usage; design of collection system. Typical factor – 2.5 to 4.0 X Average hourly Flow
- Minimum hourly flow; The minimum hourly flowrate that occurs over a 24 hour period based on annual operating data. Usage; design of collection system. Typical factor – 0.1 to 0.4 X Average hourly Flow

Wastewater Treatment

Objective:

To manage water discharges from homes, businesses, and industries to reduce the threat to the environment

- Prevent/reduce spread of disease
- Prevent/reduce environmental pollution
- To recover valubles

Methods:

- On-site systems (De-centralized)
- Offsite systems (centralized)

Treatment Requirement

- It is mandatory by law today that wastewater need to be collected and treated prior to discharge/disposal
- Treatment is for the removal of harmful particles
- Prescribed treatment requirements for wastewaters for discharged to open environment are published by pollution control authorities -
- Required Standards of treatment may vary from source to source but are generally becoming more stringent
- Final discharge of wastewater will be either into a water body or onto a land

Domestic Wastewater Treatment

Wastewater generation;

- At Cooking, Washing, Bathing, Gardening, Toilets etc.

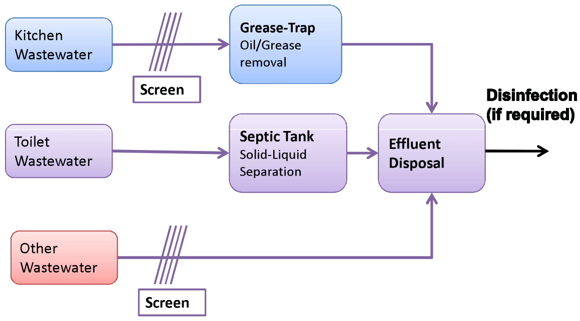
Collection;

- Usually most places in Sri Lanka wastes are collected separate as toilet wastewater and other wastewater

Conveyance and Treatment;

- Collected through a house collection system and
- On-site treatment or
- Collected through the house plumbing and conveyed to Off-site treatment through a Centralized Sewer Network
  - ❖Combined System
  - ❖Separate System

A typical onsite WW disposal system



On- Site Disposal

Commonly via a Septic Tank System

- This is a wastewater disposal system specially designed to accommodate domestic wastewater
- In Sri Lanka mostly toilet waste only is treated with a ST

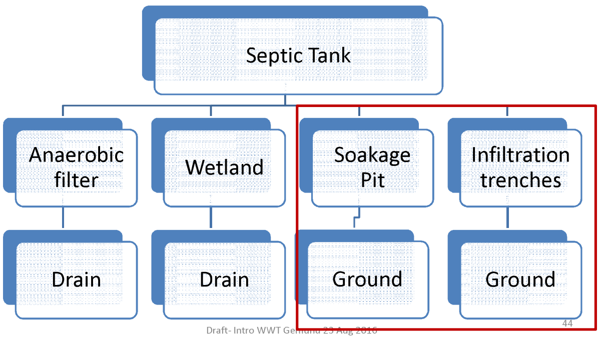
Components of a septic tank system

- Septic Tank
- Distribution system
- Septic tank effluent disposal system

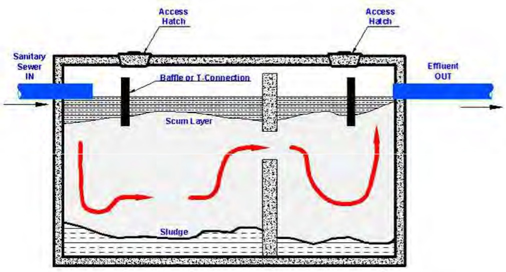
Septic Tank

- Common understanding among many is that a septic tank alone is adequate to dispose sewage safely
- But, a septic tank is only a solid-liquid separation unit used to separate solid fraction in wastewater
- It make the liquid part of waste flow to pass though it.
- This septic tank effluent still is highly polluted
- For treating this ST effluent, a facility such as a soak-away system or any other appropriate system is used.
- Soaking though most economical option is not possible everywhere, specially when the GW table is shallow or soil has poor soaking conditions etc

Common alternative options available for Septic Tank treatment systems



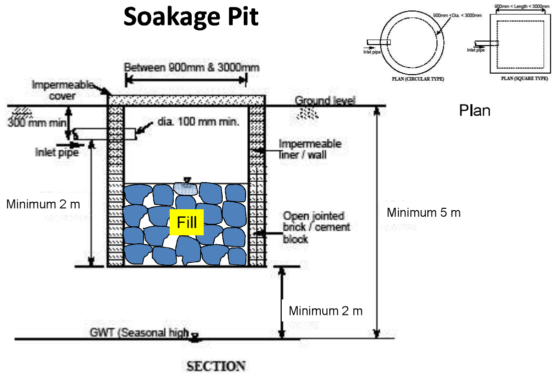
Working of a Septic Tank



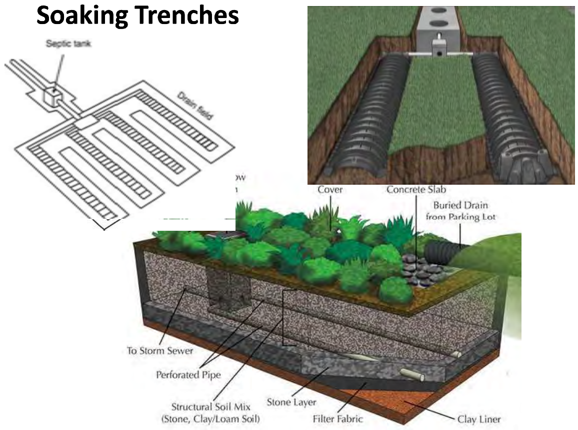
Main Function – Solid Liquid Separation

Additional functions – Anaerobic digestion

Soaking Systems
Soakage Pit



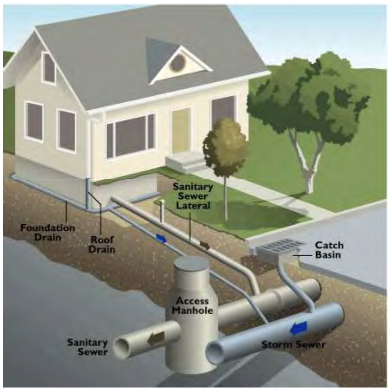
Soaking Trenches



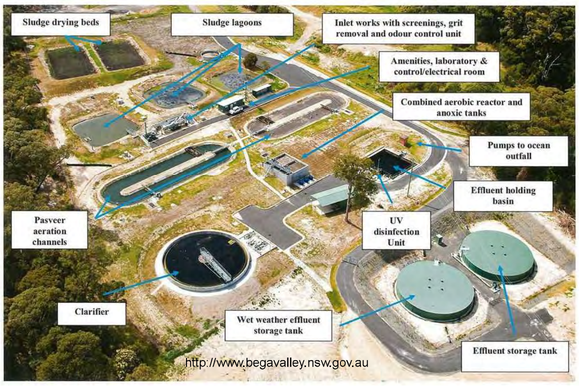
Offsite Treatment

- Commonly made via a Centralized Wastewater Treatment Facility
  - Wastewater is collected from individual units via a sewer network
  - Brought to a centralized location and
  - Treated together
- Treatment Stages
  - Pre or Preliminary treatment (optional)
  - Primary treatment
  - Secondary treatment
  - Sludge (bio-solids) disposal

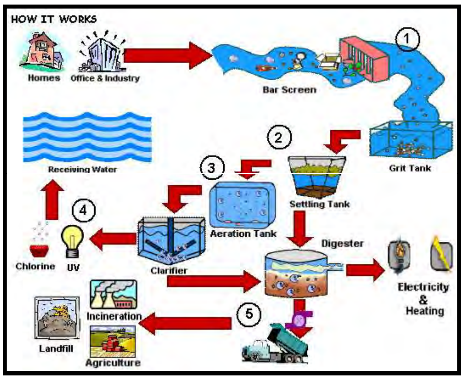
Public sewer



Layout of a typical Biological treatment plant

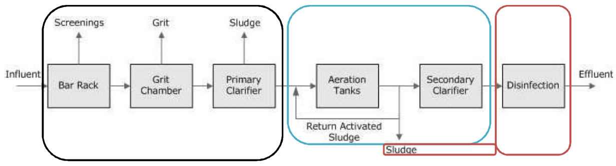


A Typical Wastewater Treatment System



1. Pre
2. Primary
3. Secondary
4. Tertiary
5. Sludge

Wastewater Treatment Chain



Typical Activated Sludge Treatment Process

PRIMARY

- In the Bar Rack coarse solids such as sticks, rags, and other debris in untreated wastewater are removed by interception. By use of fine screening even floatable matter and algae are removed.
- In the Grit Chamber grit consisting of sand, gravel, cinders, or other heavy solid materials is removed by settlement. Grit particles have high subsiding velocities with specific gravities substantially greater than those of the organic solids.

Wastewater Treatment Chain

- The Primary Clarifier is a basin where water is retained for a certain time period allowing the heavier organic solids to settle to the bottom. Efficiently designed and operated primary sedimentation tanks should remove from 50 to 70 percent of the suspended solids and 25 to 40 percent of the BOD.

SECONDARY

- Effluent wastewater from primary clarifier is mixed with the activated sludge in the Aeration Tank. The aeration tank contents the mixed liquor is well aerated to stimulated the growth of bacteria. Here soluble organic matter and some nutrients removed.
- As bacteria deplete the substrate (soluble organic matter), flocculation takes place. The soluble substrate becomes a solid biomass. These flocks of biomass will be allowed to sediment in the Secondary Clarifier.

TERTIARY

- At the end of the process the effluent water is treated to Disinfect it to make it free of disease-causing organisms.

Primary Treatment

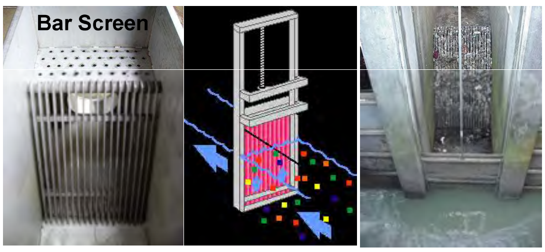
- removes large objects, non-degradable and suspended materials
- protects pumps and equipment from damage
- bar screen and grit chamber
- Reduce loading to secondary treatment

Screening

- Catches large objects that have gotten into sewer system such as rocks, branches, leaves, paper, plastics, rags, etc.
- Unless removed they cause blockages in pipes, pumps, damage pumps, valves tec. and interfere with aeration, aesthetic problems etc.
- Depending on shape/size screens are grouped as;
  - Bar racks: units with parallel bars : bar spacing >50mm known as coarse, between 25 to 50 mm medium and less than 25 mm fine bar racks
  - Screens Coarse (25 mm & above), Medium (25 to 10mm), Fine (0.11 to 10mm), Micro screens (less than .01 mm)

Design Consideration

- Coarse and medium screenings are usually bar racks
- Fine screens are of disk or drum type



Disposal of screenings: Land burial, Incineration, composting or Comminuting

Slotted screens

Grit Removal

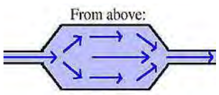
- Wastewater can contain a relatively large amount of inorganic heavy solids such as sand, gravel, clay, egg shells, coffee grounds, metal filings, seeds and other similar materials which are commonly called as grit.
- Their presence in a wastewater mainly depends upon whether the collecting sewer system is of the sanitary or combined type.
- Grit will;
  - damage pumps by abrasion and
  - cause serious operation difficulties in sedimentation tanks and sludge digesters because of their inert nature
- Commonly they are removed at a grit chambers.
- Grit chambers are usually located ahead of pumps just after screening

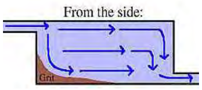
Grit Removal

- There are several devices or processes used for grit removal.
- All of them are based on the fact that grit is heavier than the organic solids that should be kept in suspension for subsequent treatment.
- Grit removal processes use gravity/velocity, aeration or centrifugal force to separate the solids from the wastewater.

a) Velocity or Gravity Controlled Grit Removal

- This method uses a channel or tank to reduce the velocity or speed of the wastewater to approximately 0.3 ms^{-1}
- As long as the velocity is controlled in the range of 0.25 to 0.35ms^{-1}, the grit removal process will remain effective.

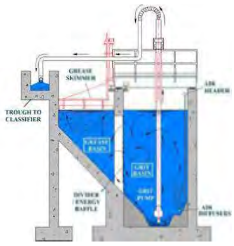




Velocity Controlled Grit Chamber

b) Aerated Systems

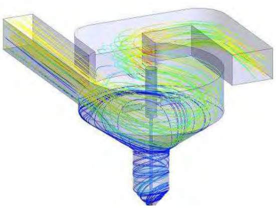
- Aerated grit removal systems use aeration to keep the lighter organic solids in suspension while allowing the heavier grit particles to settle out.



Aerated Grit Chamber

c) Cyclone type Grit Chamber

- The cyclone type Grit Chamber uses a rapid spinning motion to separate the heavy inorganic solids or grit from the light organic solids
- Then they are discharged directly to a storage container.
- Inlet pressure is a critical control factor for the cyclone grit removal process.

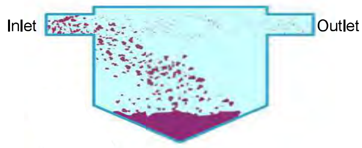


Cyclone type Grit Chamber

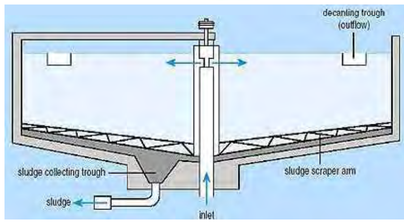
Primary Sedimentation

- This is the process of separation of suspended particles heavier than water by gravitational settling .
- Process is taken place in a sedimentation tank
- Wastewater flow is slowed down and suspended solids settle to the bottom by gravity.
- This allow sufficient time for the particles to settle to the tank bottom.
- Settle sludge need continuous withdrawal, and further processing.
- Typical sedimentation tanks can operate in three modes;
  - a) Circular, radial-flow tank;
  - b) Hopper-bottomed, upward flow tank
  - c) Rectangular horizontal flow tank;

Sedimentation Tanks

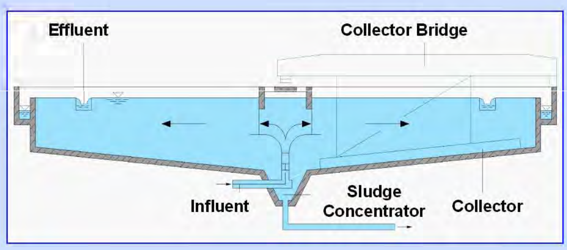


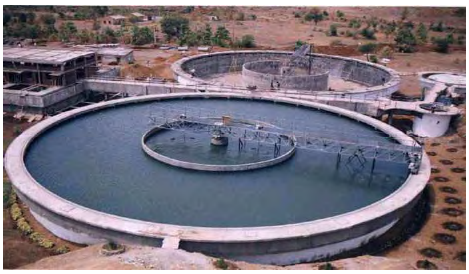
Process of Sedimentation



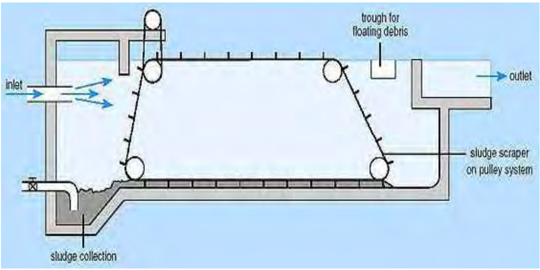
Circular Radial-Flow Tank

Circular Sedimentation Tank



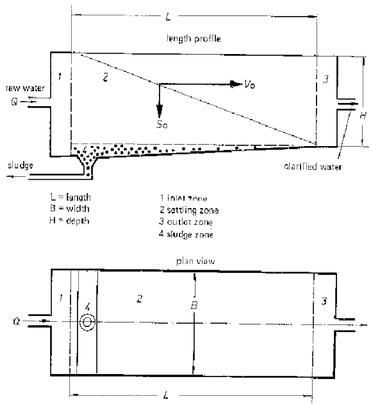


Sedimentation Tanks

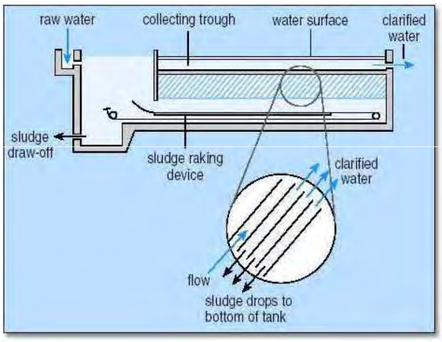


Rectangular Horizontal Flow Tank

Rectangular Shape ST



Plate/Tube settlers



Secondary Treatment

- Secondary treatment is mostly a biological process
- Primary treatment remove large floating matters, grit and suspended solids in wastewater.
- Colloids and dissolved matter, mainly organic still remain in wastewater.
- Their removal requires conversion of them into friendly products or solids which can be removed by gravity.
- Fortunately, some microorganisms naturally present in WW, can take colloids and dissolved biodegradable organic matter as their food
- They use organic matter for their growth and re-production.

Removal Mechanism

- Removal of colloidal suspension is achieved by the principal of physicochemical adsorption where, enmeshment of colloidal matter on the biological floc occur.
- Reduction of soluble organic solids (BOD or COD) is achieved by microbial bio-sorption and their further degradation and stabilization by microbes.
- Microbes convert (oxidize) them into simpler end products such as H_2O, CO_2 etc. releasing energy required for their daily activities and for the synthesis of new cells.
- Synthesized new cells are commonly known as biomass.
- As these produced biomass has specific gravities slightly higher than that of water, they can be removed by settling them in sedimentation tanks (Secondary Clarifiers).

Objectives of Biological Treatment

1. To coagulate and remove both organic and inorganic non settling colloidal particles that do not get removed in primary treatment.
2. To stabilize the dissolved organic matter that is present in wastewater.

Efficiency of a biological treatment unit depends on;

- Developing a suitable mixed culture of microorganisms
- Maintaining appropriate conditions (correct proportions of waste-matter, microorganisms, oxygen, nutrients, etc.) for the microbes to work
- Have a unit to remove the excess biomass (sludge) produced

Classification of Bio-Treatment Processes

Based on operational conditions necessary;

- Aerobic Process:
  - This process essentially requires the presence of molecular oxygen for the metabolic activity of the microorganisms involved.
- Anaerobic Process:
  - This process operate in the absence of molecular oxygen.
- Facultative Process:
  - This process can operate in both conditions in the presence or absence of molecular oxygen..
- Anoxic Process:
  - In this process the microbes convert the nitrate nitrogen into nitrogen gas in the absence of oxygen.

Classification of Bio -Treatment Processes

Based on microbial maintenance;

- Suspended Growth Processes
  - Here microbes involved in waste degradation is maintained as a suspension with appropriate mixing. Eg. Activated sludge, oxidation Ditch, Aerated Lagoon, SBR etc.
- Attached Growth Processes:
  - Here microbes involved in waste degradation is made to grow attached to an inert packing material or media such as rock, plastics etc. Eg. Trickling Filter, Anaerobic Filter, RBC.
- Lagoon system
  - Here microbes involved in waste degradation is made to grow suspended but in much dispersed conditions; Eg. Stabilization Ponds, Aerated Lagoons etc.

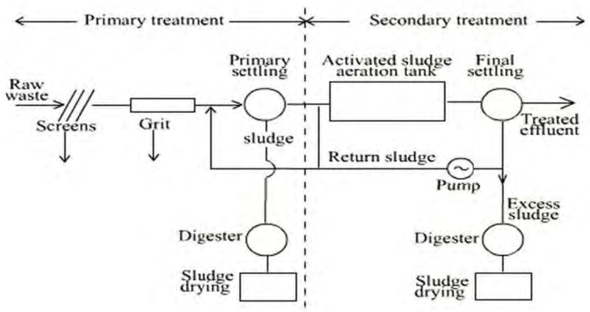
TYPICAL SSYPENDED GROWTH SYSTEM

Activated Sludge System

(Aerobic Suspended Growth System)

- Basically this is an aerobic suspended growth type biological process that uses an active mass of microbes kept in suspension in a reactor (vessel) to decompose and stabilize the soluble and particulate organic matter present in a wastewater.
- Essential elements of an activated sludge system include;
  - A reactor tank with a mixing mechanism to keep the microorganisms and waste in suspension for oxidation and stabilization
  - A setting tank to separate the microorganisms
  - Re-cycle system to feed the required microorganisms back into the reactor from the setting tank
  - An aeration system to supply oxygen requirement for the system
  - System to remove excess biomass

Flow sheet of an activated sludge system



Activated sludge plant operation involves:
1. wastewater aeration in the presence of a microbial suspension,
2. solid-liquid separation following aeration,
3. discharge of clarified effluent,
4. wasting of excess biomass, and
5. return of remaining biomass to the aeration tank.

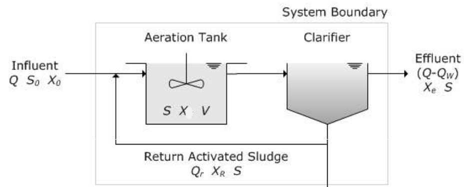
Removal Mechanism

- **<u>Removal of colloidal matter</u> - by physicochemical adsorption onto active biomass and by enmeshment in biological flocs.**
- **<u>Removal of soluble organic matter</u> - by bio-sorption and then subsequent decomposition and stabilization.**

<u>Main sub stages involved in this process include;</u>

1. Dissolution of oxygen into wastewater by aeration
2. Turbulent mixing of reactor wastewater and biomass (return activated sludge)
3. Adsorption of organic matter (substrate) by active biomass
4. Molecular diffusion of DO and soluble substrate/nutrients into activated biomass
5. Basic metabolism of microorganisms (cell synthesis)
6. Bio flocculation resulting from the production of cellular polymeric substances during the oxidation
7. Auto oxidation of cells (endogenous respiration)
8. Release of CO_2 and water from active cell mass

Schematic diagram of a completely mixed activated sludge system



Where:
Q = flowra
Q_W = waste
Q_r = flowra
V = volume of aeration tank [m^3]
S_0 = influent soluble substrate concentration [BOD g/m^3]
S = effluent soluble substrate concentration [BOD g/m^3]
X_0 = concentration of biomass in influent [g VSS/m^3]
X_R = concentration of biomass in return line from clarifier [g VSS/m^3]
X_r = concentration of biomass in sludge drain [g VSS/m^3]
X_e = concentration of biomass in effluent [g VSS/m^3]

Aeration

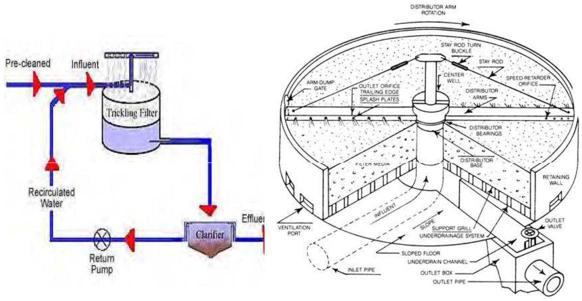
DEFFUCER TYPE

TYPICAL ATTACHED GROWTH SYSTEM

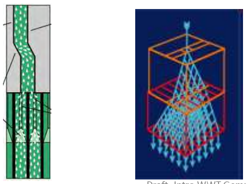
Trickling Filters

(Attach Growth System)

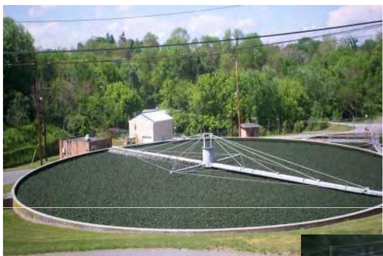
- Fixed Film Systems
  - Fixed media filters use microorganisms attached to a medium (rocks, plastic, metal, etc.)
  - The microorganisms stay in place and do not need to be cycled. Instead, wastewater is circulated past the fixed microorganisms.
  - This mimics the treatment method used some streams where microorganisms produce a slick coating on rocks and pebbles. This coating of microorganisms is able to trap and consume BOD and ammonia in the water.
  - Ex: Trickling filters, rotating biological contactors



Trickling Filter



Plastic and Synthetic Media



Trickling Filter Process

- Wastewater distributed over the top area of the filter, wastewater trickle down the filter wetting the media
- Filter packed with rock, slag, plastics, synthetic materials etc.
- In few days time a layer of microorganisms (slime layer/bio-film layer) is formed over the media surface
- Air circulation through the void space by either natural draft (temp. difference) or blowers provide oxygen
- WW trickles down the filter & organic matter transferred to bio-film.
- Over time increasing thickness of bio-film reduces penetration of oxygen to bottom layer
- Microorganisms near media face enters endogenous respiration stage. Bio-film is detach media (sloughing)
- Sloughed bio-film needs separation by a settling tank

Filter Classification

- Low rate or High Rate

Design Feature	Low rate	High rate
1. Hydraulic Loading ($m^3/m^2.d$)	1-4	10-40
Organic Loading (kg BOD/m^3.d)	0.08~0.032	0.32~1.0
Depth (m)	1.8~3.0	0.9~2,5
Recycle Ratio	0	0.5~8.0

Process Design

- Rock Media -
  - NRC (National Research Council of USA) equation used
  - Rankins method too popular
- Plastic Media

Tertiary Treatment

- This is also know as the polishing stage
- Removal of;
  - Nutrients
  - Pathogens
  - Inorganic substances if any is done.
- Examples
  - Biological nutrient removal (to control eutrophication)
  - Activated carbon adsorption
  - membrane filtration
  - Gas stripping
  - Disinfection

Wastewater Management

UNIVERSITY OF JAFFNA

Wastewater, a global problem with differing regional issues

(Image of data analysis of WHO)

Wastewater

https://www.flickr.com/photos/oddsock/9756106243

- Water that is very harmful to the environment ,that is called wastewater
- Wastewater can be contaminated with a myriad of different components : pathogens, organic compounds, synthetic chemicals, nutrients, organic matter and heavy metals.

Domestic wastewater

Sources : Kitchen , Bath rooms and Toilet

Types : Grey wastewater

Water coming after using it from Kitchen and bathroom

Black wastewater

The waste water generating from the toilets called black water will contain urine and faecal sludge.

commons.wikimedia.org

Sources

Domestic Wastewater

Industrial activities

Commercial activities

agricultural activities

surface runoff or storm water

infiltration.

Collection and Transport of wastewater

Sewerage system

The system of collecting wastewater from each waster water sources and transport to waste water treatment plant.

Two methods of conveyance:

- The separate sewerage system
  Collecting and convey wastewater and storm water separate pipe lines.
- The combined sewerage system
  wastewater and storm water both are conveying in same pipe lines.

Collection and Transport of wastewater

Separate Sewer system

Combined sewer system

http://winnipeg.ca/waterandwaste

Separate sewerage system

Advantages	Disadvantages
Grey and black water can manage separately from Surface run off	High capital costs, more expensive than combined sewer system
Limited risk of sewage flow	Requires skilled engineers and operators
Can consider use of storm water	Problems associated with blockages and breakdown of pumping equipment
Moderate operation costs	Adequate treatment and/or disposal required for a large point source discharge

Collection and Transport of wastewater

Combined sewerage system

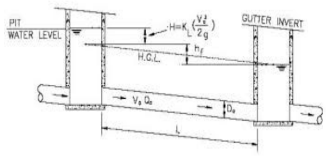
- pipes that convey domestic sewage, industrial wastewater and storm water runoff.
- Environmentally friendly and comfortable for user

Separate sewerage system

- Separate sewer systems are designed to convey wastewater and storm water in separate pipes
- Sanitary sewer systems collect and transport wastewater
- Storm sewer systems collect and transport storm water runoff

Sewerage system – Design Aspects

Gravity sewerage conveyance system



http://www.sewerhistory.org/

Combined sewerage system

Advantages	Disadvantages
Do not require on-site pre-treatment or storage of the wastewater	The initial cost is high
Suitable for urban areas	Maintenance costs are high consists mainly inspection, unblocking and repair
Storm water and wastewater can be managed at the same time	Extension of the system can be difficult and costly
Convenience method	Recycling of nutrients and energy becomes difficult
	Need skill personals

Sewerage system – Design Aspects

Design capacity and design flow

Sewer capacities shall be designed for the estimated ultimate tributary population

The capability of downstream sewers to accept future flow made tributary to the collection system shall be evaluated by the engineer.

Design parameters

1. Size of the pipe
2. Depth of the pipe line
3. Slope for gravity lines

Sewerage system – Design Aspects

Velocity calculation for gravity sewers

$$V = \frac{1}{n} Rh^{\frac{2}{3}} S^{\frac{1}{2}}$$

V = velocity

n = coefficient of roughness (Manning), n = 0.013

S = slope of energy grade line

R_H = hydraulic radius

Minimize Solids Deposition

High Velocity Protection

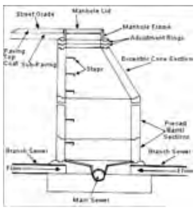
Steep Slope Protection

Sewerage system – Design Aspects

Design of Pump Station

Sewerage system – Design Aspects

Manholes



- ✓ Manholes shall be installed: at the end of each line, at all changes in grade, size, or alignment, at all intersections, and at distances required in the specifications.
- ✓ Drop manholes should be constructed with an outside drop connection. Inside drop connections (when necessary) shall be secured to the interior wall of the manhole and access shall be provided for cleaning.

http://www.msdlouky.org/

Sewerage system – Design Aspects

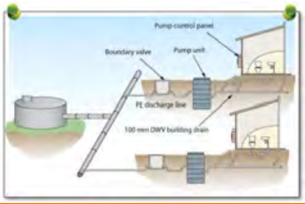
Introduction to EPA-NET software

Sewerage system – Design Aspects

Pressure sewerage conveyance system

This system should have pump in every houses

Expensive



www.dlsweb.rmit.edu.au

Wastewater Management

Wastewater management should consider the sustainable management of wastewater from source to re-entry into the environment.

Waste water management approaches can be decided by considering on, whether the area is urban or rural,

the size and density of the population,

level of economic development,

technical capacity and system of governance in place

Waste water Management

- Reuse

    Relatively clean water such as Bathing and Kitchen waste water can reuse without treatment for Irrigation and Flushing toilets.

- Recycle

    Wastewater can be reuse for non-drinking purposes after treatment (onsite or off site)

Closed loop treatment system – Wastewater should collect, treat and reuse on-site

Wastewater reclamation – Treated wastewater use for different purposes

Centralized treatment system

Conventional gravity sewers

One centralized wastewater treatment facility for certain area

Effluent discharge directly to surface water

High capital cost for construction

Transfers water away from source basin, so leakage problems etc.

Long, disruptive construction

Skilled persons need to design and maintenance

Potential for catastrophic failure

Waste water Management

- Treat and Discharge

    Wastewater can be collect ,treat and discharge into the any natural water body without harmful to the environment.

- ✓ Centralized wastewater treatment facility

    collect wastewater from many users for treatment at one or few sites

- ✓ Decentralized wastewater treatment facility

    Generally this is on-site systems, collecting and treating wastewater from individual users or small clusters of users at the neighborhood or small community level.

Decentralized treatment system

Onsite or cluster systems

Multiple treatment and soil dispersal or reuse facilities

Low-cost, shallow sewer systems for clusters

Lower capital costs

Keeps water close

Short, less-disruptive construction

Basic operation skills required

Failure consequences felt in smaller area

Centralized and Decentralized system

http://webapps.icma.org/

Waste water as a Resource

Reuse of wastewater depends on the individual household waste management practices such as separation of urine and faecal matters.

Application of wastewater as a resource,

drought-resistant source of water (especially for agriculture or industry)

- source of nutrients for agriculture
- soil conditioner
- source of energy/heat.

Challenges

Problems related to wastewater

Wastewater as a Resource

Acknowledgement

"Minimum Design Criteria for the permitting of Gravity Sewers " Adopted by the Division of Water Quality on February 12, 1996,Updated to 15A NCAC 2T Regulations on March 2008 .

"Type of Sewer Systems ",Solomon Seyoum

" Waste water Management" , PLTW

"Wastewater Management A UN-Water Analytical Brief"

Water Harmony Erasmus+

Micropollutants

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WATER HARMONY ERASMUS +

Water Harmony Erasmus+

Learning objective

- What are micropollutants?
- Knowledge about the processes of biological degradation processes
- Knowledge about biological processes in wastewater treatment
- Context of various degradation processes
- Knowledge about dimension

Water Harmony Erasmus+

Sources

- Substances, which can be found in water bodies, drinking water and wastewater in small concentrations
  range: 10^{-9} g/l (ng/l) - 10^{-6} g/l (µg/l)
- Negative characteristics in comparison to essential vital other substances with low concentration
- Mainly organic substances with anthropogenic origin which have harmful characteristics or its potential

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Water Harmony Erasmus+

Example for micropollutants

- Pharmaceuticals
- X-Ray contrast medium
- Endocrine disruptors
- Synthetic Sweetener
- Aromatic substancese
- Pesticides
- Corrosion
- Flame retardants
- Corrosion inhibitors
- Perfluoric compounds
- Microplastic
- Plasticiser
- Microplastic

Water Harmony Erasmus+

Example for micropollutants (I)

Group	Substance	Application
Pharmaceuticals	Ibuprofen	Pain killer
	Diclofenac	
	Ketoprofen	
	Carbamazepine	Antiepileptics
	Diazepam	
	Atenolol	Betablocker
	Bisoprolol, Metroprolol	
	Bezafibrate	Antilipemics
	Gemfibrozil	
	Ciproflaxicin	Antibiotikum
	Clarithomycin	
	Sulfamethoxanol	

Water Harmony Erasmus+

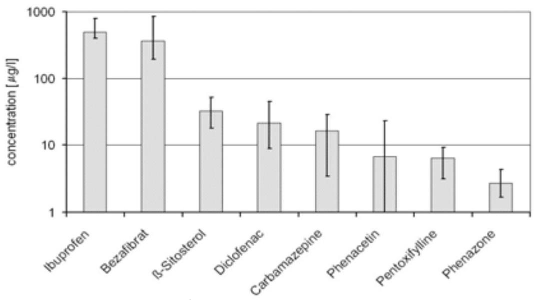
Example for micropollutants (II)

Group	Substance	Application
Estrogen	17-alpha-Ethinylestradiol	Contraceptive
	17-beta-Estradiol	
X-Ray contrast medium	Iomeprol, Iopromid	
Pesticides	Mecoprop	
	Terbutryn	
Corrosion inhibitors	TBT	
Flame retardants	TCEP	Plasticiser also
Synthetic Sweetener	Acesulfam	Sugar substitute
Endocrine disruptors	TBR	Antioxidant,
	Nonylphenol	Plasticiser, flame retardant
	Tributyltin	Anti fouling paint
Perfluoric detergents		Textile additives
Microplastic		Personal care products

Impacts of micropollutants

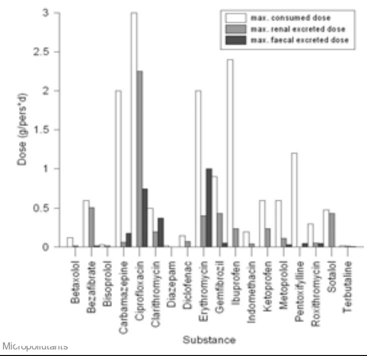
- Micropollutants are either slow or not biodegrdable
- Micropollutants are often persistant
- Metabolites and their effects are often unknown or known partially
- Accumulation in the environment and effects on plants, animals and human beings:
  - Inhibition of growth
  - Infertility
  - Metabolic disorder
  - Behaviour change
  - Weakening of immune system
  - Mutation, abnormirnity
  - Death

Pharmaceuticals in urine



Average and Min/Max conc. of PhaR in Urin (6 samples)

Pharmaceuticals in human excreta

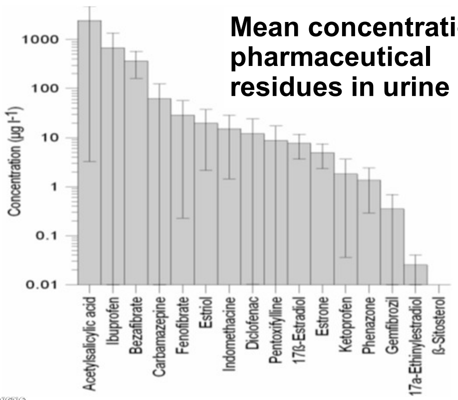


Pharmaceutical residues mainly excreted via urine.

Effect of endocrine disruptors

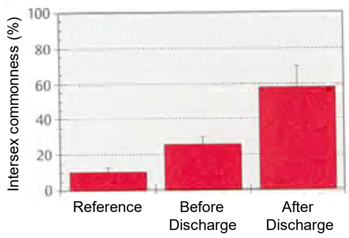
Imposex (masculinisation) of the Nordic Violet Snail

Mean concentrations of pharmaceutical residues in urine



Effect of wastewater discharge into English rivers on Common Roach (Rutilus rutilus)

Intersex (Feminisation) of males



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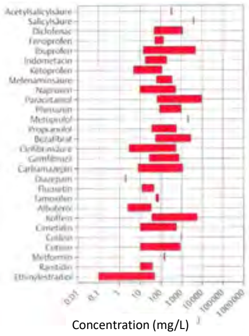
Concentration range of pharmaceuticals in open water bodies



(Fent)

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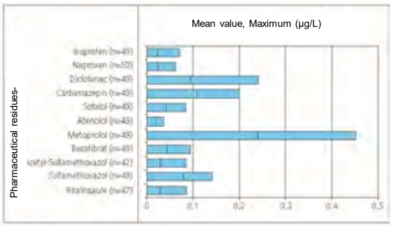
Prevalence of pharmaceuticals in the Ruhr river (Germany) 2013



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Impacts of micropollutants

- Micropollutants are either slow or not biodegrdable
- Micropollutants are often persistant
- Metabolites and their effects are often unknown
- Accumulation in the environment and effects on plants, animals and human beings:
  - Inhibition of growth
  - Infertility
  - Metabolic disorder
  - Behaviour change
  - Weakening of immune system
  - Mutation, abnorminity
  - Death

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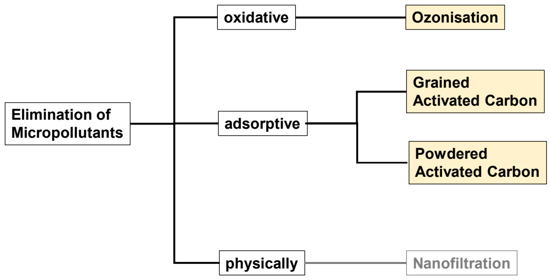
Impacts of micropollutants



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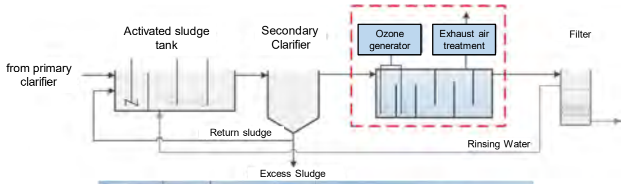
Ozonisation



(KomZ NRW)

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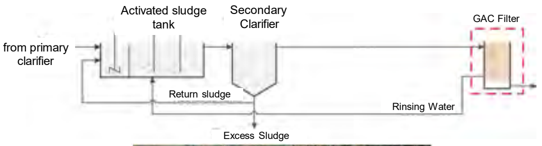
Ozonisation

- Components of the plant:
  ozone generator
  oxidation tank
  treatment of exhaust air
  process control
- Ozone is produced from liquid oxygen
- Ozone dosis: 0.6 – 0.9 g O_3/g DOC
- Retention time: 10 – 15 minutes
- Energy demand 9 – 10 kWh/kg O_3

Ozonisation

- Micropollutants are oxidised into biodegradable substances
- Nitrification is necessary, otherwise Nitrite will be oxidised to Nitrate
- Suspended solids are hindering the oxidation effectivity
- Formation of Bromate (BrO_3^-) from Bromide (Br^-) is possible
- Disinfection is possible but needs higher concentrations of O_3

GAC Filter



(KomZ NRW)

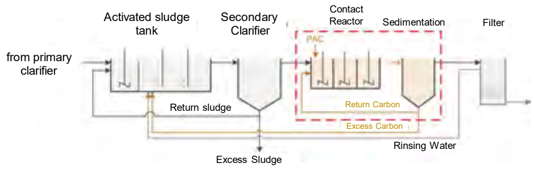
GAC Filter

- Filter with **g**ranulated **a**ctivated **c**arbon
- Suspended solids at inflow < 15 mg/L
- Filter material: activated carbon 0.6 – 2.3 mm
- Contact time: 15 – 30 minutes
  hydraulic loading 5 – 15 m/h
- Operation time: 14,000 bed volumes
  (mean value from operation experience)
- Reactivation of activated carbon is possible
  loss of 10 – 20 % has to be replaced by fresh material

PAC Filter

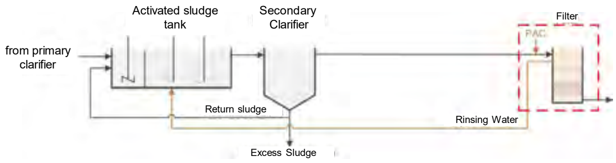
- Dosing of **p**owdered **a**ctivated **c**arbon
- Different applications are possible:
  - post treatment after filtration
  - before filtration
  - simultaneously into the activated sludge system

PAC Post Treatment



(KomZ NRW)

PAC before Filtration



(KomZ NRW)

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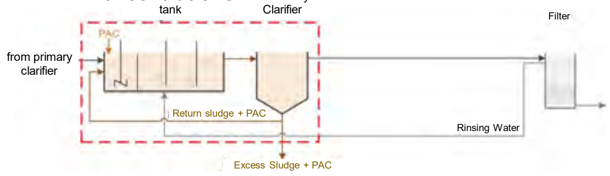
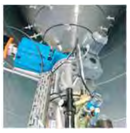
PAC simultaneous application





Dosing of PAC

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Dosing of PAC

- Dosing rate 5 – 20 mg PAC/L
- Particle diameter < 150 µm
- Return of PAC decreases dosing rate due to longer contact times
- Elimination rates of micropollutants > 80 %

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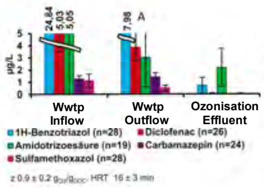
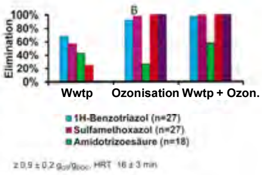
Elimination rates of micropollutants





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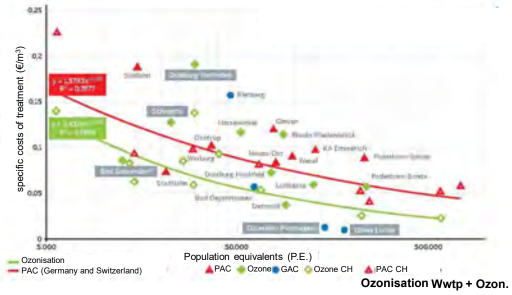
Costs for elimination of micropollutants



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Questions

- Why is the elimination of micropollutants necessary?
- Which treatment is possible for the removal of micropollutants?
- What are disadvantages and obstacles of the elimination of micropollutants?

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- Kompetenzzentrum Mikroschadstoffe NRW
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  Aspects of systems for separate urine collection and treatment - Selected techniques and potential implementation in an urban context
  Hamburger Berichte zur Siedlungswasserwirtschaft, Vol. 79, 2011
- www.koms-bw.de
  Kompetenzentrum Spurenstoffe Baden-Württemberg

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Wastewater transport and urban drainage

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Outline

- Introduction
- Design aspects
- Infiltration and leakages
- Rehabilitation
- Storm water management and floods
- Climate Change impacts
- Sustainable urban drainage systems (SUDS)

- Sewer modelling tool - SWIMM

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Wastewater collection and transport

- From urban centres, wastewater must be collected and transported to WWTPs, which could be tens of km away..

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Typical components of a sewer system

- Pumps
- Pipes (sewers) – combined, storm water, wastewater
- Weirs
- Valves
- Manholes
- Retention tanks
- Overflow discharge
- Surveillance systems (quantity and quality)
- Control systems (pumps and valves)
- Sewer models

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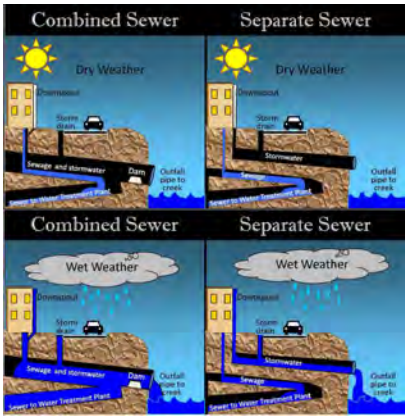

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Statistics about sewers

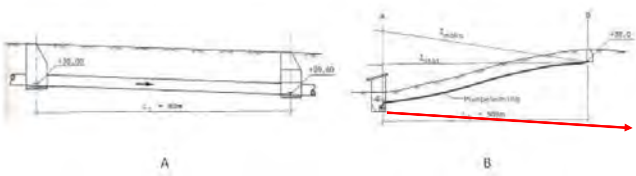
- *Need to supplement with EU++ statistics*

Country	Length of ww pipe system (km)			
	Total	m/ inhab.	Sewers [1]	Storm-water
Denmark	61.500[2]	10,9	38.130	23.370
Sweden	102.000	10,7	66.300	35.700
Finland	52.642	10,0	42.355	10.287
Norway	51.600	10,3	35.900	15.700

[1] Combined and separate [2] 79800 km (incl.stick.)

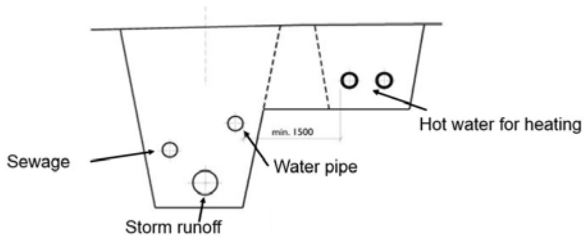
Ødegaard, 2016

A sewer pipe normally uses gravity. If ascending terrain; pump the sewage?

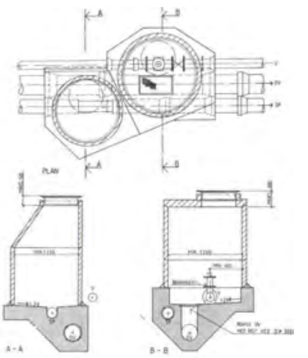


Is it possible to avoid pumping?
Maybe it is possible to dig a deep ditch for a quite small distance, until normal inclination of the terrain is obtained?
An economic calculation will decide.

Typical sewer placement in ground

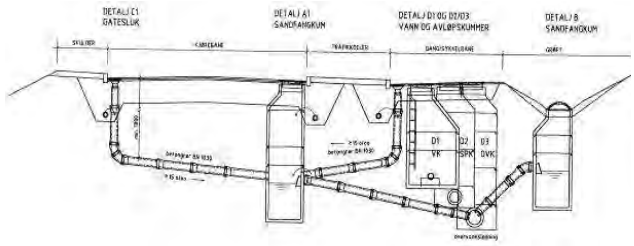


Double manholes for water, storm runoff and sewerage

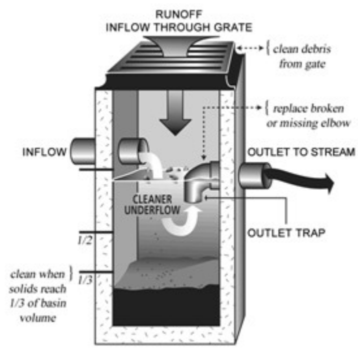


Storage tank for combined sewer overflows

Cross section of a road with pipes and sand catch basin



Catch basin for storm water runoff

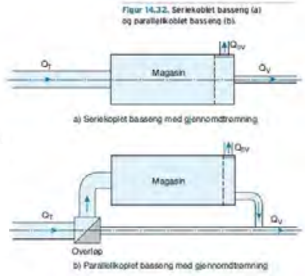


Retention tanks for reducing the storm overflow or high peaks in discharge Used in combined sewerage systems and at combined storm overflows (CSO)

Installed inline with continues throughflow

Combined sewer overflow.

Tank is installed in parallell, and fills only in wet weather



Water flows without retention and with a retention basin

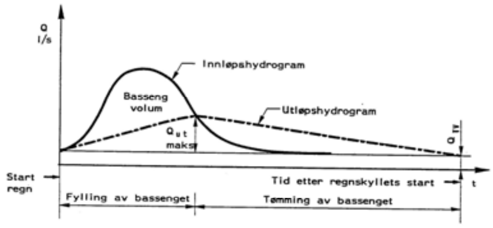


Fig. 7.28. Innløps- og utløpshydrogrammer for et basseng der hele avrenningen fra et regnskyll jevnes ut.

The retention basin are dampening the maximum flow in the system

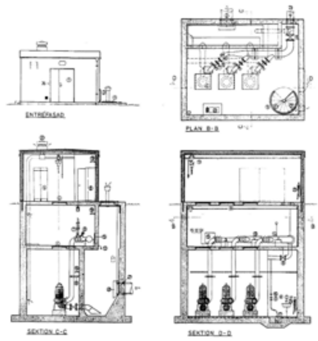
The area between the inflow and outflow curve represent volume

Retention basin (in combined sewerage system) with ”toblerone floor” to get self cleansing conditions during emtying. Water for flushing is added.

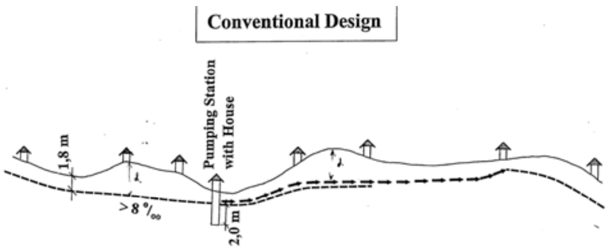
Retention basin under Tokyo

From TIME-magazine April 9, 2007

Pump station for sewage

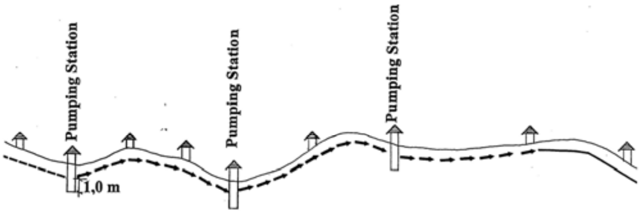


Partly gravity sewer lines with a pump station



Gravity Pipe	Ø >	100 mm
Pressure Pipe	Ø >	80 mm
Self-cleaning water flow	≥	6-7 l/s
Self-cleaning velocity	≥	0,6-0,7 m/s

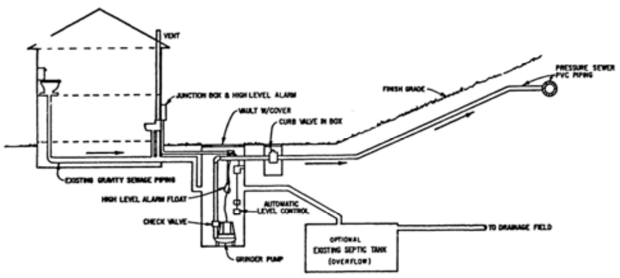
Pressure sewerage system with pumps in every house



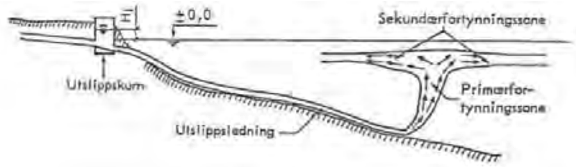
Gravity Pipe	Ø >	100 mm
Pressure Pipe	Ø >	40 mm
Self-cleaning water flow	≥	0,8 l/s
Self-cleaning velocity	≥	0,6-0,7 m/s

Pressure sewerage system

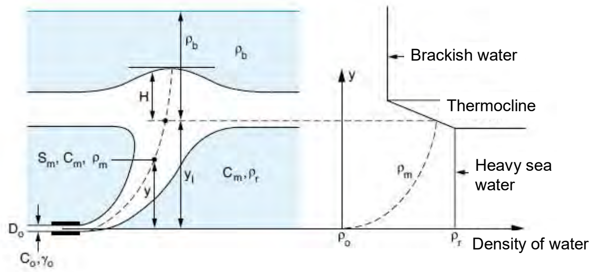
Pressure sewerage system and a pump with a grinder



An outfall for treated sewage with a manhole and pipe



The effluent jet should be located under or in the thermocline



Sewer design in general

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Wastewater from a typical European household

Item	Water use liters/person day
WC	30
Kitchen	30
Laundry of cloths	40
Shower, bathing, etc	50
Sum	150

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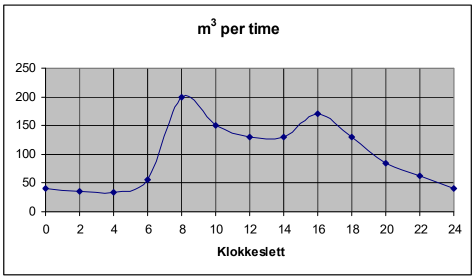
Example of variations of wastewater during a day



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Variation factors f and k

- $f_{max} = Q_{daily\ max} / Q_{daily\ average}$
- $f_{min} = Q_{daily\ min} / Q_{daily\ average}$
- $k_{max} = Q_{hourly\ max} / Q_{hourly\ average}$
- $k_{min} = Q_{hourly\ min} / Q_{hourly\ average}$

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Dimensioning for maximum wastewater

$$Q_{max} = (P \cdot q_{spes} \cdot f_{max} \cdot k_{max} + P \cdot q_{leak})/(24 \cdot 60 \cdot 60) + Q_{ind}$$

Q_{max} = Max dimensioning discharge in liters/sec
P = Number of person units
q_{spes} = Specific wastewater production (l/p day)
Q_{leak} = Specific infitration per person (l/p day)
Q_{ind} = Industry (l/s)
fmax = Daily max factor
kmax = Hourly max factor

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Requirements for sewage pipes

- No 1: High enough capacity to transport Qmax
  Qmax = P · Qspec · Fmax · Kmax + Qinfiltration
- No 2: Avoid clogging of pipes (self cleaning)

  (At least a velocity of 0,7 m/s once each day at peak hour)

  Or else, sediments will build up in the pipes and become clogged.

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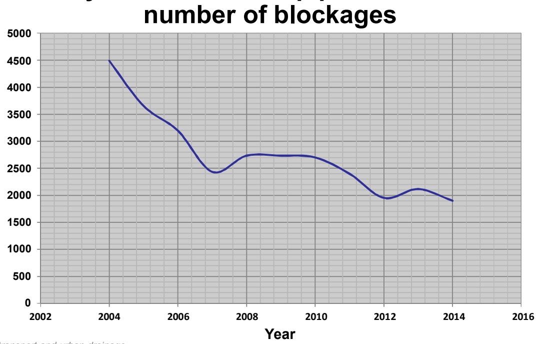
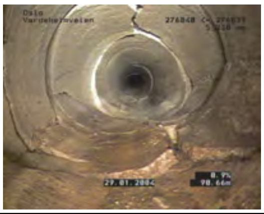
Number of blockages per year (clogging) in sewer pipes in municipalities in Norway. Renewal of old pipes has reduced the number of blockages

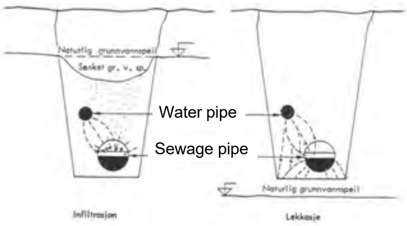


Infiltration and leakages

Leakages and sewer renewal



We assume that ca 50 % of leakages from the drinking water pipes infiltrates into the sewers



Left: ground water table is higher than the pipes are.
Right: ground water table is lower than the pipes are.

Definition of Inflow/Infiltration (I/I)

Infiltration - Water other than sanitary flow that enters a sewer system (including sewer service connections and foundation drains) from the ground, through means which include defective pipes, pipe joints, connections, or manholes. Infiltration does not include, and is distinguished from inflow.

Inflow - Water other than sanitary flow that enters a sewer system (including sewer service connections) from sources which include roof leaders, cellar drains, yard drains, area drains, drains from springs and swampy areas, manhole covers, cross connections between storm sewers and sanitary sewers, catch basins, storm waters, surface runoff, street wash waters, or drainage.

Inflow does not include, and is distinguished from, infiltration. The total amount of inflow is equal to the sum of the delayed inflow and direct inflow.

What is I/I (Inflow and infiltration)?

Source of I/I	Sewer pipe in separatsystem	Combined sewer pipe
Drainage water from buildings	Illegal connection	Planned
Storm runoff from surfaces	Illegal connections	Planned
Groundwater leaking into pipes or manholes	Not planned	Not planned
Leakages of drinking water from water supply systems	Not planned	Not planned

What is the problem with the I/I ?

Type of problem	Sewage pipes in separate systems	Combined sewer pipes
Occupy hydraulic capacity in the pipes	Yes	No usually not
Increased discharge via the CSO	No	Yes
Increased discharge via the emergency outlets in pumping stations	Yes	Yes
Increased load on the hydraulic capacity in the WWTPs	Yes	Yes
Transports pollution out via the effluents in WWTPs	Yes	Yes
Increased costs for O & M in WWTPs and pumps	Yes	Yes

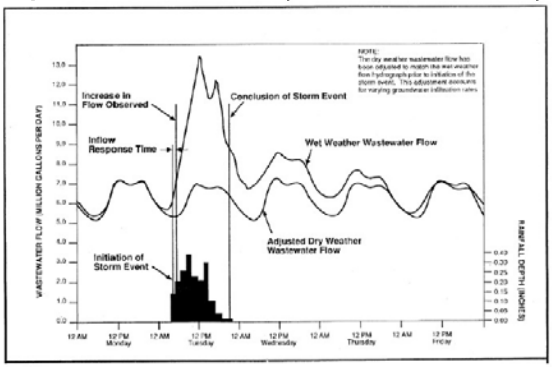
Calculation of % I/I to a WWTP using a simple dilution formula

$$FV = \left(1 - \frac{Q_{ap} c_i}{P_{Pd}}\right) \times 100$$

FV = Amount of I/I to a WWTP as an average over a whole year [%]
P_{Pd} = Production of phosphorous mg (Tot-P) per person and day [mg/pe day]
c_i = consentration of Tot-P in influent to a WWTP during a year [mg/l]
Q_{ap} = Amount of sewage per person and day [l/pe day]

Example: A WWTP has an average 4,5 mg/l Tot-P in the influent, and the city estimates sewage of 150 l/pe day and a phosphorus production of 1,6 g/pe day = 1600 mg/pe day.
The % of I/I during a year will then be 58 %.

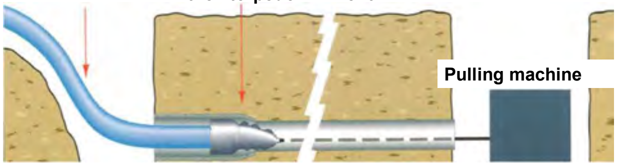
Example of rain derived I/I (Massachusetts 1993)



Infiltration/Inflow to sewer pipes in Oslo

- I/I = 1,5 l/s km of pipes as an average
- 1490 km of sewer pipes in Oslo
- 650 000 persons
- This amounts to ca. 300 l/ p d in I/I
- Real sewage in Oslo = 166 l/ p d
  Total waste water = 300 + 166 = 466 l/p d
- This tallies up to 63 % I/I (of total waste water)

Renewal of an old pipe by pulling a new pipe into the old one



To avoid digging up streets to replace old dilapidated sewers, «No Dig» has become widely used in cities. This is must faster, cheaper and less disturbing of city life. One of this methods is «Pipe cracking» or «Pipe bursting», shown here.

Sewer rehabilitation

Relining an old sewer with a hose impregnated with a plastic material.

The hose is rolled into the old pipeline and cured in place (CIPP)

www.olimb.no

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Cured in place pipe (CIPP)

www.trenchlesstechnology.com

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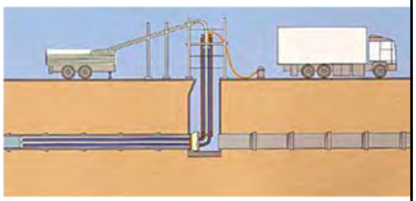
Inserting the hose via a pipe shaft and pushing in the hose with pressure from water pumped in behind the front of the hose



SSTT 2008SSTT (2008) No-dig Handbook.
Scandinavian Society for trenchless technology, Drammen/ København, 2008

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No Dig methods for renewal of sewer pipes

Technology	Description	Dia.	Max. Length	Deterioration	Latera Con-nections	Cleaning Required1
Cementitious Lining	Cementitious lining applied to a cleaned and dried host pipe wall	4" to 160"	2,000 ft	Partial	Reinstated when blocked	High
Polymeric Lining	Spray-on lining applied to a cleaned and dried host pipe wall	4" to 108"	2,000 ft	Partial	Not normally blocked	High
Sliplining	Insertion of a new pipe and grouted f or structural support	6" to 160"	1,500 ft	Partial or Fully	Must be exca-vated	Low
CIPP	Insertion of impregnated liner and cured with water, UV, or steam	4" to 108"	2,000 ft	Partial or Fully	Reinstated robotically	High
Close-Fit Lining	Insertion of a deformed liner reverted back to a original shape	4" to 60"	1,500 ft	Partial or Fully	Must be exca-vated	Medium
Pipe Bursting	Insertion of new pipe while bursting or splitting the host pipe	4" to 48"	1,000 ft	Fully	Must be exca-vated	Low
Spiral Wound Lining	Insertion of a thermoplastic profile that is grouted for structural support	6" to 120"	450 ft	Partial or Fully	Reinstated robotically	Medium
Expandable PVC	Insertion of a pipe heated and pressurized to the host pipe shape	4" to 16"	150 psi	500 ft	Class IV	Must be excavated
Melt-in-Place	Liner heated by an air driven pig and pressurized tightly to the host	6" to 12"	150 psi	500 ft	Class IV	Reinstated robotically

www.trenchlesstechnology.com

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Storm water management and floods

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A convective rain cell. This type of rainstorm occurs in summer and has normally the highest rain intensity

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The Rational Formulae for calculation of storm runoff

$$Q = \varphi A I$$

Q = Storm runoff in liter per second (liters/s).
φ = Runoff coefficient.
A = Area. Catchment that contributes to runoff (ha).
I = Rainfall intensity (l/s ha).

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Area Description	Runoff Coefficient (?)
Business	
Downtown	0.70-0.95
Neighborhood	0.50-0.70
Residential	
Single-Family	0.30-0.50
Multiunits, detached	0.40-0.60
Multiunits, attached	0.60-0.75
Residential (suburban)	0.25-0.40
Apartment	0.50-0.70
Industrial	
Light	0.50-0.80
Heavy	0.60-0.90
Parks, cemeteries	0.10-0.25
Character of surface	**Runoff Coefficient (?)**
Pavement	
Asphaltic and concrete	0.70-0.95
Brick	0.70-0.85
Roofs	0.75-0.95
Lawns, sandy soil	
Flat, 2 percent	0.05-0.10
Average, 2-7 percent	0.10-0.15
Steep, 7 percent	0.15-0.20
Lawns, heavy soil	
Flat, 2 percent	0.13-0.17
Average, 2-7 percent	0.18-0.22
Steep, 7 percent	0.25-0.35

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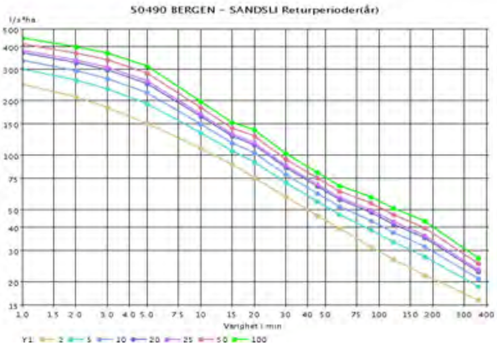
Rainfall intensity in Bergen - l/s ha vs. rain duration (min) and return period



Green is 100 year return periode

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Maximum storm runoff occurs when: The rain duration = the time of concentration for the area $T_{rain} = t_c$

Time of concentration (t_c) is the time the runoff uses from the far edge of the actual drainage area to the point of dimensioning

$t_c = t_s + t_p$ = time on the surface + time in the pipes

t_s = ca. 5 – 7 minutes in cities

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<u>Example:</u> Calculate time of concentration for an area in a city. The length of the pipe is 1260 meter.

<u>Solution:</u>
Time on the surface t_s is estimated to 6 min.
Velocity in the pipes is estimated to 1,5 m/s.
Time of flow in the pipe
$t_p = 1260/1{,}5 = 840$ sec

Time of concentration is $t_c = t_p + t_s = 840/60 + 6 = 14 + 6 = 20$ min

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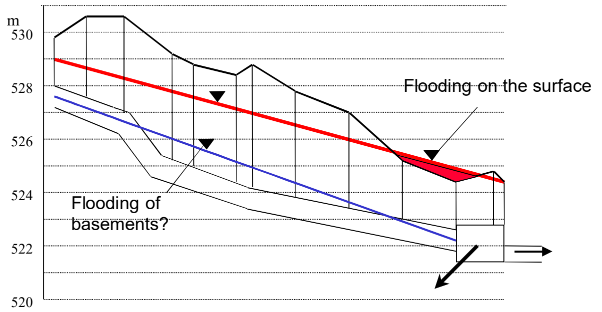
Problems when pipes have to small capacity



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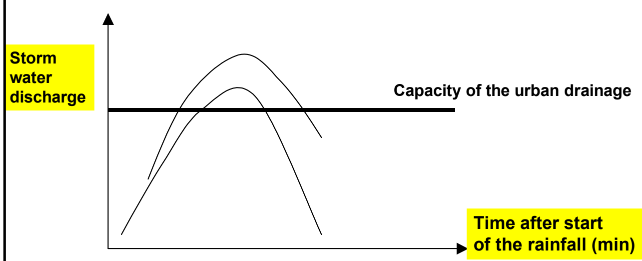
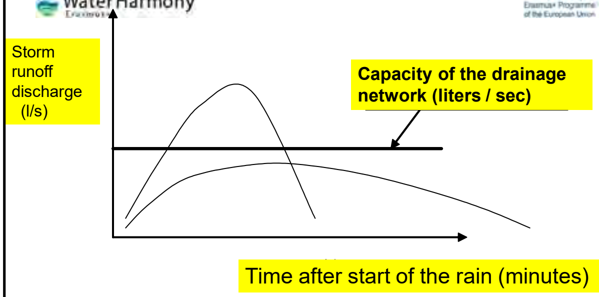
A small increase in the hydrograph / rain may cause a much bigger increase of the problems and flooding



Sustainable urban drainage systems (SUDS)

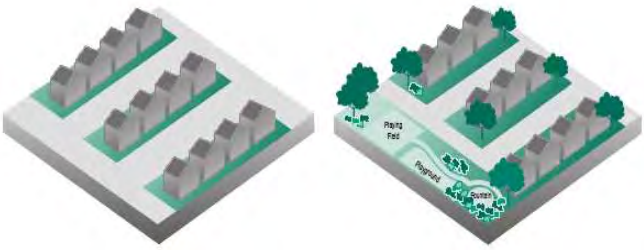


The effect of delaying the storm runoff over a longer time, is a less Qmax.
Can be achieved by using retention and infiltration of storm runoff.
These methods are called SUDS (Sustainable Urban Drainage Systems)

Discharge as little as possible of storm water to the drainage network!

Storm runoff should be infiltrated into the ground or handled at the surface, if possible. (SUDS)
SUDS = Sustainable urban drainage systems

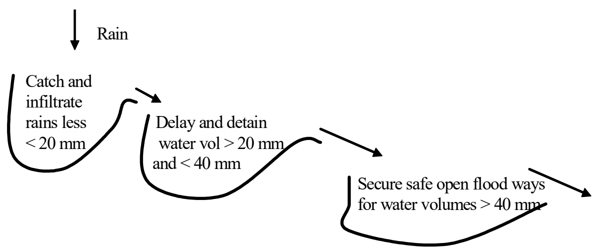
Installations for handling of storm runoff must be introduced early in the area planning stage.



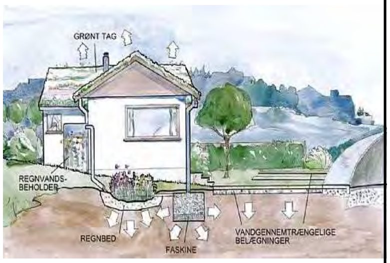
Measures could be enforced by the Plan and Building Act

- Saving and strengthen the vegetation like trees, grass areas, etc.
- The width of the roads.
- Permeable road and parking surfaces.
- Use of infiltration solutions.
- Infiltration trenches and ponds.
- Maximum allowable discharge to the pipe network.
- Use of swales instead of conventional gutters.
- Use of "green" roofs.
- Cisterns for collection of runoff from the roofs.
- Use of detention in open dams and ponds.
- Etc.

Principles for handling of storm runoff
3-stages strategy
The numbers are examples and must be locally adjusted



The first stage in the 3-stage strategy could have the measures shown in the figure:



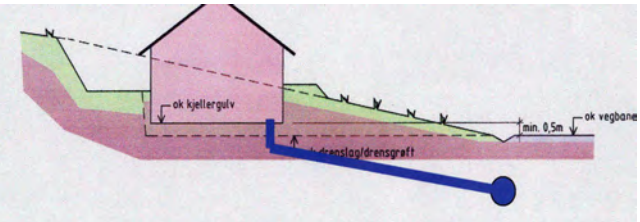
Haven.dk 2010

Design rains and floodings- example

Design rain * (1 in "n" years)	Main type of areas	Dimensioning occurrence of flooding** (1 in "n" year)
5	Areas with a low damage potential Rural areas	10
10	Residential areas	20
20	City centre / Industry areas / commercial areas	30
30	Underground areas / Areas with a very high damage potential	50

* No surcharge above the top of the pipes
** Flooding allowed to the basement floors, usually 90 cm over top of the pipes.

Recommended design rain return periods



Example: Norway

Dimensioning return periods for the critical level (The basement floor):
In housing areas: 1 time every 20 year
In town centers: 1 time every 30 year

Open flood ways (The 3rd stage)

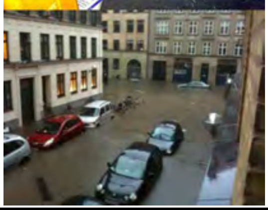
The capacity of the open flood ways should be calculated and recorded on maps. Lower lying areas must be able to receive the discharge.

Streets, roads, park areas etc. may be a part of the flood way. Flood ways should only pass public areas. If the flood way must pass private ground, this should be incorporated in the area planning process and deals should be negotiated with the owners of the area.
Flood ways should slow down and retain water as much as possible.

Terrain models need to be used when calculating directions of the flood ways, flood levels and the flooded areas.

The challenge of climate change

A «monster rain» hit Copenhagen 2th of July 2011.
It was a 1000 years event according to old statistics.
The 3 hour long rain caused damages for 1000 million Euro.



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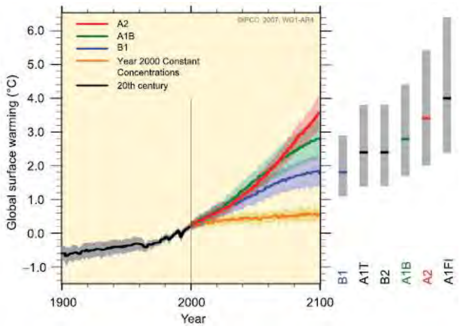
IPCC - UNs Panel for climate change



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Sewer design & modelling tool

Introduction to USEPA SWMM

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"…This means that cloudbursts that could have been expected once in 20 years will now become a one-in-5-year occurrence".

IPCC 2013

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Hydrologic Modeling Features

- Spatially and time varying rainfall
- Evaporation of standing surface water
- Snow accumulation and melting
- Interception from depression storage
- Infiltration into soil layers
- Percolation into shallow groundwater
- Interflow between groundwater & channels
- Nonlinear routing of overland flow

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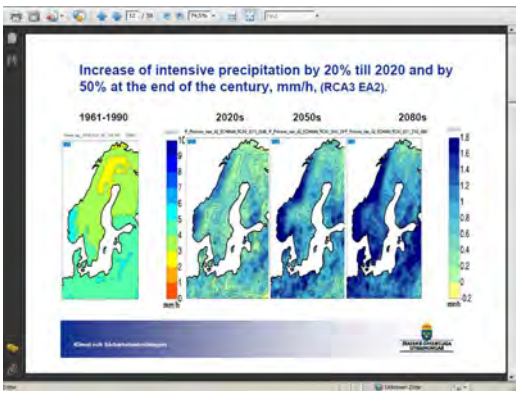

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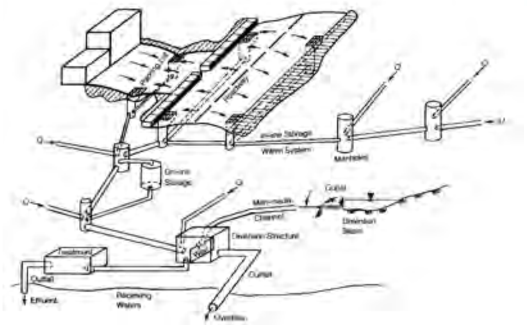
What Is SWMM?



SWMM is a **distributed**, **dynamic rainfall-runoff** simulation model used for **single event** or long-term (**continuous**) simulation of runoff quantity and quality from **primarily urban** areas.

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Flow Routing Algorithms in SWMM5

- Steady Flow
  - simple hydrograph translation
  - applicable only to branched networks
- Kinematic Wave
  - gravity force balanced by friction force
  - attenuated & delayed outflow due to channel storage
  - applicable only to branched networks
- Dynamic Wave
  - solves full St. Venant eqns.
  - accounts for channel storage, backwater effects, pressurized flow, and reverse flow
  - applicable to any network layout
  - requires smaller time step

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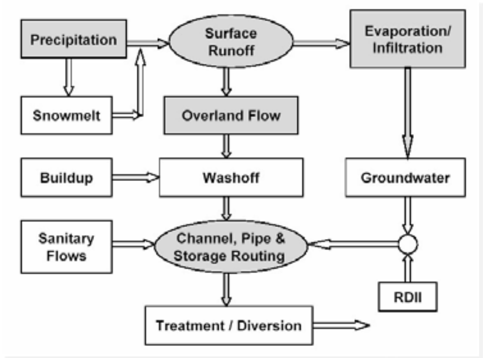
SWMM's Process Models



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Flow Routing Algorithms in SWMM5

- Steady Flow Routing
  - Actually just sums instantaneous subcatchment runoff for all subcatchments upstream of the selected channel
- Kinematic Wave
  - Uniform, unsteady flow
  - No backwater, no surcharge, tree branch systems only unless flow splits are input
- Dynamic Wave
  - Non-uniform, unsteady flow
  - Backwater, surcharge, looped or parallel sewers, street routing of flooded sewer manholes

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Hydraulic Modeling Features

- Handles drainage networks of any size
- Accommodates various conduit shapes as well as irregular natural channels
- Models pumps, regulators, storage units
- Allows external inflows from runoff, groundwater, RDII, sanitary, DWF, and user-supplied time series
- Uses flexible rule-based controls for pumps and regulators
- Models various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding

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Schematic Illustration of SWMM Routing Algorithm

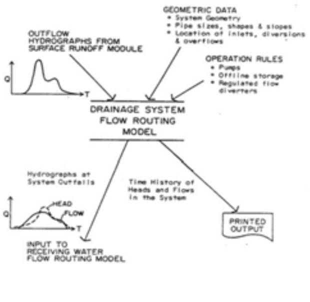

Figure 5-1. Schematic Illustration of EXTRAN.

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Water Quality Modeling Features

- Pollutant buildup over different land uses
- Pollutant washoff during runoff events
- Reduction in buildup from street cleaning
- Reduction in washoff from BMPs
- Inflows from user-defined sources and sanitary DWF
- WQ routing through the drainage network
- User-defined treatment functions

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Typical Applications of SWMM

- Design and sizing of drainage system components including detention facilities
- Flood plain mapping of natural channel systems
- Control of combined and sanitary sewer overflows
- Generating non-point source pollutant loadings for wasteload allocation studies
- Evaluating BMPs and LIDs for sustainability goals

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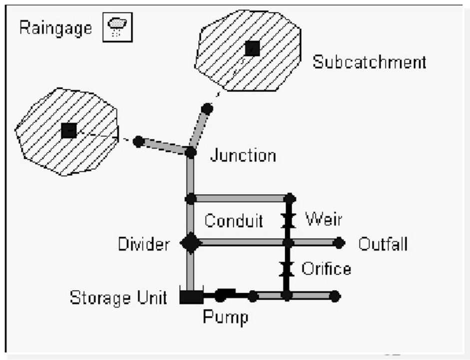
SWMM 5's Visual Objects



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Limitations of SWMM

- Not applicable to large-scale, non-urban watersheds
- Not applicable to forested areas or irrigated cropland
- Cannot be used with highly aggregated (e.g., daily) rainfall data
- Its an analysis tool, not an *automated* design tool

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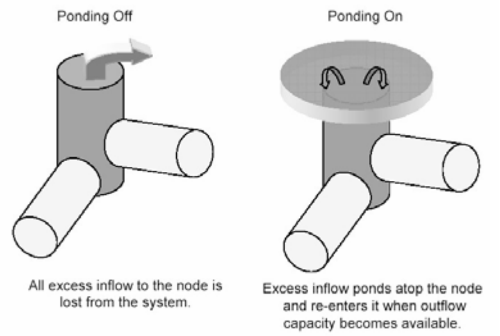
Node Flooding Options



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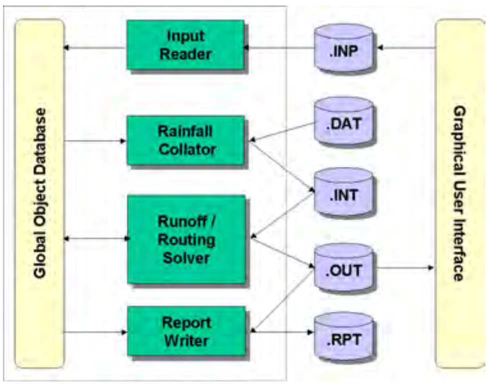
Structure of SWMM 5



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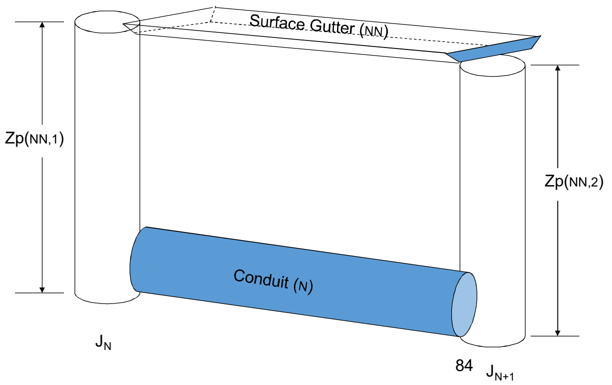
Surface Routing of Flood Flows



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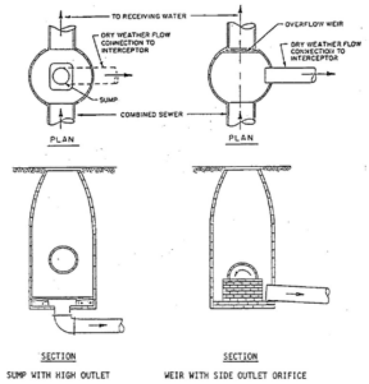
Orifices and Weirs



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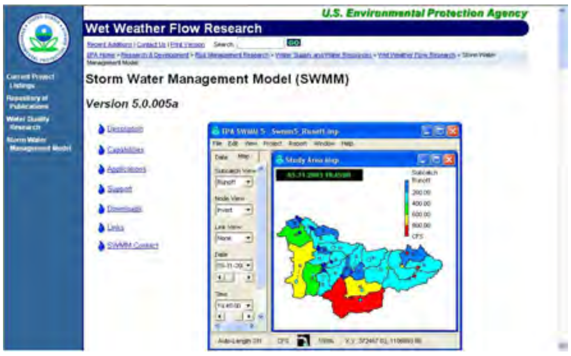
EPA SWMM Web Site

http://www.epa.gov/ednnrmrl/swmm/



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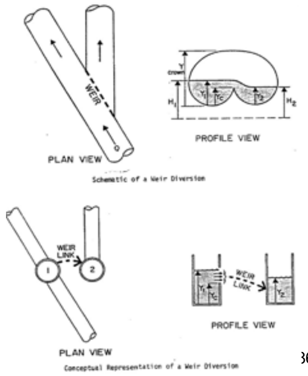
Representation of Weirs



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The SWMM-USERS List Server

List servers provide a means for subscribers to get quick answers to questions and participate in discussions relating to the list server topics. Subscription is free, and subscribers receive all the e-mail that is sent to the list and can in turn send e-mail to the list.

The SWMM-USERS list server is a forum for users of the public-domain USEPA SWMM program to share ideas and ask questions on issues related to stormwater management modeling. A searchable archive of past questions and answers is available through our SWMM Q&A database.

To subscribe to a list, send an email to listserv@listserv.uoguelph.ca. Do not put anything in the subject line and, in the body of the message, include the following line (with NO other text and no brackets):

SUBSCRIBE SWMM-USERS [first name] [last name]

For example,

SUBSCRIBE SWMM-USERS JANE DOE

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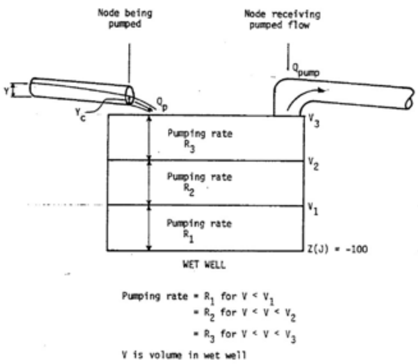
Representation of Pump



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SWMM Wrappers With GIS Interfaces

- XP SWMM – XP Software (www.xpsoftware.com)
- Mike SWMM – DHI (www.dhisoftware.com)
- InfoSWMM - MWH Soft (www.mwhsoft.com)
- PC SWMM – CHI (www.computationalhydraulics.com)

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Mechanical processes

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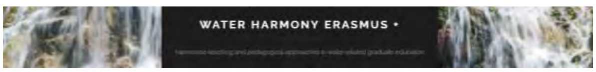


CONTENT

- Screening and comminution
- Sand and grit removal
- Sedimentation
- Flotation
- Filtration
- Membrane processes

Primary water treatment:

- The turbidity of water is following:
  - little turbidity, M up 50 mg/L;
  - average turbidity, M=50÷250 mg/L;
  - turbid, M=250÷1500 mg/L;
  - high turbidity, M over 1500 mg/L.

Buckets are facilities for artificial lagoons

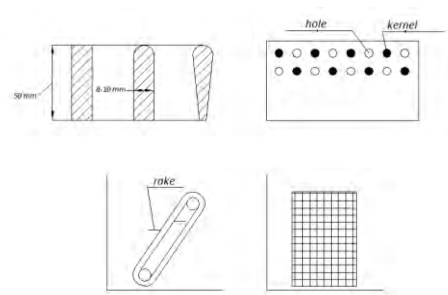
1 - ladle;
2 - water intake;
3 - dam.

Straining on the grill and netting

- The first and the most rude mechanical water clarification is filtering it through the bars and mesh.
- The function of these structures - protection (protects the subsequent construction of the contamination and damage).

Grates are structurally frames with rods placed on it. The size of the lattices (400 ÷ 1400), (1000 ÷ 2000) mm. The distance between the bars is called “prozori” (16 ÷ 20) mm.

The construction of different lattice types:



Theoretical basis of settling :

- Stokes equation:

$$u = \frac{d^2}{18\mu} \cdot g \cdot (\rho_T - \rho_Ж)$$

where u - rate of particles, [m/s];
d - particles diameter, [m];
μ - viscosity, [Pa·s];
18 – coefficient from Re for deposition rate;
g - acceleration of gravity, 9,81 [m/s·s];
ρ – solid particle density (ρ_S) and liquid (ρ_L), [kg/m^3].

- Stokes equation has two assumptions:
  - Spherical form of particles;
  - during sedimentation particle shape does not change its form.
- During deposition the size, density, and particle shape and physical properties of the system change. Then, correction factor is entered in the Stokes equation.

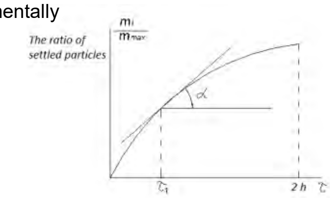
Stokes equation

$$u = \frac{d^2}{18\mu} \cdot g \cdot (\rho_T - \rho_Ж) \cdot K$$

- where K – coefficient taking into account the deviation from the Stokes equation conditions (concentration, the rheological properties of the system, and particle shape).

The hydraulic size of particles:

- The hydraulic size of particles is rate of particles precipitation at 283÷288 K in mm/s.
- Determine experimentally

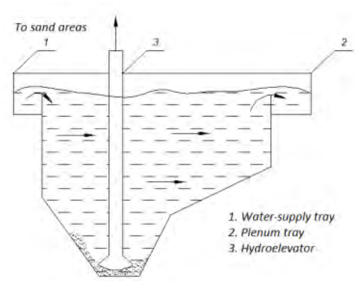


For each τ it's built tangent, which will be magnitude of the velocity, i.e. u_0 in each period of time

Water defending:

- The simplest device for discharge from the water of heavy mineral impurities (mainly sand) is **a sand trap**.
- Sand traps are most widely used in treatment systems with a horizontal rectangular movement of water, horizontal circular motion of the water, round shape with tangential supply of water and aerated.

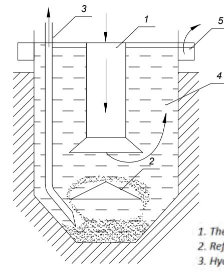
Scheme of horizontal sand trap :



Sedimentation tanks:

- The sump is the main structure mechanical treatment of water is used to remove deposited or pop coarse substances.
- Depending on the direction of flow sumps are divided into:
  - horizontal,
  - vertical,
  - radial.

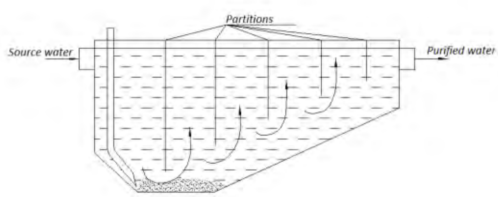
Scheme of vertical sedimentation tank:



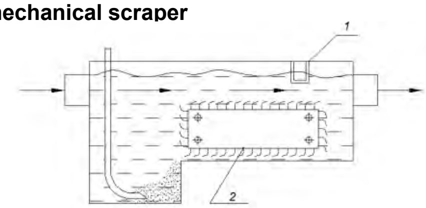
1. The central feeding tube with a bell
2. Reflector
3. Hydroelevator (yl wire)
4. Settling zone
5. Water discharge tray (depth less than 7 m, diameter less than 10 m, Q less than 30000 m^3/day

1. Центральная подающая труба с р
2. Отражатель
3. Гидроэлеватор (илопровод)
4. Отстойная зона

Scheme of horizontal sedimentation tank with partitions:

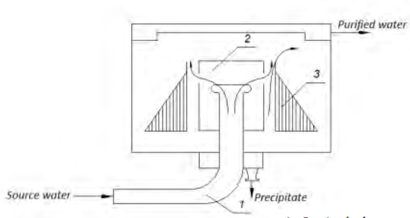


Scheme of horizontal sedimentation tank with mechanical scraper



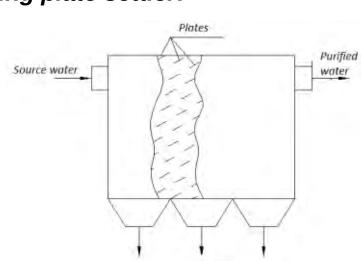
1. Apparatus for removing floating particles
2. Mechanical scraping device

Scheme of horizontal sedimentation tank with central inlet:



1. Central pipe
2. Quieting chamber
3. Mechanical scrapers

Driving plate settler:



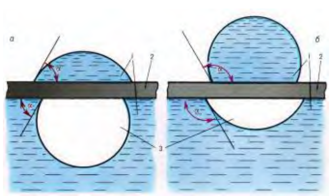
The main branches of using flotation

- 1) for water containing various oil products, fats and oils. Various organic industries, pulp, tanneries, textile and food enterprises, perfume and pharmaceutical industries;
- 2) for the removal of activated sludge after secondary clarifiers in the biological treatment schemes;
- 3) for the natural water preparation;
- 4) for certain radioactive materials removing;
- 5) for cleaning of coarse and fine particles, as well as pop-up metals.

The essence of the method

- There are three phases take part in the flotation process: solid, liquid and gaseous. The interaction exists between this particles:
- 1) adhesion (sticking) of the hydrophobic particles and gas (air);
- 2) the adhesive forces between the gas and liquid, i.e. surface tension forces.

. The hydrophilic (a) and hydrophobic (b) surfaces in a three-phase system of water - solid body - air.



1 - water; 2 – solid body; 3 - air; α- contact angle

Physical and chemical basis of the flotation process

The flotation efficiency depends on:

- size and wettability (hydrophobicity) of particles removed from water;
- the nature of the fluid (the surface tension);
- number and size of the gas phase bubbles.

Basic techniques of providing the required concentration of air bubbles in water

- air saturation of water and the flotation process is carried out at various pressures. The pressure change results in a uniform release of air bubbles throughout the entire of water volume;
- air dispersion is carried out by mechanical means in flotators with the impeller or mixers;
- necessary size and number of air bubbles is provided by using membranes and porous materials;
- by the chemical mean with gas phase forming as a result of chemical reaction or biochemical processes.

Schematic diagrams of the flotation cleaning

- According to the method of water saturation of air the flotation is classified on the pressure and vacuum flotation.
- When the pressure flotation water saturation of air is carried out under a pressure between 0.3 ÷ 0.5 MPa, and the process takes place at atmospheric pressure.
- When vacuum flotation water is saturated with air at atmospheric pressure, and the process is carried out by suction.

Advantages and disadvantages of vacuum flotation

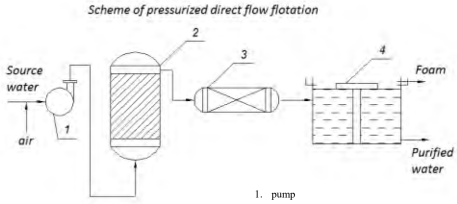
- **Advantages**: the formation of gas bubbles and their coalescence takes place in a relaxed atmosphere (the probability of bubble-destruction of the aggregates particle is minimized).
- **Disadvantages**:
- insignificant degree of water saturation of the gas bubbles, however, by this method can not be used at high concentration of suspended solids (less than 250 ÷ 300 mg / l);
- necessity to construct a hermetically sealed flotators and placing scrapers into them.

Advantages and disadvantages of pressure flotation:

- reaching of water cleaning higher level (85÷95%) than with mechanical cleaning;
- forming of foam-slurry with a lower moisture;
- more compact installation than in mechanical cleaning.

The main schemes of pressure flotation

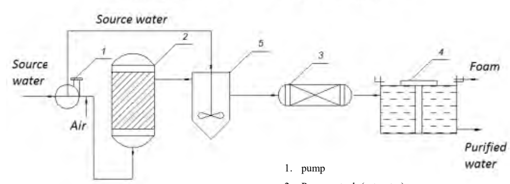
Scheme of pressurized direct flow flotation



1. pump
2. Pressure tank (saturator)
3. Reducing valve
4. flotator
5. mixer

The main schemes of pressure flotation

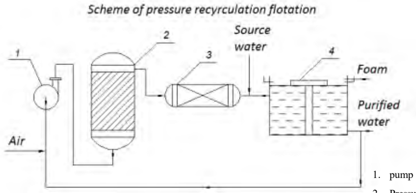
Scheme of pressure partially direct flow flotation



1. pump
2. Pressure tank (saturator)
3. Reducing valve
4. flotator
5. mixer

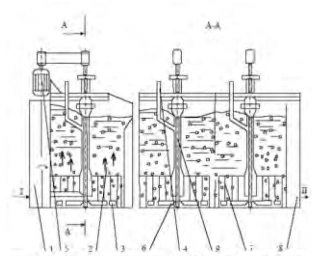
The main schemes of pressure flotation

Scheme of pressure recyrculation flotation



1. pump
2. Pressure tank (saturator)
3. Reducing valve
4. flotator
5. mixer

Scheme of the impeller flotator:



Scheme of two chamber impeller flotation installation
I - waste water supplying; II - purified water supplying

I- the supply of raw water; II- yield of purified water 1- reception chamber; 2- flotation chamber; 3- fixed part of the impeller; 4- air supply pipe; 5- engine; 6- moving part of the impeller; 7- quieting chamber; 8- chamber of purified water; 9- motor shaft;

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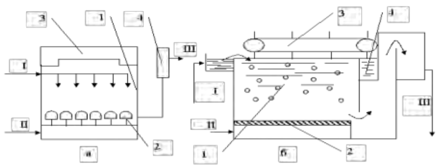
Scheme of the flotator with elements of porous material:



a- with porous caps, б- with porous plates; I- source water supplying; II- air supplying; III – purified water taping; 1- flotation chamber; 2- porous elements; 3- installation of foam taping; 4- level regulator.

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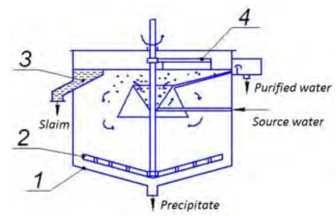
Scheme of the flotator «Aeroflotor»:



1 - chamber; 2 – scraper; 3 – slaim container; 4 – scraper for foam cuting.

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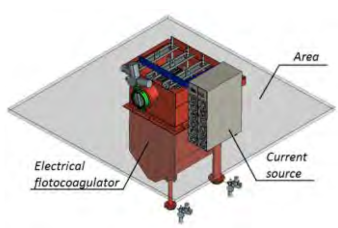
General form of the electrical flotocoagulation installation:



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Filtration

- Filtration is the final stage of clarification.
- Filtration method with prior sedimentation keep allows to get water of any required clarification level.

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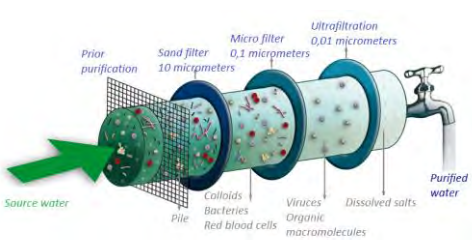
Filtrations spectrum



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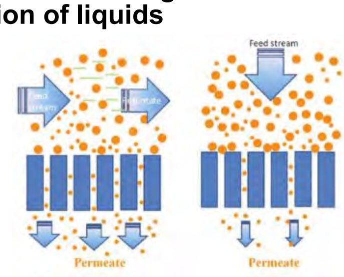
Deadlock and tangential mechanical filtration of liquids



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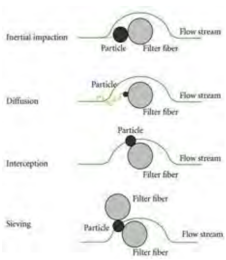
Filtration mechanism:



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Filtration materials:

- Grids;
- Fabrics;
- Grit loading:
  - sand, quartz sand, dolomite, concrete block,
  - clay, shale, fly ash granulation
  - anthracite, gravel, gravel, marble chips, glass chips,
  - blast furnace slag,
  - foamed styrene.

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- **Mechanical filtration** for removing of high volume pollutions
- **Mechanical filtration** for providing of environment specified purification

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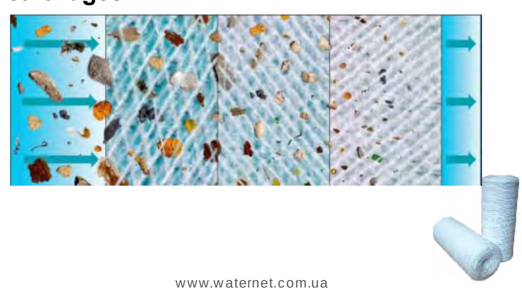
The structure of the filter layer filament cartridges



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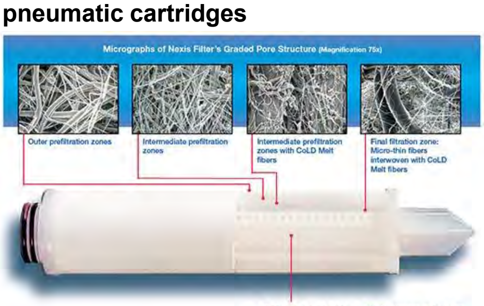
The structure of the filter layer extrusion pneumatic cartridges



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Types of filtering on grit loading:

- Depends on flow rates:
  - slow filtration – u=0,1÷0,3 m/h;
  - fast filtration – u=5÷12 m/h;
  - Over fast filtration – u=30÷100 m/h.
- Depends on ratio between removing particles size and grains of filtering loading:
  - detention of impurities on the surface of the filter material (film-filtration); volume of it (volume filtration);
  - detention of impurities in the pores of the filter layer (volume filtering);
  - simultaneous formation of films and their deposition of impurities in the pores.

Physical and chemical principles of filtration:

- Film filtration is the base of slow filtration.
- When filtered water through grit loading at low speed so-called biofilm is formed on the grains. Slurry holding takes place on most biofilm.
- When fast filtration biofilm isn't growing. The slurry retention occurs between the grains. At the same time on a particle, the following forces take place:
  - Adhesion forces between particle and grains of loading;
  - oppositely acting flow forces that tend to pull suspended particles from the grit loading.

Classification of filters with grit loading:

1. depends on filtration rate:
   - slow (0,1÷0,3 m/h);
   - fast (up 25 m/h);
   - Over fast (up 100 m/h);
2. depends on operating pressure:
   - open gravity-fed (or free-flow) - the differential pressure is created due to the difference in water levels on the filter and the tank of clean water;
   - pressure - working pressure generated by the pump up to 0.6 MPa;

Classification of filters with grit loading:

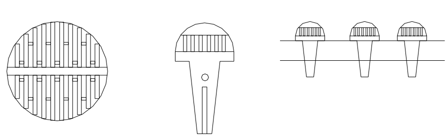
3. depends of directions filtering flow quantity:
   - single-threaded - filtering is done from top to bottom;
   - double-flow - the movement is carried out simultaneously in two directions;
4. depends on the circumference of the filter material:
   - fine-grained filters - grain size 0,1÷1,0 mm
   - medium-grained - grain size 1,0÷2,2 mm
   - coarse - grain size up 40 mm
5. depends on filtering levels quantity:
   - one-layer; two-layer; multi-layers.

Basic requirements for the design of the filters:

- filtration must be carried out in a direction from a higher layer in size by loading the layer with a smaller load;
- filter design should provide a uniform distribution of water across the surface, which is achieved by different types of drainage systems;
- the drainage system should also provide an intense and efficient filter flushing.

Types of drainage systems:

Slotted pipes **Cap type**



Requirements to grit loading:

1. Grading:
   - in slow filters 0,3-40 mm;
   - in fast filters 0,5-2,2 mm.
2. Hydrophobic properties of grain surface;
3. The porosity of the material;
4. Chemical resistance to water;
5. Mechanical abrasion resistance;
6. Availability and low cost opportunities.

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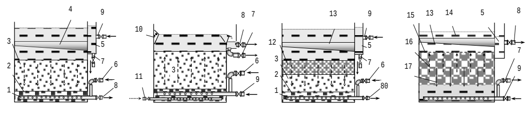
Schemes of the main filter types:



- 1 – drainage system: 2 – supporting gravel layer; 3 – filtering layer; 4 – gutters for water supply: 5 – distribution channel; 6 –purified water feeding; 7 – purified water drainage; 8 – filtrate outlet; 9 – supplying raw water pipeline; guide ledge; 11 – air feeding; 12 – anthracite; 13 – gutter for the distribution of raw water and tap wash; 14 – space above filter; 15 – upper restraint system; 16 – the direction of the filtration flow; 17 – the direction of the wash water flow.
- a - open fast filter circuit; б - filter circuit with an upward flow of water and air-water washing; в – two-layer filter; г - filter circuit with a floating filter layer.

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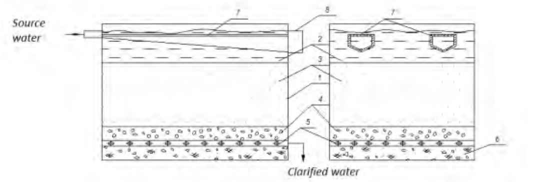
Opening soon filters (gravity-fed):



- 1 - case; 2 - a layer of water above the filter material; 3- sand filtration layer; 4 - the supporting layer of gravel; 5 - drainage system; 6-layer anthracite, gravel, crushed stone (this layer acts as a support layer); 7- wash troughs; 8 - overflow pocket.

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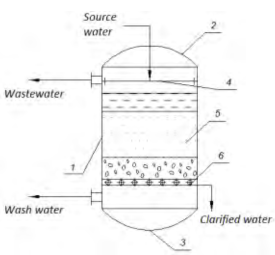
Pressure filters:



1. Case
2. Upper bottom
3. Lower bottom
4. Upper dispenser
5. Filtering working layer
6. Drainage dispenser

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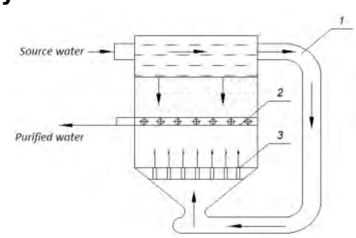
Two-layer filters:



1 – supply line; 2 upper drainage and distribution system; 3- bottom distribution system

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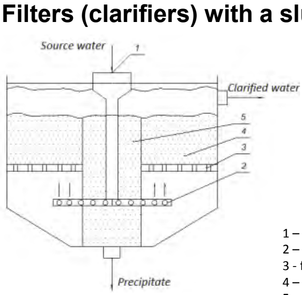
Filters (clarifiers) with a sludge blanket:



1 – air separator;
2 – feed dispenser (source water drainage);
3 - failure grille;
4 – sedimented layer;
5 – sludge outlet tube;

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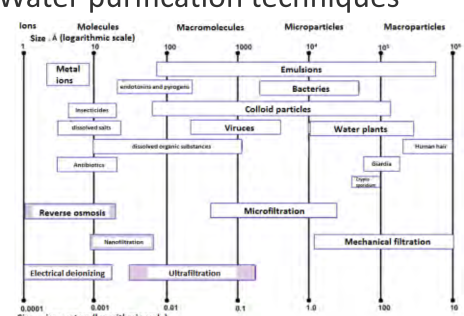
Water purification techniques



Mechanical processes www.waternet.com.ua

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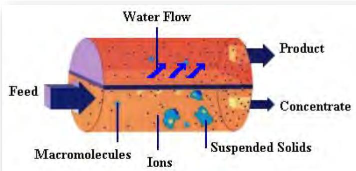
Microfiltration:

Removing particles size: **0,15-50 micrometers**

Work pressure: **0,1-0,2 MPa**

Using for water purification from **slurries** and some bacteria



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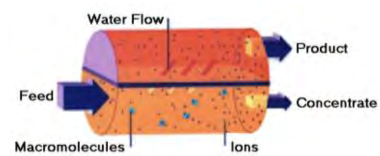
Ultrafiltration:

Removing particles size : **0,003-0,2 мкм**

Work pressure: **2-3 атм**

Using for water purification from **colloids, bacteries and viruces, large organic molecules**



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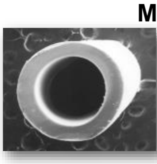
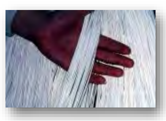
Membranes kinds:

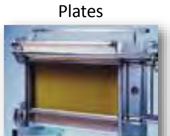


Hollow fiber

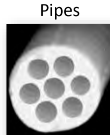


Sheets

Plates



Pipes



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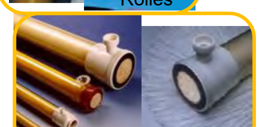
Membranes elements kinds:

Rolles

Ceramics

Sleels



Fibers

Lamellars

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Examples of systems:

Total membranes area 1632 sq.m.!

Coagulation

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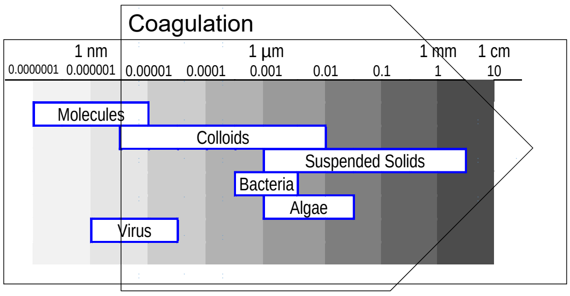
Norwegian University of Life Sciences
harsha.ratnaweera@nmbu.no

CONTENT

- Coagulation process
- Particle and phosphate removal mechanisms
- Coagulants and dosing
- Flocculation and separation

Coagulation can remove most pollutants from water and wastewater



Coagulation = precipitation and agglomeration

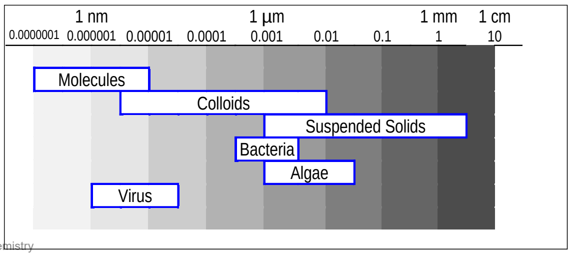
- agglomeration of colloids and smaller particles
- precipitation of some dissolved pollutants

Particle size matters in settling!

Diameter of particles		Order of size	Particle settling time for 1 m	
mm	microns		inorganic	organic
10	10 000	Gravel	1.3 sec	4 sec
1	1 000	Coarse sand	10 sec	30 sec
0.1	100	fine sand	2 min	16 min
0.01	10	Slit	3 hours	1 day
0.001	1	Bacteria	13 days	3 months
0.0001	0.1	Colloidal	> 3 years	30 years
0.00001	0.01	Colloidal	> 200 years	> 200 years

Mechanical and chemical treatment

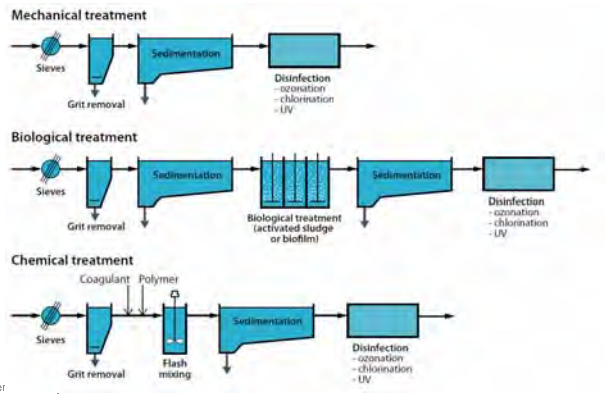
Typical removal rates	Mechanical	Chemical
SS	60%	80-90%
COD	30%	50-70%
Tot-P	15%	70-90%
Tot-N	15%	25-30%



Main objectives of coagulation

- In wastewater
  - Remove particles
  - Remove phosphates
- In drinking water
  - Removal of particles (Bacteria, virus, turbidity, etc)
  - Removal of colour (NOM)

Coagulation- one of the main processes



CONTENT

- Coagulation process
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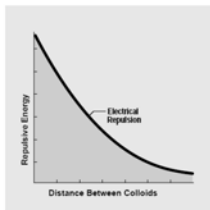
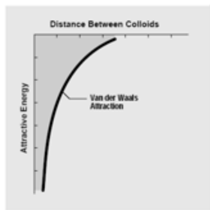
Mechanisms of coagulation

- Particle removal
  - Compression of Double Layer
  - Adsorption-charge neutralization
  - Bridging
  - Sweep floc
- Phosphate removal
  - Chemical (co)precipitation
  - Adsorption on to complexes

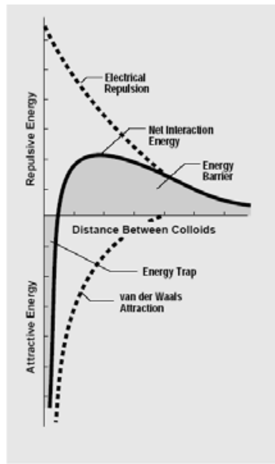
Particle stability



Electrostatic repulsion is always shown as a positive curve.

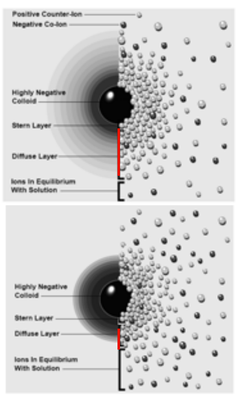


Van der Waals attraction is shown as a negative curve.



Interaction
The net interaction curve is formed by subtracting the attraction curve from the repulsion curve.

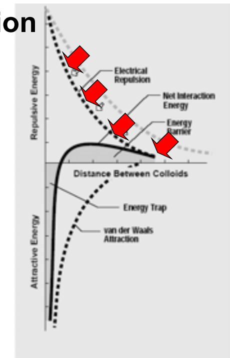
M1. Double layer compression



Firmly attached counter ions ➔ Stern layer

Ions attracted by "-" layer but repelled by Stern layer ➔ Diffuse layer

Co-ions (same charge as the particle) ➔ in equilibrium.



Compression
Double layer compression squeezes the repulsive energy curve reducing its influence. Further compression would completely eliminate the energy barrier.

Shultz-Hardy rule: impact of the counter-ions: z^6

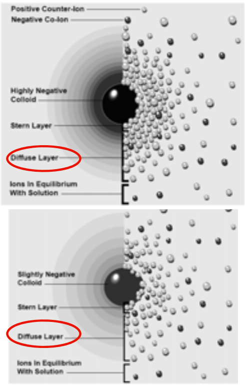
Positive species: ions/complexes

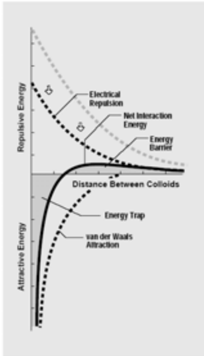
- Cationic organic polymers
- Hydrolysis: "+" charged species

$Al^{3+} + H_2O \Leftrightarrow Al(OH)_3 + H^+$

$Al^{3+} + H_2O \Leftrightarrow Al(OH)^{2+} + H^+ \Leftrightarrow Al(OH)_2^{+} + H^+ \Leftrightarrow Al(OH)_3 + H^+$

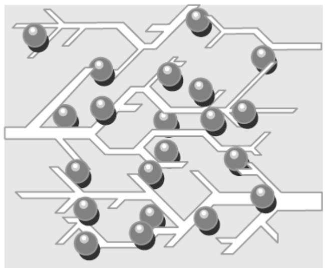
M2. Adsorption- Charge Neutralization





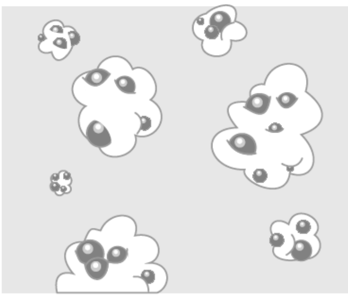
Charge Reduction
Coagulant addition lowers the surface charge and drops the repulsive energy curve. More coagulant can be added to completely eliminate the energy barrier.

M3. Bridging



Bridging
Each polymer chain attaches to many colloids.

M4. Sweep floc



Sweep Floc
Colloids become enmeshed in the growing precipitate.

Phosphate removal mechanisms

- M1: Chemical reactions with Al, Fe, Ca with P resulting in MeP-complexes

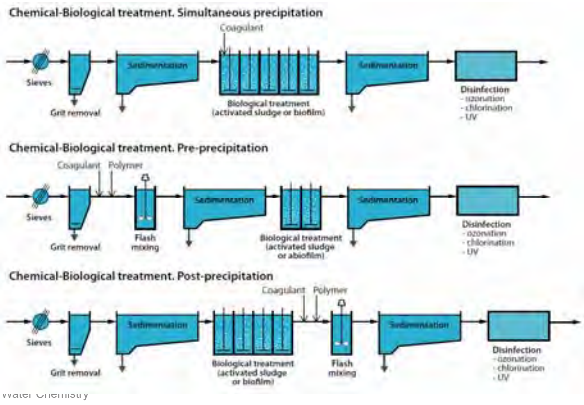
  $Me^{3+} + PO_4^{3-} \rightarrow MePO_4 \quad (MePO_4)_x\,(OH)_{3-3x}$

- M2: Adsorption or sweep floc of MeP, complex and various ions to particles which separates.

Coagulants and mechanisms

Water type	Drinking water coagulation		Wastewater coagulation	
Mechanism and coagulant type	Inorganic coagulants	Organic coagulants	Inorganic coagulants	Organic coagulants
Double-layer compression	Occasionally	Not applicable	Used when seawater is available	Not applicable
Adsorption-charge neutralisation	Dominant	Occurs with cationic polymers	Occurs frequently	Occurs with cationic polymers
Inter-particle bridging	Not applicable	Dominant	Not applicable	Dominant
Colloidal entrapment (Sweep floc)	Occasionally	Not applicable	Dominant	Not applicable

Process variations with coagulation



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Selection of coagulants

- **Traditional**
  - Al3+ (Aluminium sulphate, Aluminium chloride)
  - Fe3+ (Iron Chloride, Iron chloride sulphate)
  - Ca2+ (Calcium hydroxide)
  - Fe2+ (Iron Sulphate)
- **New (innovative)**
  - Pre-polymerized (PAX, PIX)
  - With Slica/water glass
  - With Ca2+
  - With flocculants
  - Chitosan
  - Ti^{4+} & Zr^{4+}

Challenges in coagulation

- Too little P after pre-precipitation (biological processes require >0.2 mg-P/l)
- Too low pH after pre precipitation (Biological processes)
- Too strong binding of P to Al/Me so poor accessibility of P to plants (unfavorable as a fertilizer)
- Too much sludge?
- Sludge too difficult to process?
- Working pH range vary
- Price Fe^{2+} vs Fe^{3+} (Fe^{2+} is cheaper but can be used in simultaneous coagulation)

Influence of Prepolymerisation

Coagulant	OH/Me	Me[PO], %
Aluminium sulphate	0	57
Iron Chloride	0	56
Poly-Aluminium Chloride I	1.1	43
Poly-Aluminium Chloride II	1.7	35
Poly-Aluminium Chloride III	1.9	25

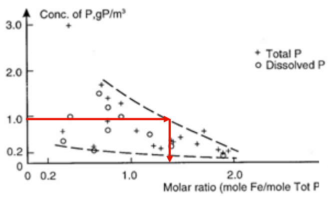
Ratnaweera, Fettig and Ødegaard, 1992

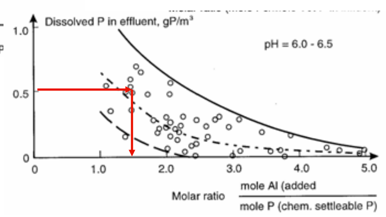
OH/Al $\uparrow$ Al[PA] $\uparrow$ ⇨ Al[PO] $\downarrow$

Molar ratio between Al and P

- Results from several research shows that it requires 1.4 times of P moles to remove 1 mole of Al or Fe at working pH ranges.
- However much higher doses (Al/P=3 to 4) are used in practice to achieve 80-95% removals of phosphates.
  - Hydrolysis & phosphate precipitation: competitive & simultaneous reactions.
- Optimal pH
  - Depends om coagulant
  - In practice: pH= 5.8-6.2 for Al^{3+} and 5.5-6.0 for Fe^{3+}

Proportion between Me and P in simultaneous WWTP





Calculation example - 1

- P is precipitated by adding 250 g/m3 of ALS with 8% Al w/w. The wastewater contains 14 g-P/m3. What is the molar ratio (MR) applied?

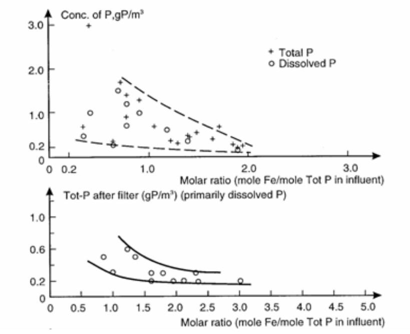
- Added Al = 0.08 x 250 g/m3 / (27 g Al/m3) = 0.74 mole Al/m3
- P-content = (14 g-P/m3)/(31 g -P/mole) = 0.45 mole P/m3
- MR Al/P = 0.74/0.45 = 1.64 mole-Al/mole-P

Design of WWTP: coagulant dosing

- Two methods:
  - Total phosphorus
  - Dissolved plus suspended phosphorous

Cp (total P) = Sp (soluble P) + Xp (suspended P)

Tot-P design



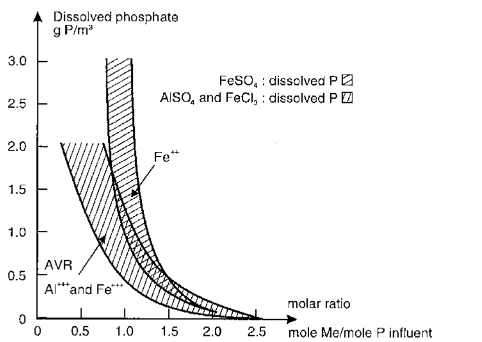
Design parameters

Effluent concentration: 2-3 g P/m^3	Biological phosphorus removal Simultaneous precipitation, Fe^{++} or Al^{+++}, MR = 0.8 Preprecipitation, Al^{+++}, MR = 1.
Effluent concentration: 1-2 g P/m^3	Simultaneous precipitation, Fe^{++} or Al^{+++}, MR = 1 Preprecipitation, Ca^{++} + Fe^{++}, pH 8-9, MR (Fe) = 1 Direct precipitation, Ca^{++}, pH 10-11 Direct precipitation, Al^{+++}, MR = 1.5 Post precipitation, Al^{+++}, pH 6.5-7.2, MR = 1
Effluent concentration: 0,5-1 g P/m^3	Simultaneous precipitation, Fe^{++} or Al^{+++}, MR = 1.5 Simultaneous precipitation + preprecipitation or soil ponds, Fe^{++} or Al^{+++}, MR = 1.5 Post precipitation, Al^{+++}, pH 5.5-6.5, MR = 2 Direct precipitation, Ca^{++}, pH 10-11 + sea water Preprecipitation, Ca^{++} + Fe^{++}, pH 9-10, MR (Fe) = 1.5
Effluent concentration: 0.3-0.5 g P/m^3	Simultaneous precipitation, Fe^{++} or Al^{+++} + contact filtration Fe^{++} or Fe^{+++}, MR both processes = 2. Post precipitation, Al^{+++}, pH 5.5-6.0, MR = 2, + contact filtration, Fe^{+++}, MR = 2.

Table 10.2
Example of processes of technical-financial relevance to obtain given effluent concentrations for total phosphorus.
The abbreviation MR (molar ratio) means: Number of moles of metal ions added per mole of total phosphorus in the influent.

Henze et al, 2002

Dissolved + Suspended P Design



).23 *Average concentration of dissolved phosphate, Sp, in the effluent from a simultaneous precipitation plant as a function of the metal dosing (Me/P). pH and calcium variations in the wastewater have not been taken into consideration. The importance of these is shown in Fig 10.24. The oxygen saturation has typically been 25 per cent. Treatment of wastewater from Lundtofte, (Denmark) /1/.*

Henze et al, 2002

Calculation example-2

- P has to be removed from a WWTP (1200 m^3/d) with $FeCl_3$. The effluent requirement is 1.5 g-P/m^3, and the influent has 13 g-P/l. The effluent has 15 SS g/m3 with 3% P. What is the required $FeCl_3$ dosage?

- P has to be removed from a WWTP (1200 m3/d) with FeCl3. The effluent requirement is 1.5 g-P/m3, and the influent has 13 g-P/l. The effluent has 15 SS g/m3 with 3% P. What is the required FeCl3 dosage?

- Cp = 1.5 g-P/m3
- Xp = 15 gSS/m3 x 0.03 g-P/SS = 0.45 g-P/m3
- Sp = Cp-Xp = 1.5-0.45 = 1.05 g-P/m3.

- From the Figure, 1.05 g-P/m^3 gives MR of 0.7-1.2 mole Fe^{3+}/mol P.
- Choose Fe3+/P=1.1; Fe^{3+} = 1.1 x P = 1.1 x 13g-P/m^3 / 31 gP/mole

= 0.46 mole Fe^{3+}/m^3

= 0.46 mole/m3 x 162.5 g/mole = 75 g 100% $FeCl_3$/m^3

= 75/32%= 234 g-$FeCl_3$/m^3

Molar weight of P = 31

Molar weight of $FeCl_3$ = 162.5

Average dosing

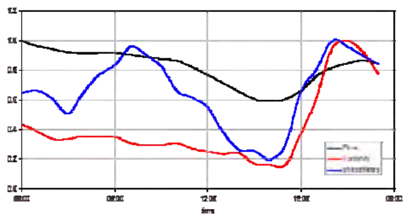
Coagulant	Optimal pH	Normal dosage, mg-Me/l
Al3+	6.0-7.0	1.5-3.0 mg Al/l
Fe3+	4.5-5.5	3.0-6.0 mg Fe/l
PAX	6.5-7.5	1.0-2.5 mg Al/l

- Why is it necessary to add almost twice Al for Fe?
- If you have a hard water with high pH, which coagulant?
- If you have soft water and pre precipitation, which coagulant?

Dosing control in coagulation

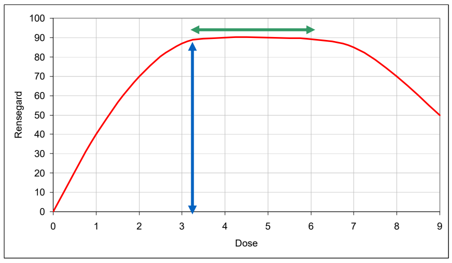
- Optimal dosage = f(Q, SS, P, pH)
- Common dosing strategy : D=f(Q), not optimal as one parameter (Q) is not proportional to the parameters critical for coagulation.

Conclusion: using two or more parameters will secure more optimal dosing



Waste of coagulants?

- Optimal dosage = minimum dosage needed to achieve the required treatment efficiency.
- Best removal doesn't mean optimal dosage as an equally good removal may be achieved with a dosages in a broader range. re



CONTENT

- Coagulation process
- Particle and phosphate removal mechanisms
- Coagulants and dosing
- Flocculation and separation

Design of WWTP: flocculation and sedimentation

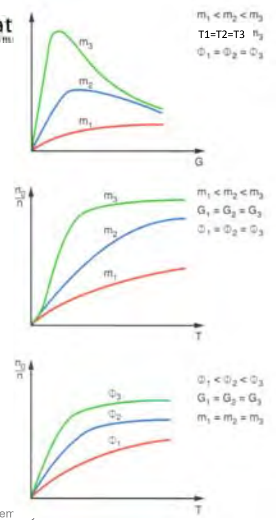
- Minimum total time in flocculation chambers
  - 10-15 mins if 4 chambers
  - 12.5-20 mins if 3 chambers
  - 20-30 mins if 2 chambers
- Sedimentation tanks
  - Depth >2.5m
  - Surface load 1.0 & 2.0 m^3/m^2.h (at Qdim & Qmxdim)
  - Surface load 2.4 & 4.8 m^3/m^2.h for pre-settling (at Qdim & Qmxdim)
- High-rate settlers like lamella, actiflo etc may have much higher surface loads.

Flocculation intensity

- Rate of aggregation ($\frac{n_o}{n}$) of smaller particles to flocks (aggregates) is a function of
  - Velocity gradient, G
  - Mixing time (duration), T (reactor volume/Q)
  - Concentration of particles, ϕ

$G = (\frac{W}{\mu_a})^{-1/2}$ or in a pipe: $G = \frac{(f.v^3)^{0.5}}{2.d.v}$

- W=added energy per volume, watt/m2
- μ_a = absolute viscosity, kg/m.sec
- f= coefficient of resistance, f=100Re$^{-0.25}$, where R=v d/θ; v= flow m/sec; d= diam, m; θ=kinetic viscosity, m^2/sec



G-value (Velocity gradient)

- M= number of chambers
- ϕ = concentration of particles
- T = retention time

- Sedimentation needs big and heavy flocs (lowering G)
- Flotation needs light and smaller flocs (high & even G)

Flocculation

- Organic flocculants
  - PAA, very low dosages (1-2% of coagulants), 15-25 costly as coagulants
- Can reduce the sludge volume considerably
  - surface loads can increase from 0.5-3.0 to 3-10 m/h
- Construction
  - Pedal flocculators
  - Tube-flocculators

Flocculators

Figure 300. Paddle type flocculator.

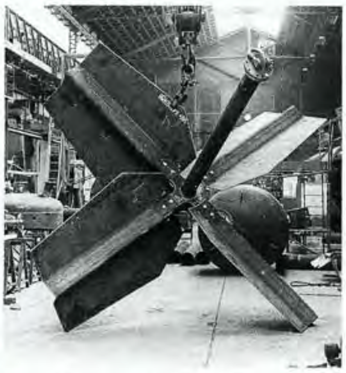
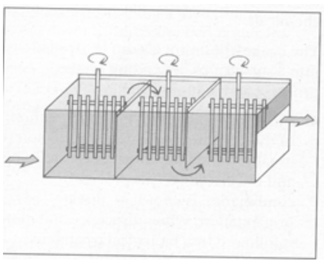
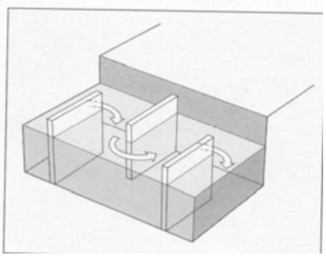


Figure 301. Propeller type flocculator.

Flocculation chambers vs flocculation channels

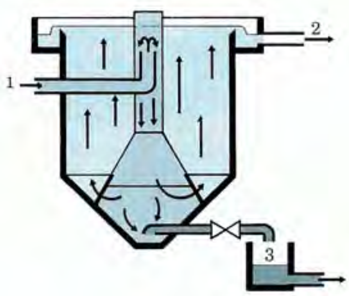




Advantages and disadvantages?

Separation

- Sedimentation
- Flotation
- Filtration



1 – Raw water.
2 – Treated water.
3 – Drain.

Figure 303. Cylindroconical settling tank.

Figure 305. Type P circular scraper settling tank. General view.

Flotation tank

Figure 302. Moulle facility (Northern France) for LE-Dumez. Surface water clarification by flotation. Battery of four dual-cell flocculators: Flow: 4 x 300 $m^3.h^{-1}$.

Reference literature

- Wastewater Engineering: Treatment and Resource Recovery. Metcalf & Eddy, 2013
- About Water Treatment, Kemira Kemwater, 2003
- Hardcover, 220 Pages, Published 2003
- Design of Municipal Wastewater Treatment Plants MOP 8, Fifth Edition (Wef Manual of Practice 8: ASCE Manuals and Reports on Engineering Practice, No. 76), 2009
- Coagulation and Flocculation in Water and Wastewater Treatment, John Bratby, Third Edition, 2016

Lesson 8: Chemical processes. Disinfection

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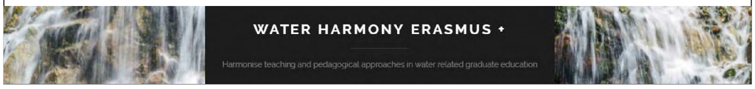


What drinking water can be called pure?

- Pure drinking water:
- **It contains**:
  - optimal calcium-magnesium-bicarbonate balance and **has** a high quality bacteriological and parasitological, radiological and organoleptic as well as physico-chemical parameters of water quality
- **It does not contain:**
  - Active chlorine and its organic compounds; nitrates and nitrites; salts of heavy metals; pesticides and other harmful organic substances; bacteria, fungi, parasites and viruses.

Aquatic pathogens

- Pathogens - microorganisms capable of causing human disease (often fatal).

Bacteria	Viruses	Protozoa
Campylobacter jejuni, Campylobacter Coli	Adenoviruses	Entamoeba histolytica
Salmonella (non typhi) Shigella spp	Enteroviruses Hepatitis A	Giardia intestinalis Cryptosporidium parvum
Escherichia Coli (E.Coli) (pathogens) Vibrio cholerae Yersinia enterolitica Pseudomonas aeruginosa Aeromonas spp	Enteroviruses hepatitis A, hepatitis E Norwalk virus Rotavirus Small round viruses	Dracunculus medinensis

Bacteriological and parasitological indexes

Index	Units	WHO	USEPA	EU	SanPin
Total bacterial count	CFU*	-	None	10 (at 22°C) 100 (at 37°C)	50
Total coliforms	Quantity in 100 ml	None	5%	None	None
Thermotolerant coliforms	Quantity in 100 ml	None	-	None	None
Fecal streptococcus	Quantity in 100 ml	-	-	None	-
Coliphages	PFU ** in 100ml	-	-	-	None
Spores of clostridia	20 ml	-	-	< 1	None
Giardia cysts	50 ml	-	None	-	None

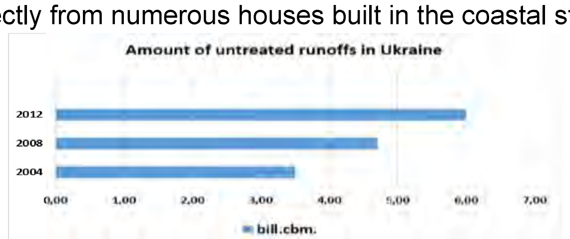
*Colony forming units
**Plague forming units

Radiological indexes of water quality

Index	Units	WHO	USEPA	EU	SanPin
General α - radioactivity	Bq / l	0.1	0.555	-	0.1
General β - radioactivity	Bq / l	1.0	-	-	1.0
Total Radium-226 and Radium-228	Bq / l	-	0.185	-	-
Effective dose	mSv / y	-	0.04	0.1	-
Tritium	Bq / l	-	-	100	-
Uranium	mg / l	-	30	-	-

Situation in Ukraine

- 2/3 of Ukraine's population use water from surface sources, in particular, from the Dnieper River basin, where untreated water is discharged by powerful chemical, petrochemical and metallurgical industries, as well as the runoff from fields and untreated water directly from numerous houses built in the coastal strip.



- The situation is compounded by the fact that almost all the water treatment plants in Ukraine were mostly built over 25 - 30 years ago, technically and physically outdated and unable to deal with the cleaning of contamination.

Consequences

- Chlorination of such kind of water forms chloro-organic substances that are very dangerous to humans; contact the mucous membranes of the esophagus, stomach, intestines with these carcinogens can cause cancer of the digestive system.

- Poor-quality water is one of the reasons that in recent years, the spread of such diseases is observed in Ukraine, as a stomach ulcer, gallstones, respiratory diseases, angina pectoris, myocardial infarction, cholecystitis.
- Only in the last 10 years recorded numerous cases of water-related and, in particular, drinking water-related diseases such as cholera, typhoid, viral hepatitis A, dysentery, salmonellosis

Consumption

- 60% of Ukrainians refuse to drink water from the centralized water supply systems;
- 9 out of 10 people of Kiev refused to drink water from the tap;
- Only 43% of them drink water only after pretreatment (by active carbon);
- More than half of the capital's residents do not use water supplied by "Kievvodokanal".

What should we do?

- In such circumstances, the task is to minimize the impact of all kinds of toxic compounds on the environment and living organisms;
- The main methods of disinfecting water, which are used for reducing the toxic impurities are:
  - **Chlorination.**
  - **Ozonation.**
  - **Ultraviolet water treatment.**
- All these methods are accompanied by oxidative processes

Oxidative methods

- Oxidation methods can be classified into:
- **natural**, which include the cleaning of water in nature under the influence of air oxygen, as well as under the influence of solar radiation;
- **artificial,** when the cleaning is done by effective oxidants (O_3, H_2O_2, MnO_2 , ClO_2, Cl_2, $HClO^-$, ClO etc.);
- **special**, such as thermo-oxidative, photocatalyst, electrochemical, radiation methods.

Chlorination

- Chlorine and its compounds possess a high bactericidal effect. It is explained by the action of chlorine and its compounds on bacterial cell protoplasm enzymes and microorganisms, which leads to their death.

Germ inactivation for chlorinated water*

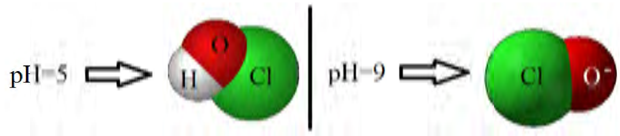
Germ	Time
E. coli O157:H7 Bacterium	Less than 1 minute
Hepatitis A Virus	About 16 minutes
Giardia Protozoan	About 45 minutes
Cryptosporidium Protozoan	About 15,300 minutes (10.6 days)

* Laboratory testing results using chlorine demand free water with 1ppm (1mg/L) 7.5, 77 °F (25 °C) and in the absence of cyanuric acid.

- The action of chlorine is varied depending on pH.
- With the adding of chlorine into the water formed hypochlorous (hydrogen (I) oxychlorate) and hydrochloric acid:

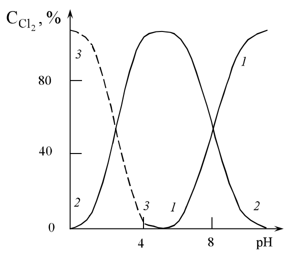
$$Cl_2 + H_2O = HOCl + HCl$$

- Increasing the pH of water solutions leads to the formation of hypochlorite ions - ClO^-.



- The chlorine acts as an oxidant in an acidic environment, in which there is no dissociation of hypochlorous acid.
- At pH>4 molecular chlorine is almost absent, $HOCl = H^+ + OCl^-$, HClO functions.
- In the future, with increasing pH ClO^- ion influences

$OCl^- + H_2O = Cl^- + HO^*$



Condition of active chlorine in aqueous solutions, depending on pH: 1 - ClO^-; 2 – HClO, 3 - $Cl2_2$

$$E^0_{Cl2/2Cl^-} = 1{,}359B; \quad E^0_{HClO+H^+/Cl^-+H_2O} = 1{,}47\,B; \quad E^0_{ClO^-+H_2O/Cl^-+OH^-} = 0{,}906\,B;$$

- In the presence of ammonium compounds in water hypochlorous acid forms as well as chloramine NH_2Cl and dichloramine $NHCl_2$. Chlorine in the form of chloramine called bound "active" chlorine.
- The formation of halogenated compounds associated with the fact that about 90% of active chlorine reacts oxidation:

$$R\text{-}CHO + HOCl \rightarrow R\text{-}COOH + HCl,$$

- and about 10% of chlorine reacts substitution :

$$R\text{-}CH_2\text{-}CH{=}CH\text{-}R_2 + HOCl \rightarrow R\text{-}CHCl\text{-}CH{=}CH\text{-}R_2 + H_2O.$$

- Sources of the "active" chlorine are calcium chlorate, hypochlorite, chlorate, chlorine dioxide. Calcium chlorate (bleach) obtained by reacting calcium hydroxide and chlorine:

$$Ca(OH)_2 + C1_2 = CaOC1_2 + H_2O.$$

- Hypochlorite (oxychlorate) sodium formed by passing chlorine gas through an alkaline solution:

$$Cl_2 + 2NaOH = NaClO + NaCl.$$

- Calcium hypochlorite is prepared by chlorination of calcium hydroxide at a temperature of 25–30 °C:

$$Ca(OH)_2 + 2Cl_2 = Ca(ClO)_2 + CaCl_2 + 2H_2O$$

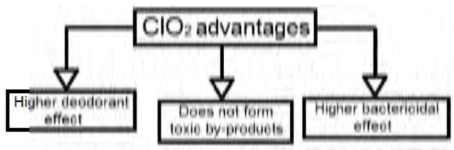
- A strong oxidizing agent is sodium chlorate and $NaClO_2$, which decomposes with the release of ClO_2:

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$$

$$5NaC1O_2 + 4HCl \rightarrow 5NaCl + 4ClO_2 + 2H_2O$$

- In an alkaline environment ClO_2 decomposes at a high speed by the reaction:

$$2ClO_2 + 2NaOH = 2NaClO_2 + NaClO_3 + H_2O$$



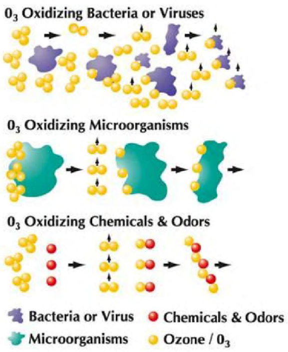
Residual chlorine

- Residual chlorine present in drinking water. It is very volatile and a small concentrations of it can quickly evaporate from the water. However, free chlorine represents a serious danger to human health at high concentrations.
- Standards of residual chlorine in the water:

Residual chlorine	The concentration of residual chlorine, mg/dm^3	Time required for chlorine to contact with water, min, not less than
1. Free	0,3-0,5	30
2. Bound	0,8-1,2	60

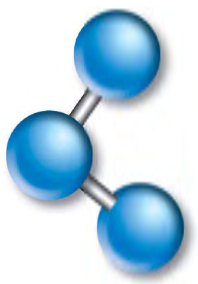
Ozonation

- Total virulent and bactericidal effect is achieved when using ozone. Ozone oxidation can effectively decolorize both drinking and waste water, improves taste, eliminates odors and flavors, holds a deep water disinfection.



Ozone O_3

- In nature, ozone is in the upper atmosphere. At the temperature of -111.9°C ozone is transformed into the unstable liquid. The relative molecular mass of 48 g/mol; density (at 0°C and a pressure of 0.1 MPa) 2.154 g/L; melting point -197.2±0.2°C; heat of formation 143.64 kJ/mol; coefficient of solubility in water at 0°C -0,394 kg/m^3; the redox potential of 2.07V.
- Technical Ozone is not explosive, but is very toxic. The maximum allowable concentration in the air of the working area is equal to 0.1 mg/m^3. The disinfecting effect of ozone on the air based on a high oxidizing ability due to their ease of return of active oxygen atom.



The decomposition of ozone in the air

$$O_3+M \underset{k-1}{\overset{k1}{\rightleftarrows}} O_2+O^{\bullet}+M$$

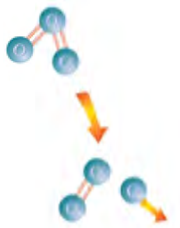
- k1 = 7,8 • 1011 [-2340/(RT)], l•mol $^{-1}$ • s $^{-1}$;
- k-1 = 1,24 • 10-10 [-1090/ (RT)], l•mol $^{-1}$• s $^{-1}$;

$$O + O_3 \overset{k2}{\rightarrow} 2O_2$$

- k2 = 2,9 • 109 [-3700/(RT)], l•mol $^{-1}$• s $^{-1}$,
- where M – random particle.

The decomposition of ozone in the water

- In water, ozone decomposition reaction mechanism is rather complicated, since the degradation rate is influenced by many factors:
  - the conditions for the transition from the gaseous ozone into the liquid phase,
  - the ratio between the partial pressure of the gas
  - its solubility in aqueous solution, the kinetics of oxidation by ozone in the water pollution.

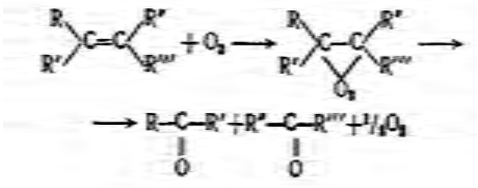


Oxidation by ozone

- The action of ozone in an oxidation process can occur in **three different ways**:
  - direct oxidation with one oxygen atom;
  - the accession of the whole molecule of ozone to the oxidizing agents to form ozonides;
  - increased catalytic oxidizing action of oxygen present in the ozonized air.

Direct oxidation

- Ozonolysis is a process for fixing the ozone double or triple carbon bond with its subsequent cleavage and formation of ozonides which as ozone, are unstable compounds and degrade rapidly:



Examples of oxidizing different substances with ozone

- Ozone oxidizes both inorganic and organic substances dissolved in the wastewater. Consider a few examples:
  - Metal compounds are oxidized by ozone to compounds of higher valence. For example, reaction with iron and manganese compounds occur as follows:

$$2FeSO_4+H_2SO_4+O_3=Fe_2(SO_4)_3+3H_2O+O_2,$$
$$MnSO_4+O_3+2H_2O=H_2MnO_3+O_2+H_2SO_4,$$
$$2H_2MnO_3+3O_2=2HMnO_4+3O_2+H_2O.$$

- The oxidation of hydrogen sulfide:

$$H_2S+O_3=H_2O+SO_2,\ 3H_2S+4O_3=3H_2SO_4.$$

- Thiocyanate ion (thiocyanate ions) react with ozone according to the scheme:

$$NCS^-+2O_3+2OH^- \rightarrow CN^-+SO_3^{2-}+2O_2+2HA$$
$$CN^-+SO_3^{2-}+2O_3 \rightarrow CNO^-+SO_4^{2-}+2O_2.$$

The oxidation process is recommended in a neutral or weakly acidic medium at a temperature of 5–25 °C.

- Ammonia is oxidized with ozone in an alkaline environment to a nitric acid and water:

$$NH_3+4O_3 \rightarrow 4NO_3^-+4O_2+H_2O+H^+.$$

With increasing pH from 7 to 9 increases in the reaction rate in 10-20 times. Therefore, from an economic point of view advantageous to use ozone for oxidation of ammonia when alkaline water is formed and there is no need for a special alkalization.

- Urea in aqueous solutions can be oxidized to nitric acid, ozone, carbon dioxide and water. A feature of the reaction is that it starts after a certain period of time after the submission of ozone. The higher the initial concentration of urea, the less time is required to start the reaction. Thus, when the content of urea of 50 mg/l the oxidation process starts after 220 minutes and at 550 mg/l, 30-40 minutes after the filling with ozone.

The reaction rate is highly dependent on pH. At pH 2.5 it is very low, ie. e. oxidation hardly occurs. With increasing alkalinity the reaction rate increases.

- Ozone rapidly reacts with cyanide in a weakly alkaline environment and forms initially less toxic cyanates completely. The last ones can be hydrolyzed in water or oxidized with ozone. In general, the oxidation reaction of cyanide with ozone represented by the following equations:

$$CN^-+O_3 \rightarrow OCN^-+O_2\uparrow,\ OCN^-+2H^++2H_2O \rightarrow CO_2+H_2O+NH_4+,$$
$$OCN^-+2H_2O \rightarrow HCO_3^-+NH_3,\ 2OCN^-+H_2O+3O_3 \rightarrow 2HCO_3^-+3O_2+N_2\uparrow.$$

Initially, free cyanide oxidized, and then connected with the metal complexes.

It is found that the ozone oxidation rate in alkaline cyanide solution (pH = 10,5-13,0) is practically independent of the concentration of OH^- ions. The reaction rate depends on the concentration of cyanide ions and ozone.

If the ozone concentration in the gas mixture is constant and sufficient to oxidize then

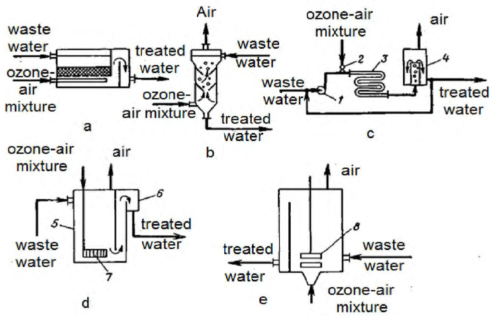
$$v = - d[CN^-]/d\tau - k2[CN^-]n.$$

When the concentration of cyanide in the solution equals 10-4 -10-2 mol/l, pH of solution 13.5 and the ozone feed rate of 17.0 mg/min n = 0,5.

- Ozone shows high activity in a wide range of concentrations (from 0 to 1000 mg/l) to the phenols. The mechanism of oxidation of phenol by ozone in acidic or alkaline solutions is the same, although the reaction rate under these conditions is significantly different.

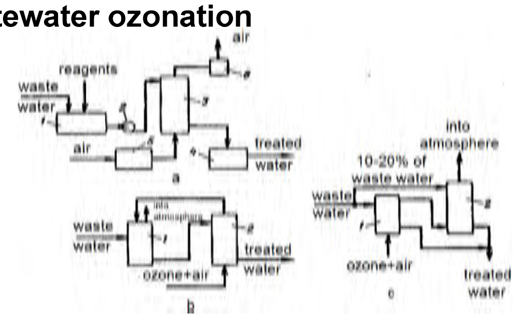
With an increase of the pH constant value of phenol decay rate increases by more than a half. The primary intermediate reaction product is catechol, then ohinon. After a series of transformations produced carboxylic acid.

Contact devices for ozonation:



a - with a nozzle; b - a bubble column with plates; c - a coil reactor; d - a bubble column with a porous plate; e - column with a mechanical turbine type stirrer; 1 - Pump; 2 - injector-mixer; 3 - coil; 4 - air separator; 5 - contact chamber; 6 - collection chamber; 7 - a diffuser; 8 - turbine

Technological schemes of installations for wastewater ozonation



- a - single-stage: 1 - mixer; 2 - pump; 3 - reactor; 4 - collector; 5 - ozone treatment plants; 6 - flue gas cleaning unit;
- b - two-stage with pre-ozonation;
- c - two-stage with separation of the waste water into two streams: 1, 2 - reactors

Technological schemes of installations for wastewater ozonation

- An important indicator of the ozonation process is the utilization rate of ozone. It is recommended to carry out a two-stage cleaning system in order to increase the rate. According to scheme **B** prior ozonation is carried out by a spent ozone-air mixture containing about 2 mg/l ozone. In the second reactor there is the final oxidation of impurities. According to the scheme **C** the process is also carried out in two reactors. In the first goes 80-90% of the total supplied amount of waste water, and the rest - in the second reactor. The ozone-air mixture passes successively both reactors. The ozone concentration in this case in the flue gas does not exceed 0.01% (wt.).

The decomposition of residual ozone

- Since ozone approaching to a strong toxic agents (superior, for example, hydrocyanic acid)at wastewater ozonation plants provided flue gas purification stage from ozone residues.
- The residual ozone destruction applied by:
  - **adsorption;**
  - **pyrolysis;**
  - **catalysis.**
- The catalyzed destruction leads to rapid decomposition of ozone into oxygen and atomic oxygen in the presence of a catalyst (platinum mesh) at 60-120°C. The contact time is less than 1 second.

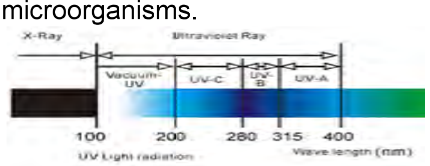
UV irradiaton

- Wastewater treatment process is significantly reduced when used in conjunction of ultrasound and ozone, ultraviolet radiation and ozone. Ultraviolet radiation accelerates oxidation in 102-104 times.
- The oxidation process can be divided into **two stages**:
  - the photochemical excitation of molecules by UV irradiation;
  - oxidation by ozone.

UV installation for water disinfection

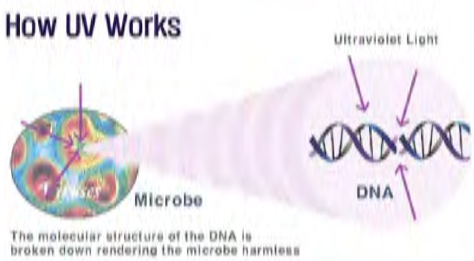
UV radiation classification

- UV-radiation covers a wavelength range from 100 to 400 nm. Vibrations with a wavelength of 100 to 200 nm is called hard or vacuum ultraviolet. Their energy can be enough for the destruction of organic molecules. Oscillations with a wavelength of 200 to 400 nm generated in special mercury or xenon lamps, and are widely used for disinfection of air and water from various microorganisms.



UV radiation effect on microorganisms

- Disinfectant (bactericide) effect has only a part of the spectrum of UV-radiation in the wavelength range 205-315 nm with maximum effectiveness of 260±10 nm.



Irradiation dose

- The effectiveness of disinfection of water (the portion of microorganisms killed by UV irradiation) is proportional to the light intensity (mW/cm^2) and time of treatment (s).
- The product of these two quantities is called a irradiation dose (mJ/cm^2) and is a measure of bactericidal power communicated to microorganism.
- The **minimum dose of UV** radiation for the disinfection of drinking water, - **16 mJ/cm^2**. It provides a reduction of pathogenic bacteria in the water by at least 5 orders of magnitude, as the indicator bacteria by 2-6 orders. This dose reduces the amount of viruses in the order of 2-3.

Advantages of UV disinfection method

- The most important quality of UV water treatment is the absence of a change in its physical and chemical characteristics even at doses much higher than practically necessary.
- The widespread method of UV disinfection of water explained by its advantages such as:
  - versatility and effectiveness of the impact on the various microorganisms in water;
  - ecological, safety for human life and health;
  - relatively low price;
  - low operating costs;
  - low capital cost;
  - ease of maintenance facilities.

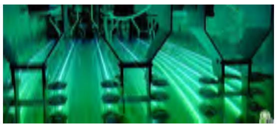
Disadvantages of UV disinfection method

- A serious drawback of UV disinfection is the absence of aftereffect, i.e. purified water can become contaminated again in subsequent stages of processing or transport.
- UV radiation kills microorganisms water, but the cell walls of bacteria, fungi, viruses protein fragments remain in the water. When used as a drinking water it is desirable to remove them by means of fine filtering.
- Complex method of UV irradiation and ozonation of water is the most effective way to overcome the shortcomings

Photochemical phenomena of system water-oxygen-ozone-hydrocarbons

- The system led to the synthesis of hydroxyl and hydroxyde-peroxyde radicals. When used as a radiation source for mercury lamps with low or high-pressure ozone decomposition process proceeds to O• (‘D), which is a singlet, and therefore reacts with water at high speed with forming a radical HO• by the following mechanism:

$$O\bullet\ (‘D) + H_2O \rightarrow 2\ HO\bullet$$



Mercury lamps with different pressure

- With values of wavelength $\lambda <$ 242 nm direct photodissociation of the water with forming of hydrogen atoms and hydroxyl radicals can occur:

$$H_2O \xrightarrow{h\nu} H\bullet + HO\bullet\ (x2п)$$

- All other radical synthesis processes HO• can be considered as minor.

Why should we use microchlorination?

- Ozonation and UV water treatment on a stage of it from organic compounds based on highly reactive radicals.
- The radicals react readily with a variety of impurities and inside walls of pipes and devices, which leads to their rapid disappearance. It is possible for the secondary pollution of water with microflora to occur.
- In order to prolong the action of processes of ozonation and UV treatment, in practice, used post chlorination.
- Microchlorination makes it possible to transport treated water to consumers over long distances.

Integrated water treatment

- The most efficient technology of integrated water treatment is the next order of steps:
  - Primary ozonation with the suppression of the microflora and the primary decomposition of hard degradable organic compounds.
  - Water treatment with ultraviolet radiation, which will completely clear the water from organic compounds due to the synthesis of oxygen-containing radicals (HO• и $HO_2\bullet$)
  - The sorption of residual carbon-containing products on activated charcoal (usually birch)

Lesson 8: Chemical processes. Wastewater disinfection

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WATER HARMONY ERASMUS +
Harmonise teaching and pedagogical approaches in water related graduate education

Annotation

- Technological scheme of wastewater treatment is shown.
- Fundamentals of chemical oxidation, stripping of ammonia, as well as the methods of disinfection of waste water - chlorination, ozonation, and ultraviolet irradiation are reviewed.

Keywords

- WASTEWATER, TECHNOLOGY, POLLUTION, MICROORGANISMS, DISINFECTION, OXIDATION, CHLORINATION, OZONATION, ULTRAVIOLET RADIATION.

Content

- Introduction
- Chemical oxidation
- Ammonia stripping
- Disinfection processes of ww

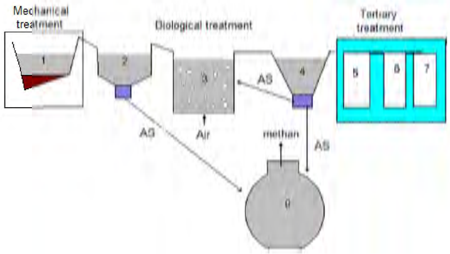
Introduction

Why should we treat the wastewater?

- Wastewater may contain high numbers of microorganisms, protozoa, organic and toxic substances, helminth eggs. If non-compliance with these requirements the water pollution, violation of self-purification processes and the subsequent violation of the biocenosis may occur.

Introduction

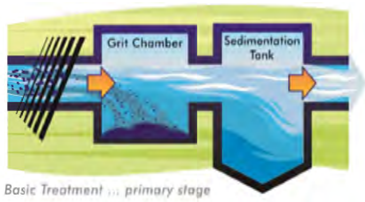
Waste water treatment plant



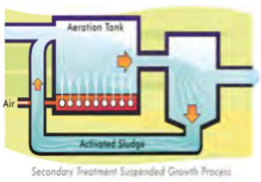
1 - grit chambers; 2 - primary sedimentation tanks; 3 - aeration tank; 4 - secondary sedimentation tanks; 5 - biological ponds; 6 - clarifier; 7 - chemical treatment; 8 - methan tank; AS - activated sludge.

Introduction

Mechanical treatment
The scheme begins with mechanical cleaning. It is most often used gratings and grit chambers. Gratings are delayed largest impurity. Grit chambers are necessary in order to retain the sand, including other small particles.



Introduction



Secondary treatment
In the aeration tank, wastewater is vigorously mixed with air and microorganisms acclimated to the wastewater in a suspension for several hours. This allows the microorganisms through their enzymes to break down the organic matter in the wastewater. The mass of microorganisms grows and the excess biomass (including discharged microorganisms) is removed by settling.

Introduction

Tertiary treatment
Biological ponds are artificially created ponds for biological wastewater treatment based on the processes that occur in the self-purification of water bodies. Ponds have a small depth - 0.5 - 1m. This provides a significant surface of contact with air and water to provide the entire heating of the water column and its mixing.

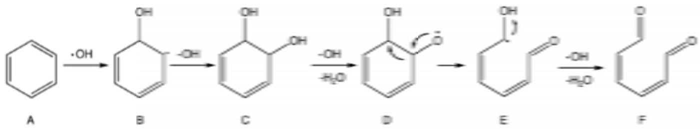
The duration of being water in the pond - 8 - 12 days. The fish can be bred in these ponds.

Chemical oxidation

- **Oxidation processes**, are a set of chemical treatment procedures designed to remove organic (and sometimes inorganic) materials in waste water by oxidation through reactions with hydroxyl radicals (•OH). In real-world applications of wastewater treatment, however, this term usually refers more specifically to a subset of such chemical processes that employ ozone (O_3), hydrogen peroxide (H_2O_2) and/or ultraviolet radiation.

Chemical oxidation

- The OP procedure is particularly useful for cleaning biologically toxic or non-degradable materials such as aromatics, pesticides, petroleum constituents, and volatile organic compounds in waste water. Additionally, OPs can be used to treat effluent of secondary treated wastewater which is then called tertiary treatment.



Chemical oxidation

The mechanism of •OH production depends on the sort of OP technique that is used. For example, ozonation, UV/H_2O_2 and photocatalytic oxidation rely on different mechanisms of •OH generation:

•UV/H_2O_2:

$$H_2O_2 + UV \rightarrow 2\bullet OH$$

Homolytic bond cleavage of the O-O bond of H_2O_2 leads to formation of 2•OH radicals

Chemical oxidation

•Ozone based OP:

$$O_3 + HO^- \rightarrow HO_2^- + O_2$$

Reaction between O_3 and a hydroxyl ion leads to the formation of H_2O_2 (in charged form)

$$O_3 + HO_2^- \rightarrow HO_2\bullet + O_3^-\bullet$$

A second O_3 molecule reacts with the HO_2^- to produce the ozonide radical

$$O_3^-\bullet + H^+ \rightarrow HO_3\bullet$$

This radical gives to •OH upon protonation

$$HO_3\bullet \rightarrow \bullet OH + O_2$$

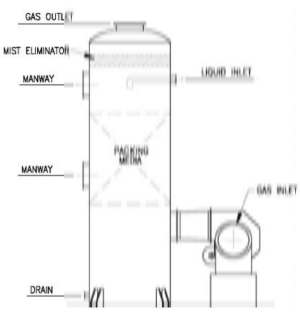
Ammonia stripping

- In a waste stream, ammonium ions exist in equilibrium with ammonia.

$$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O$$

- 1. Below pH 7, virtually all the ammonia will be soluble ammonia ions.
- 2. Above pH 12, virtually all the ammonia will be present as a dissolved gas.
- 3. The range between 7 and 12, both ammonium ions and dissolve gas exist together.
- 4. Percentage of dissolved gas increases with temperature and pH. Where temperature and pH favor removal of ammonia from solution.

Ammonia stripping



In the stripper, the pH and temperature are adjusted before the water enters the stripper.

As the water is distributed over the internal packing media, it is broken up into small droplets which create a tremendous amount of surface.

Air enters the bottom of the tower from a fan and travels upward through the packing. Since the ammonia is partially present as a dissolved gas, some of the ammonia transfers from the water to the air.

Disinfection processes

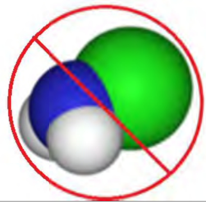
- The purpose of disinfection in the treatment of waste water is to substantially reduce the number of microorganisms in the water to be discharged back into the environment for the later use of drinking, bathing, irrigation, etc.

Disinfection processes

- Common methods of disinfection include:
  - **chlorination;**
  - **ozonation;**
  - **ultraviolet light.**

Disinfection processes

- **Chlorine** and its compounds possess a high bactericidal effect. It is explained by the action of chlorine and its compounds on bacterial cell protoplasm enzymes and microorganisms, which leads to their death.
- Chloramine, which is used for drinking water, is not used in the treatment of waste water because of its persistence.



Disinfection processes

- When dissolved in water, chlorine converts to an equilibrium mixture of chlorine, hypochlorous acid (HOCl), and hydrochloric acid (HCl):

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

- In acidic solution, the major species are Cl_2 and HOCl, whereas in alkaline solution, effectively only ClO^- (hypochlorite ion) is present. Very small concentrations of ClO_2^-, ClO_3^-, ClO_4^- are also found.

Disinfection processes

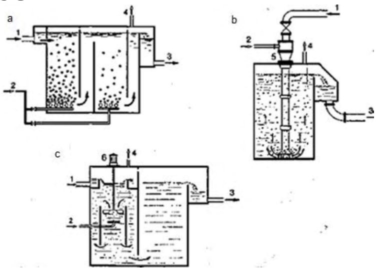
The amount of active chlorine introduced per volume unit of waste water, is called chlorine dose and expressed in g/m^3.

- To reduce Coli-forms by 99.9% the following chlorine doses are required, g/m^3:
  - After the mechanical purification 10;
  - After chemical cleaning 3-10;
  - After the complete biological purification and partial 3-5;
  - After filtration on sand filters 2-5.

Disinfection processes

a - two-section bubbling chamber;
b - camera equipped with an injector;
c - camera equipped with an impeller;

1,3 - wastewater supply and disposal of treated water;
2 - supply of ozone-air mixture;
4 - release of ozone-air mixture;
5 - an injector;
6 - an impeller unit



contact chamber with injection of the ozone-air mixture with wastewater

Disinfection processes

- One disadvantage is that chlorination of residual organic material can generate chlorinated-organic compounds that may be carcinogenic or harmful to the environment. Residual chlorine may also be capable of chlorinating organic material in the natural aquatic environment. Further, because residual chlorine is toxic to aquatic species, the treated effluent must also be chemically dechlorinated, adding to the complexity and cost of treatment.

Disinfection process

UV irradiation

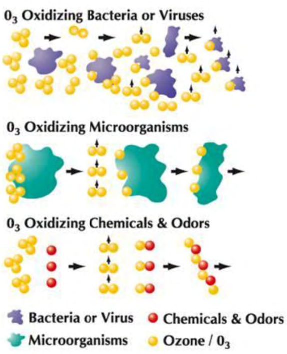
- Wastewater treatment process is significantly reduced when used in conjunction of ultrasound and ozone, ultraviolet radiation and ozone. Ultraviolet radiation accelerates oxidation in 10^2-10^4 times.

The oxidation process can be divided into **two stages**:
- the photochemical excitation of molecules by UV irradiation;
- oxidation by ozone.

Disinfection processes

Ozonation

- Total virulent and bactericidal effect is achieved when using ozone. Ozone oxidation can effectively decolorize both drinking and waste water, improves taste, eliminates odors and flavors, holds a deep water disinfection.



Disinfection processes

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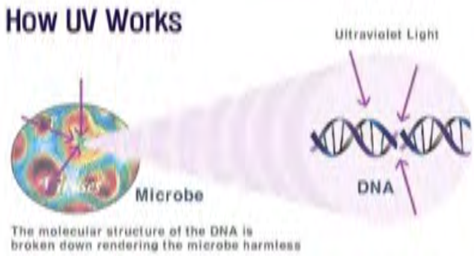

Disinfection processes

- The most important quality of UV wastewater treatment is the absence of a change in its physical and chemical characteristics even at doses much higher than practically necessary.
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Disinfection processes

- A serious **drawback** of UV disinfection is the absence of aftereffect, i.e. purified water can become contaminated again in subsequent stages of processing or transport.
- UV radiation kills microorganisms water, but the cell walls of bacteria, fungi, viruses protein fragments remain in the water.

<u>Complex method of UV irradiation and ozonation of wastewater is the most effective way to overcome the shortcomings</u>

Disinfection processes

Photochemical phenomena of system water-oxygen-ozone-hydrocarbons led to the synthesis of hydroxyl and hydroxyde-peroxyde radicals. When used as a radiation source for mercury lamps with low or high-pressure ozone decomposition process proceeds to O• (‘D), which is a singlet, and therefore reacts with wastewater at high speed with forming a radical HO• by the following mechanism:

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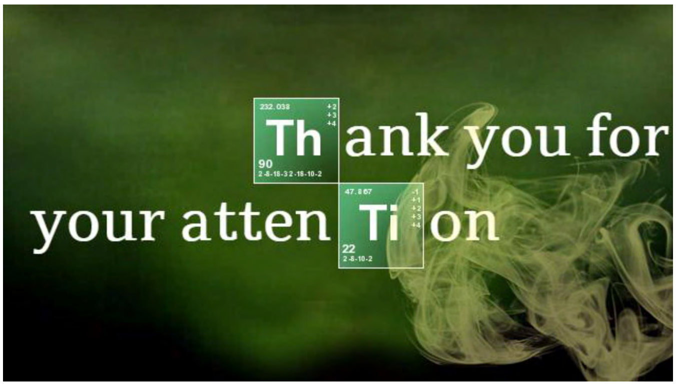
Mercury lamps with different pressure



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Biological processes organic matter

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Learning objective

- Knowledge about the processes of biological degradation processes
- Knowledge about biological processes in domestic wastewater treatment
- Context of various degradation processes
- Knowledge about dimension

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Main objective of biological wastewater treatment

- Substances which have negative impact on water quality have to be converted by simple biological processes into harmless substances:
  - Gases: N_2, CO_2, CH_4
  - Soluble substances: H_2O, NO_3^-, HCO_3^-
  - Solids: Biomass, flocs

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Determination of different food conditions

- <u>Source of Energy</u>
  - **Chemotrophic:** energy generation of microorganism (MO) by reduction-oxidation processes (chemical conversion)
  - **Phototrophic:** utilisation of electro-magnetic radiation (light)
- <u>Carbon source</u> (for generation of biomass):
  - **heterotrophic:** microorganism are using organic compounds
  - **phototrophic:** microorganism are using non organic compounds (CO_2)
- <u>Donator of hydrogen or electrons</u> (substance which will be oxidised):
  - **litrotrophic:** MO are using inorganic substances: NH_4^+, NO_2^-, H_2, S_2^-)
  - **organotrophic:** MO are using organic substances
- <u>Temperature:</u>
  - **mesophile:** range of growth of MO 20 – 42 °C
  - **thermophile:** range of growth of MO 40 – 70 °C

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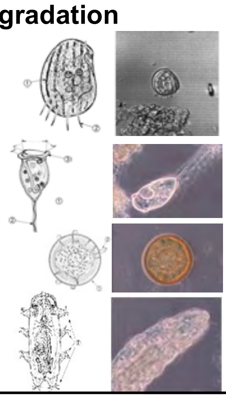
Microorganismn aerobic degradation

- **Protozoa**
  - **Ciliates**
    unicellular organism
    free swimming organism
    robust, grazing of flocs
  - **Vorticella convalaria**
    good oxygen supply
  - **Mastigophorans**
    flagellates for locomotion
  - **Rotifer**
    multicellular organism
    high generation time and sludge age



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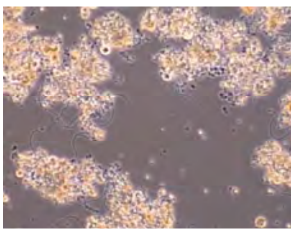
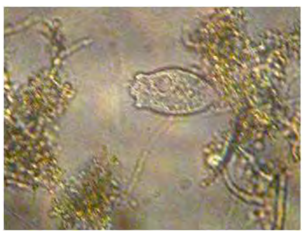
Microorganismen aerobic degradation

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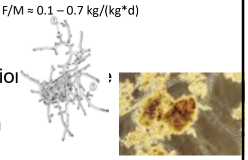
Microorganismen aerobic degradation

- **Filamentous bacteria**
  - Many bacteria may form filaments
  - High number of filamentous bacteria have negative impact on sedimentation
  - Many forms may occur: bulking sludge, floating sludge, foam
  - Bulking sludge when SVI > 150 ml/g
  - Problem on many wwtp's
  - Reasons:
    - Wastewater composition
    - Low F/M-ratio
    - High concentration of fatty acids
    - Low oxygen concentrations

Nocardia
F/M ≈ 0.1 – 0.7 kg/(kg*d)



Microthrix parvicella
F/M ≈ 0.05 – 0.2 kg/(kg*d)

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Aerobic degradation of organic matter

Energy metabolism (Dissimilation)

$CH_2O + O_2 \Rightarrow CO_2 + H_2O + Energy$

Growth of biomass (Assimilation)

$5\ CH_2O + NH_3 + Energy \Rightarrow C_5H_7NO_2 + 3\ H_2O$

Total reaction (outside view)

$15\ CH_2O + 5\ O_2 + 2\ NH_3 \Rightarrow 2\ C_5H_7NO_2 + 5\ CO_2 + 11\ H_2O$

450 g — 160 g — 34 g — Biomass 226 g

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Aerobic degradation of organic matter

- **Assimilation** (growth)
  while high food supply (high organic loads)
  - High production of biomass ⇒ high sludge growth
  - Low specific rate of oxygen consumption
  - Degradation of substances with high energy yield
- **Dissimilation** (energy metabolism)
  while low food supply (low organic load)
  - Low production of biomass ⇒ less sludge
  - Respiration of stored organic material
  - High rate of specific oxygen consumption
  - Extensive degradation of organic substances

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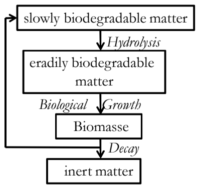
Conversion processes

- **Main processes during degradation of organic matter**
  - Adsorption and sorption of organic matter at and in microorganisms
  - Transport into the cells (resorption, osmotic processes)
  - Storage of organic substances and products inside cells
  - Conversion into biomass, intermediate products, CO_2, H_2O



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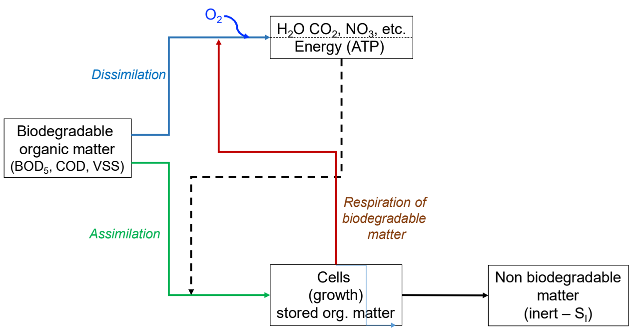
Scheme of aerobic degradation of organic matter



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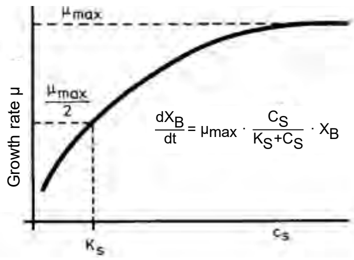
Monod Kinetics



$$\frac{dX_B}{dt} = \mu_{max} \cdot \frac{C_S}{K_S + C_S} \cdot X_B$$

X_B Biomass [g/m³]
μ growth rate [1/d]
μ_{max} maximum growth rate [1/d]
C_S Concentration substrate [g/m³]
K_S Half saturation coefficient [g/m³] (Concentration of substrate at $\mu_{max}/2$)

- Degradation of organic matter is controlled by enzymes
- For readily biodegradable substances enzymes are still present ⇒ immediate and rapid degradation

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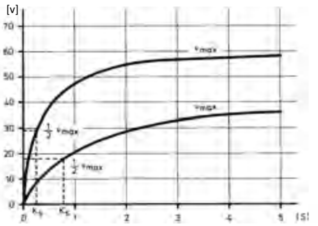
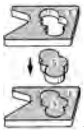
Reaction kinetics



$$\frac{dC_S}{dt} = v_{max} \cdot \frac{C_S}{K_S + C_S} \cdot X_B$$

- v reaction rate [g/(m³*d)]
- v_{max} max. reaction rate [g/(m³*d)]
- S Concentration of substrate [g/m³]
- K_S Half saturation coefficient [g/m³] (Concentration of substrate at $v_{max}/2$)



- Substrate and Enzymes form a Enzyme-Substrate-Complex
- Rate of enzyme reaction is similar to the concentration of enzyme-substrate-complex
  ⇒ **Michaelis-Menten equation**

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Kinetics

- Bacterial growth by division of cells
- Growth rate

$$\frac{dX_B}{dt} = \mu \cdot X_B \qquad X_B(t) = X_{B,0} \cdot e^{(\mu \cdot t)}$$

X_B = concentration of biomass [g/m³]
t = time [d]
μ = growth rate [1/d]

- Decay

$$\frac{dX_B}{dt} = -b \cdot X_B \quad X(t) = X_{B,0} \cdot e^{(-b \cdot t)}$$

b = decay rate [1/d] ≈ 0.05 – 0.10 * μ_{max}

- Generation time t_d: period, in which duplication occurs

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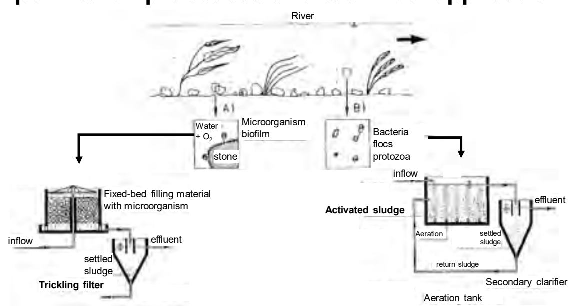
Self-purificaion processes and technical application



- Strengthening of natural self-purification processes by technidal applications

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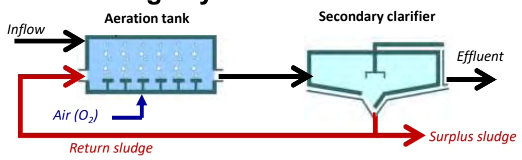
Activated sludge system



Aeration tank: organic matter = substrate for microorganism
microorganism and oxygen (air)
⇒ growth of microorganism ⇒ wastewater treatment

Secondary clarifier: separation of sludge by sedimentation, thickening of sludge
⇒ non biodegradable soluble substance and rest of suspended solids

Return sludge: Return of sedimentated sludge
⇒ decoupling of retention time from sludge retention time

Surplus sludge: removal of grown sludge
⇒ control of mixed liquor

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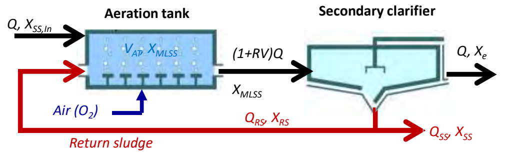
Activated sludge system



Q	inflow into aeration tank
$X_{SS,IN}$	suspended solid inflow
V_{AT}	Volume aeration tank
X_{MLSS}	mixed liquor concentration
X_e	solid concentration effluent
Q_{RS}	flow of return sludge
X_{RS}	solid concentration return sludge
Q_{SS}	flow of surplus sludge
X_{SS}	suspended solids in effluent

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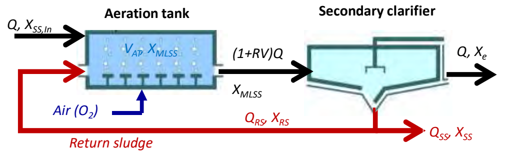
Activated sludge system



Flow balance secondary clarifier:
$Q_{RS} = RV * Q$
$RV = \frac{Q_{RS}}{Q}$
$(1+RV)*Q = Q + Q_{RS}$

Solid balance secondary clarifier[1]:
$B_{MLSS} = B_{xe} + B_{XRS}$
$(1+RV)*Q*X_{MLSS} = Q*X_e + Q_{RS}*X_{RS}$
$(1+RV)*Q*X_{MLSS} = Q_{RS}*X_{RS}$

Xe ≈ 0 g/m³
$X_{MLSS} = \frac{Q_{RS} * X_{RS}}{(1+RV)*Q}$
$X_{MLSS} = \frac{RV * X_{RS}}{(1+RV)}$

Parameters activated sludge system

- **F/M ratio**

$$B_{BOD} = \frac{B_{d,BOD,}}{X_{MLSS} \cdot V_{AT}} \left[\frac{kg\ BOD_5}{kg\ MLSS * d}\right]$$

$$B_{COD} = \frac{B_{d,COD}}{X_{MLSS} \cdot V_{AT}} \left[\frac{kg\ COD}{kg\ MLSS * d}\right]$$

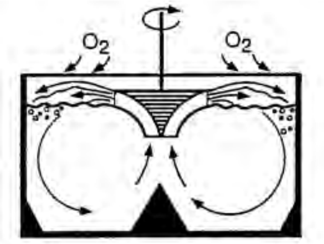
- **Sludge age**

(medium retention time of sludge in activated sludge system)

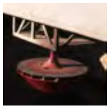
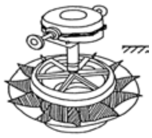
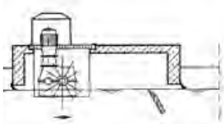
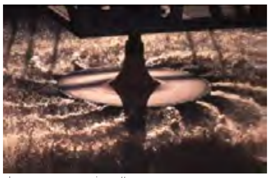
$$t_{MLSS} = \frac{X_{MLSS} * V_{AT}}{SS_d} = \frac{X_{MLSS} * V_{AT}}{X_{SS} \cdot Q_{SS} + X_e \cdot Q}\ [d]$$

Aerators activated sludge system

- Surface aerators



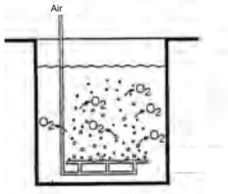
Aerators activated sludge system

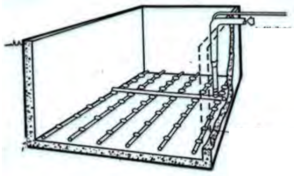






Input of oxygen into activated sludge systems

- Bubble or pressure aeration by aerators (diffusors)
  - Aeration and mixing
  - Different forms of aerators
  - Different sizes of bubbles







Aerators in activated sludge systems

Plate aerator


Disc aerators



Diffusors

Air compressors

Rotary piston compressor

Screw compressor


Turbo compressor

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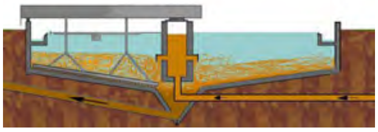
Secondary clarifier



- Tasks:
  - Separation of mixed liquor (solid-liquid separation)
  - Low concentration of suspended solids in the effluent
  - Regular distribution of the inflow on the tank
  - Avoidance of hydraulic short-cuts and turbulences
  - Thickening of sludge
  - Storage of sludge during stormwater inflow

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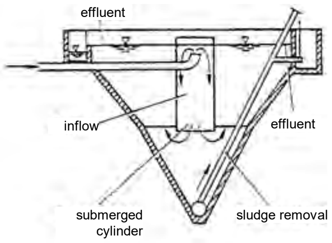
Secondary clarifier – vertical loading



+ Good separation of sludge
- High capital costs due to depth
- Mainly for small treatment plants

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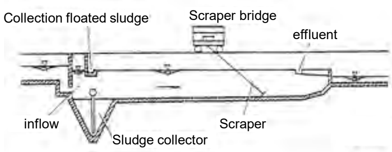
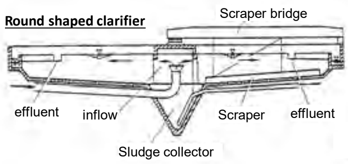
Secondary clarifier – horizontal loading



+ Low demand of space
+ Continious sludge recycling
+ Low capital costs
- High loading of weirs
- Constant velocity of water

Round shaped clarifier



+ Simple inflo construction
+ Continious sludge recycling
+ Low capital costs
+ Simple water and sludge
+ Low loading of weirs
- High demand of space esp. for various tanks

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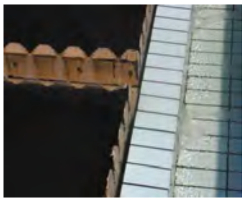
Secondary clarifier – effluent constructions



Overfall weir

Overfall weir with submerged wall

Floating sludge

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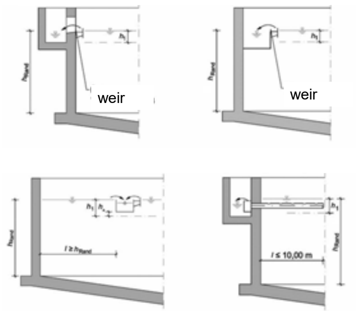
Secondary clarifier – effluent constructions



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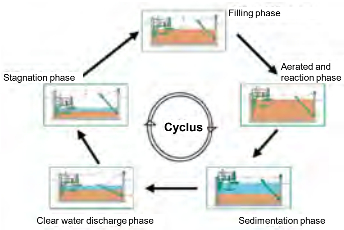
Secondary clarifier – sludge collection

Round shaped tank with scraper bridge

Rectangular tank with lifted scraper shield

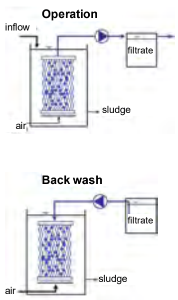
Sequencing batch reactor (SBR)

- Non constant water level and volume in in the reactor
- Different reaction phases in one reactor
- No constant inflow
- Control of the duration of the different phases

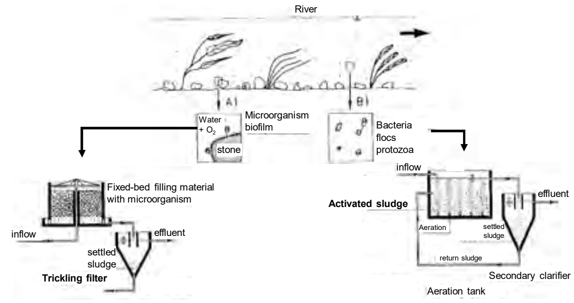


Sequencing batch reactor (SBR)

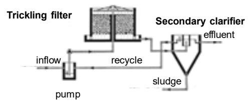
Membrane biological reactors (MBR)



Self-purificaion processes and technical application



Trickling filter



Trickling filter

- Obligate aerob => only removal of orgnanic matter and nitrifikation
- Mass of active sludge can't be determined
- Retention time of wastewater: approx. 10 – 20 minutes
- Distribution of biomass in the trickling filter has a gradient
  upper part: high loads and high acitivity
  lower part: microoganism with longer generation time
- Thickness of biofilm depends on the load
- Surplus sludge will be washed out
- Recycle can increase effluent quality
- Mainly on small wwtp's (< 10.000 cap)
  often as combined plants with activated sludge systems or pond systems

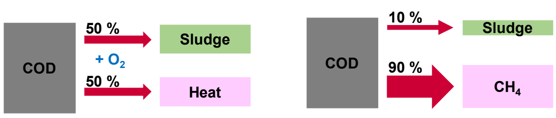
Rotating biological contactor (RBC)

Energy profit of bacteria degrading glucose

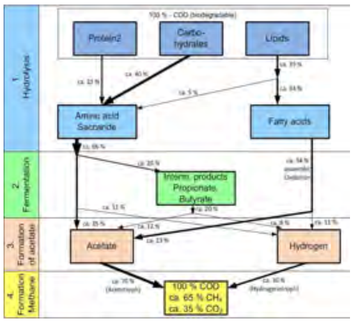
- Aerobic:
  $C_6H_{12}O_6 + 6\ O_2$ ⇨ $6\ CO_2 + 6\ H_2O$
  Energy profit ⇨ - 1,100 kJ
- Anaerobic:
  $C_6H_{12}O_6$ ⇨ $3\ CH_4 + 3\ CO_2$
  Energy profit ⇨ - 172 kJ

COD-Balance

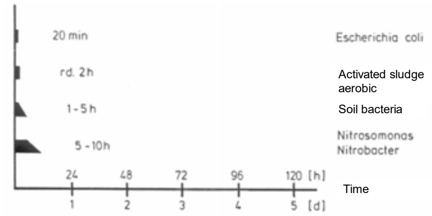
- Comparison aerobic and anaerobic degradation



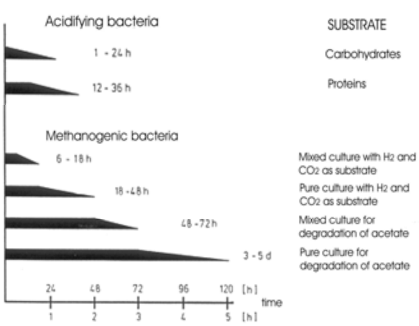
Scheme of anaerobic degradation



Generation time of aerobic bacteria



Generation time of anaerobic bacteria



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Advantages anaerobic treatment

+ Appropriate for high COD-concentrations
+ High volumetric load => Small volumes required
+ Low sludge production
  (3 –10-lower than with aerobic treatment)
+ Low energy demand, no aeration necessary
+ Yield of biogas
+ Lower cost than for aerobic treatment
+ Degradation of substances which are non-biodegradable under aerobic conditions
+ Suitable for hot climate conditions

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Disadvantages anaerobic treatment

- Efficiency of degradation of organic substances only up to 70 – 80 %,
  => aerobic post-treatment required
- Balance of volatile fatty acids
- Long adaptation phases necessary
- Sensitivity towards oszillating temperature, pH-value, changing concentrations and loads
- Detailed monitoring systems required
- Sometimes pH-control required

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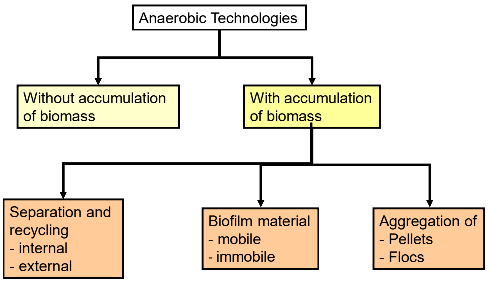
Structure of anaerobic technologies



Biological processes nitrogen & phosphorus

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Learning objective

- Knowledge about the processes of the removal of nitrogen and phosphorus from wastewater by biological processes
- Knowledge about systems with enhanced biological treatment processes

Nitrogen in wastewater

- Nitrogen in domestic wastewater is mainly from human excreta

$$CON_2H_4 + 3\ H_2O \xrightarrow{\text{Urease}} 2\ NH_4^+ + OH^- + HCO_3^-$$

- Hydrolysis from urea to Ammonia (ammonification) takes often place in sewer systems

Pathways of nitrogen

- Incorporation in biomass by degradation of organic matter
- Necessity of elimination:
  - Load per person: 10 g N/(cap*d)
    this is a concentration of 65 g/m³ with a volume of 150 l/(cap*d)
  - Nitrogen content of grown sludge: 0.07 gN/g MLSS
  - Sludge production rate:
    40 g BOD/(cap*d) * 1 g MLSS/g BOD_5 = 40 g MLSS/(cap*d)
    40 g MLSS/(cap*d) * 0.07 g N/g MLSS = 2.8 gN/(cap *d)
  - Nitrogen removal by incorporation:
    2.8 /0.150 l/(cap*d) = 18 gN/m³
  - Nitrogen which has to be eliminated:
    65 – 18 g N/m³ = **37 g N/m³**

⇒ **Targeted nitrogen elimination is necessary!**

Pathways of nitrogen

- “excess” of nitrogen not bound in biomass has to be eliminated in two steps
- first step:
  conversion of ammonia to nitrate – Nitrification
  conversion of nitrate to nitrogen – Denitrification
- Removal of nitrogen from domestic wastewater only by denitrification
- After biological treatment an residual organic nitrogen remains, which is incorporated in non-biodegradable organic substances
  approx. 1 - 2 g N/m³

Nitrification

$$NH_4^+ + 2\ O_2 \Rightarrow NO_3^- + H_2O + 2\ H^+ + \text{energy}$$

- Characteristics of nitrification process:
  - High energy demand : 4,6 g O_2 per g NH_4-N
    with integration of biomass growth: 4,25 g O_2 per g NH_4-N
  - Production of 2 mol H^+ per mol NH_4-N
- Energy from the reaction above will be used for the production of new biomass (growth)
- Source for carbon for the production of biomass is anorganic (CO_2/CO_3^{2-})
- **Nitrifiers are autotrophic bacteria!!**

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Nitrification

- **Nitritation** (oxidation of Ammonium) by **Nitrosomonas**
  $NH_4^+ + 1{,}5\ O_2 \rightarrow NO_2^- + H_2O + 2\ H^+$ (+243-352 kJ/mol)
  $15\ CO_2 + 13\ NH_4^+ \rightarrow 10\ NO_2^- + 3\ C_5H_7NO_2 + 4\ H_2O + 23\ H^+$
  $\mu_{max} = 0{,}47 * 1{,}103^{(T-15)}$ [d⁻¹]
- **Nitratation** (oxidation of niitrite) by **Nitrobacter**
  $NO_2^- + 0{,}5\ O_2 \rightarrow NO_3^-$ (+63 - 80 kJ/mol)
  $5\ CO_2 + NH_4^+ + 10\ NO_2^- + 2\ H_2O \rightarrow 10\ NO_3^- + C_5H_7NO_2 + H^+$
  $\mu_{max} = 0{,}79 * 1{,}071^{(T-15)}$ [d⁻¹]
- **Total**
  $NH_4^+ + 2\ O_2 \rightarrow NO_3^- + H_2O + 2\ H^+$ (4,57 g O_2/g NH_4-N)
  $NH_4^+ + 1{,}98\ HCO_3^- + 1{,}86\ O_2 \rightarrow 0{,}98\ NO_3^- + 0{,}02\ C_5H_7NO_2 + 1{,}88\ H_2CO_3 + 1{,}04\ H_2O$
  (4,25 g O_2/g NH_4-N)

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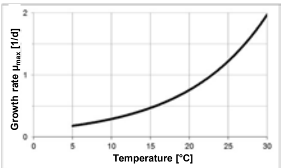
Effect of temperature on nitrification

	Growth rate				Sludge age
Temp.	Nitrosomonas		Nitrobacter		
[°C]	[1/d]	[h]	[1/d]	[h]	[d]
10	0,29	82,8	0,58	41,4	3,44
20	0,76	31,6	1,04	23,1	1,32
30	1,97	12,2	1,87	12,8	0,53



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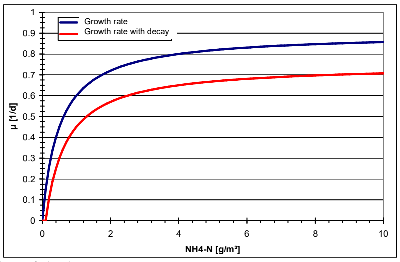
Kinetics Nitrification

$$\mu = \mu_{max} \bullet \frac{S_{NH}}{K_{NH} + S_{NH}} - b_A$$

Parameter	Unit	Range	common
Maximum growth rate μ_{max} (T = 20 °C)	1/d	0,6 – 0,8	0,8
Half-saturation K_{NH}	g/m³	0,5 – 1,0	1,0
Decay rate b_A	1/d	0,05 – 0,15	0,15
O_2-Half saturation	g/m³	0,15 – 2,0	0,4



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Denitrification

- Denitrification:
  Reduction of oxidised nitrogen-compounds (nitrite, nitrete) to nitrogen (N_2) by heterotrophic bacteria due to the absence of oxigen (anoxic conditions)
- *„Respiration with oxygen “:*
  $$2CH_3OH + 3O_2 \Rightarrow CO_2 + 4H_2O$$
- *„Respiration with nitrate “:*
  $$5\,CH_3OH + 6\,NO_3^- \Rightarrow 5\,CO_2 + 7\,H_2O + 3\,N_2 + 6\,OH^-$$
- Energy yield at „respiration of nitrate“ 10 % lower than using oxygen ⇒ aerobic conditions are preferred instead of aerobic condition by bacteria
- Most of heterotrophic bacteria are able to do both degradation processes
- Yield of buffer capacity (1 mol/mg NO_3-N)

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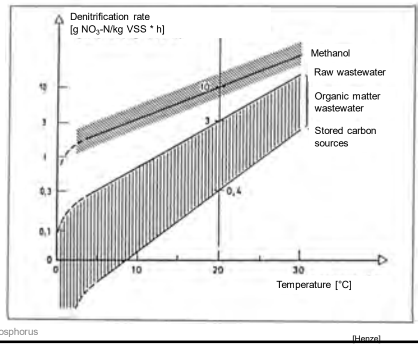
Dependency of denitrification on substrate



[Henze]

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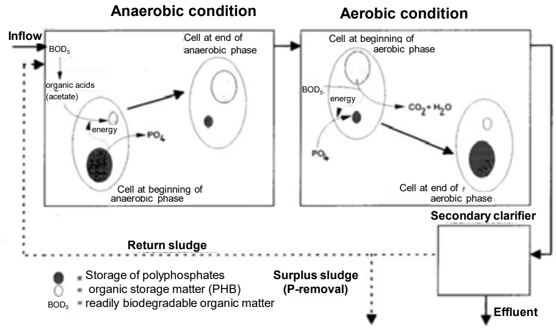
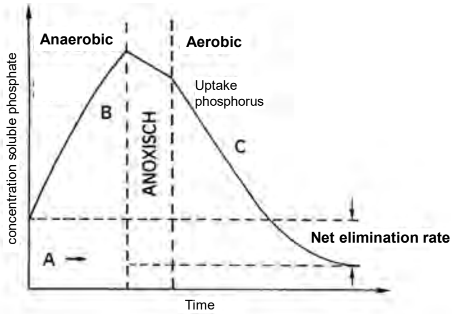
Enhanced biological phosphorus removal

- Principle
  - Sequencing alternation of anaerobic and aerobic conditions
  - Accumulation of phosphorus by organisms (PAO)
  - P-content in sludge increase from 1,5 - 2 % to 3 - 5 %
- Processes
  - Anaerobic condition
    - Degradation of polyphosphate with energy yield (P-removal)
    - Fermentation of readily biodegradable substances (formation of organic acids)
    - Uptake of organic acids for the formation of intracellular storage compounds
  - Aerobic conditions
    - Degradation of storage compounds and yield of energy
    - Uptake of phosphate (degradation of polyphosphates)

Enhanced biological phosphorus removal (EBPR)

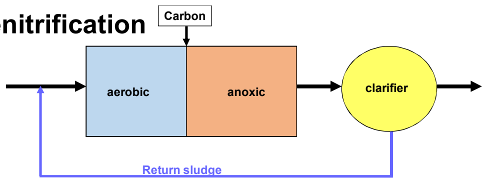


Enhanced biological phosphorus removal (EBPR)



„Net elimination rate " is caused by the incorporation of phosphorus into the grown surplus sludge.

Post-Denitrification

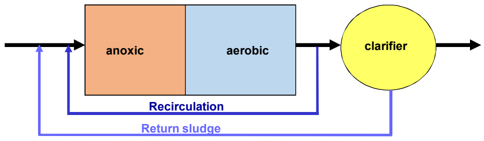


- \+ nearly every NO_3-N-effluent concentration can be achieved
- \+ no internal recirculation
- \+ suitable for biofilm systems

- \- Costs for chemicals due to dosing of carbon source
- \- Risk of formation of nitrite
- \- Risk of enhanced concentrations of organic matter (COD) in the effluent

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation
Wastewater | Return sludge | Recirculation

Pre-Denitrification

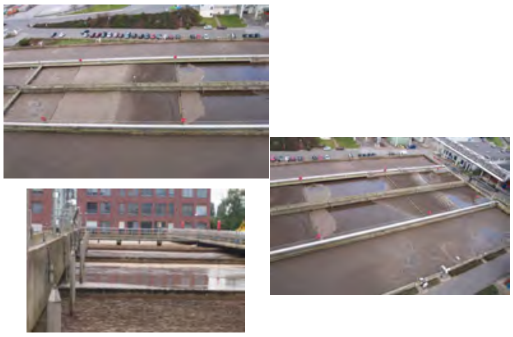


- \+ optimal use of organic carbon (BOD5) from wastewater
- \+ small volumes for denitrification due to high denitrification rates
- \+ alternating zones (aerated/non-aerated) for different loadings and times
- \+ easy to control

- \- High internal flow rates

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation
Wastewater | Return sludge | Recirculation

Pre-Denitrification

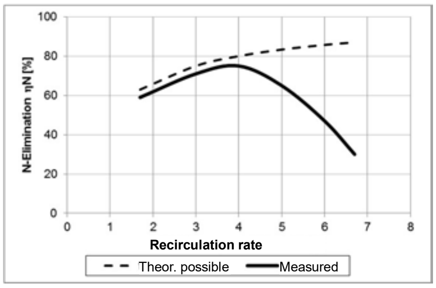


Elimination rates with pre-Denitrification

Recirculation rate RR

$$RR = \frac{S_{NO3,D}}{S_{NO3,eff}}$$

$$\eta_{DN} \leq 1 - \frac{1}{1+RF}$$



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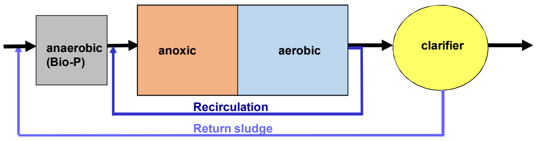
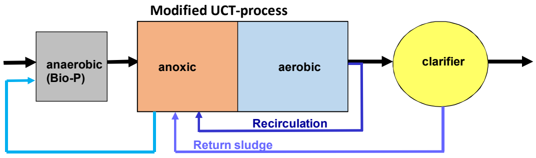
Pre-Denitrification with EBPR

Modified Bardenpho-, Phoredox-, A2/O-process



Modified UCT-process



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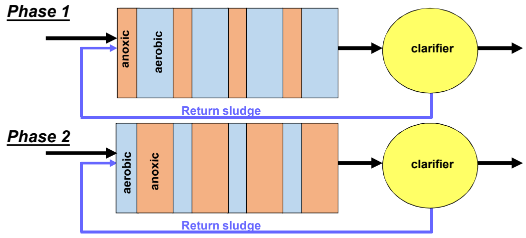
Intermittant Denitrification



+ high flexibility to changing inflow conditions
+ low effluent concentrations can be achieved

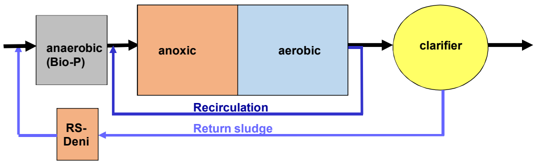
- high effort for mechanical engineering
- high area and volume demands
- Separation of aeration and mixing
- Not suitable for biofilm systems

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation
Wastewater | Return sludge | Recirculation

Water Harmony

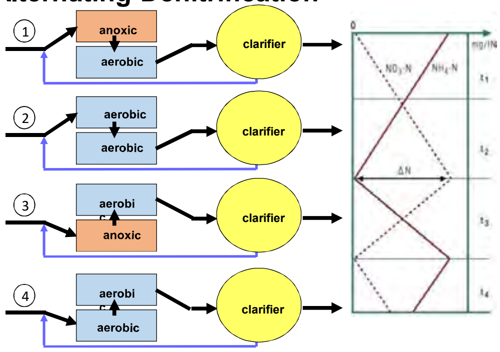
Pre-Denitrification with EBPR

modified Johannesburg-process



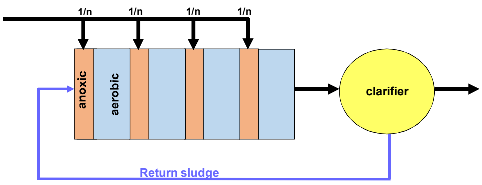
Water Harmony

Alternating Denitrification



Water Harmony

Cascade Denitrification



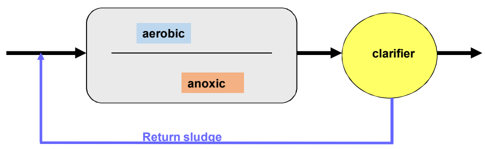
+ no internal recirculation flows
+ cascade reactor
+ higher mass of sludge

- Distribution of inflow difficult
- EBPR only in a small amount

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation
Wastewater | Return sludge | Recirculation

Water Harmony

Simultaneous Denitrification



+ high flexibility to changing inflow conditions
+ no internal recirculation necessary
+ robust operation
+ mainly for small plants

- Completely mixed systems, small reaction rates
- Large tank volumes (often also for sludge stabilisation)
- Oxygen will be displaced from nitrification to denitrification zones

Aerobic - Nitrification | Anoxic - Denitrifikation | Sedimentation
Wastewater | Return sludge | Recirculation

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Simultaneous Denitrification

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Combined processes in wastewater treatment

Important factors to consider when designing combined processes

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Contents

- Flowsheets with combined unit processes
- Treatment efficiencies when processes are combined
- Factors to be considered when designing combined WWTP
- Costing of WWTPs

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Combined processes

- WWTPs always have mechanical pre-treatment
- Modern treatment plants seldom limits to chemical or biological processes.
- When combining biological and chemical processes, the treatment goals for individual unit processes must be decided considering downstream processes.
- There are many other factors (land, personnel, transport etc) to be considered when designing new or upgraded WWTPs

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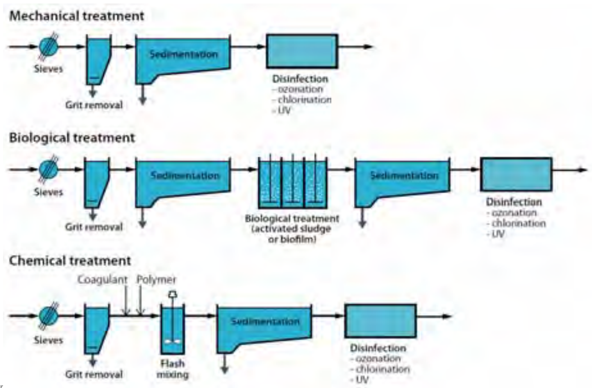
Simple processes



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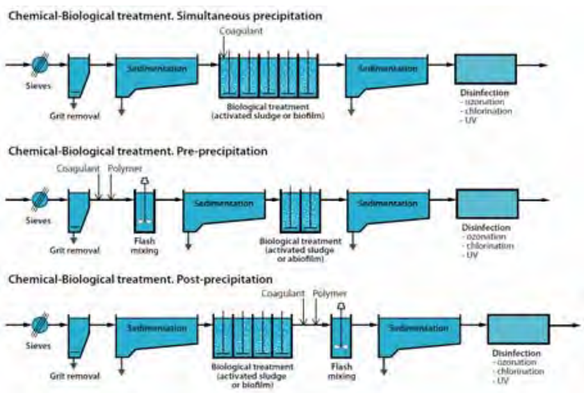
Combined processes for SS, C and P removal



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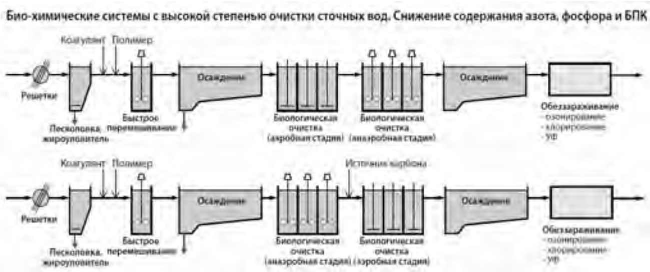
Advanced processes for SS, C, N, P removal



Need to translate and correct some figures

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Choice of the process

Calculation basis (specific load)
Q = 400 l/pd, BOF_5 = 60 g/pd, SS = 70 g/pd, Tot P = 1,8 g/pd, Tot N = 12 g/pd
BOF_5 = 150 mg/l, SS = 175 mg/l, Tot P = 4,5 mg/l, Tot N = 30 mg/l

Process	Scheme	SS Restkons. mg/l	SS Renseeff. %	BOF_5 Restkons. mg/l	BOF_5 Renseeff. %	Tot P Restkons. mg/l	Tot P Renseeff. %	Tot N Restkons. mg/l	Tot N Renseeff. %
Mechanical									
Coarse screen	FB	150-175	10 - 20	120-140	10 - 20	3,5 - 4,5	5 - 15	28 - 30	0 - 10
Septic tanks	FB/S	90 - 130	35 - 55	100-125	15 - 25	3,0 - 4,0	10 - 20	25 - 28	5 - 15
Primary treatment	FB S	80 - 120	40 - 60	100-125	15 - 25	3,0 - 4,0	10 - 20	25 - 28	5 - 15
Chemical									
Primary preci.	FB ↓ F S	20 - 30	80 - 85	35 - 55	65 - 75	0,3 - 0,6	85 - 95	20 - 25	20 - 35
Secondary prec.	FB S ↓ F S	15 - 20	85 - 90	30 - 50	70 - 80	0,3 - 0,6	80 - 90	20 - 25	20 - 35
Biological									
Active sludge	FB S AS S	15 - 30	80 - 90	15 - 35	85 - 90	2,5 - 3,5	40 - 50	20 - 25	20 - 35
Biofilm	FB S BF S	15 - 30	80 - 90	15 - 35	85 - 90	3,0 - 4,0	30 - 40	20 - 25	20 - 35
Bio/Chem with P rem									
Pre-prec.	FB ↓ F S AS/BF S	15 - 25	85 - 90	10 - 25	90 - 95	0,3 - 0,6	85 - 95	20 - 25	20 - 35
Simultaneous prec	FB S ↓ AS S	15 - 25	85 - 90	15 - 35	80 - 90	0,5 - 0,8	80 - 90	20 - 25	20 - 35
Intermed. Prec	FB S BF ↓ F S	10 - 20	90 - 95	10 - 25	90 - 95	0,3 - 0,6	85 - 95	20 - 25	20 - 35
Post prec	FB S AS/BF S ↓ F S	10 - 20	90 - 95	10 - 25	90 - 95	0,2 - 0,5	90 - 95	20 - 25	20 - 35
Bio/chem with N-rem									
Pre DN AS	FB DN-AS N-AS S ↓ F S	10 - 20	90 - 95	5 - 15	> 95	0,2 - 0,5	90 - 95	8 - 12	65 - 75
Post DN BF	FB ↓ S N-BF ↓ DN-BF ↓ F S	10 - 20	90 - 95	5 - 15	> 95	0,2 - 0,5	90 - 95	3 - 8	75 - 90
Comb BN BF	FB DN-BF N-BF ↓ DN-BF ↓ F S	10 - 20	90 - 95	5 - 15	> 95	0,2 - 0,5	90 - 95	3 - 8	75 - 90

FB: pre treat; S: separation; F: flocculation; AS: Act. Sludge;
BF: Biofilm; N: nitrification, DN: Denitrification

↓ Coagulant addition
↓ C-source addition

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CEPT: Chemically Enhanced Primary Treatment

- Goal with the CEPT is to improve conventional sedimentation process
  - Mechanical ⇨ CEPT ⇨ Coagulation
  - Dose, gFe/m3: 0 ⇨ 5 -50 ⇨ 30-120
  - BOD: 30 ⇨ 50% ⇨70%,
  - SS: 60 ⇨ 80% ⇨ 90%;
  - TP: 15 ⇨ 70% ⇨ 90%,
  - TN: 15 ⇨ 25% ⇨30%

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Important factors when designing combined WWTP

1. Process applicability
2. Applicable flow rate
3. Flow variation
4. Influent WW characteristics
5. Inhibiting and unaffected constituents
6. Climatic conditions
7. Plant/reactor size based on kinetics/loadings
8. Plant/reactor size based on reaction rates/loadings
9. Performance
10. Treatment residuals
11. Sludge processing
12. Environmental constraints
13. Chemical requirements
14. Energy requirements
15. Other sources
16. Personnel requirements
17. O&M requirements
18. Supporting processes
19. Reliability
20. Complexity
21. Compatibility
22. Adaptability
23. Economic life cycle analysis
24. Land availability

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Process applicability

- Past experience
- Data from pilot- and full scale plants, literature
- If new or unusual conditions, pilot plant tests are required.

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Applicable flow range

- Process should match the applicable flow ranges.
  - Reed beds or natural treatment systems may not be suitable for highly dense populations
  - *What could bb suitable for the Beijing GaoBeidian WWTP: 1 000 000 m3/d (>4 mill pe)?*

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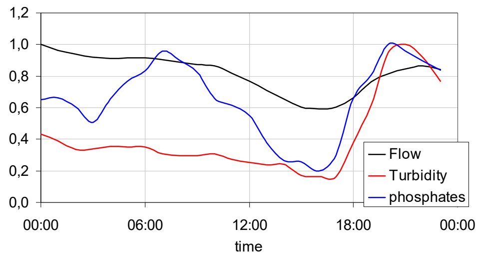
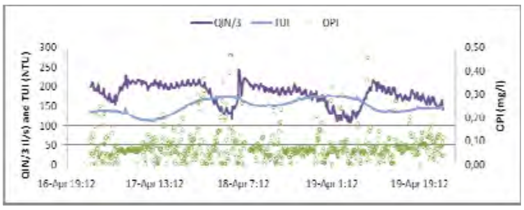
Flow variation

- Most unit operations must be designed to operate in a wide flow range. (wet/dry, floods, shock loads etc)
- Most processes work best at narrow flow ranges.
- Flow equalisation tanks (or use the sewer system capacities)



Influent flow characteristics

- Influent quality affects the most unit processes – type and process parameters
  - Industrial wastewater with high COD
  - Periodic loads (industry, tourism, etc)
  - Shock loads

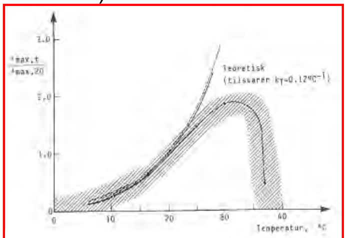


Inhibiting and unaffected constituents

- Presence of inhibiting components (especially in biological)
- Components which will not be removed by all processes
  - Organic matter, P, N
  - Heavy metals

Climatic constraints

- Temperature affects the most process conditions
  - Dimensions to manage all situations
  - Odour, sludge floating, etc
  - Impact of climate change (special focus)



Nitrification rate vs temperature *(Henze et al, 1990)*

Process sizing based on reaction kinetics or process loading criteria

- Dimensioning based on reaction kinetics:
  - Reactor types: complete mix / plug flow reactors
  - Kinetic rate coefficients

  - Complete mix reactor to keep the toxic concentrations low.
  - Plug flow reactor to keep the filamentous bacteria low.

Process sizing based on mass transfer

- Addition of oxygen to water
- Drying of biosolids in sludge treatment
- Removal of volatile organics from ww
- Stripping of ammonia
- Ion exchange etc
  - Literature & practical experience

- If mass transfer coefficients can not be developed, design will be based on loading criteria
  - Tank capacity in Activated Sludge tanks (kg BOD/m3.d)
  - E.g.: If 10 kg BOD/m3.d works fine and 15 kg BOD/m3.d don't, 10kg BOD/m3d is selected.

Performance

- Effluent quality
- Treatment efficiency
- Variability or stability
- Laws and regulations
  - N removal in sensitive coastal areas
  - P removal in sensitive lakes & rivers

Treatment of residuals

- Types & amounts of residuals: liquid, solid, gas must be known and be prepared.
- Pilot plant studies are done to identify & quantify the residuals

- Sludge: heavy metal content
- WW reuse?
- Discharge criteria

Sludge processing

- Any constraints that makes the sludge processing and disposal non-feasible or expensive?
  - Heavy metals
  - Transport costs
  - Disposal limitations
  - Possibilities for energy production

Environmental constraints

- Physical conditions
  - Wind directions and prevailing winds
  - Proximity to residential areas: noise and odour
  - Noise and traffic to/from the plant

- Env conditions
  - Treatment levels: nutrients

Chemical requirements

- What resources and what amounts are required for stable and feasible operation?
- Transport and storage costs
- Impact on residuals (heavy metals?)
- Handling : HSE *(HMS på norsk)*

- C-source?

Energy requirements

- Energy need
- present & future supply & costs

- Sludge digestion
- Incinerators
- Chemical vs Biological

Other resources requirements

- What are the other resources required for successful operation?
  - Agreements with industries / suppliers
  - Farmers?
  - Capacity vs coverage?
  - Financial stability

Personnel requirements

- How many people and which qualifications are needed?
- Are they readily available?
- Training needs?
- Shift work?

- Access to specialised knowledge
- Norwegian model of inter-municipality plants
- IT –proficiency?

Operating and maintenance requirements

- What special operating or maintenance requirements will be needed to provide?
- What spare parts and servicing are needed and their availability
- Level of automation and instrumentation

Supporting processes/services

- What services /processes are needed?
- How would they affect the O&M – if they become non operative?

- Lab services
- External assistance

Reliability

- What is the long term reliability of unit processes?
- How easily the processes could fail?
- How easy to repair /re-establish the normal status
- What will be needed for that?

- Shock loads?
- Closing for repairs

Complexity

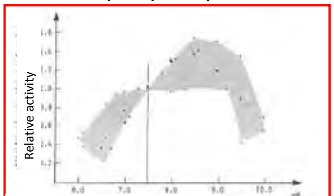
- How complex the process to run under routine or emergency conditions?
- What levels of training needed for operators?

- Possibility for process optimisation?
- Possibility handle changes

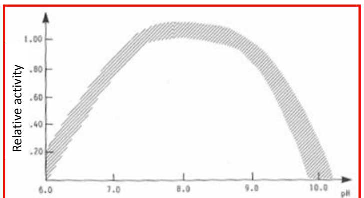
Compatibility

- Can new unit processes function together with existing ones?
- Expansion possibilities?
- Changes to match future requirements

Post or pre precipitation?

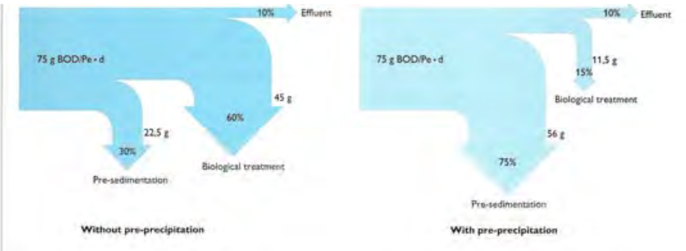


Dependency of nitrification on pH (Sutton and Jank, 1976).



Dependency of denitrification on pH (Henze et al. 1990).

Sequence



Adaptability

- Can the process modified to meet the future requirements?
  - Laws
  - Influent quality and quantity
  - New coagulants?
  - New instruments?
  - New automations?

Economic life-cycle analysis

- Initial capital costs and operational costs
- Long term operational costs
- Available funding

- Eastern Europe
- Developing countries
- China

Land availability

- Sufficient land? Also for expansions?
- Access to facilities
  - Transport for personnel
  - Transport of supplies
- Price of the land
- Neighbours
- Buffer zones
- Recipients of effluents: (flow rates)

- Why WWTPs in Monaco / Antibes etc have extremely compa water treatment processes and efficient & expensive air purification systems?

Why pilot tests?

- Reasons for setting up tests
- Pilot –plant size
- Non-physical design factors
- Physical design factors
- Design of pilot testing program

Process alternatives

- Assumed efficiency and cost estimates of various WW treatment methods:
  1. Mechanical treatment
  2. Chemical treatment:
     a) Chemical enhanced mechanical treatment, high load
     b) Chemical treatment, low load, called primary precipitation
  3. Biological treatment:
     a) High load activated sludge method (0,5 kg BOD_5/kg SS*d)
     b) Normal load activated sludge method (0,2 kg BOD_5/kg SS*d)
  4. Biological/Chemical treatment:
     a) Simultaneous precipitation (by normal load activated sludge)
     b) Pre-precipitation (pre-precipitation followed by normal load activated sludge)
  5. Nitrogen removal, biological/chemical (by pre-denitrification, simultaneous precipitation)

Wastewater specific load and composition
(for design calculations)

	Specific load	Concentration, g/m3	
	g/(pe*d)	at 250 l/pe*d	at 400 l/pe*d
BOD_5	62.5	250	150
SS	62.5	250	150
Total P	3.0	12	7.5
Total N	12.0	48	30

Treatment efficiencies in combined processes

	BOD_5		SS		Tot. P		Tot. N		Sludge production	
Process	%	mg/l	%	mg/l	%	mg/l	%	mg/l	g DS/m³	%
Raw WW	0	250	0	250	0	12	0	48	-	-
Mechanical	30	175	60	100	15	10	15	40	125	4
Chemical:										
a) High load	50	125	80	50	70	3.6	25	36	250	3
b) Low load	70	75	90	25	90	1.2	30	34	350	3
Biological:										
a) High load	70	75	80	50	30	8.4	25	36	185	2
b) Normal load	~90	20	90	25	30	8.4	30	34	205	2
Biological/chemical										
a) Simultaneous precipitation	~90	20	~90	20	~90	1,0	35	31	250	2
b) Pre-precipitation	~95	10	~95	15	~95	0,5	35	31	380	2
Biological/chemical, N-rem.: Predenitrification, simultaneous prec.	~95	10	~97	10	~90	1,0	70	15	275	1,5

European cost estimates

Treatment process	Capital cost	Operation and maintenance cost	Total cost NOK/m³ ww)
Mechanical	0,89	0,4	1.29
Chemical:			
a) High load	0,95	0,61	1.55
b) Low load	1,08	0,67	1.76
Biological:			
a) High load (no presettling)	1,21	0,67	1.88
b) Normal load (presettling)	1,46	0,67	2.13
Biological/chemical			
a) Simultaneous precipitation	1,5	0,87	2.37
b) Pre-precipitation	1,35	0,81	2.16
Biological/chemical, N-removal: Pre-denitrification, simultaneous prec.	2,29	1,28	3.57

Step-wise building of WWTP

TABLE 9. UNIT COSTS IN US $/KG POLLUTANT FOR STEP-WISE DEVELOPMENT OF WASTEWATER TREATMENT PLANTS
(Numbers in parentheses are the percentage of the total cost attributed to the removal of the given pollutant)

Step:	BOD	Phosphorus	Nitrogen
No → Mechanical	4 (100)	–	–
No → Biological, high load	2 (100)	–	–
No → Chemically enhanced No → Primary precipitation	1.3 (50) 1.0 (50)	19 (50) 15 (50)	– –
Mechanical → Primary precipitation	0.4 (50)	4 (50)	–
Mechanical → Biological, high load	1 (100)	–	–
Biological → Biological/chemical	0.3 (5)	10 (95)	–
Biological/chemical → Nitrogen removal	–	–	10 (100)

Step–wise development of an existing mechanical treatment plant for 100,000 pe

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DECENTRALIZED WASTE WATER TREATMENT

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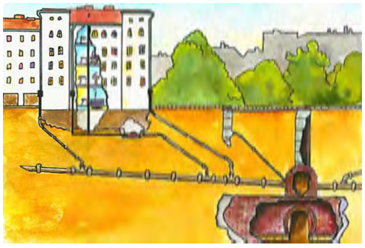
MUNICIPAL SEWAGE SYSTEMS

Within the territory of cities all amenities are usually provided by the centralized systems of water supply and sewerage.



http://santehexp.ru/wp-content/uploads/2014/04/image001.jpg

http://tekil.ru/wp-content/uploads/2011/09/kanal_014.jpg

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WE SHALL CONSIDER NEXT QUESTIONS

- What requirements should to satisfy of good local sewage system ?
- What processes occurs at treatment of sewage water inside of local sewer?
- The role of microorganisms at sewage water purification.
- Drain systems, the processes inside of their and some important notes.
- How does long the septic system can run?
- Requirements for its proper operation.
- Source separation systems.
- Membrane bioreactors.
- Small waste water treatment plants.
- Wetlands.

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WHERE IS NO CENTRAL SEWAGE SYSTEM THE PROBLEM OF HOUSEHOLD EFFLUENTS IS RESOLVED IN A SPECIAL WAY.

In this case homeowner is required the local sewage. For safe disposal of the sewage water which is generated in the house, it is necessary the adequate treatment of this water.

http://nua.in.ua/wp-content/uploads/2016/01/stroitelstvo-kottedzhey-2.jpg

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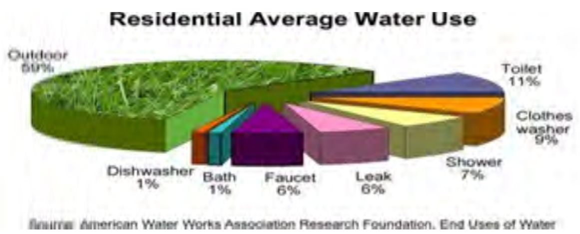
DECENTRALIZED WASTEWATER TREATMENT

We all prefer to live with a certain of comfort, despite the place of residence, whether it is a cottage, apartment or country house. We consume a certain quantities of fresh water for different purposes and we produce about the same amount of domestic wastewater.



http://www.envirohaven.com/wp-content/uploads/2013/11/Grey-Water-Pie.jpg

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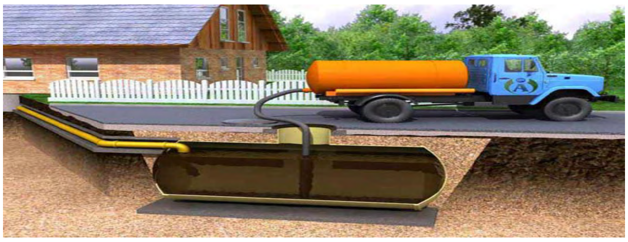
WHAT CONDITIONS SHOULD TO SATISFY OF GOOD LOCAL SEWAGE SYSTEM?

1. Local sewage should not pollute the drinking water sources, either surface or ground water, or water bodies that are used for bathing or recreational purposes.
2. The untreated sewage water should not be exposed so as to have access to human beings or animals.
3. Local sewage should not to give unpleasant smell, and should not become a place for breeding flies.
4. Local sewage should not cause harm to public health and adversely affect the receiving environment.

THE SIMPLEST KIND OF LOCAL SEWER IS CREATED USE OF A CESSPOOL.

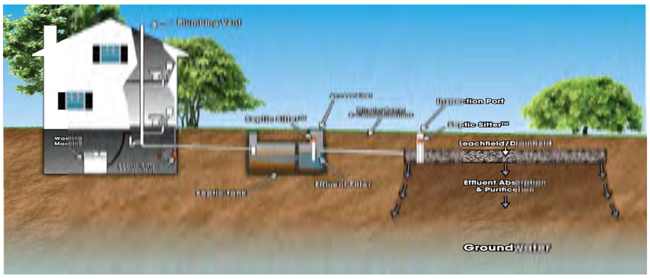
The maintenance of cesspools is reduced to regular pumping of accumulated effluents by means of special sanitary cars and of delivering these effluents onto sewage treatment plants.



http://kanalizaciyainfo.ru/wp-content/uploads/2013/10/ustrojstvo-vygrebnoj-yamy-v-chastnom-dome-varianty-i-materialy5.jpg

THE DESIGN OF LOCAL SEWAGE

Local sewage consist of plumbing devices in the house, of sewer pipes, of septic tank and drainage network for discharging of treated wastewater into the ground.



http://gawain.membrane.com/construction_management/excavation-services/septic-systems2.jpg

BUT THE USE OF CESSPOOLS IS LEGAL ONLY WHERE THE QUANTITY OF EFFLUENTS FOR ONE DAY DISCHARGE NOT EXCEED ONE CUBIC METER.

So either anyone will use a cesspool and live in uncomfortable conditions, or anyone will enjoy all the amenities of modern appliances, when there are local waste water treatment facilities.

http://decorate.panaromalife.com/wp-content/uploads/2016/02/Put-On-Top-Of-Kitchen-Cabinets.jpg

http://design-ideas.dressesdesignsdecors.com/design-ideas/bathroom/bathroomrenovationsjohannesburg2.jpg

THE MAIN PART OF LOCAL SEWAGE IS A SEPTIC TANK.

Here bacteria are starts to decompose human waste products into environmentally acceptable substances.

http://www.waste-tankering.co.uk/wp-content/uploads/2014/05/670px-Care-for-a-Septic-System-Step-1Bullet1.jpg

WHAT COMPOSITION OF HOUSEHOLD EFFLUENTS IS? WHAT KIND OF EQUIPMENT FOR LOCAL SEWAGE IS REQUIRED? HOW DOES THIS EQUIPMENT WORKS?

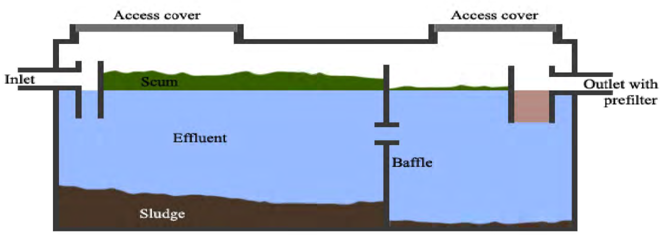
Table Average composition of domestic sewage

Parameter	Concentration (mg/l)	Parameter	Concentration (mg/l)
Carbohydrates	95	Magnesium	15
Fats	100	Zinc	0.2
Proteins	115	Manganese	0.15
Detergents	43	Copper	0.15
Phosphorus	10	Lead	0.1
Sulphur	46	Nickel	0.04
Chloride	50	Chromium	0.03
Boron	2	Tin	0.015
Sodium	80	Silver	0.01
Potassium	19	Cadmium	<1
Calcium	70	Mercury	<0.1

http://drrajivdesaimd.com/wp-content/uploads/2012/11/composition-of-sewage.gif

TYPICALLY THE SEPTIC TANK CONSIST OF TWO UNITS.

The first unit is a settling compartment.
Inside of it the sewage water is accumulated and undergoes of initial segregation.



http://0201.nccdn.net/1_2/000/000/130/619/image2.png

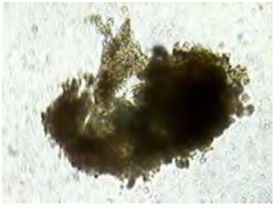
THE PROCESSES INSIDE OF SETTLING COMPARTMENT

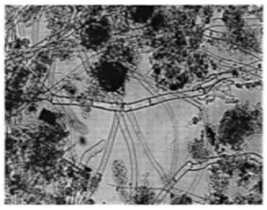
- Inside the settling compartment the heavy impurities settle the bottom, forming a sludge and light impurities float to the surface of water, forming a scum. The scum is seen on the photo at right.
- In such a way, the bulk of water becomes freed from impurities which have a specific density difference from the specific density of water.

http://septick.ru/articles/images/max/zailivanie-septika.jpg

THE MECHANISMS OF MICROBIOLOGICAL TREATMENT.

The microorganisms of active sludge when contacting with organic substances of sewage water are consume some part of these substances, releasing into water carbon dioxide, nitrate ions, sulfide ions etc. Other part of organic matter is transformed into the biomass of bacterium cells forming additional sludge.





http://www.biogest.com/wp-content/uploads/sludge-floc/before-disintegration.jpg

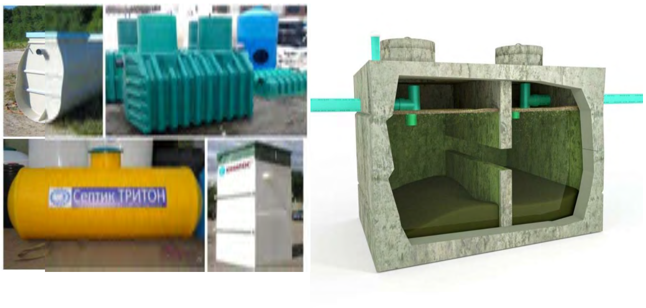
THE PROCESSES INSIDE OF SECOND COMPARTMENT

In this compartment the wastewater treatment is continuing under action of heterotrophic bacteria.

- The sludge, generated inside of second compartment as result of bacteria action is gradually deposited on the bottom and as result the waste water becomes cleaner and cleaner.
- After a stay in the second compartment of certain time the waste water becomes so pure that it can be pumped into the drainage pit, trench, etc.

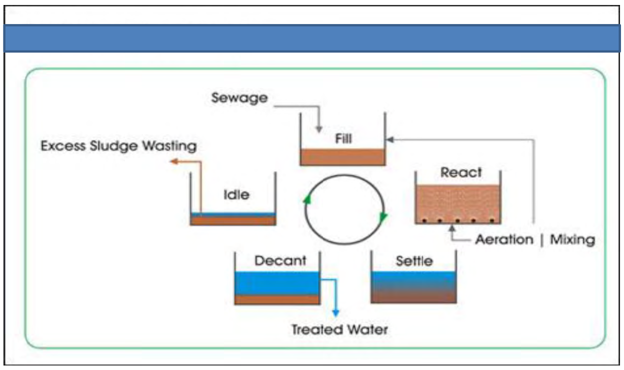
http://rio.ua/files/images/items/1005/1005644b75bd0430.jpg

DESIGN OF SEPTIC TANKS MADE OF PLASTIC AND CONCRETE



http://kniga-stroyka.ru/images/170316_97.jpg

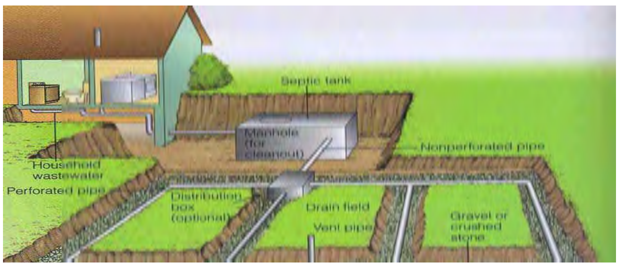
LAYOUT OF PROCESSES INSIDE OF SEPTIC TANK



http://www.3rtechnology.in/images/product/sbr_operating.jpg

DISCHARGING OF TREATED EFFLUENT INTO THE SOIL

From septic tank the end products of digestion sewage water are discharged into the drainage field that uses microorganisms to final destruction these products naturally in the soil.



http://www.co.thurston.wa.us/HEALTH/ehoss/images/drainfield.jpg

TECHNICAL DETAILS

Discharging occurs through the perforated pipes of appropriate diameter disposed on the washed gravel. The gravel bed perform the function of initial filtration layer of septic field.

http://fundamentdomov.ru/wp-content/uploads/2016/02/4-25.png

DISPOSITION OF SEPTIC

When creating of local sewage system the septic is displaced at certain distance from the house. Minimal distance is about 2-3 meters.

- In the case of small volumes of sewage water discharge one can use the septic unit in conjunction with the drain well.

http://kvartirnyj-remont.com/wp-content/uploads/2015/09/3_117-750x499.jpg

ESSEMBLING OF DRANAGE SYSTEM

This is the picture of drain field made of perforated pipes on the gravel bed.

http://postroy-sam.com/wp-content/uploads/2013/11/drenazh-i-pole-filtracii-dlya-septika-3.jpg

USING OF DRAIN WELL IS JUSTIFIED ONLY AT HIGH WATER ABSORPTION CAPACITIES OF SOILS.

In other cases it is required to use more complicated drainage systems containing many drainage pipes or special drainage units like shown here.

http://www.eco-nomic.com/Trench%20Type%20Septic%20System%20Drainfield.JPG

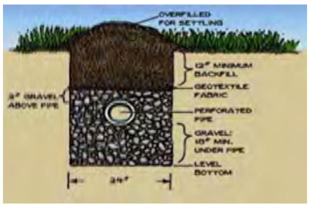
CONSTRUCTION OF DISTRIBUTION BOX

From the septic tank to the laterals of drain field the treated effluent is directed through a distribution box

http://sindicato-uno.cl/m_carrasco/wp-images/smilies/leach-field-distribution-box-i9.JPG

DESIGN OF DRAINAGE TRENCHES AND OF INSPECTION NODES

Above the soil filter is top soil in which grass is planted.
The drain field is normally 0,3-0,6 meter below the surface.



http://1landscapedesign.ru/wp-content/uploads/2014/02/razrez-drenazh.jpg

http://krasnodarskiy.xyz/wp-content/uploads/st-d100z-1.jpg

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DAMAGE IN THE SEPTIC

If the effluent cannot soak into the soil surrounding the drain field, sewage may back up, overflow into the house or puddle on the surface of the ground.

http://www.davidzuidema.com/images/Homeimage.jpg

http://www.cpssepticandsewer.com/images/stories/failedleachline.jpg

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HOW LONG SHOULD A SEPTIC SYSTEM LAST?

How big should a septic tank be for a proper operation of local sewage system?

# Bedrooms	Home Square Footage, M^2	Tank Capacity, M^3
1 or 2	Less than 150	3,3
3	Less than 150	4,5
4	Less than 350	5,6
5	Less than 450	5,6
6	Less than 550	5,9

http://www.ehow.com/way_5183882_size-septic-tank-do-need_.html

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POSSIBLE CAUSES OF PROBLEMS WITH A SEPTIC SYSTEM.

1. **Faulty design of the septic system.**
2. **The drain field system placed in unsuitable soil.**
3. **The septic system is too small for the house it serves.**
4. **The septic system is improperly constructed.**
5. **High water table.**
6. **Physical damage.**

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HOW BIG SHOULD A DRAIN FIELDS BE FOR A PROPER OPERATION OF LOCAL SEWAGE SYSTEM?

- **Determining the required size of a drain field is more complicated.**
- **The first thing to consider is the nature of the soil in which the drain fields is to be constructed.**
- **Because water has to be absorbed in the soil, one must to know how fast it can be absorbed.**
- **This is called the percolation rate and is expressed as the time it takes for water in a test hole to decrease in level by one centimeter (minutes/cm).**

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DAMAGE IN THE UNITS OF SEPTIC SYSTEM

http://www.classicdrainage.com/assets/Clogged_pipe.jpg

http://cdn.balkanplumbing.com/wp-content/uploads/Tree-Roots-Inside-Sewer-Pipe.jpg

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CHOOSING OF DRAIN FIELD SIZE DEPENDING OF PERCOLATION RATE

Required Septic Absorption Trench Length in Feet versus Soil Percolation Rate & Wastewater Flow Rate

		2 Bedrooms			3 Bdrms			4 Bdrms			5 Bdrms			6 Bdrms	
	Septic Wastewater Effluent Input Flow Rate (Gallons per Day) [1]														
Soil Percolation Rate in Minutes / Inch	**220 gpd**	**260 gpd**	**300 gpd**	**330 gpd**	**390 gpd**	**450 gpd**	**440 gpd**	**520 gpd**	**600 gpd**	**550 gpd**	**650 gpd**	**750 gpd**	**660 gpd**	**780 gpd**	**900 gpd**
1 - 5	92	108	125	138	162	187	184	216	250	230	270	312	275	325	374
6 - 7	110	130	150	165	195	225	220	260	300	275	325	375	330	390	450
8 - 10	123	145	167	184	217	250	245	290	333	306	360	417	367	433	500
11 - 15	138	162	188	207	244	281	275	325	375	344	406	469	413	488	563
16 - 20	158	186	214	236	279	321	315	372	429	393	464	536	472	557	643
21 - 30	184	217	250	275	325	375	367	433	500	459	542	625	550	650	750
31 - 45	220	260	300	330	390	450	440	520	600	550	650	750	660	780	900
46 - 60	245	290	333	333	433	500	489	578	667	612	722	833	734	867	1000[2]

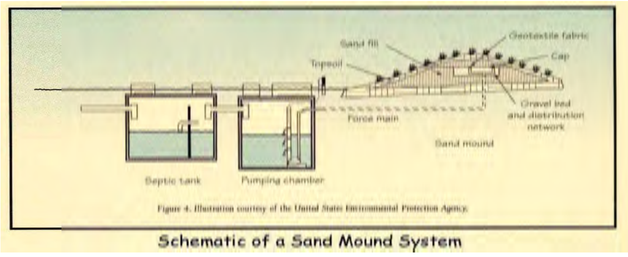
Dosing not required (but recommended)

Dosing system or alternative design is required if the total drainfield (soakbed / leachfield) trench length is 500 feet or more in length.

http://sindicato-uno.cl/m_carrasco/wp-images/smilies/leaching-field-size-i7.jpg

THE MOUND SYSTEM

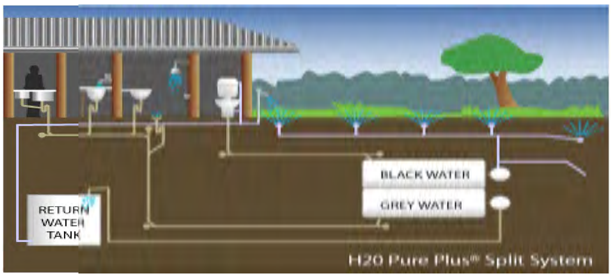
If ground water or percolation rate are unsuitable, it may be possible to install a "mound" system. In a mound system, a suitable soil is placed above the unsuitable soil. A conventional system is then installed in the mound.



http://www.realtyresourceguide.com/septics/sandmound_copy.jpg

SOURCE SEPARATION SYSTEMS

This systems offers the possibility of recover nutrients, reducing release of micro pollutants to the environment, and increase degree of the water recycling.



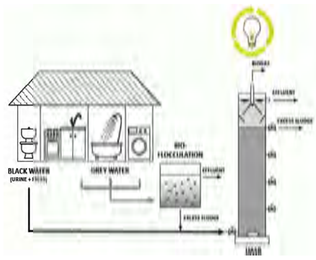
http://h2opureplus.com/images/blackgrey.gif

A MOUND LEACH FIELD IN A LOCAL SEWAGE SYSTEM

http://www.articleinput.com/wp-content/uploads/2015/03/sandmound1-520x245.jpg

SOURSE SEPARATION IS DRIVING INNOVATION IN DECENTRALIZED WASTEWATER TREATMENT

Novel approach allow also to reduce the discharge of water into soil and get an additional energy source as shown in picture below.

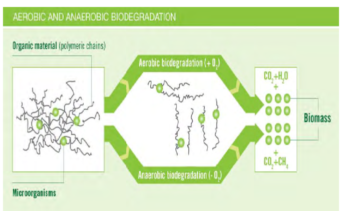


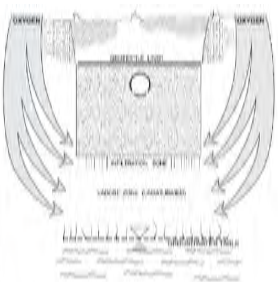
http://i.ytimg.com/vi/Y7SuiMDymBA/mqdefault.jpg

AEROBIC AND ANAEROBIC BIODEGRADETION

At present time the popular becomes the hybrid system that uses a combination of anaerobic and aerobic sections.

.





Source: Apinis Associates, 1998

http://www.apinatbio.com/eng/immagini/big/chart_01.gif

BENEFITS OF SOURCE SEPARATION

Gray water is the largest contributor to total volume of sewage water in the household.

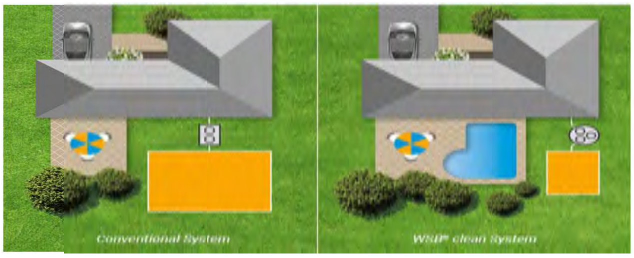
At the same time gray water is the least contaminated

In the absence of kitchen wastewater, gray water is low in organic content.

Novel approach allow one to reduce the discharge of water into soil and get an additional energy source

ADDITIONAL PROFIT

The useful free area around the house is extended due to reducing of required area for the drain field.



http://www.rh2o.com/sites/all/themes/rh2o/css/images/wastewater-backyard.jpg

The toilets of low dilution was approbated in several projects where was shown how from the human rests to get addition sources of energy and fertilizes .

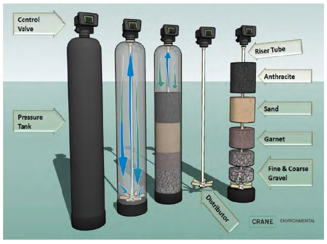
Processed feces

http://nursingcrib.com/wp-content/uploads/urine.jpg

http://www.myessentia.com/blog/wp-content/uploads/2010/05/biosolids.jpg

INSTRUMENTATION

Purification of grey water up to required quality can be attained by different devises

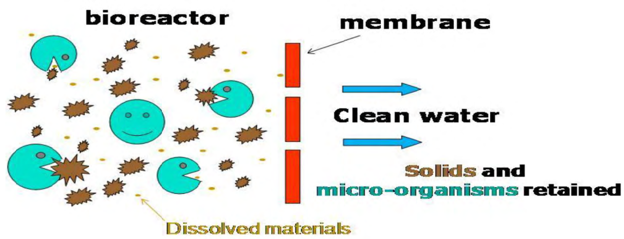


http://www.avloppscenter.se/shop/11994/art94/h6182/15086182-origpic-173141.jpg

http://www.omegagroup.gr/omega/portals/0/Images/Επεξεργασια_νερου/Multimedia-filter.png

MEMBRANE BIOREACTORS

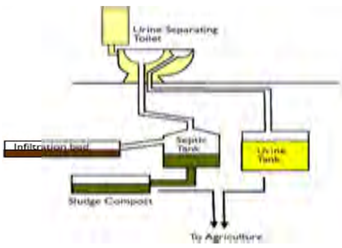
Last innovation within the range of decentralized systems for wastewater treatment include the using of membrane bioreactors.



https://upload.wikimedia.org/wikipedia/commons/2/2c/MBR_Schematic.jpg

NEXT BREAKTHROUGH

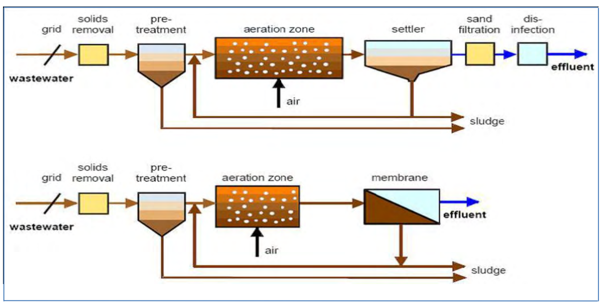
It is the use of range of toilets with very low dilution



https://grist.files.wordpress.com/2010/03/toilet_463.jpg

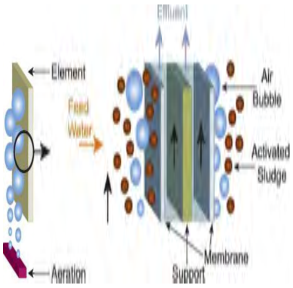
http://www.fujitaresearch.com/reports/_img/023-WW-Tileot.gif

THE BASIC DIFFERENCE BETWEEN ORDINARY WASTE WATER TREATMENT SYSTEM AND OF MEMBRANE BIOREACTOR



http://www.studmed.ru/docs/static/7/2/1/6/5/7216553685c.png

SCHEMATIC OF ELEMENTARY UNIT OF MBR AND THE PICTURE OF MBR MODULE



http://sc02.alicdn.com/kf/HTB1qTO6HFXXXXc5XVXXq6xXFXXX5/MBR-Plant-Membrane-Bioreactor-Membrane-Bio-reactor.jpg

Water Harmony Erasmus+ | Co-funded by the Erasmus+ Programme of the European Union

SMALL WASTEWATER TREATMENT PLANTS CAN SERVE FEW HOUSES WITHIN THE COMMUNITY AREA.

http://www.osieagle.ca/services/design/PP/images/Saputo Art.jpg

DECENTRALIZED WASTE WATER TREATMENT

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SMALL WASTE WATER TREATMENT PLANTS

Septic tanks, biological reactors, membrane bioreactors, soil-box planters, natural and artificial soil filters, as well as multimedia filters and other functional devices being connected in a certain sequence forms a small waste water treatment plants

This is example of WWTP designed of septic tank and membrane bioreactor

http://www.delphinws.de/uploads/pics/Kleinklaeranlage_DELPHIN_classic_plus_S_M_Schnitt_03.png

DECENTRALIZED WASTE WATER TREATMENT

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DISPOSAL OF LARGE QUANTITIES OF TREATED WATER INTO GROUND OCCURS THROUGH A LARGE DRAINAGE SYSTEM

http://tikko35.ru/wp-content/uploads/2013/04/infiltracionie-bloki-foto03.jpg

DECENTRALIZED WASTE WATER TREATMENT

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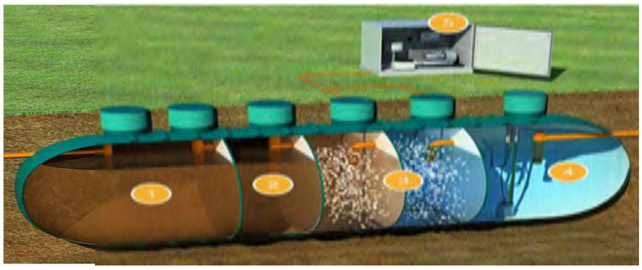
THIS IS THE SMALL WWTP CONSISTING OF:

sludge storage unit (1), pre-treatment unit (2), biological compartments (3), final clarification unit (4) and control system (5).



http://www.rh2o.com/sites/all/themes/rh2o/css/images/commercial-howitworks.jpg

DECENTRALIZED WASTE WATER TREATMENT

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WETLANDS ARE USED ALSO

Wetlands is a permanently waterlogged areas populated by hydrophytic plants such as reeds, comprise a variety of sub-surface micro-habitats of differing oxygenation and red-ox potential.

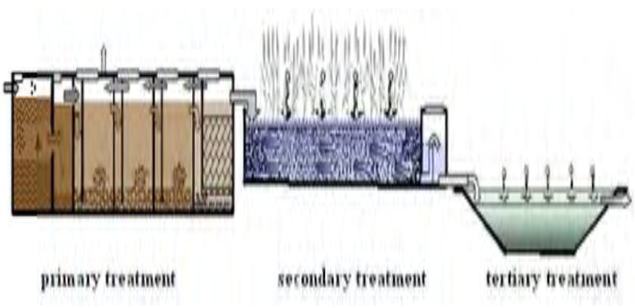
http://blumberg-engineers.com/uploads/images/middle_constructed_wetlands.JPG

DECENTRALIZED WASTE WATER TREATMENT

WaterHarmony Erasmus+

Co-funded by the Erasmus+ Programme of the European Union

SCHEMA OF ADVANCED SMALL WASTE WATER TREATMENT PLANT



http://www.cseindia.org/userfiles/pix1(2).jpg

Industrial wastewater

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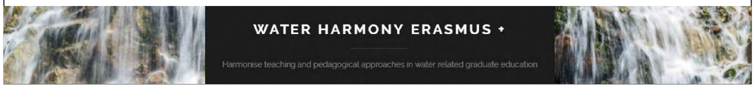


Outline

- Wastewater generated in industries
- Treatment concepts – general remarks
- Overview of treatment processes
- Solid-liquid separation
- Removal of dissolved inorganic substances
- Removal of dissolved organic substances
- Final remarks

Wastewater generated in industries

Important types of industrial wastewater:

- Process water
- Water from rinsing and cleaning processes
- Scrubber and vacuum pump water
- Water from hydraulic transport processes
- Blow-down water from cooling systems
- Concentrates from water treatment processes
- Sanitary water
- Polluted rain water

Treatment concepts – general remarks

Development

<u>In the past</u>: Treatment in a central mechanical-biological plant on-site or together with domestic wastewater (end-of-pipe)

<u>Now</u>: Decentralized (pre-)treatment of separate wastewater streams (point-of-source), followed by a central plant if needed

Challenges with separate wastewater streams

1. small volumetric flow rates
2. high concentrations of pollutants
3. often discontinuous flow

Treatment concepts – general remarks

Conclusions

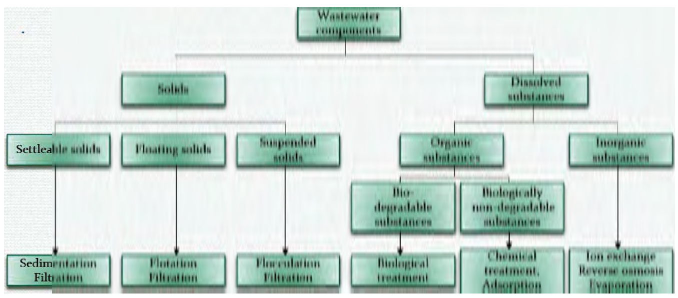
For pre-treatment purposes, biological processes are suited if

- the substances to be removed are degradable,
- the process is not affected by other toxic substances, and
- adequate adaptability to the fluctuating conditions is possible.

Therefore, physical-chemical or chemical processes must often be applied for the (pre-)treatment of separate streams.

These processes are also important as process-related measures for emission reduction.

Overview of treatment processes



Solid-liquid separation

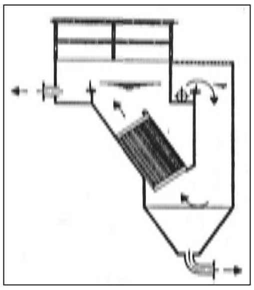
Sedimentation in inclined-plate settlers

Idea: Enlargement of the effective settling area

Important aspect: Up-flow operation

Typical design parameters:
- distance between plates: 20 -100 mm
- angle of inclination: 55 - 60°

Manufactured sizes: Q = 1 - 300 m^3/h



Inclined-plate settler (Courtesy Vereinigte Kesselwerke)

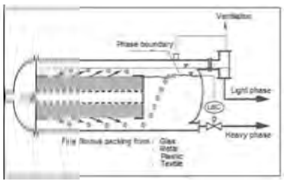
Solid-liquid separation

Oil removal by coalescence separators

Operating principle:
Formation of larger oil drops from fine oil droplets (5 - 20 μm) by hydrodynamic effects

General requirements in Germany:
Effluent concentrations < 5 mg/L HC when tested with a water/oil mixture according to DIN 1999

Limitation of mechanical oil separation:
Removal of stable emulsified oil droplets



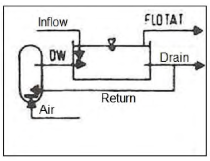
Coalescence separator

Solid-liquid separation

Dissolved air flotation (DAF)

Operating principle:
- saturation of recycled effluent with pressurized air
- formation of air bubbles in the flotation basin
- attachment of particles on air bubbles
- floating of the air-solid aggregates to the surface

Typical design parameters:
- hydraulic surface loading: 2 - 15 $m^3/(m^2 \cdot h)$
- operating pressure: 2 - 6 bar
- recycle ratio: 0.1 - 0.5 (except sludge thickening)
- air : solids ratio: 3 - 100 L_N / kg TSS



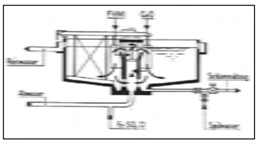
Principle of DAF

Solid-liquid separation

Flocculation in circular reactors

Principle:
- dosing of metal coagulants (iron or aluminium salts) into the inflow
- floc formation in the central part of the reactor, supported by polymer addition
- floc separation by settling in the outer volume of the reactor

Operating parameters:
- hydraulic surface loading: 2 - 6 $m^3/(m^2 \cdot h)$
- coagulant dosages: 5 - 50 mg/L Me
- pH adjustment: pH = 5.5 - 7.5



Turbo-Circulator (Courtesy Ph. Müller)

Solid-liquid separation

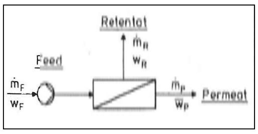
Micro- and Ultrafiltration

Operating principle:
Separation of an inflow (feed) stream into a filtrate (permeate) stream and a concentrate (retentate) stream by organic or inorganic membranes with well-defined pore sizes

Differentiation:

Microfiltration → separation size 50 - 10,000 nm
operating pressure 0.5 - 5 bar

Ultrafiltration → separation size 5 - 50 nm
operating pressure 1 - 10 bar



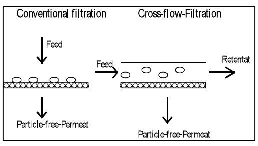
Principle of membrane filtration

Solid-liquid separation

Micro- and Ultrafiltration

Design selection criteria:
- TSS feed concentration
- recovery
- operating mode
- energy demand
- residuals and their disposal
- fouling potential of the membrane
- rinsing and cleaning procedures

Operating mode:
→ cross-flow (applied in wastewater treatment)
→ dead-end (used for process water treatment)



Operating modes of membrane filtration

Solid-liquid separation

Typical applications in industries

Inclined-plate settlers: Removal of particles and chemical flocs, e.g. after precipitation of heavy metals from metal-plating wastewater streams

Coalescence separators: Pre-treatment of wastewater containing oil droplets, e.g. effluents from machine shops

Dissolved air flotation: Removal of hydrophobic solids with low density, e.g. from wastewater streams generated in food industries and slaughterhouses

Compact flocculation: Coagulation of fine particle and colloids, e.g. for producing process water from river water

Solid-liquid separation

Typical applications in industries

Microfiltration: Removal of fine particles and oil droplets from all kinds of small wastewater streams

Ultrafiltration: Separation of emulsions (e.g. drilling oils, compressor condensates) with cross-flow inorganic membranes

Separation of proteins from whey, soya extracts etc.

Recovery of dyes and sizing agents from dying of textiles

Recovery of water-based paints from electrocoating processes

Separation of activated sludge flocs from effluents in membrane bio-reactors

Removal of dissolved inorganic substances

Ion exchange

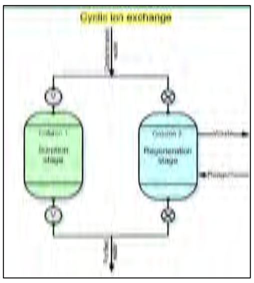
Operating principle:

Uptake of cations or anions from wastewater by porous resin beads that release a stoichiometric amount of ions (of the same charge) originally bound to the resin (sorption stage)

Desorption of these ions from the resin by applying a concentrated solution of the ions initially present on the resin (regeneration stage)

Operating mode:

→ co-current (for high ion concentrations)
→ counter-current (for high effluent qualities)



Source: http://www.ion-exchange.com.aa

Removal of dissolved inorganic substances

Precipitation of heavy metals

Principle of precipitation processes:

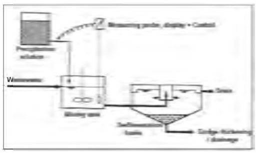
Transformation of dissolved substances by chemical reactions in components with low solubility

→ Hydroxide precipitation: Precipitation of metal ions as hydroxides or basic salts

Solubility product $L = a(Me^{z+}) \cdot a(OH^-)^z << 1$

→ Sulphide precipitation: Precipitation of divalent metal ions as sulfides

Solubility product $L = a(Me^{2+}) \cdot a(S^{2-}) << 1$



Precipitation stage

Removal of dissolved inorganic substances

Oxidation

Principle of oxidation processes:

Release of electrons by a substance, increase of its oxidation state

Oxidizing agents in industrial wastewater treatment, applied for instance for the detoxification of cyanide:

- Hydrogen peroxide H_2O_2

$$CN^- + H_2O_2 + H_2O + H^+ \Leftrightarrow NH_4^+ + HCO_3^-$$

- Ozone O_3

$$CN^- + O_3 + 2\,H_2O + H^+ \Leftrightarrow NH_4^+ + O_2 + HCO_3^-$$

- Sodium hypochlorite NaOCl

$$2\,CN^- + 5\,OCl^- + H_2O \Leftrightarrow N_2 + 5\,Cl^- + 2\,HCO_3^-$$

Removal of dissolved inorganic substances

Reduction

Principle of reduction processes:

Uptake of electrons by a substance, decrease of its oxidation state

Reducing agents in industrial water and wastewater treatment, applied for instance for the detoxification of chromate:

- Sodium hydrogen sulfite $NaHSO_3$

$$Na_2Cr_2O_7 + 3\,NaHSO_3 + 4\,H_2SO_4 \Leftrightarrow Cr_2(SO_4)_3 + 3\,NaHSO_4 + Na_2SO_4 + 4\,H_2O$$

followed by hydroxide precipitation of $Cr(OH)_3$

- Fe(II) salts, e.g. $FeSO_4$

$$Na_2CrO_4 + 3\,FeSO_4 + 4\,NaOH + 4\,H_2O \Leftrightarrow Cr(OH)_3 + 3\,Fe(OH)_3 + 3\,Na_2SO_4$$

Removal of dissolved inorganic substances

Reverse Osmosis

Operating principle:
similar to Micro- and Ultrafiltration

Characteristic differences:

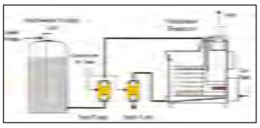
- separation size 1 - 2 nm (dense membranes)
- operating pressure 10 - 200 bar
- very good removal of ions and large organic molecules
- limited rejection of dissolved gases and small uncharged molecules, e.g. silicic acid

Source:
http://www.ameriwater.com/products

Removal of dissolved inorganic substances

Evaporation

Operating principle:
Separation of wastewater and both dissolved and suspended substances by applying energy in order to transform the water into vapor



Source:
http://www.wastewaterevaporators.com

Boundary conditions:

→ high energy demand (ca. 800 kWh/m^3) for single-stage evaporation

→ precipitation of salts, formation of deposits

→ pollution of condensate by volatile compounds

→ corrosion and foam generation

Removal of dissolved inorganic substances

Typical applications in industries

Ion exchange:	Regeneration of process solutions in metal-plating companies
	Recovery of noble metals and non-ferrous metals from metal-plating rinsing waters
	Removal of residual heavy metals from wastewater streams after a precipitation stage
Precipitation:	Removal of heavy metals in wastewater from metal-plating industries and from flue gas washing processes
	Removal of fluoride (as CaF_2), sulfate (as $CaSO_4$ or as ettringite), phosphate (as $MePO_4$ with iron and aluminium salts, or as hydroxyl apatite with calcium hydroxide), and ammonium (as struvite) in wastewaters of different origin

Removal of dissolved inorganic substances

Typical applications in industries

Oxidation:	Detoxification of cyanide and nitrite in wastewater streams from metal-plating industries
Reduction:	Detoxification of chromate and nitrite in effluents from metal-plating processes
Reverse Osmosis:	Concentration of wastewater streams from chemical industries, electroplating, and landfills (in Germany)
	Recovery of process water in the semiconductor industry and other sectors
Evaporation:	Recovery of resources from wastewater streams
	Pre-treatment prior to combustion, e.g. in pulp production

Removal of dissolved organic substances

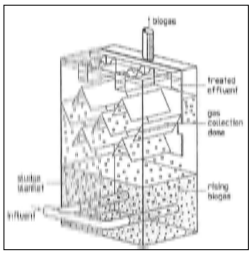
Anaerobic biological treatment

Principle:

- conversion of organic matter to biogas (CH_4, CO_2) that can be utilized
  → gain instead of consumption of energy
- two-stage process:
  1. pre-acidification, 2. methane production
- production of surplus sludge quite small

Operating parameters:

- hydraulic loading: 2 - 30 kg COD / (m^3 · d)
- temperature: 30 - 40°C (mesophilic conditions, preferred operating mode)



Scheme of an UASB-reactor
(Lettinga und Hulshoff Pol, 1991)

Removal of dissolved organic substances

Aerobic biological treatment

Principle:

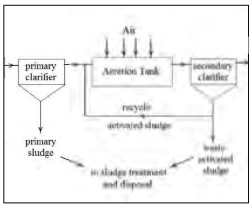
- conversion of organic matter to CO_2, H_2O and biomass; yield up to 50 %
- removal of nitrogen (nitrification/denitrification)

Process realisation:

- (multi-stage) activated sludge systems
- biofilm reactors

Operating parameters:

- sludge loading: < 0.1 - 0.5 kg BOD / (kg MLSS · d)
- hydraulic retention time: 6 - > 24 h



Flow diagram of the activated sludge process

Removal of dissolved organic substances

Application of biological processes in industries

Anaerobic treatment:	Pre-treatment of wastewater with high concentrations of biodegradable organic matter (COD = 1.5 - 40 g/L), e.g. wastewater from food industries, breweries and pulp and paper production
Aerobic treatment:	Removal of biodegradable organic matter from waste-water generated by all kind of industries, in particular by food companies, petrochemical plants, chemical industries, tanneries, textile companies, and paper mills
	Post-treatment of anaerobically treated wastewater in order to remove residual BOD and nutrients (nitrogen, phosphorous)

Removal of dissolved organic substances

Adsorption

Principle:

Accumulation of organic substances at the inner surface of a porous solid (adsorbent), most often activated carbon

Process configurations:

- application of powdered material in a three-step batch process that includes a) dosing, b) reaction and c) separation of the adsorbent
- use of granular adsorbent as a filter material in a continuously operated adsorption column

Source: http://generalcarbon.com

Removal of dissolved organic substances

Oxidation at low temperatures

... with hydrogen peroxide H_2O_2:

Activation by UV-irradiation or addition of Fe(II)-salts (Fenton's reagent) in order to generate OH radicals

$$H_2O_2 + Fe^{2+} \Leftrightarrow {}^{\bullet}OH + OH^- + Fe^{3+}$$

If iron salts are used, they will precipitate as hydroxides, i.e. management of residuals will be required.

... with ozone O_3:

Combination with UV-irradiation for an increased generation of hydroxyl radicals is advantageous

$$O_3 + H_2O \overset{h \cdot \nu}{\Leftrightarrow} 2\,{}^{\bullet}OH + O_2$$

Removal of dissolved organic substances

Oxidation at high temperatures

Operating principle of "wet oxidation":

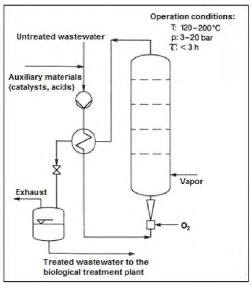
Conversion and partial mineralization of refractory organic substances with air or oxygen

Process schemes:

→ low-pressure oxidation (p = 6 - 10 bar, T = 140 - 180 °C)

→ high-pressure process (p = 20 - 200 bar, T = 250 - 330 °C)

→ oxidation in super-critical water (still under development)



Scheme of the wet oxidation process

Removal of dissolved organic substances

Combustion

Principle:

Evaporation of water and oxidation of organic substances in a gas burner

Pre-condition:

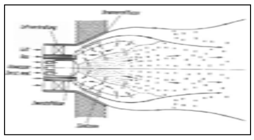
High concentration of organic material (> 10 % by mass, or COD > 100 g/L)

Estimate of the net calorific value:

$$H_U \text{ [kJ/kg]} = 13 \cdot \text{COD [g/kg]})$$

Operational challenge:

Handling of slag from salts in the wastewater



Gas burner for wastewater combustion (System BASF)

Removal of dissolved organic substances

Application of physico-chemical processes in industries

Adsorption:	Removal of specific components or total COD, e.g. in chemical or metal-processing industries
Low-temperature oxidation:	Pre-treatment of wastewater with refractory matter (COD concentrations of 0.5 - 5 g/L)
	Removal of chelating agents in wastewater from metal-plating industries
High-temperature oxidation:	Pre-treatment of chemical wastewater with refractory matter (COD content of 5 - 100 g/L)
Combustion:	Disposal of wastewater with very high organic content, e.g. in chemical industries and refineries

Final remarks

- Industrial wastewater treatment can be based on a central biological plant, but it often requires the application of physical-chemical or chemical processes for the (pre-)treatment of separate streams.
- These processes must be selected and designed by taking all of the specific boundary conditions into account.
- Therefore standard solutions are not the best option but individual process configurations have to be developed in order to obtain optimal removal efficiencies at reasonable costs.

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Residuals management

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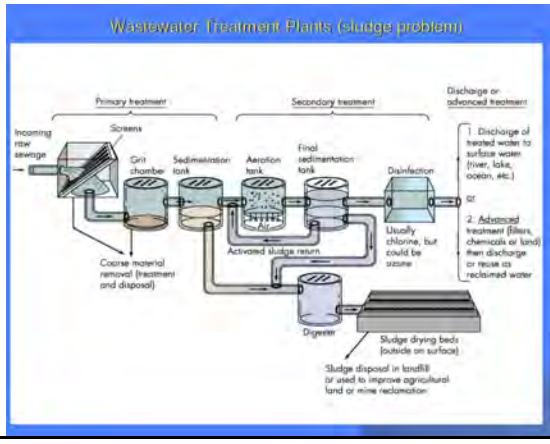

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CONTENT

1. Summary
2. The classification and nature of sludge
3. Sludge thickening
4. Sludge dewatering and drying
5. Sludge conditioning
6. Stabilization treatment of sludge
7. Comprehensive utilization and final disposal of sludge
8. Residuals management in different countries

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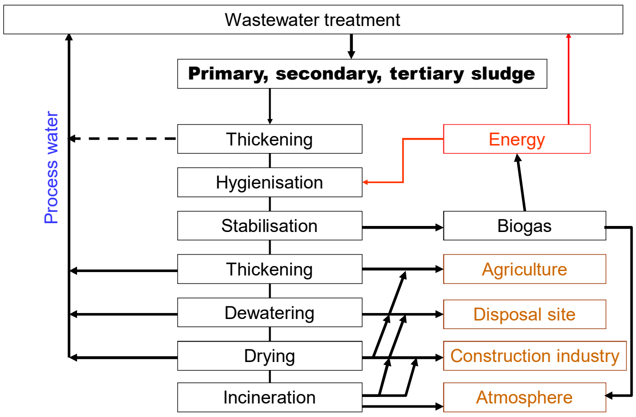

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1. Summary

The sludge treatment can be regarded as a continuous step of the sewage treatment, the final treatment of sewage sludge is the ultimate placing place of pollutants in the wastewater. Therefore, the sludge treatment has a very significant meaning in water treatment.

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The purpose of sludge treatment is:

- Sludge stabilization: the organic matter in which the final conversion to non oxygen consumption substances;
- Dehydration: remove a large amount of water contained in the sludge, reduce its volume, easy to transport and final treatment;
- The realization of favorable material recycling: such as paving, waste recycling, fertilization, etc..

Various methods of sludge treatment :

- Sludge thickening (gravity concentration, air flotation concentrate, centrifugal concentration)
- Sludge stabilization (anaerobic digestion, aerobic digestion, heat treatment)
- Sludge conditioning (chemical method, heat treatment)
- Sludge dewatering (drying bed, vacuum drum, filter, centrifugal dewatering, sludge drying and incineration)

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Sludge classification

- **Classified according to compositions**
  - Sludge: dominated by organic matter
  - Sediment: dominated by inorganic materials

Residuals and management

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Sludge disposal:

- Security landfill
- Sewage sludge compost
- Sludge delivery
- Utilization in building materials

Residuals and management

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- **Divided by sludge source**
  - Primary settling sludge: from primary settling tank
  - Excess sludge: from two settling tanks after activated sludge process
  - Humus sludge: from two settling ponds after the biological membrane method
  - Digested sludge: Raw sludge after digestion (cooked sludge)
  - Chemical sludge: sludge produced by chemical precipitation method

Residuals and management

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2. Classification and properties of sewage sludge

2.1 Sludge classification

2.2 Properties of sludge

Residuals and management

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Properties of sludge

- **The water content of sludge**

The ratio of water in the sludge and the sludge in weight.

Sludge water content is generally very high, so the proportion is close to 1.

Residuals and management

The relationship between the volume, weight, and solids concentration of the sludge is as follows：

$$\frac{V_1}{V_2}=\frac{W_1}{W_2}=\frac{100-P_2}{100-P_1}=\frac{C_2}{C_1}$$

P_1, V_1, W_1, C_1 - the sludge volume, weight and solids concentration in the water content of P_1

P_2, V_2, W_2, C_2 - the sludge volume, weight and solids concentration in the water content of P_2.

Purpose and function

- Objective: to reduce the water content, so that the volume can be reduced to a certain extent.
- Function: to reduce the investment, land occupation and operation cost of the subsequent treatment facilities.

- **Volatile solids（VSS）and ash**

the approximate amount of organic matter content of the volatile solids; ash content of inorganic content

- **Properties of sludge**

Water content of sewage sludge

Types	Water content (%)
Primary settling sludge	95-97
Humus sludge	92-96
excess sludge	98-99

Characteristic

- Concentrated for reducing the water in the sludge

Pore water ,70%: concentration method

Capillary water ,20%: natural drying; mechanical dewatering

Attached water and internal water , 10%: drying and incineration

- After the concentration of the sludge is still in liquid.

3. Sludge thickening

3.1 Purpose and function

3.2 Characteristic

3.3 Concentration method

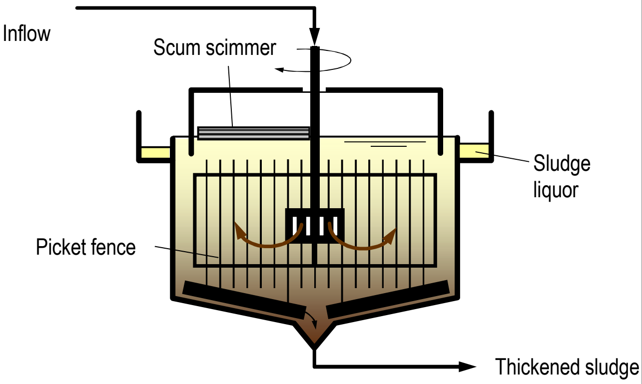
Concentration method

- Gravity concentration

Using wet sludge tank, intermittent and continuous;

Design parameters: residence time <24h, general fetch 7-12h; Often used Coe-Clevenger, Dick, Fitch and Kench method for design ； Rising velocity (surface loading).

Features: large storage capacity, low operating requirements, operating costs, covers an area of large, concentrated efficiency is not high enough.



Thickening by Flotation

Pre treatment: mostly chemical flocculation

Slude is placed in contact with air-saturated water (full flow or recycle pressurization)

Air bubbles attach to solid particles
→ lower specific gravity than water

Floating Sludge bubble composite is collected at the surface

Water is recovered under a scum baffle and removed

Dimensioning of gravity thickeners surface

Solids overflow rate

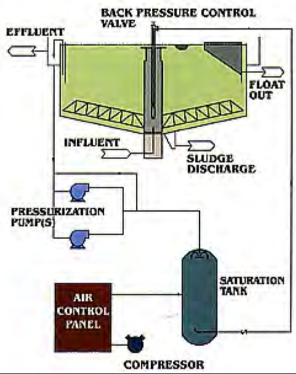
$$q_{TSS,Th} = \frac{Q_{WAS} \cdot X_{Th,in}}{A_{Th}}$$

$q_{TSS,Th}$	Specific solids overflow rate (kg TSS / (m^2 d))
Q_{WAS}	Inflow to thickener (m^3/d)
$X_{Th,in}$	Solids concentration in thickeners inlet (kg TSS / m^3)
A_{Th}	Surface of thickener (m^3)

Typical values for solids overflow rate $q_{TSS,Th}$ and concentration of thickened sludge X_{Th}

	$q_{TSS,Th}$	X_{Th}
Primary sludge	80 – 120	80 - 150
Primary and secondary sludge	50 - 70	50 - 100
Secondary sludge	25 - 30	20 - 35

Thickening by Flotation



- Thickening by Flotation

Often use air flow and pressurized dissolved air floatation

Design parameters: solid loading rate, gas / solid ratio

Features: good separation effect, concentrated sludge moisture content is low, reliable work, covers an area of small, the odor problem, to oil, high operation cost, complicated operation, no sludge storage capacity.

Flotation unit

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● Centrifugal concentration

Continuous operation, less land occupation, good sanitary conditions, high power consumption, equipment and operation requirements are very high.

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Characteristic

- For the removal of the gap between water and capillary water
- After the dehydration of sludge loss of mobility; the formation of mud, mud cake

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4. Sludge dewatering and drying

4.1 Purpose and function

4.2 Characteristic

4.3 Main methods

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Volume reduction

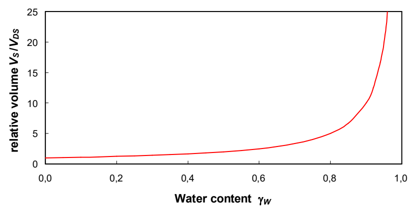
Water content in stabilised sludge > 95% !

→ Reduction of water content and volume

Sludge volume

$V_S = V_{DS} + V_W = V_{DS} + \gamma_W V_S$ With water content $\gamma_W = \frac{V_W}{V_S}$

→ $V_S = \frac{1}{1-\gamma_W} V_{DS}$



→ **non-linear relation!**

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Purpose and function

To further reduce the moisture content, in order to facilitate the final treatment of sludge.

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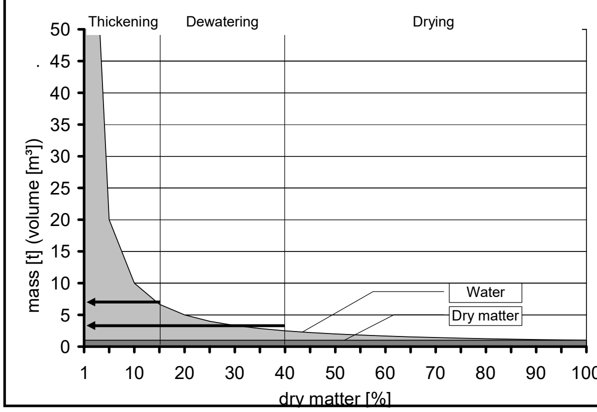
Volume reduction



Dewatering

Conditioning with flocculation agents (poly-electrolytes) for efficient dewatering

Unit	Operation	Method	γ_W	γ_{DS}
Decanter	Continuous	Centrifuge	> 0.7	< 0.3
Chamber filter press (large plants)	Batch-wise	Hydraulic pressure through plates in water-tight chambers	> 0.6	≤ 0.4
Belt filter press (small plants)	continuous	Pressed between two filter belts around staggered rollers	> 0.7	≤ 0.3

There are 4 ways to cause the pressure difference：

（1） Rely on the static pressure of the sludge itself （Drying field）；

（2） Causing negative pressure on one side of the filter medium （Vacuum filter）；

（3） Pressurized sludge to the moisture content of the media （Filter press）；

（4） Centrifugal force （Centrifugal dewatering）.

Drying bed

- Thin sludge layer (< 20 cm)
- Sand layer as drainage and filter layer
- Sludge is first dewatered by drainage then air-dried through evaporation
- Applicable for small plants

Dimensioning → $\gamma_W \approx 0.55$ (Imhoff, 1990)

Plant type	Specific surface
Only mechanical treatment	13 PE/m^2
Trickling filter	6 PE/m^2
Activated sludge plant	4 PE/m^2

➢ **Filter press**

Equipment frequently used is belt filter and frame filter press;

Plate and frame filter press to intermittent operation， belt filter is continuous operation.

The parameters of device modeling are： frame area （m^2）， belt width （m）. The water content of sludge after filtration rate can reach about 75%.

Main method

- Vacuum filter, belt filter, filter press, centrifugal drying bed, etc..
- Pretreatment requirements

	Concentrate	adjust
Vacuum drum	√	√
Plate pressure filtration	√	√
Belt filter	√	√
Drying bed	Not always	No need

➢ **Centrifugal dewatering**

The performance of the centrifuge is evaluated by the factors of separation:

The ratio of centrifugal force and gravity.

General separation factor at 1000-1500 for low speed centrifuge; 1500-3000 for medium speed centrifuge; Greater than 3000 for high speed centrifuge.

There are two types of commonly used centrifuge tube and horizontal.

➢ **Sludge drying bed**

Sludge drying bed is a flat field, due to the natural evaporation and infiltration of water in the drying bed, volume gradually decreases, gradual disappearance of liquidity.

The water content of sludge can be reduced to 65%.

Sludge drying bed and embankment generally by the partition, mud tank, filter layer, drainage system, impervious base etc., The main factors affecting the sludge drying bed are climate conditions and the nature of the sludge.

Conditioning approach

● Factors affecting the performance of concentrated dehydration

➢ Particle size

➢ Charge on the surface： Electric repulsion force

➢ Hydration of sludge granules： Hydration shell

● Conditioning approach

➢ Increasing particle size

➢ Reduced electric repulsion force

➢ Reduce the degree of hydration

5. Sludge conditioning

5.1 Purpose and function

5.2 Conditioning approach

5.3 Common conditioning methods

Common conditioning methods

● Conditioning dosing method

The principle is to use chemical drugs to undermine the affinity between slurry， reduce the specific resistance of sludge by conditioning. The use of drugs known as conditioner. The net water coagulant can be used as a soil conditioner.

Conditioner is divided into organic and inorganic conditioner. The inorganic conditioner commonly used iron and aluminum, the main organic coagulant polyacrylamide series.

Purpose and function

Purpose： Improvement of concentration and dewatering performance of sludge.

Effect： Reducing adhesion of water to particles， improve the recovery rate of sludge particles.

● Heating conditioning method

Heated sludge under high pressure, the purpose is to destroy the connection between the water and the sludge particles, and the sludge was dissolved or hydrolyzed under high temperature and high pressure, to destroy the cells and release the moisture inside the cells, Improved dewatering performance.

● Other adjustment methods

Adding inert material, etc.

6. Stabilization treatment of sludge

6.1 Anaerobic mesophilic sludge stabilisation

6.2 Processes in digester

6.3 Simultaneous aerobic sludge stabilisation

Characteristic values of digester

Mean residence time of sludge

Small units, badly mixed	< 30 d
Medium size units with mixing	20 d
Large plants with mixing	12 – 16 d
Biogas production related to degradation of organic substances	0.9 m^3 / kg $VSS_{degr.}$
Degradation of organic substances	40 – 55%

6.1 Anaerobic mesophilic sludge stabilisation

Digester

Heated to 33 – 37° C → process rates are higher

Content of digester is mixed → Sludge and water obtain a similar residence time

Storage unit

Not heated → little biological activity

Not mixed → separation of sludge and process water, which is directed to WWTP

→ **Control of loading to WWTP, app. 10% of N-loading**

Further thickening

6.3 Simultaneous aerobic sludge stabilisation

- No primary clarifier → no primary sludge
- High sludge age SRT, app. 25 d
- Activated sludge tank is larger than that combined with an anaerobic sludge stabilisation
- No biogas production
- Possibly combined with storage or thickener unit
- Stable and simple operation

6.2 Processes in digester

Anaerobic degradation

$$2\ C_5H_7NO_2 + 8\ H_2O \rightarrow 5\ CH_4 + 3\ CO_2 + 2\ NH_4^+ + 2\ HCO_3^-$$

Degradation of organic substances of app. 50%

Biogas production: 63% CH_4 (Methane)
35% CO_2
2% other gases (N_2, H_2, H_2S)

→ **electricity and heating**

Organic nitrogen is converged to NH_4^+

→ **N-loading of WWTP**

7. Comprehensive utilization and disposal of sludge

- Sludge utilization

Factors that can be used: Nutrients and organic compounds, recycling energy, extracting valuable raw materials.

- Agricultural application

High nutrient organic fertilizer, can improve soil, the problem is affecting toxins, pathogens and heavy metals and the environment (odor).

- Recovery of useful substances
- Other comprehensive utilization : Methane, brick, paving, etc..

- Enter the environment

- Landfill - alone or with the municipal waste landfill. should be stabilized before landfill treatment, choose a good landfill site, management and prevention of groundwater pollution, collection and treatment of leachate .
- Incineration - a large number of reducing the amount of organic solids and volume, sterilization; the main problem is air pollution and economy.
- Putting on the ground - toxic, harmful substances into the deep wells or waste pit, economic factor limitation.
- Landfill in ocean- cost and other issues are worth discussing.

8. Residuals management in different countries

- China
- Germany
- Norway
- Poland
- Sri Lanka
- Ukraine

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RECOVERY, RECYCLING AND REUSE

Prof. Harsha Ratnaweera,
harsha@nmbu.no
Norwegian University of Life Sciences

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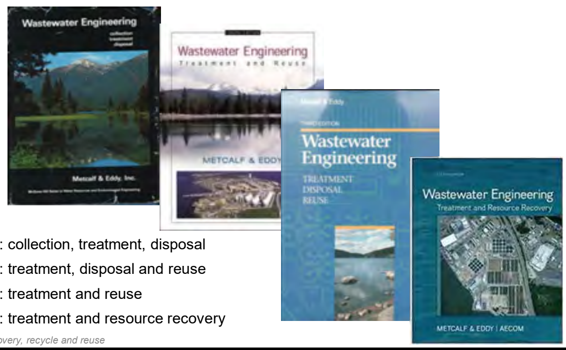
Focus of the industry changes



- 1972: collection, treatment, disposal
- 1980: treatment, disposal and reuse
- 2003: treatment and reuse
- 2014: treatment and resource recovery

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The future: WWTPs or energy plants?

Frank Rogallo, Aqualia

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Beneficial use of wastewater

- Reuse of water
- Sludge as a fertiliser & soil conditioner
- Recovery of nutrients
- Recovery of salts /other matters
- Energy recovery and production

•Industrial wastewater reuse & recycling will not be addressed in this lecture, although they have additional benefits – food additives, heavy metals etc

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Glossary

Term	Definition
Beneficial Use	Use of water directly by people for their economic, social or environmental benefit.
Criteria	Standards rules or tests on which a decision can be based.
Direct Reuse	Use of recycled water delivered directly for beneficial reuse including into a water supply system.
Environmental Buffer	A water body or aquifer which lies between a recycled water discharge and a water supply intake or extraction well. An environmental buffer will often provide additional natural treatment.
Greywater	Wastewater from bathing and washing facilities. Human wastes from toilets and food wastes from the kitchen are excluded.
Guidelines	Recommended or suggested standards, criteria, rules or procedures that are advisory, voluntary and unenforceable.
Indirect Reuse	Use of recycled water delivered into a river, reservoir or groundwater aquifer from which water supply is drawn at a point downstream.
Non-Potable Use	Use of water for purposes that do not require drinking water quality.
Potable Use	Use of water for purposes that require drinking water quality.
Recycled Water	Water recovered by treatment of wastewater, greywater or stormwater runoff to a quality suitable for beneficial use. Synonym of reclaimed water.
Regulations	Standards, criteria, rules or requirements that have been legally adopted and are enforceable by government agencies.
Return Flow	The return of recycled water flows back to the river from which the water supply was drawn.
Standard	An enforceable rule, principle or measure established by a regulating authority for example numerical water quality limits.
Wastewater	Used water discharged from homes, businesses, industry or agriculture.
Water Reclamation	The process of treating wastewater and recovering recycled water of a quality which is suitable for beneficial use.
Water Recycling	Use of recycled water for beneficial purposes.
Water Reuse	Use of recycled water; using water multiple times for beneficial purposes.

*Adapted from Glossary of Water Reuse developed by the IWA Specialist Group on Water Reuse.

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Water stress index

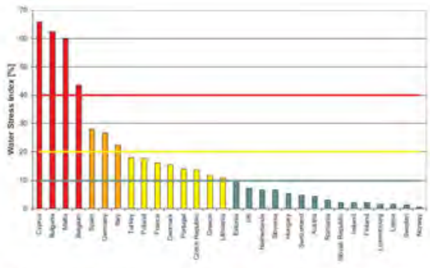

Figure 1 Water stress index % (abstraction/availability ratio). WSI below 10%: low; WSI from 10% to 20%: moderate, WSI from 20% to 40%: high and WSI above 40%: severe.

WW reuse in EU, 2013

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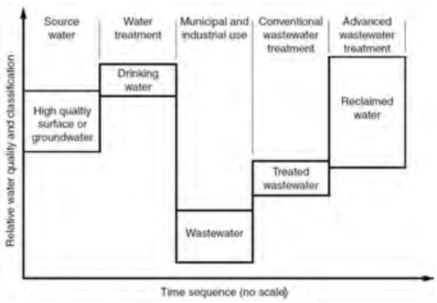
Change of water quality during municipal use



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Water reuse categories and typical applications

Category	Typical application
Agricultural irrigation	Crop irrigation Commercial nurseries
Landscape irrigation	Parks School yards Freeway medians Golf courses Cemeteries Greenbelts Residential
Industrial recycling and reuse	Cooling water Boiler feed Process water Heavy construction
Groundwater recharge	Groundwater replenishment Salt water intrusion control Subsidence control
Recreational/environmental uses	Lakes and ponds Marsh enhancement Streamflow augmentation Fisheries Snowmaking
Nonpotable urban uses	Fire protection Air conditioning Toilet flushing
Potable reuse	Blending in water supply reservoirs Blending in groundwater Direct pipe to pipe water supply

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Blackwater and Greywater recycling

https://www.youtube.com/watch?v=y8kipgTJDUw

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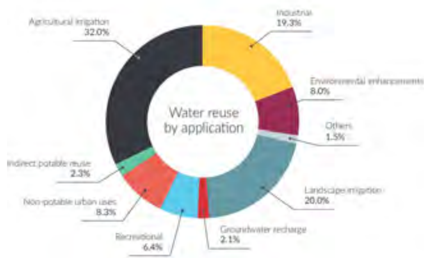
Global water reuse after advanced (tertiary) treatment: Market share by application



Source: Lautze et al. and Global Water Intelligence 2014.

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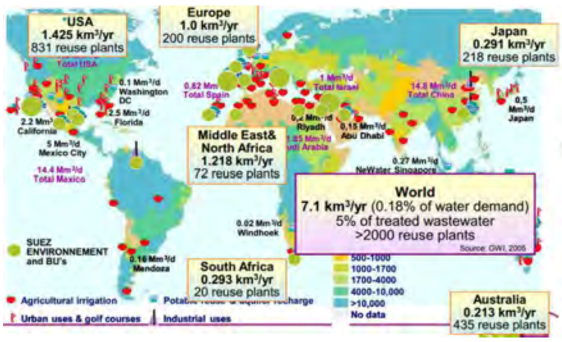
Global trends



Lazarova, Water reuse global trends, 2005

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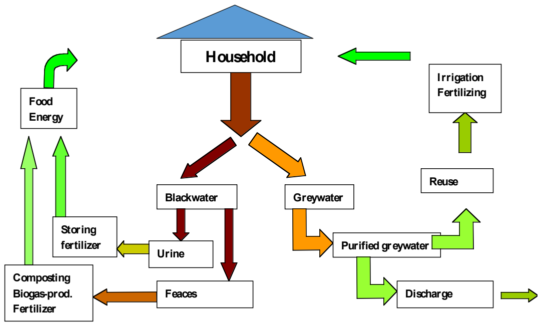
Wastewater as a resource



Arve Heistad, NMBU

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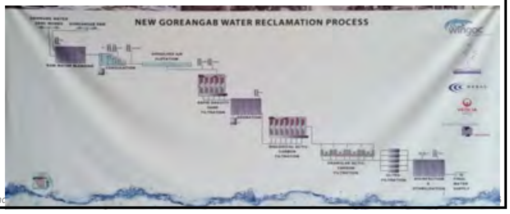
Science, Tech & Environment

Recycling sewage into drinking water is no big deal. They've been doing it in Namibia for 50 years.

- The Goreangab DWTP turns sewage from Winhoek's 300 000 residents back into potable water. It opened in 1968 and was the first such plant in the world.



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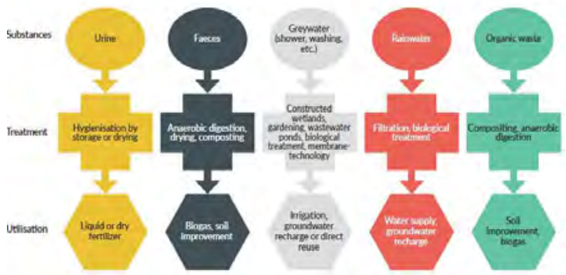
Waste segregation and possible utilization options



Source: UNESCO-IHP/GTZ (2006, Fig. 4, p. 15).

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Example - Singpore

Water scarcity in Singapore

- ❑Small land area
- ❑Densely populated

Based on freshwater resources alone, Singapore is one of the world's most "water-scarce" countries

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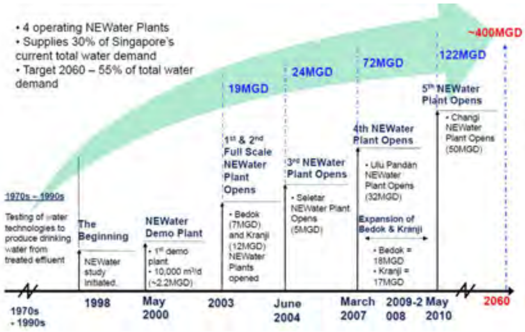
Water recovery and reuse principles in Singapore

to capture every drop of rain that falls on Singapore

to collect every drop of used water

to recycle every drop of water more than once

Singapore- NeWater story



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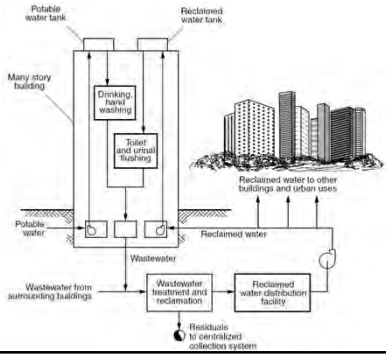
Non-potable use

- For cooling towers
- For toilet flushing
- For gardening
- For agriculture

Non-potable domestic use



Non potable use examples

Careful and appropitate use

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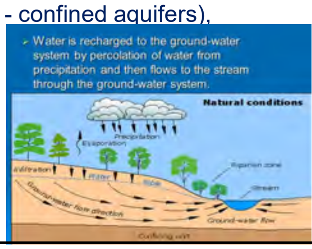
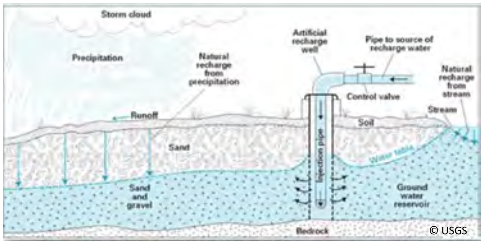
Ground water recharge

Typical methods:

- Field flooding
- Recharge basins
- Excavated pits,
- Recharge (injections wells - confined aquifers),



Artificial recharge with recycled water



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Sludge: fertilizer / soil conditioner

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Usage of sludge in agriculture. EU

- COUNCIL DIRECTIVE of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC)
- Only if the national authorities regulates its use.
- Limit values for concentrations of heavy metals
  - in the soil
  - in sludge
  - maximum annual quantities into the soil

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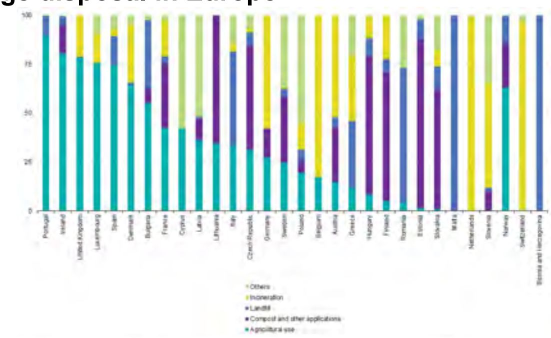
Sludge disposal in Europe



(*) Belgium, Denmark, Greece, Spain, Cyprus, Lithuania, Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden and the United Kingdom: 2012. Italy: 2010. Croatia: not available.
Source: Eurostat (online data code: env_ww_spd)

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Legislation for sludge treatment

Hygienisation – Prevent infection of humans and animals

Stabilisation– Prevent smell

Dewatering– Ease of handling

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Use of sludge – EU practice

- on grassland or forage crops: > 3 weeks to be harvested;
- on fruit and vegetable crops during the growing season, with the exception of fruit trees;
- on ground intended for the cultivation of fruit and vegetable crops which are normally in direct contact with the soil and normally eaten raw >10 months before harvesting.

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Use of sludge – EU practice

- Sludge and soil on which it is used must be sampled and analysed.
- Countries must keep records registering:
- Where conditions so demand, Member States may take more stringent measures than those provided for in this Directive

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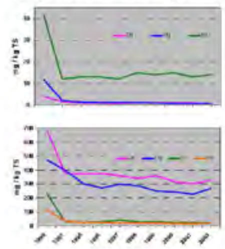
Reductions of HM in sludge in Norway

Heavy metals in sludge



Tungmetaller	% reduksjon (1980-2003)
Cd	78
Pb	81
Hg	93
Ni	67
Zn	53
Cu	43
Cr	90

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Food matrix

Fruit	Salad (e.g. ready to eat crops)	Vegetables	Horticulture	Combinable and animal feed crops	Grassland and forage: Harvested	Grassland and forage: Grazed
Top fruit (apples, pears, etc.) Stone fruit (plums, cherries etc.) Soft fruit (currants and berries) Vines Hops Nuts	Lettuce Radish Onions Beans (including runner, broad and dwarf French) Vining peas Mangetout Cabbage Cauliflower Calabrese/broccoli Courgettes Celery Red beet Carrots Herbs Asparagus Garlic Shallot Spinach Chicory Celeriac	Potatoes Leeks Sweetcorn Brussels sprouts Parsnips Swedes/turnips Marrows Pumpkins Squashes Rhubarb Artichokes	Soil based glasshouse and polythene tunnel production (including tomatoes, cucumbers, peppers etc.) Mushrooms Nursery stock and bulbs for export Basic nursery stock Seed potatoes for export Basic seed potatoes Basic seed production	Wheat Barley Oats Rye Triticale Field peas Field beans Linseed/flax Oilseed rape Sugar beet Sunflower Borage	Maize silage Grass silage Haylage Hay Herbage seeds	Grass Forage Swedes/turnips Fodder mangolds/ beet/kale Forage rye and Triticale Turf production

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The Safe Sludge Matrix

CROP GROUP	UNTREATED SLUDGES	CONVENTIONALLY TREATED SLUDGES	ENHANCED TREATED SLUDGES
FRUIT	✗	✗	✓ (10 month harvest interval applies)
SALADS	✗	✗ (30 month harvest interval applies)	✓ (10 month harvest interval applies)
VEGETABLES	✗	✗ (12 month harvest interval applies)	✓ (10 month harvest interval applies)
HORTICULTURE	✗	✗	✓ (10 month harvest interval applies)
COMBINABLE & ANIMAL FEED CROPS	✗	✓	✓
GRASS & FORAGE - GRAZED	✗	✗ (Deep injected or ploughed down only) (3 week no grazing and harvest interval applies)	✓ (3 week no grazing and harvest interval applies)
GRASS & FORAGE - HARVESTED	✗	✓ (No grazing in season of application) (3 week no grazing and harvest interval applies)	✓ (3 week no grazing and harvest interval applies)

NOTE: ✓ *All applications must comply with the Sludge (Use in Agriculture) Regulations and DETR Code of Practice for Agricultural Use of Sewage Sludge (to be revised during 2001).*
✗ *Applications not allowed (except where stated conditions apply)*

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Methylmercury in rice?

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Valuable resources in wastewater:

In household wastewater:

*** 90 % of N**
*** 80 % of P**
*** 80 % of K**
*** 40-75 % of org.matter**

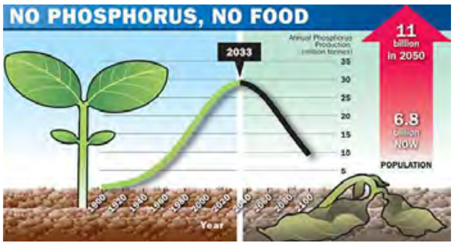
comes from the toilet fraction (blackwater)

Arve Heistad, NMBU

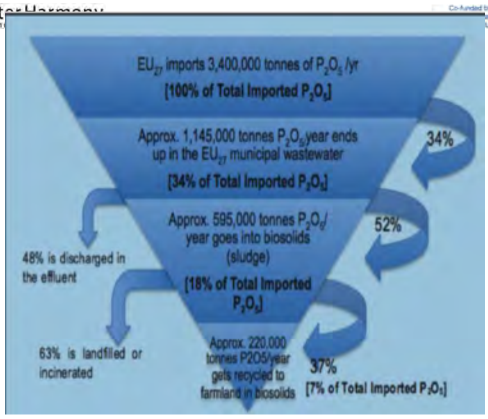
Recovery of nutrients

- Phosphates: mineral P reserves diminishing; need increases and no substitute
- Nitrogen: Abundant in the atmosphere but takes a considerable energy input to capture it and convert it into a fertilizer product
- Organic carbon

Phosphorus crisis



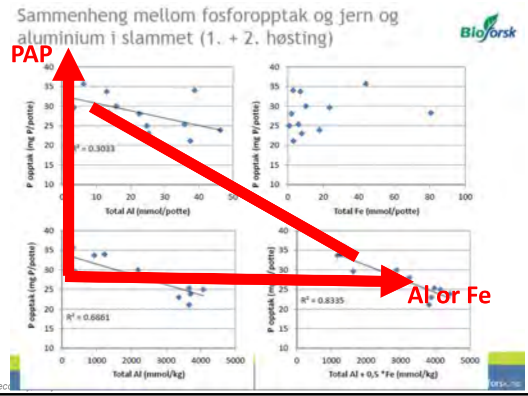
Norway: 2000 t-P/year in wastewater
Commercial fertilizer use: 8-9000 t-P/year



Impact of WW treatment on plant availability of P

- Bio-P removal: Plant Availability = mineral fertilizer
- Coagulation with Fe or Al: Plant Availability decreases with increasing content of Fe and Al in the sludge
- Coagulation with Ca: Reduces plant availability less than Fe and Al

Plant availability of phosphates (PAP)



Recovery of phosphates

- Direct use as a fertilizer
- Struvite production

$$Mg^{+2} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \cdot 6\,H_2O$$

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Recovery of nitrogen

Ammonia Stripping
- Up to 96% of N as NH3/NH4+ as Ammonium Nitrate/Sulphate Fertilizer
- Requires: T>60°C
- Problems: carbonate scaling, noise, air pollution and high pH

Ion Exchange
- Up to 97% N as NH4+ or up to 90% N as NO3 as a fertilizer
- Requires: extensive pretreatment
- Problems: complex bed regeneration and extensive pretreatment

Struvite Recovery
- Up to 90%-P & up to 40%-NH3 as slow-release fertilizer
- Requires: addition of magnesium source and pH≈7-8
- Problems: possible crystallization in pipes

$$Mg^{+2} + NH_4^+ + PO_4^{3-} + 6H_2O \rightarrow MgNH_4PO_4 \cdot 6\,H_2O$$

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Other valuable material from sludge

- A study of 50 WWTPs in US:
  - 13 most lucrative elements (Ag, Cu, Au, P, Fe, Pd, Mn, Zn, Ir, Al, Cd, Ti, Ga, and Cr) with a combined value of US $280/ton of sludge
  - 1 ton of sludge contains 16.7 g of Silver and 0.33 g of gold

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Energy from WW and sludge

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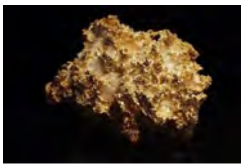
The Washington Post
Democracy Dies in Darkness

13.10.2017

Scientists digging in Swiss sewage find millions in gold and silver



- EAWAG found, per year, entering the sewer nationwide: 43 kg of gold; 3,000 kg of silver; 1,070 kg of gadolinium; 1,500 kg of neodymium; and 150 kg of ytterbium.

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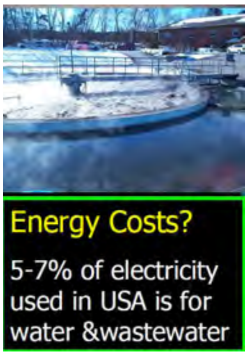

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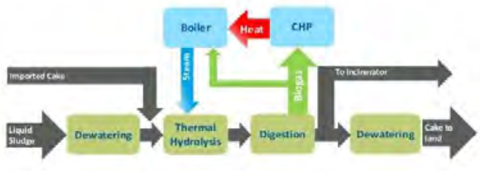
Energy from sludge

- Thermal hydrolysis



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Biogas for vehicles

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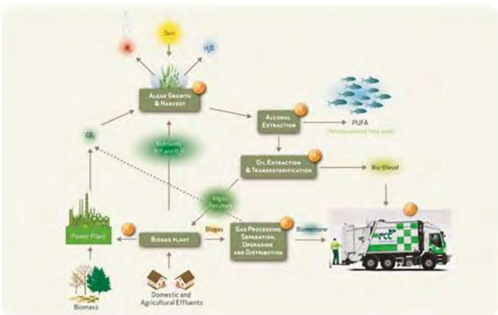
Biofuels from microalgae.



EU FP7 All-gas project

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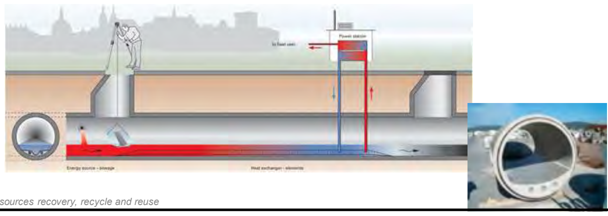
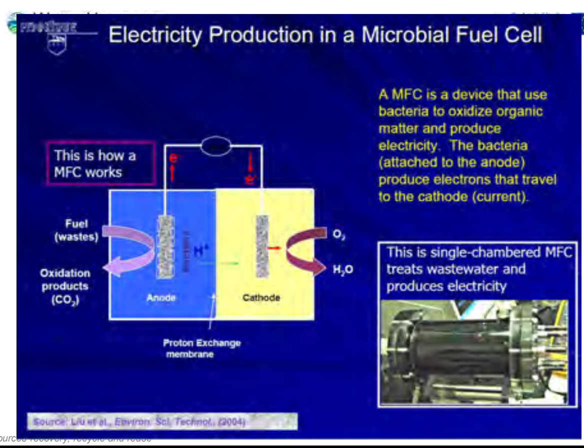
Energy recovery from high pressure distribution mains

- Zeropex of Norway: Difgen technology: a pressure-reducing system generating electric power from the pressure drop in fluids. Used in the place of a traditional pressure reducing valve (PRV) it combines the pressure control from chokes and electricity generation from hydroturbines.





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- Energy required for secondary wastewater treatment
  - 1,200 to 2,400 MJ/1000 m3
- Energy available in wastewater for treatment,
  - 5 000-6 000 MJ/1000 m3
- Energy available in wastewater is 2 to 4 times the amount required for treatment

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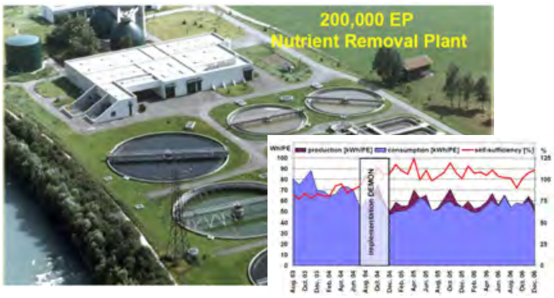
Energy self-sufficiency
Starss WWTP, Austria



8% to national grid

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Energy from effluent drop

- Vienna, Austria AWTP discharges 560 000 m3/d (148 MGD) to Danube River
- Drop to Danube River from plant outfall
  - 5 m (16.5 ft drop) between headworks and Danube River
- Electricity requirements for operation = 175 000 kWh/d (63.8 Million kWh per year)
- Vertical axis turbine produces 1.5 Million kWh per year used on-site in treatment plant's grid (2.6% of plant use)

http://www.aquamedia.at/templates/index.cfm/id/27096

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Basic sources for this presentation

- Maetrials from Associate Prof. Sergii Kontsevoi, serkon157@ukr.net, National Technical University KPI named after Igor Sikorsky
- Water Encyclopedia, Volume 1, Domestic, Municipal, and Industrial Water Supply and Waste Disposal. Jay H. Lehr (Editor-in-Chief), Jack Keeley (Editor), Janet Lehr (Associate Editor). ISBN: 978-0-471-73687-5. 952 pages, 2005
- Water reuse : issues, technologies, and applications / written by Takashi Asano … [et al.]. ISBN-13:978-0-07-145927-3. 1503 pages, 2007
- PUB, Singapore's National Water Agency: https://www.pub.gov.sg

https://www.youtube.com/user/pubwebadmin

Utility Management

Olga Sanginova
National Technical University of Ukraine
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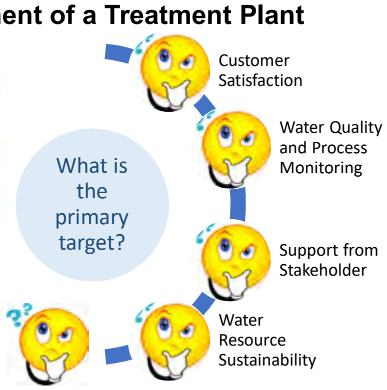
CONTENT

- Management of a Treatment Plant
- Effective Utility Management
- Surveillance and Control
- Water Quality and Process Monitoring
- Models and Simulation Programs
- Reporting

Management of a Treatment Plant



Effective Utility Management (EUM)

- A comprehensive water sector utility performance assessment and management framework, endorsed by the U.S. Environmental Protection Agency and ten national water sector associations dedicated to improving products and services, increasing community support for water services, and ensuring a strong and viable utility into the future.

A Primer for Water and Wastewater Utilities, January 2017

Main Components of EUM

- Ten Attributes of Effectively Managed Water Utilities
- Keys to Management Success
- Where-to-Begin Self-Assessment Tool

10 Attributes of Effectively Managed Water Utilities

1. Product Quality
2. Customer Satisfaction
3. Employee and Leadership Development
4. Operational Optimization
5. Financial Viability

10 Attributes of Effectively Managed Water Utilities

6. Infrastructure Viability
7. Operational Resiliency
8. Community Sustainability
9. Water Resource Adequacy
10. Stakeholder Understanding and Support

Where-to-Begin: Self-Assessment Tool

- Assessment of Current Conditions
- Ranking of Importance of Each Attributes
- Determination of Importance and Level of Achievement
- Selection of the Most Important Attributes

Keys to Management Success

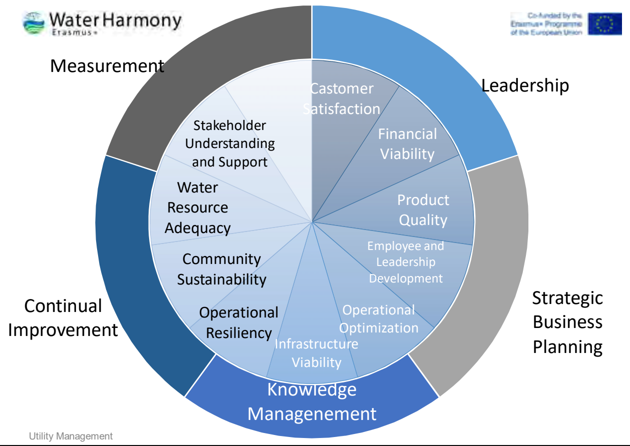
1. Leadership
2. Strategic Business Planning
3. Knowledge Management
4. Measurement
5. Continual Improvement Management

Selection of the Most Important Attributes

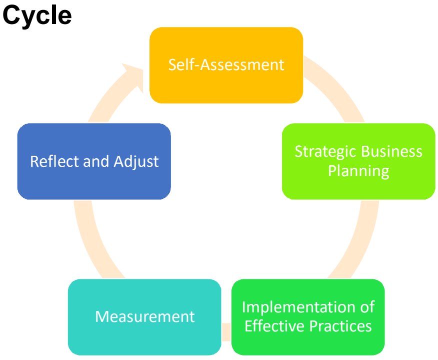
Rating											
Lower Achievement	5										
	4		PQ								
	3				CS						
Higher Achievement	2										
	1										
		1	2	3	4	5	6	7	8	9	10
		More Important								Less Important	

Ranking

PQ - Product Quality
CS - Customer Satisfaction



EUM Cycle



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Practical Tools that Implement EUM

- **Lean** – set of methods are aimed at identifying and "waste" in processes
- "Waste is non-value-added activity that refers to any inefficiency in resource use and deployment
- **Six Sigma** statistical methods offer "how to" techniques to make implementation happen and deliver results

Source: Resource Guide to Effective Utility Management and Lean, 2012

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Identifying Lean Wastes with DOWNTIME

- **D**efects
- **O**verproduction
- **W**aiting
- **N**on-utilized or under-utilized resources/talent
- **T**ransportation
- **I**nventory
- **M**otion
- **E**xcess Processing

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Key Lean principles

- Focus on the customer
- Reduce the complexity of processes
- Use metrics and visual controls to provide rapid feedback to improve real-time decision-making
- Involve employees in continual improvement and problem-solving activities
- Use a whole-systems perspective that seeks to optimize processes across multiple goals

Source: Resource Guide to Effective Utility Management and Lean, 2012

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Methods Relevant to Water-Sector Utilities

Method	Goal and Focus of Improvement	Examples
Standard Work	Document the best way to perform a task/operation to make it easy to work efficiently and effectively	Step-by-step and visual documentation of processes for operating facility equipment, emergency response processes, compliance monitoring, job performance standards
5S (or 5S+Safety)	Improve the organization, cleanliness, safety, and efficiency of work areas	Maintenance and repair truck layout, organization of chemical supplies, desk organization
Lean Event (e.g., Kaizen Event)	Eliminate inefficiency and non-value added activity (waste) in repeatable processes in a short time period	Reducing time to respond to service delivery calls or back-ups; improving billing, contracting, or hiring processes

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Methods Relevant to Water-Sector Utilities

Method	Goal and Focus of Improvement	Examples
Total Productive Maintenance (TPM)	Integrate effective maintenance practices into all employees' work to minimize breakdowns, accidents, and other losses	Wastewater treatment plant operator practices, such as drying operations in the solids handling area; monitoring, inspecting, and adjusting pumps, motors, generators, air compressors, and other plant equipment
Six Sigma	Eliminate variation or defects in processes or address complex problems using statistical analysis	Optimizing plant digester operations, identifying root causes of effluent variations or sanitary sewer overflows, optimizing the use of chemical disinfectants

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Methods Relevant to Surveillance and Control

- Surveillance and Control/Water Quality and Process Monitoring
  - Histogram
  - Layering
  - Lean Event Charter
  - Plan-Do-Check-Act Project Worksheet
  - Control chart
  - SIPOC Process Definition Sheet
  - Fishbone diagram
  - ABC-analysis
  - Brain storm
- Models and Simulation Programs
  - STOAT
  - WEAP
  - SimEau

Source: Resource Guide to Effective Utility Management and Lean, 2012

Resources

- Effective Utility Management: A Primer for Water and Wastewater Utilities. (June 2008). www.watereum.org/resources/
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Thank you for your attention!

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Operation and maintenance
Trouble shooting of processes

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Troubleshooting
- identify the problem – What?
- understand the probable causes- Why?
- resolving the problem – How?

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Troubleshooting: Mechanical bar screens

Problems	Probable causes	Solutions
Obnoxious odours, flies and other insects	Accumulation of rags and debris	Increase frequency of removal and disposal to an approved facility
Excessive grit in bar screen chamber	Flow velocity low	Remove bottom irregularity, or resole the bottom. Increase flow velocity in a chamber of flush regularly with a hose.
Excessive screen clogging	Unusual amount of debris in wastewater. Check industrial wastes	Use a coarser screen or identity source of waste causing the problem so its discharge in the system ca be stopped.
Screening downstream screens	Overflow, damaged bars	Repair or replace screen


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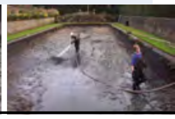
Troubleshooting: Grit removal

Problems	Probable causes	Solutions
Grit packed on collectors	Collector operating at too high speed	Reduce collector speed Increase speed of grit removal from collector
	Bucket elevator/removal equip. too slow speeds	Removal system speed
Rotten eff odor in grit chamber	Hydrogen sulphide formation	Wash chamber and dose with hypochlorite
Accumulated grit in chamber	Submerged debris	Wash chamber daily. Remove debris
	Flow velocity too low or broken chain or flight	Repair equipment
Corrosion of metal and concrete	Inadequate ventilation	Increase ventilation and perform annual repair and repainting

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Troubleshooting: Grit removal

Problems	Probable causes	Solutions
Removed grit is grey in color, smells, and feels greasy	• Inadequate air flow rate	• Increase velocity in grit chamber.(0.3 m/s usually optimum unless operating strategy calls for lower velocity
Surface turbulence in aerated grit chamber is reduced	• Diffusers covered by rags or grit	• Clean diffusers and correct screens or other pretreatment steps to prevent
Low recovery rate of grit	• Bottom scour at excessive speeds	• Maintain velocity near 0.3 m/s
	• Too much aeration	• Reduce aeration • Increase retention time by using or reducing flow to unit
Overflowing grit chamber	• Pump surge problem	• Adjust pump controls or control infiltration and inflow
Septic waste with grease and gas bubbles rising in grit chamber	• Sludge on bottom of chamber	• Wash chamber daily

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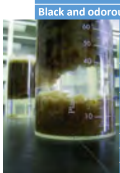
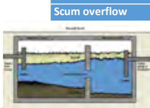
Troubleshooting – primary settling

Problem	Probable causes	Solutions
Floating sludge	Sludge decomposing in tank	Increase sludge removal rate or frequency
	Sludge withdrawal line clogged	Flush or clean lines
	Decomposition of accumulated sludge in dead zones	Clean tank bottoms and improve design
Black and odorous septic	Improper sludge removal pumping cycles	Increase sludge removal rate or frequency
	Inadequate pre-treatment of organic industrial wastewater	Improve pre-treatment or/and pre-aeration
	Sewage decomposing in collection systems	Add chemicals or aerate collection systems
	Recycle of excessive strong digester supernatants	Improve sludge digestion to obtain better quality supernatants
	Sludge withdrawal line clogged	Clean line
	Too high septic dumping	Regulate septic loading rates
	Inadequate run time for sludge collectors	Increase run time or run continuously
Scum overflow	Frequency of removal inadequate	Increase removal frequency
	Too high industrial wastewater loads	Limit loading of industrial wastewater
	Improper alignment of skimmer	Adjust alignment
	Inadequate depth of scum baffle	Increase baffle depth

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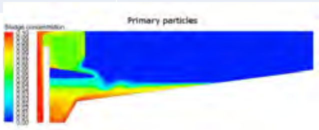
Problem	Probable causes	Solutions
Sludge hard to remove from hopper	Low velocity in withdrawal lines	Increase velocity
Undesirable low solids content in sludge	Hydraulic overload	Provide more even flow distribution in all tanks, consider equalization tank
	Too high sludge removal rate	Reduce frequency and duration of sludge pumping
	Reduced tank vol. (dead zones)	Clean tank bottoms, improve design
Short-circuiting of flow through tanks	Uneven weir setting	Change wear setting
	Damaged/missing inlet line baffles	Repair or replace baffles
	Design weakness	Improve design using CFD simulations or pilot tests
Surging flow	Improper programming of influent flow	Improve programming



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Problem	Probable causes	Solutions
Excessive sedimentation in inlet channel	Velocity too low	Increase velocity (by closing some of tanks) or agitate with air or water
Poor suspended solids removal	Hydraulic overloading	Use more tanks or equalisation tanks, or add chemicals
	Short-circuiting	See "short-circuiting of flow through tanks"
	Inadequate removal of sludge	Increase sludge removal rate and frequency
	Industrial waste	Eliminate industrial waste which cause problems
	Density currents due to temperature differences	Eliminate storm flows from sewers
	Density currents due to winds	Install wind barriers
Excessive growth on surface weirs	Accumulation of wastewater solids and resultant growth	Frequent and thorough cleaning

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Troubleshooting - Filtration

Problem	Probable causes	Solutions
Frequent break-through	Insufficient coagulation	Optimize coagulation condition
	Too small particles/flocs	Optimize polymer dosing
	Too high or fluctuating hydraulic load	Equalize and/or reduce load
Too high headloss	Too large particles/flocs	Optimize polymer dosing
	Too high hydraulic load	Reduce load
Mud-balls	Insufficient backwashing	Optimize backwashing
		Chlorination of filter
Insufficient particle removal	Insufficient coagulation	Optimize coagulation condition

Troubleshooting - Flotation

Problem	Probable causes	Solutions
Insufficient flotation	Too low air bubbles concentration	Increase recycle flow
	Too large and/or dense flocs	Optimize coagulant and/or polymer dosing
		Optimize flocculation

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Troubleshooting: Flocculation tanks

Problems	Probable causes	Solutions
Floatables	• Air bubbles lifting sludge to the surface	Look for air suction whirls or weirs
	• Decomposed deposits form black floatable cakes	See "Deposits"
Deposits	• Insufficient preliminary or primary treatment	By direct or pre-precipitation plants the preliminary or primary treatment can be insufficient. Control the performance of screens, grit chambers and primary settling tanks
	• Undissolved precipitant	Control precipitant dissolver function Control that precipitant dose point has good mixing conditions. Alternatively increase agitation velocity in the first flocculation tank.
	ow agitation velocity	Low velocity of agitators may cause sedimentation in the flocculation tanks. Try to increase the velocity, but be aware of destroyed and poor removal rates.

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Coagulation stage

Problem	Probable causes	Solutions
Floating sludge	See "sedimentation tanks"	See "sedimentation tanks"
Deposits in flocculation tanks	Undissolved coagulants, if solid coagulants used	Control coagulant dissolver function
	Too low agitation velocity or too low flow	Increase agitation velocity or flow rate, but be aware of floc breakage at too high speeds
Bad flocculation	Coagulation pH outside optimum range	Adjust coagulant dosing to keep pH within optimal ranges
		Use an alternative coagulant more suitable for pH / alkalinity
	Insufficient coagulation/ precipitation	Increase dosing if pH not too low
		Add or increase flocculent dosage
	Insufficient mixing of coagulant with wastewater	Control dosing point. Add precipitants to a point with more intensive mixing
		Increase mixing speed in the first flocculation chamber
	Too high hydraulic overloading in flocculation tank	Flocculation time should be more than 10-15 minutes
	Too low hydraulic overloading in flocculation tank	Too long flocculation periods may destruct flocs. Reduce retention time by reducing number of flocculation chambers
	Short-circuiting in flocculation tanks leading to too low retention times	Use baffles or improve design of channels

Problem	Probable causes	Solutions
Too small flocs at the end of flocculation	Inadequate coagulant or flocculent dosage	Adjust dosage
	Inadequate mixing of coagulants	Improve mixing by adjusting dosing point and dosing conditions
	Poor flocculation conditions	Improve velocities in flocculation stage
	Floc breakage when entering sedimentation tank	Control velocities in narrow passages, weirs, bends. Velocities should be <0.2 m/s preferably <0.1 m/s.
Bad separation	Too high surface loads	Reduce surface load by increasing sedimentation tanks
		Reduce surface loads by adding polymers
	Erosion of sludge blanket	Let sludge scrapers run continuously. Control scarper velocity is >0.5m/min
	Turbulent flow regime in settling tank	Control the wastewater distribution among multiple settling tanks
		Design improvement
Bad treatment efficiencies	Too low coagulant dose	Adjust dosing
	Too high coagulant dose	Adjust dosing
	Coagulation pH outside optimum range	Adjust coagulant dosing to keep pH within optimal ranges
		Use an alternative coagulant more suitable for pH / alkalinity

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Simultaneous precipitation

Problems	Probable causes	Solutions
Unsatisfactory precipitation	Too low dosing rate	• Control molar ratio. Control pH after increasing dosing rate!
	Too low pH	• Control molar ratio • Control nitrification by analyzing nitrate and nitrite in the aeration tank • If nitrification – control alkalinity • Add lime, soda or sodium bicarbonate
	Malfunctioning dosing system	• Dosing should be flow proportional or time proportional. Manual, ambient dosing is not recommended.
Unsatisfactory sedimentation	Floc size and weight may depend on dosing point.	• Try other dosing points: – Aerated grit chamber inlet – Aeration tank inlet – Aeration tank outlet – Return sludge
Unsatisfactory separation	See sedimentation	
Aeration equipment clogging	This is often a problem by iron dosing in aeration tanks. See "Aeration"	

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Troubleshooting: Aeration tanks

Problems	Probable causes	Solutions
White and fluffy foam	Low sludge age caused by too low MLSS in aeration tanks (e.g. plant start up)	Control settled sludge volume. If too low: Increase recycled flow and decrease sludge wasting.
	Poisoning caused by harmful discharges to the plant	• Control oxygen uptake rate and assess the result using Figure 6.5 • Find the source of the poisoning • Empty the aeration tanks and start once again.
Dark, greasy foam	High sludge age causes growth of bacteria that secretes a fat-material. This material forms the foam.	• Control MLSS and sludge age • Increase sludge wasting rate

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Troubleshooting: Aeration tanks

Problems	Probable causes	Solutions
Other foaming problems	Discharge of fat, soap, detergents and various types of industrial wastewater may cause different types of foaming. It is impossible to say if the foaming is harmful to the process without further investigation.	 
Sludge accumulation	Bad mixing	• Increase aeration • Control that aerators are not clogged
	Bad tank design	• Improve tank design
Aeration system failures		• Improve aeration system
Sludge bulking	Filamentous bacteria or fungi	• See Table for sludge bulking

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(Post) sedimentation tanks

Problem	Probable causes	Solutions
Floating sludge	Air bubbles lifting sludge to the surface	Stop air suction whirls or weirs;
	Decomposed deposits	Increase sludge pumping frequency
		Increase sludge scraper velocities or running times
	Sludge accumulation in dead zones	Clean and reduce accumulation in dead zones
Too high suspended solids in effluent	Sludge escape	Improve sedimentation performance by increase settling time or chemicals
	Poor settable flocs	Increase chemicals
	Dead zones in the tank	Clean and reduce dead zones
	Short-circuiting	Improve design
Low sludge solids concentration	Inadequate sludge thickening time in sludge hoppers	Reduce sludge pump starting frequency
	Water follows sludge during removal	Reduce sludge pumping frequency and increase pump starting frequency
	Too high sludge concentration may cause water channels in sludge	Improve sludge scarping and increase pump starting frequency or rate
Difficult to remove sludge	Too high sludge solids concentration	Increase sludge pump start frequency or rate
	Sand and other coarse particles in sludge	Improve pre-treatment (sand trap etc

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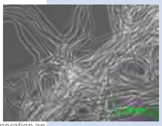
AS-Sludge bulking due to filamentous bacteria

Problems	Probable causes	Solutions
Sludge bulking caused by filamentous bacteria	Low oxygen content of aeration tank (<0.5 g O_2/m^3)	• Increase total air supply or regulate distribution in tanks or between multiple tanks to bring oxygen content at all places above the minimum level.
	Discharge of wastewater with high carbohydrate content	• Usual by food industry effluents. Equalize the discharges throughout the day at the source or at the treatment plant. Distribute the influent all over the aeration tank – step aeration.
	• Nutrient deficiency	• This may be the case at plants with industrial discharge. This is out of question when influent nutrients are higher than: ○ Tot-N 5% of BOD_5 ○ Tot-P 1% of BOD_5 ○ Fe 0.5% of BOD_5 ○ If there are shortage of any of these, they may be added
	• Flushing of accumulated materials from the sewer system	• More frequent flushing of pipes with little slope



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AS-Sludge bulking NOT due to filamentous bacteria

Problems	Probable causes	Solutions
Sludge bulking caused by other means then filamentous bacteria	• High and even sludge loading	• If sludge loading exceeds 0.5 kg BOD5/kg SS d, it should be decreased. The loading may be decreased, or the total biomass of the system increased (by decreased sludge wasting).
	• Low pH caused by nitrification	• Decrease nitrification by decreasing the biomass of the system (by increased sludge wasting), if nitrification is not intended • Increase alkalinity by sodium bicarbonate adding
Sludge bulking caused by other means than filamentous bacteria.	• Low influent pH	• Find the source and neutralize before discharging
	• Temperature changes	• Experience shows that some plants are exposed to temporarily bulking every spring and autumn.

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AS- Poor effluent

Problems	Probable causes	Solutions
Unsatisfactory separation	• Peak loads caused by uneven pumping	• Decrease pump time • Differentiate pump sizes • Overflow a part of the wastewater back to pumping sump
	• Hydraulic overload	• Build retention basin • Overflow some wastewater if the total removal rate then improve • Upgrade the sewer system • Try to improve sludge settleability. Use polymer or other flocculants.
	• Too high solids loading rate	• Adjust MLSS and return sludge flow to the solids loading capacity of the settling tanks
	• Sludge bulking	• See own section
	• Improver hydraulic regime	• Check loading of multiple tanks • Check that effluent weirs are horizontal and distribute flow equal over the weir length

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AS- Poor effluent

Problems	Probable causes	Solutions
Unsatisfactory decomposition	• Peak loads of organic matter (BOD_5). Even if the average loading during a day is not higher than normal, peak loads at short time intervals will cause lac of oxygen	• Increase total air supply • Regulate air supply by oxygen content or time • Equalize BOD_5 - discharges
	• Too low MLSS content in aeration tank	• Increase MLSS by reducing sludge wasting
	• General organic overload	• Improve preliminary treatment • Introduce pre-precipitation • Increase aeration tank volume
	• Sludge bulking	• See sludge bulking
	• Poisoning	• Find the source and stop the discharges

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Online sensors

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AS- Poor effluent

Problems	Probable causes	Solutions
Unsatisfactory settle ability of activated sludge	• Deflocculation caused by too strong turbulence	• Decrease air supply to the outlet part of the aeration tank • Remove hydraulic jumps or weirs if there are any between aeration tanks and settling tanks
	• Poisoning	• See "Unsatisfactory decomposition"
	• Sludge bulking	• See sludge bulking
	• High sludge age may cause "pin point flocs", which means a turbid effluent	• Increase sludge wasting
	• Low sludge age may lead to small, nearly transparent flocs in the effluent, even though the effluent, even though the effluent is otherwise clear	• Decrease sludge wasting

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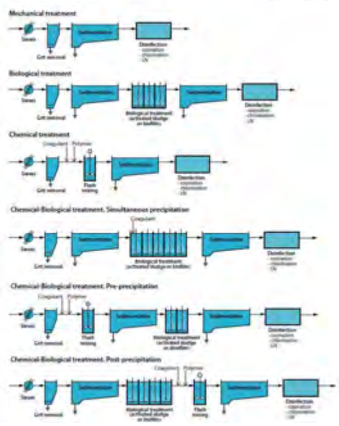
Process combinations



State Higher Educational Institution
"Ukrainian State University of Chemical Technology"

ECONOMIC SCHEME OF WASTE WATER TREATMENT

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WATER HARMONY ERASMUS +

Harmonise teaching and pedagogical approaches in water related graduate education

PLAN

1. ***Special aspects of production (operational) activity of water-and-sewage and industrial enterprises. Waste water classification***
2. ***Capital assets of water disposal system and production program. Efficiency of use***
3. ***Prime cost of water disposal and setting of rates***

1. Special aspects of production (operational) activity of water-and-sewage and industrial enterprises. Waste water classification

Water disposal classification can be presented as the groups listed below:

1. Household waste waters;
2. Industrial waste waters: industry, construction, transport, and agriculture.

In their turn, waste waters discharged from the territory of industrial enterprises are divided by their composition into three types:

1. production waters formed in the process of production of various goods, articles, materials;
2. atmospheric waters – rainwaters and waters from snow melting;
3. domestic waters – waste waters from toilet areas of industrial buildings and constructions, as well as from shower bath units available in the territory of enterprises.

Enterprises operating water supply and sewerage systems (depending on the volumes of their work) are divided into:

1. large-scale enterprises, of capacity exceeding 200 thous. m3 per day;
2. medium-scale enterprises, of capacity from 20 to 200 thous. m3 per day;
3. small-scale enterprises, of less than 20 thous. m3 per day capacity.

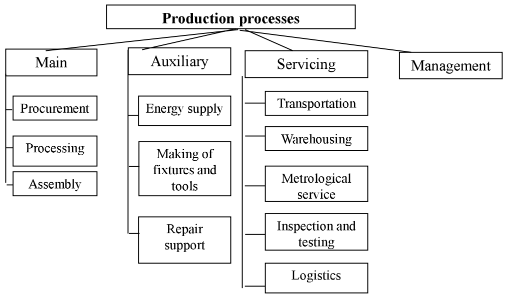

Fig. 1 Structure of production processes [2]

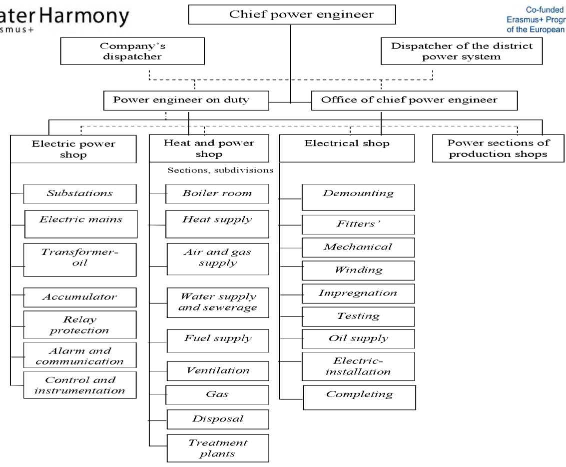

Fig. 2 Organization and production structure of power utilities at the large enterprise [2]

2. Capital assets of water disposal system and production program. Efficiency of use

Table 1 – Classification of groups of capital assets in the system of water disposal of water-and-sewage enterprises [3]

Groups	Minimum allowable useful life periods, years
group 2 – capital expenditures on land improvements not related to construction	15
group 3 – buildings,	20
constructions,	15
transmitting equipment	10
group 4 – machines and equipment	5
including:	
computing machines, other machines for automatic data processing, related means for data readout/printing, computer programs connected with them (except the programs which acquisition costs are recognized as royalty, and/or programs recognized as intangible asset), other information systems, commutators, routers, modules, modems, uninterruptible power supply units and means for their connection to telecommunication networks, telephones (including cell phones), microphones and radio stations which value exceeds 2500 hryvnias	2
group 5 – transport vehicles	5
group 6 – tools, devices, accessories (furniture)	4
group 7 – animals	6
group 8 – perennial plants	10
group 9 – other capital assets	12

Structure of capital assets at water-and-sewage enterprises of Ukraine is characterized, on average, by the ratio below, %:

- buildings – 7;
- constructions and transmitting equipment – 88;
- machines and equipment – 3;
- transport vehicles – 1;
- other capital assets –1.

The main performance indicators for the use of capital assets are as follows:

1. Return on assets (Ra) – index which reflects production output per 1 hryvnia of capital assets of an enterprise [4]:

$$Ra = PO / CAaa$$

where PO – production output;
CAaa – average annual value of capital assets.

2. Capital-output ration (Rco) – index showing the need in capital assets to provide fulfilment of a unit of the volume of work:

$$Rco = CAaa / PO$$

3. Capital-labor ratio (Rcl) is calculated according to the formula:

$$Rcl = CAaa / Npers$$

where Npers – average registered number of production personnel.

Table 2 – Indices characterizing quality and efficiency of work of water disposal system of the company as a whole and its structural subdivisions (departments) [5]

Indices characterizing quality and efficiency of work of water disposal system	Evaluation criteria
1	2
Water disposal system *of the company as a whole*	
Capacity utilization rate	Planned capacity utilization rate
Proportion of treated waste waters of total waste water volume	Proportion of treated waste waters of total waste water volume, according to the plan
Consumption of drinking water for operational needs	Planned consumption of drinking water for operational needs
Consumption of reagents and other materials	Standard consumption of reagents and other materials
Power consumption:	Standard power consumption
by pump stations	
by waste water purifiers	
Consumption of reference fuel	Standard consumption of reference fuel
Actual level of labor productivity	Planned level of labor productivity
Degree of mechanization of labor	Planned level of degree of mechanization of labor
Prime cost of services	Planned level of prime cost
Compliance of the number and qualification of workers with qualification requirements	Standard number of workers; wage and rate reference book
Number of accidents on networks for the reporting year	Number of accidents on networks for the previous year

Pump stations	
Maintenance of specified modes of operation of pump units	Specified modes of operation
Provision of timely adjustment of the mode of station operation in case of changing regimes of waste water inflow	Specified modes of operation
Provision of proper sanitary condition	Control data
Observance of standard rates of consumption of electric power, fuel, compressed air and water for own needs	Standard consumption of electric power, fuel, compressed air and water for own needs
Coefficient of production capacity utilization	Planned coefficient of production capacity utilization
Compliance of the number and qualification of workers with the demand and qualification requirements concerning pump station operations	Standard number of workers by profession; wage and rate reference book
Network system	
Provision of trouble-free and reliable acceptance and removal of waste waters from the territory of residential place to places of their further treatment/use	Trouble-free and faultless operation
Maintenance of rational modes of operation of sewerage network facilities	Specified rational modes of operation
Reduction of number of accidents on the networks and provisions of their immediate elimination	Planned target costs for the fulfilment of emergency works
Observance of the schedule of Planning - Production Work and assurance of quality of repair works	Schedule of Planning - Production Work
Compliance of the number and qualification of workers with the demand and qualification requirements concerning network system operations	Standard number of workers by profession; wage and rate reference book

Treatment plants	
Reliability and continuity of waste water treatment and sludge treatment according to prescribed requirements	Trouble-free and faultless operation
Quality of treatment of waste waters and sludge to the level ensuring their possible use/ disposal	Rules of surface water protection from contamination by waste waters
Maintenance of specified modes of operation of treatment plants	Specified modes of operation of treatment plants
Coefficient of production capacity utilization	Planned coefficient of production capacity utilization
Observance of the schedule of Planning - Production Work and assurance of quality of repair works	Schedule of Planning - Production Work
Observance of standard rates of consumption of electric power, fuel, compressed air and water for own needs	Standard consumption of electric power, fuel, compressed air and water for own needs
Observance of standard rates of consumption of reagents and other operating supplies	Standard consumption of reagents and other operating supplies
Compliance of the number and qualification of workers with the demand and qualification requirements concerning treatment plant operations	Standard number of workers by profession; wage and rate reference book

3. Prime cost of water disposal and setting of rates

Costs related to production and selling of goods (services) at housing and communal service enterprises and companies are grouped according to items below:

1. Raw stuff and materials.
2. Fuel for process needs.
3. Electric power to be used in the technological process.
4. Purchased resources (purchased water).
5. Production works and services of third party contractors and enterprises.
6. Return waste (to be estimated).
7. Labor payment costs.
8. Social spendings.
9. Costs associated with preparation and development of new production facilities.
10. Costs associated with operation of machines and equipment.
11. General production costs.
12. General economic costs.
13. Non-production (commercial) costs.

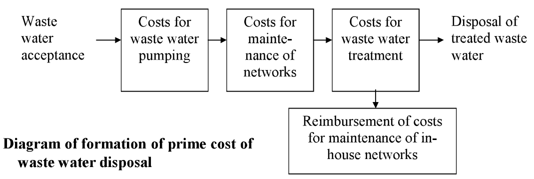

Fig. 3 – Diagram of formation of prime cost of waste water disposal

Sum of semi-variable and semi-constant costs comprises prime cost of waste water disposal:

$$PC = Svar + Sconst$$

where Svar – semi-variable costs, UAH;
Sconst – semi-constant costs, UAH.

Table 3 – Input indices for determination of rates of water supply and water disposal services per specific consumers, thous. UAH

Indices	Water disposal	
	Basic values	Planned values
Volumes of water disposal, thous..m^3 in total, including with regard to:		
citizens		
budgetary organizations		
other groups of consumers		
Amounts of total cost of water disposal, thous. UAH, including with regard to:		
citizens		
budgetary organizations		
other groups of consumers		

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Water-and sewage enterprises are **natural monopolists** carrying out their activity under tight control of the local authorities and the State administration. Rates of such enterprises are more responsive to the amount of costs than to the level of demand. Relative stability of monopolistic rates during the periods of demand fluctuations is explained by the capital structure (high level of fixed costs).

The main objective of economic justification in setting the rate is:

- transition of water-and-sewage systems to break-even operations by turning to payment of products (services) in the amount ensuring reproducible process, i.e. transition to payment for servicing according to its value;
- taking measures on economic assessment and analysis, which would stimulate the companies to ensure higher quality of consumer services;
- prevention of setting of monopolistically high tariffs and rates using economic methods, ensuring of social protection of citizens in the course of allocation and payment of services.

Economically justified tariff (T) is determined according to the formula:

$$T = PC + K$$

where PC – total cost per unit of service, UAH/ 1 m^3;

K – capital investment expenses, less profit tax, UAH/ 1 m^3.

Besides, the rate can be calculated according to formula:

$$Tt = TCwd / Q$$

where TCwd – sum of total cost of water disposal for the certain group of consumers, thous. UAH;

Q – volumes of water disposal of the relevant groups of consumers, thous.m^3.

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Thank you for attention!

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4. S.O. Fedulova. Environmental Economics: Training tool / S.O. Fedulova, P.I. Koreniuk. – Dnipropetrovsk: USUCT, 2014. – 274 p.
5. G.K. Agadzhanov. Economics of Water-and-Sewage Enterprises: Training tool / G.K. Agadzhanov Khark. Nat. Acad. of Mun. Economy. – 2nd edition, revised and updated. – Kh.: KhNAME, 2010. – 392 p.

Project Planning

[first draft – pictures compressed]

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Contents

What is this about?

Project

Temporary endeavor undertaken to create a unique **product, service of result**

Planning

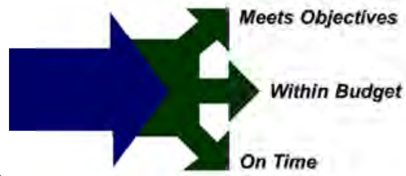
Processes required to **establish the scope** of the project, **refine the objectives**, and **define the course of action**

Project

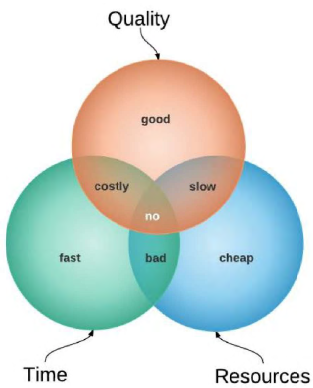
An organized effort to achieve a predefined goal

- It has **objectives**, **scope** and **constraints**
- Clear products are produced

Successful project:



Does the balance exist?

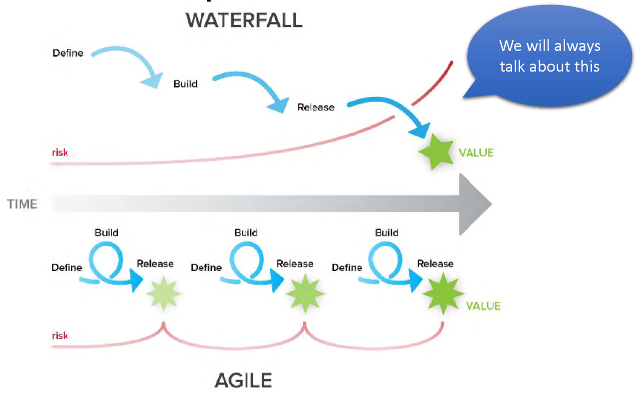


How to get there? – Through Planning!

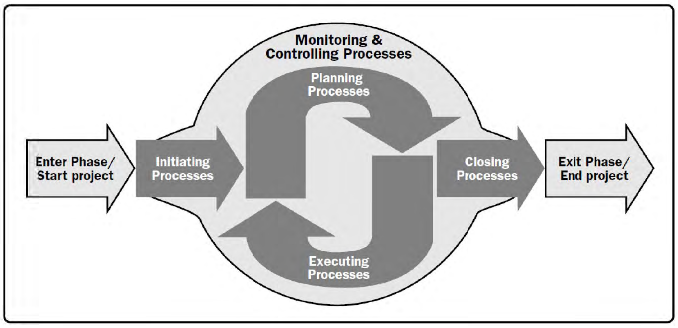
Reasons for planning:

- Validation of achievability
- Help identify key milestones
- Aid to thought process
- For communication
- Aids delegation
- Basis of costing
- Resource management
- To help with 'What if'
- **As a basis for control**

Project Management Methodology: **Predictive or Adaptive?**



Process groups interactions



Process groups and knowledge areas

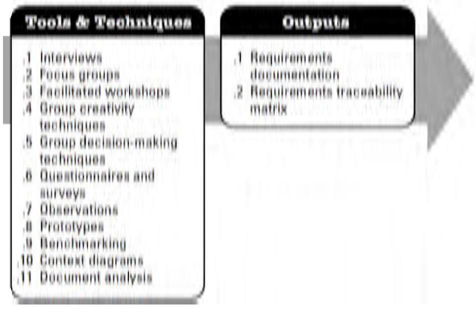
Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
4. Project Integration Management	4.1 Develop Project Charter	4.2 Develop Project Management Plan	4.3 Direct and Manage Project Work	4.4 Monitor and Control Project Work 4.5 Perform Integrated Change Control	4.6 Close Project or Phase
5. Project Scope Management		5.1 Plan Scope Management 5.2 Collect Requirements 5.3 Define Scope 5.4 Create WBS		5.5 Validate Scope 5.6 Control Scope	
6. Project Time Management		6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activity Resources 6.5 Estimate Activity Durations 6.6 Develop Schedule		6.7 Control Schedule	
7. Project Cost Management		7.1 Plan Cost Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Costs	

Process groups and knowledge areas

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring and Controlling Process Group	Closing Process Group
8. Project Quality Management		8.1 Plan Quality Management	8.2 Perform Quality Assurance	8.3 Control Quality	
9. Project Human Resource Management		9.1 Plan Human Resource Management	9.2 Acquire Project Team 9.3 Develop Project Team 9.4 Manage Project Team		
10. Project Communications Management		10.1 Plan Communications Management	10.2 Manage Communications	10.3 Control Communications	
11. Project Risk Management		11.1 Plan Risk Management 11.2 Identify Risks 11.3 Perform Qualitative Risk Analysis 11.4 Perform Quantitative Risk Analysis 11.5 Plan Risk Responses		11.6 Control Risks	
12. Project Procurement Management		12.1 Plan Procurement Management	12.2 Conduct Procurements	12.3 Control Procurements	12.4 Close Procurements
13. Project Stakeholder Management	13.1 Identify Stakeholders	13.2 Plan Stakeholder Management	13.3 Manage Stakeholder Engagement	13.4 Control Stakeholder Engagement	

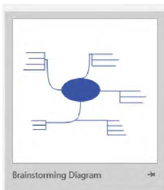
Scope: Collecting requirements

- Determine, document and manage stakeholder needs and requirements to meet project objectives

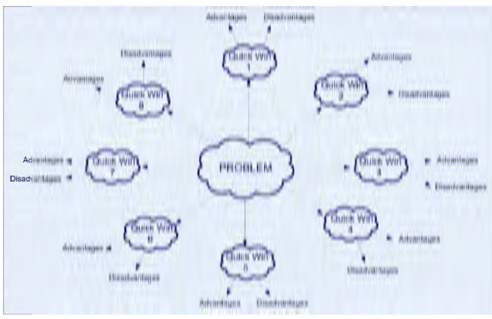


Group creativity techniques

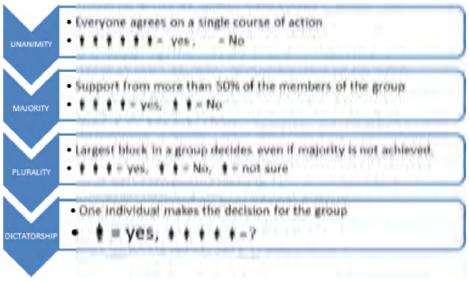
- Brainstorming



MS Visio



Group decision making



Result – Requirements Traceability Matrix

Requirements Traceability Matrix

Project Name:	
Cost Center:	
Project Description:	

ID	Associate ID	Requirements Description	Business Needs, Opportunities, Goals, Objectives	Project Objectives	WBS Deliverables	Product Design	Product Development	Test Cases
001	1.0							
	1.1							
	1.2							
	1.2.1							
002	2.0							
	2.1							
	2.1.1							
003	3.0							
	3.1							
	3.2							
004	4.0							
005	5.0							

Define Scope

- Scope description (progressively elaborated)
- Acceptance criteria
- Deliverables
- Exclusions
- Constraints
- Assumptions

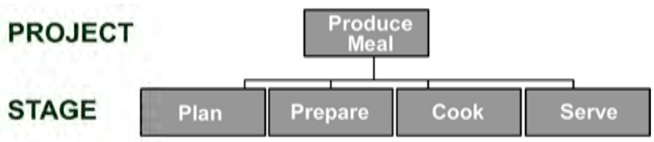
Work Breakdown Structure (WBS)

A Hierarchical Breakdown of Activities

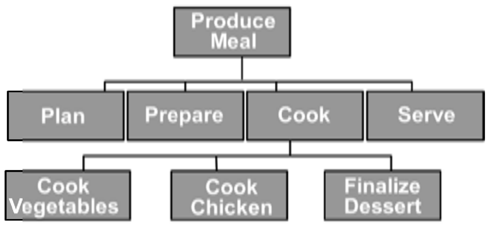
1. You decide to invite 4 friends around for a proper sit down chicken dinner
2. You check with your partner and they agree ('agreement to proceed')
3. However, you have to organize as your partner is busy

So what does the plan look like?

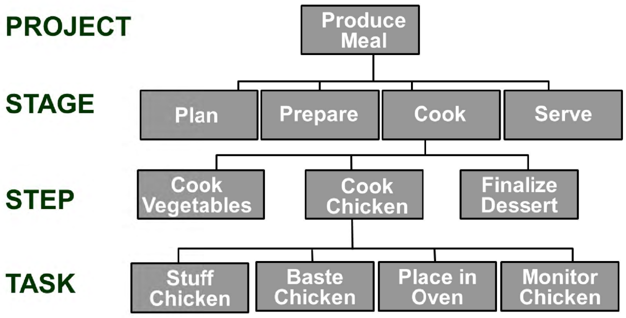
WBS



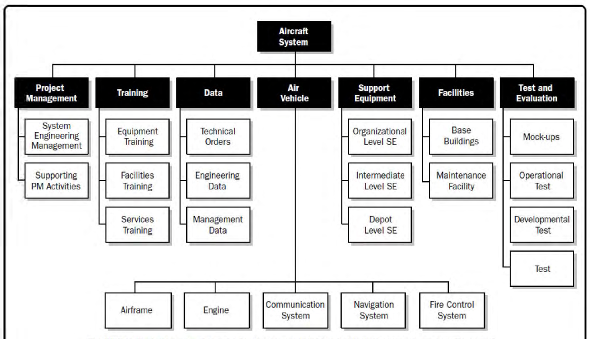
WBS



WBS

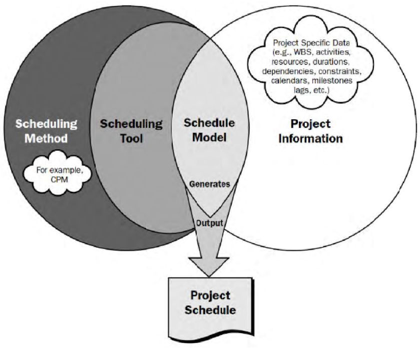


WBS with deliverables



The WBS is illustrative only. It is not intended to represent the full project scope of any specific project, nor to imply that this is the only way to organize a WBS on this type of project.

Time planning



Activities

WBS:	CAL0002.0	Title :	Customer Survey

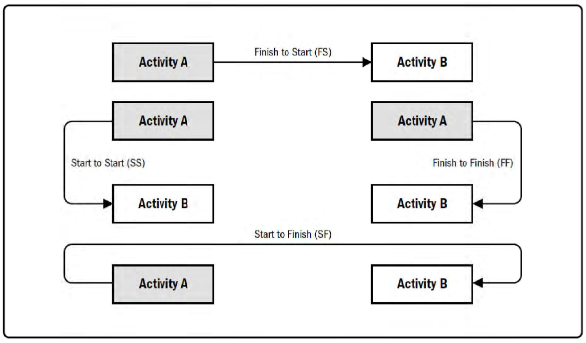
Assigned to: Aravind K. Walker

Description:

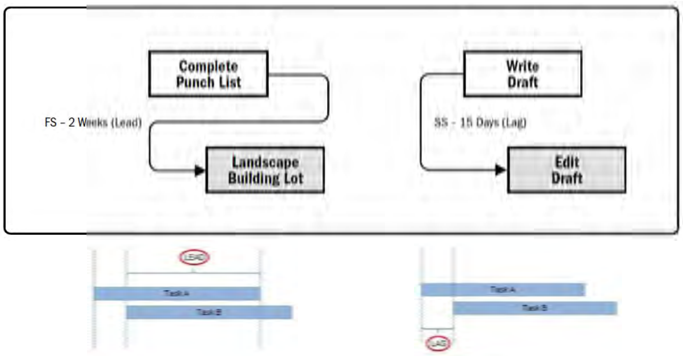
The Customer Survey is designed to identify and capture at least 12 pieces of key data, which be used to inform our product innovation and future product portfolio

WBS number	Activity Details
CAL0002.1	Stakeholder meetings
CAL0002.1.1	Identify stakeholders to invite
CAL0002.1.2	Organise and hold meetings
CAL0002.1.2.1	Identify suitable dates and communicate
CAL0002.1.2.2	Hold the meetings and capture feedback
CAL0002.1.3	Prioritise feedback and obtain agreement
CAL0002.2	Produce the Survey and run trial
CAL0002.3	Review trial and make amendments
CAL0002.3.1	Review the trial feedback
CAL0002.3.2	Make amendments to form
CAL0002.3.3	Obtain final agreement
CAL0002.4	Carry out the Surveys

Sequence activities

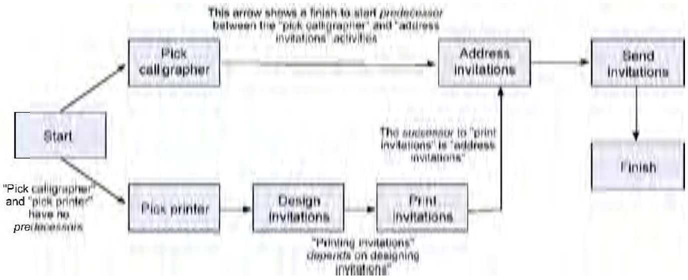


Leads and lags



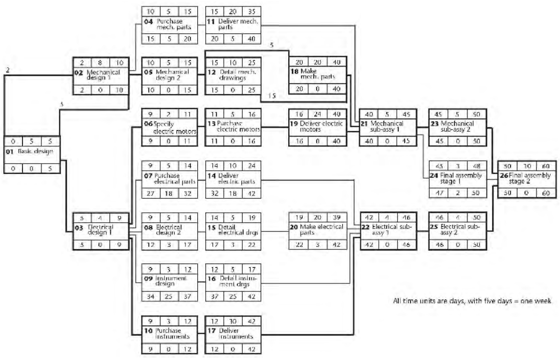
Network diagram

In simple project



Network diagram

In more complicated project…



Estimate resources and durations

DURATION ESTIMATING WORKSHEET

Project Title: ____________ Date Prepared: ____________

Parametric Estimates

WBS ID	Effort Hours	Resource Quantity	% Available	Performance Factor	Duration Estimate

Analogous Estimates

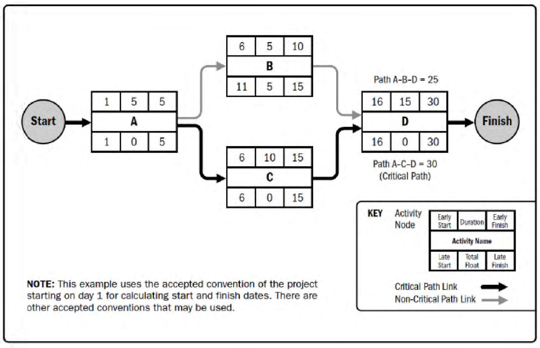
WBS ID	Previous Activity	Previous Duration	Current Activity	Multiplier	Duration Estimate

Three Point Estimates

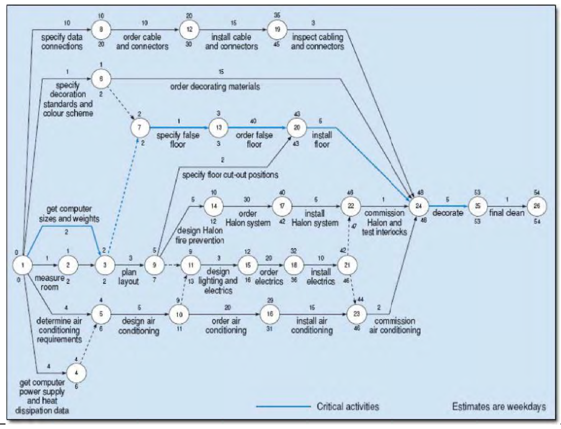
WBS ID	Optimistic Duration	Most Likely Duration	Pessimistic Duration	Weighting Equation	Expected Duration Estimate

- **Triangular Distribution.** $tE = (tO + tM + tP) / 3$
- **Beta Distribution** (from the traditional PERT technique). $tE = (tO + 4tM + tP) / 6$

Understanding critical path



Understanding critical path



Result – Schedule

Milestone Schedule

Activity Identifier	Activity Description	Calendar units	Project Schedule Time Frame: Period 1	Period 2	Period 3	Period 4	Period 5
1.1.MB	Begin New Product Z	0					
1.1.1.M1	Complete Component 1	0					
1.1.2.M1	Complete Component 2	0					
1.1.3.M1	Complete Integration of Components 1 & 2	0					
1.1.3.MF	Finish New Product Z	0					

Data Date

Summary Schedule

Activity Identifier	Activity Description	Calendar units	Project Schedule Time Frame: Period 1	Period 2	Period 3	Period 4	Period 5
1.1	Develop and Deliver New Product Z	120					
1.1.1	Work Package 1: Component 1	67					
1.1.2	Work Package 2: Component 2	53					
1.1.3	Work Package 3: Integrated Components 1 and 2	53					

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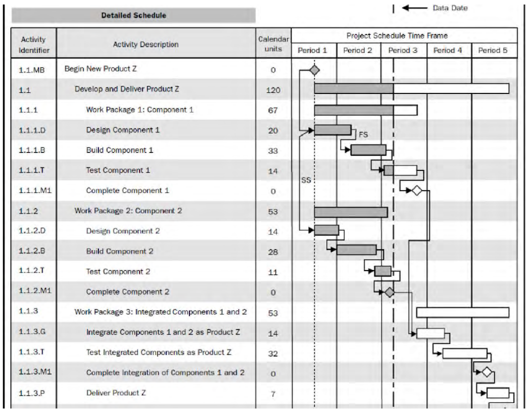
Result – Schedule



Detailed Schedule

Activity Identifier	Activity Description	Calendar units
1.1.MB	Begin New Product Z	0
1.1	Develop and Deliver Product Z	120
1.1.1	Work Package 1: Component 1	67
1.1.1.D	Design Component 1	20
1.1.1.B	Build Component 1	33
1.1.1.T	Test Component 1	14
1.1.1.M1	Complete Component 1	0
1.1.2	Work Package 2: Component 2	53
1.1.2.D	Design Component 2	14
1.1.2.B	Build Component 2	28
1.1.2.T	Test Component 2	11
1.1.2.M1	Complete Component 2	0
1.1.3	Work Package 3: Integrated Components 1 and 2	53
1.1.3.G	Integrate Components 1 and 2 as Product Z	14
1.1.3.T	Test Integrated Components as Product Z	32
1.1.3.M1	Complete Integration of Components 1 and 2	0
1.1.3.P	Deliver Product Z	7

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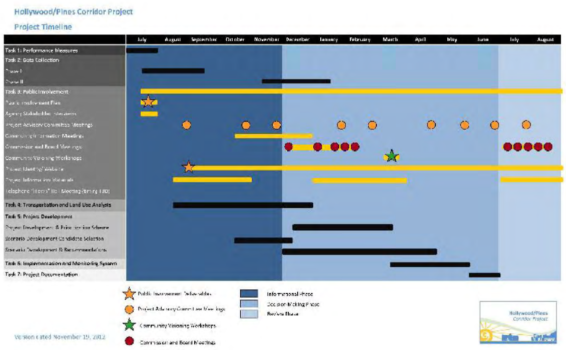
Result – Schedule



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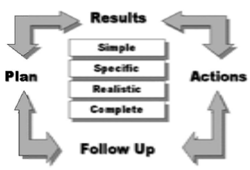
A good plan

- All steps covered
- Timescales clearly shown
- Resources clearly marked
- Deliverable driven
- Reviews included
  - Quality
  - Risk
  - Progress
- Re-planning points



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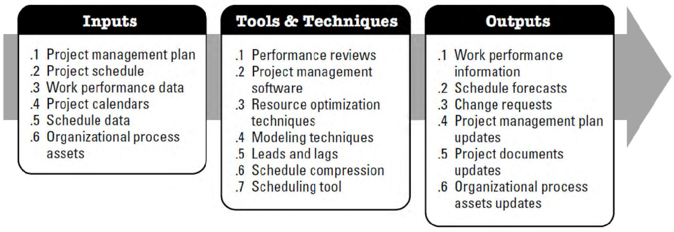
Control schedule



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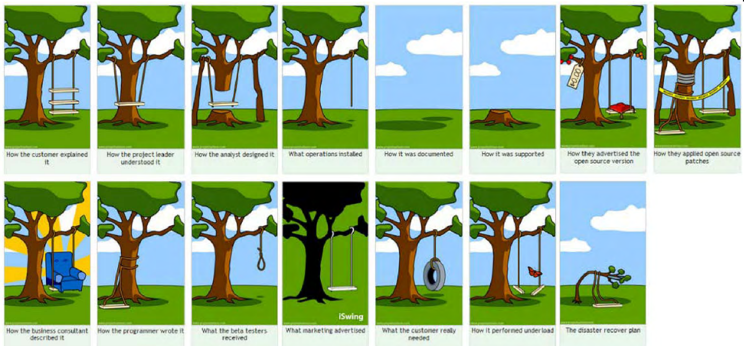
One of the projects…



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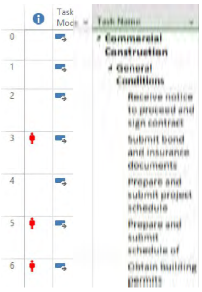
Project Management Software

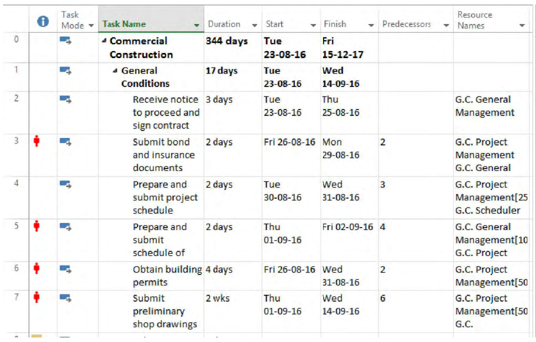
MS Project

WBS

Activities

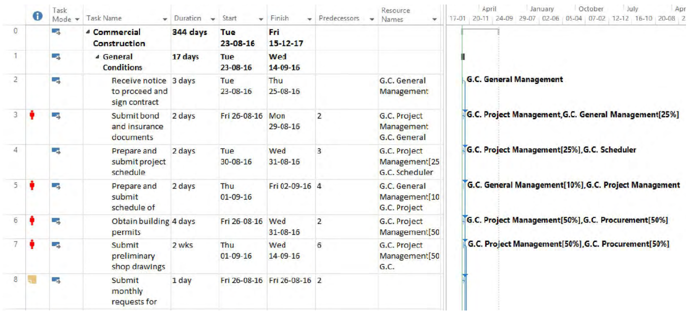


Resources/Durations



	Task Mode	Task Name	Duration	Start	Finish	Predecessors	Resource Names
0		Commercial Construction	344 days	Tue 23-08-16	Fri 15-12-17		
1		General Conditions	17 days	Tue 23-08-16	Wed 14-09-16		
2		Receive notice to proceed and sign contract	3 days	Tue 23-08-16	Thu 25-08-16		G.C. General Management
3		Submit bond and insurance documents	2 days	Fri 26-08-16	Mon 29-08-16	2	G.C. Project Management G.C. General
4		Prepare and submit project schedule	2 days	Tue 30-08-16	Wed 31-08-16	3	G.C. Project Management[25 G.C. Scheduler
5		Prepare and submit schedule of	2 days	Thu 01-09-16	Fri 02-09-16	4	G.C. General Management[10 G.C. Project
6		Obtain building permits	4 days	Fri 26-08-16	Wed 31-08-16	2	G.C. Project Management[50
7		Submit preliminary shop drawings	2 wks	Thu 01-09-16	Wed 14-09-16	6	G.C. Project Management[50 G.C.

Schedule – Gantt



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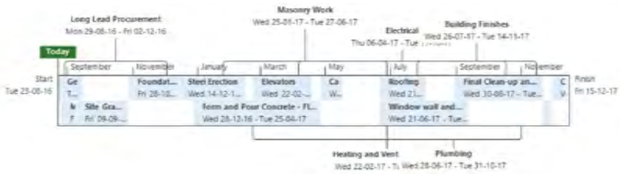
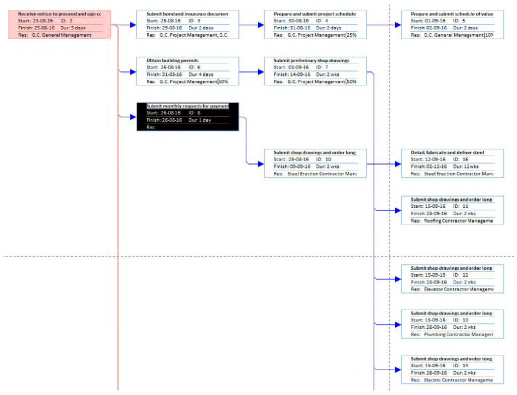
7		Submit preliminary shop drawings	2 wks	Thu 01-09-16	Wed 14-09-16	6	G.C. Project Management[50 G.C.
8		Submit monthly requests for	1 day	Fri 26-08-16	Fri 26-08-16	2	

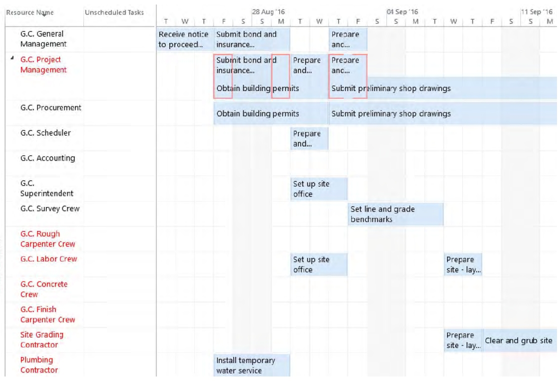
Schedule – Timeline



Network diagram



Team planner



Lesson 22: Impact of Climate Change on Wastewater Treatment

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I. Climate

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Climate

Climate is a measure of the average pattern of variation in meteorological variables in a given region over long periods of time.

Meteorological variables :
temperature, humidity, atmospheric pressure,
wind, precipitation, atmospheric particle count and other

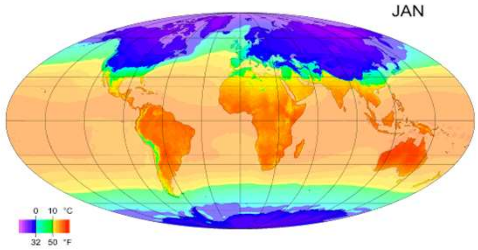
Climate is different from weather. Weather describes the short-term conditions of meteorological variables in a given region.

Climate

The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents.

Climates can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation.

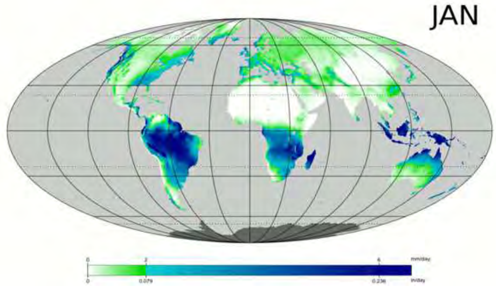
Monthly average surface temperatures from 1961–1990.



This is an example of how climate varies with location and season

http://en.wikipedia.org/wiki/Climate

Precipitation by month



http://en.wikipedia.org/wiki/Climate

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Regional climate

Region's climate is generated by the **climate system**, which has five components:

- atmosphere, — Troposphere: 0 to 12 km , Stratosphere: ~to 50 km, Mesosphere: ~to 80 km, Thermosphere: ~ to 700 km, Exosphere: ~ to 10,000 km
- hydrosphere,
- cryosphere, - earth surface where water is in solid form
- Lithosphere, - earth crust and the uppermost mantle
- biosphere

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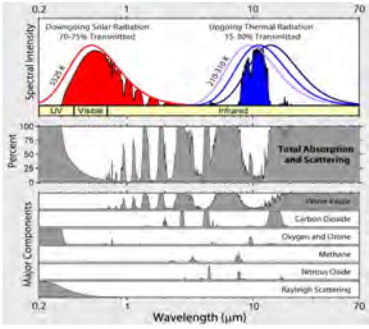
Radiation transmitted by the atmosphere



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II. Climate system

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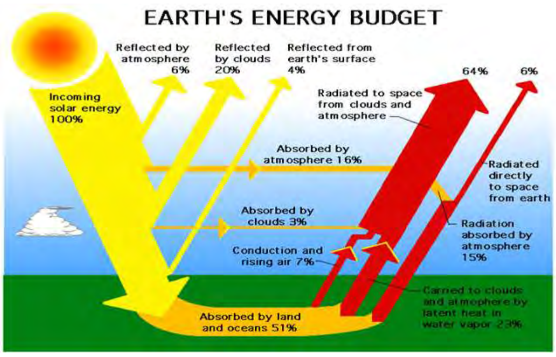

http://science-edu.larc.nasa.gov/EDDOCS/whatis.html

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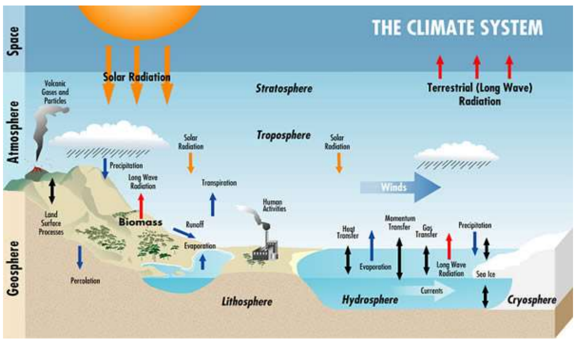
Climate system



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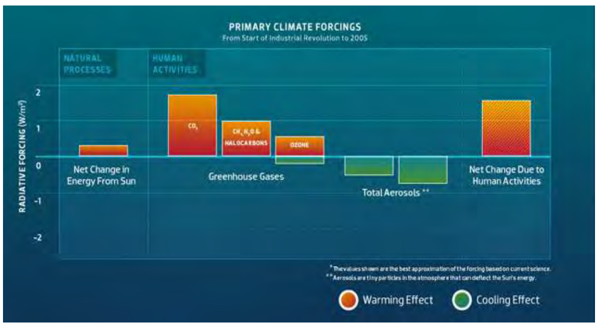
Radiative forcing on earth (IPCC 2013)



National Academy of Sciences 2011

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III. Climate change

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United Nations framework convention on climate change

"A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"

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Climate Change

Intergovernmental Panel on Climate Change (IPCC) defines climate change as:

- Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

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Evidence of global temperature increases since 1900

- Recorded temperature changes
- The observed rise in sea level of 4-8 inches
- The shrinkage of mountain glaciers
- Reduction of northern hemisphere snow cover
- Increasing sub-surface ground temperatures

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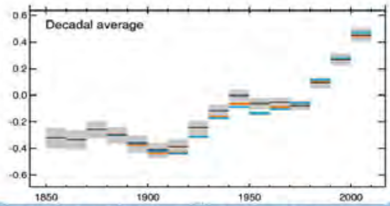
Observed globally averaged combined land and ocean temperature anomaly



(IPCC 2013, Fig. SPM.1a)

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

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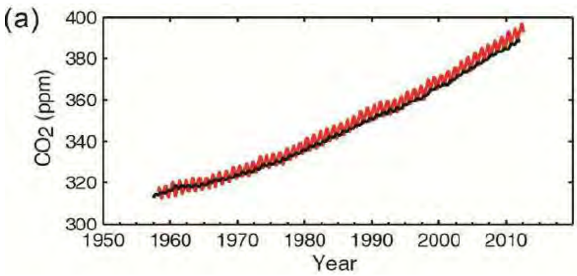
Anthropogenic CO2 contents in the atmosphere (IPCC 2013)



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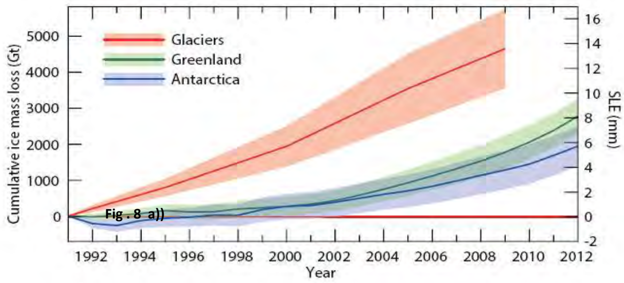
Glacier mass loss (IPCC 2013)



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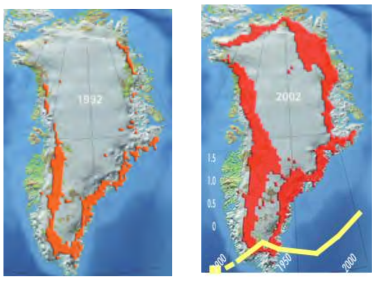
Greenland ice sheet



– The red areas on these two images show the expansion of seasonal melting of the Greenland ice sheet from 1992 to 2002 (GEO4).
– The Yellow line shows the temperature increased by 1ºC from 1900 to 2000

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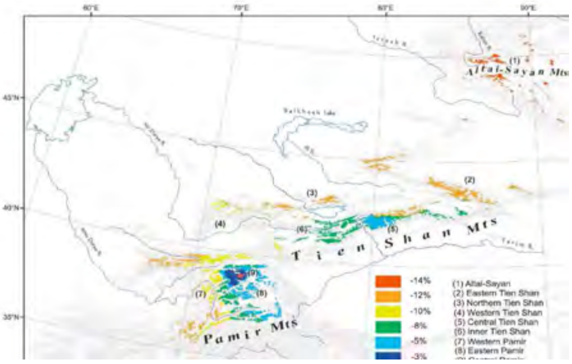
Losses of glacier area in Asia (IPCC 2013)



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UPSALA Glacier (Argentina)

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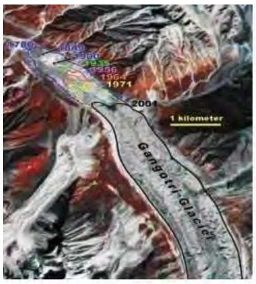
Glaciers in Himalaya



Glaciers in the Himalaya
- store about 12,000 km³ of freshwater, are receding and thinning
- supports perennial rivers such as the Indus, Ganga and Brahmaputra which, in turn, are the lifeline of millions of people (IPCC)

Composite satellite image of the Gangotri Glacier terminus has retracted since 1780 (courtesy of NASA EROS Data Center, 9 September 2001). **(IPCC 2007)**

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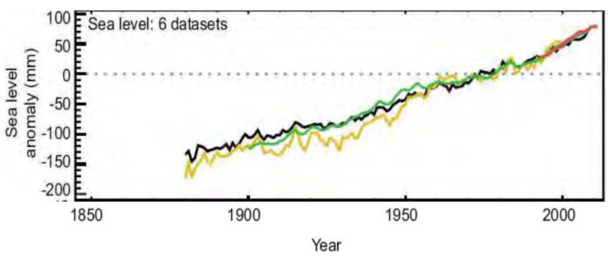
Mean sea level rise (IPCC 2013)



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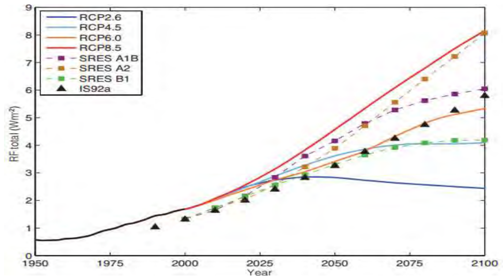
RCP ccenarios - IPCC AR5 2013



Forcing by CO2 has increased

- 1.24 Wm-2 (1993)
- 1.4 Wm-2 (2001)
- 1.7 Wm-2 (2013)

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IV. Climate change impacts

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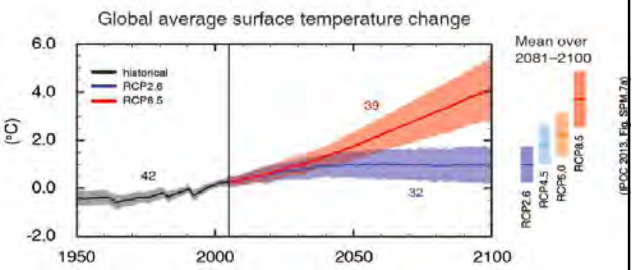
Projections - GMST anomaly



Without more mitigation, global mean surface temperature might increase by 3.7° to 4.8°C over the 21st century.

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Climate change impacts

The impacts and risks associated with these changes are real and are already happening in many systems and sectors essential for human livelihood, including water resources, food security, energy security, coastal zones and health

An estimated 200 million people could be displaced as a result of climate impacts climate-related disasters by 2050 (IPCC 2007)

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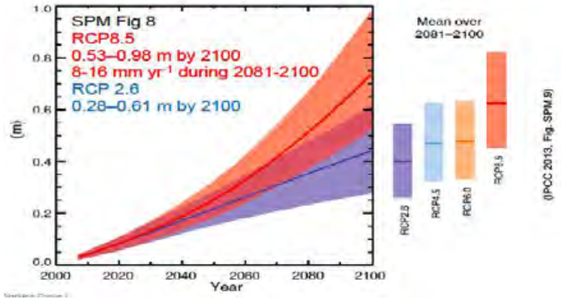
Projections – GMSL rise



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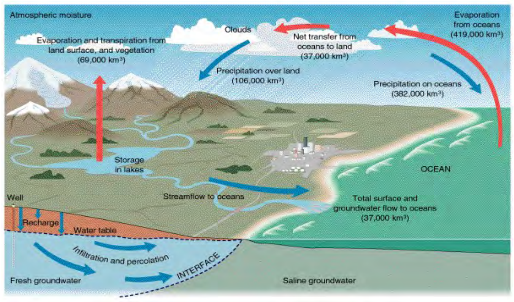
Impacts on water resources - Hydrologic cycle



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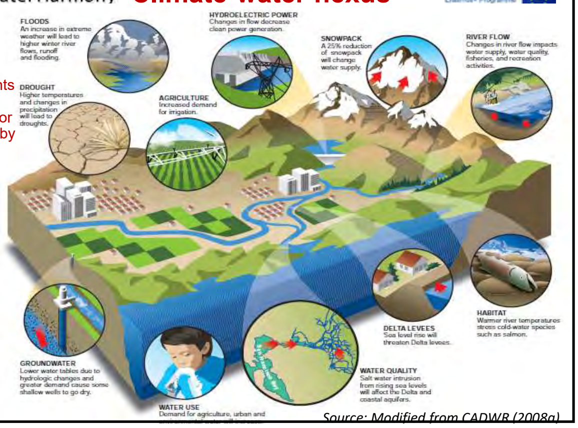
Climate-water nexus

Components of urban water sector impacted by climate change



Source: Modified from CADWR (2008a)

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Impacts on water sector

- **Extreme events**

Extreme events, floods and droughts, coastal storms will be more frequent

The devastating effects of extreme events, temperature increases and sea level rise have consequences for all, particularly the poor, and will only worsen in the future.

- **Sea level rise associated with temperature increase**

Inundation of low lying areas, coastal marshes and wetlands, exacerbate flooding and increase the salinity in rivers, bays and aquifers.

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Impacts on wastewater quantity

- Reduced water usage during frequent droughts decreases water that flows into the wastewater transmission and treatment systems while waste load is same resulting high pollutant concentrations
- Increased scarcity of water resources will demand more reuse of wastewater,
- Fluctuation of wastewater quantities

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Impacts on wastewater quality

- Varying pollutant concentrations and types in a wide range than before
  - Droughts will cause high pollutant concentrations
  - Floods will cause different pollutants, sediments in waste water
- Increased pollution and temperatures can result in blooms of harmful algae and bacteria in wastewater

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Impacts on wastewater quality

- Seal level rise affect coastal areas
  - Water level rise in water bodies reduce the discharge of storm water/ treated wastewater under gravity flow to water bodies
    - Wastewater logging create poor water quality in coastal inland water bodies
  - Salinity may increase in CSOs

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Impacts on wastewater treatment

- Water courses could have a lower dissolved oxygen content leading to tighter discharge consent standards to maintain water quality standards
- Potential for odour generation in warmer conditions and risk of causing nuisance to customers
- Impact on sludge as prolonged wet periods may restrict sludge to land recycling route
- Stringent standards for reduction of greenhouse gas emissions
- Increase of investment needs (energy use, processes,) of treatment

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Impacts on wastewater treatment

- Warmer weather may have a positive effect on biological treatment processes, which operate more effectively at higher temperatures
- Stringent standards due to reduced final effluent discharge dilution (reduced assimilative capacity of receiving water bodies)
- Flooding on wastewater treatment facilities, interruption to service
- Sea water level will make it difficult to discharge treated water under gravity
- Sludge drying handling and disposal become more expensive

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V. Adaptation to climate change impacts on wastewater

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Climate change mitigation and adaptation

There are two main responses to climate change, viz:

- climate change mitigation is cutting the emissions that cause climate change;
- climate change adaptation is preparing for the impacts of climate change.

IPCC has defined climate adaptation as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities**".**

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Adaptation

UNFCCC Nairobi Work Program

- Climate modelling, scenarios and downscaling–

  Promoting the development of, access to, and use of information and data on projected climate change.

- Climate related risks and extreme events – Promoting understanding of impacts and vulnerability, emphasizing current and future climate variability and extreme events, and the implications for sustainable development.

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Adaptation – water sector

Adaptation is a local issue

– Depends on geographical, climatic, bio-physical as well as socio-economic characteristics

Adaptation options are many, including:

Structural options ensure water quantity and quality**:**

- Dikes (embankments, levee), sewer networks, drainage
- Retention pond for artificial recharge, dams
- Desalination technology
- Coastal wall, flood proofing
- Green Buildings

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Adaptation - water sector

Non-Structural options to ensure quantity and quality **:**

- National and sectoral policies
- Demand management, water pricing
- Efficient water use, reuse
- Watershed management
- Insurance
- Awareness campaign

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Adaptation of wastewater systems for climate resilience

- Make structures to be safe against extreme events (floods, coastal storms,)
- Risk of failure of operation
  plan for emergency options

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Adaptation of wastewater systems for climate resilience

- Upgrade existing water infrastructure and management practices due to uncertainty of projected hydrological changes

  Statistical parameters of hydro-meteorological data series are not stationary. Historical hydro-meteorological data become not useful to make projection. Modern tools considering climate change projection would be necessary

  Design criteria on stormwater inflows different return periods to be redefined

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Adaptation of wastewater systems for climate resilience

- Adopt modern technologies for wastewater treatment facilities to reduce greenhouse gas emissions
- Promotion of ecosystem management practices, such as biodiversity conservation, e.g. by conserving and restoring mangroves to protect people from storms
- Behavioral change at the individual level,
  Reduce wastewater generation
  Onsite treatments

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Technological trends

Prof. Harsha Ratnaweera,
harsha@nmbu.no
Norwegian University of Life Sciences

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Outline

- Influence of financing on technological trends
- Global technological trends – and overview
- Examples of technological solutions
- The future: A paradigm shift

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Market drivers
↓
Investments
↓
Technological trends
↓
Technological innovations

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GDP World = 77.6 trillion USD

71 trillion USD = 90% of world's GDP is dependent on water

589 billion USD = Water and wastewater treatment and distribution market (4% annual growth)

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Market drivers for global water investments (and developments)

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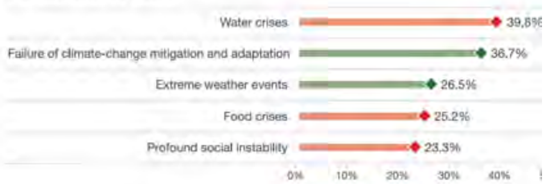
Global risks- associated with water

For the next 10 years



Source: Global Risks Perception Survey 2015, World Economic Forum

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Global water market & drivers

Note: At present this does not include Smart Water Grid Market revenue estimates

Frost & Sullivan

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http://www.wateronline.com/topic/water-innovations-magazine

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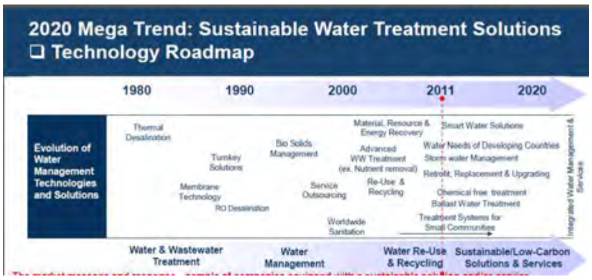

FROST & SULLIVAN

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Drivers and responses

- With stricter nutrient standards,
  - investment for filtration has increased in recent years
- With strained water resources globally,
  - water reuse has increased
- increased pressure to move to inherently safer technologies:
  - Innovative disinfection
- New legislations
  - Increased treatment requirements
  - Ballast water treatment ($30 billion global market)

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Mega trends in water industry: 2020

Water & Wastewater Treatment Equipment Market: Revenue Forecasts by Key Technologies (World), 2010-2015

Total Market Segmented by Technology (Total Global Market Size in 2010 = **$34.59 billion**)

	$ Billion	Market Share (%)	CAGR 2010-2015 (Low (<5%) / Med (5-8%) / High (> 8%))
Membrane Bioreactors (MBR)	0.7	1.9	Very High
RO	1.8	5.1	High
MF	1.0	2.8	High
UF	1.2	3.5	High
NF	0.4	1.3	Med
UV	0.5	1.6	High
Ozone	0.1	0.6	High
UASB (Municipal)	0.2	0.5	High
Chlorination	1.1	3.5	Med
Demineralisation	0.8	2.4	Med
WW Pre-Treatment	1.4	4.2	Low
W&WW Clarifiers	3.5	9.9	Med
Other Primary WW	3.8	11.1	Med
Activated Sludge	3.7	10.7	Med
Other Biological WW	4.0	10.9	Med
Sludge Thickening	1.5	4.4	Low
Sludge Dewatering	1.8	5.2	High
Sludge Digestion	0.7	2.0	High
Sludge Drying	0.7	2.0	High
Filtration	5.5	16.0	Med

Source: Frost & Sullivan

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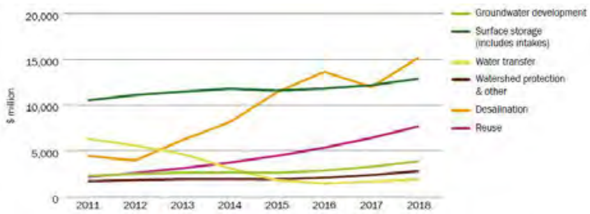
Water resources development market



© Global Water Intelligence

Global perspectives

- Resources
- Treatment
- Distribution
- Use
- Wastewater
  - Areas
  - examples

Partially from Eco-inovation – EIO thematic report

Distribution

- Demand-driven distribution
  - leakage is highly correlated with pressure: use of distributed monitoring infrastructure and control software to supply on demand
- Self-healing pipe materials or other non-invasive pipe repair techniques
  - more durable or can self-heal; easier leak detection
- Leakage detection
  - detect these losses and remediate them in good time
- Recovery of energy from distribution networks
  - detect these losses and remediate them in good time

Resources

- Cost-effective, low energy desalination
  - degradation of coastal aquifers due to over-abstraction
- Diffuse pollution
  - leaching of nutrients, pesticides and herbicides, soil compaction by cattle and faecal contamination from livestock
- Anoxic water bodies, algal blooms, manganese mobilization etc.
  - Rise rise in temperature due to climate change : algal blooms and anoxic conditions: release of metals from sediments etc: aeration

use

- Low / no water industrial processes
  - thermal transport (cooling) and kinetic energy (cleaning) by air.
  - Irrigation: will need to be less water-intensive.
- Point-of-use treatment systems (UV/ozone) grey water, rainwater harvesting
  - Attitude (user patterns) change
- Irrigation
  - Water-efficient irrigation, irrigation on demand and using brackish water

Treatment

- Real-time network monitoring and management
  - distributed monitoring networks, integrated with smart systems for measuring and adjusting parameters such as chemical dosing, flow and pumping rates, leakage detection
- Low-pressure, self-cleaning, chemical-free membrane systems
  - 'functionalized' membrane materials - savings in energy and chemicals.
- Nearly-chemical-free water and wastewater treatment including „synthetic biology
  - 'functionalized' membrane materials and "super bugs" : savings in energy and chemicals.
- Low energy UV/non-UV disinfection
  - UV Disinfection: require lot of energy today
- Cost of membranes
  - membrane life span and the specific energy requirement

Wastewater

- Recovery of energy from wastewater
  - to reduce WTP/WWTPs own energy requirements
- Recovery of resources from wastewater
  - N & P, industrial wastewater
- Low energy aeration
  - 50% of energy requirment : air blowers
- Reduction in sewer loading
  - Separate sewers: source separation
- Decentralised wastewater treatment
  - Reduce investment costs
- New coagulants
  - More efficient and less toxic

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Technological developments

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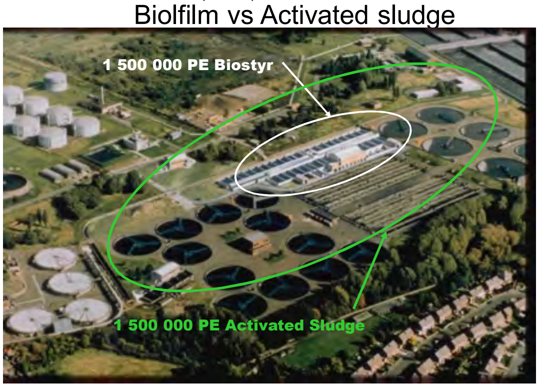
Reduction of plant footprint

Biolfilm vs Activated sludge



Frank Rogalla, Aqualia

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Reduction of plant footprints

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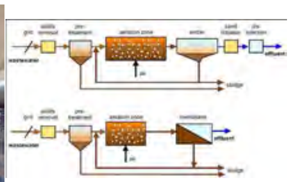
Reduction of plant footprint

Membrane bio-reactors



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Particle removal

Fine Sieves:

- *Majority of TSS can be removed with sieves >500 microns.*
- *New systems with 100 microns*
- *Combination of sieves with chemicals*

Salsnes/Trojan: 50% TSS & 20% BOD removal

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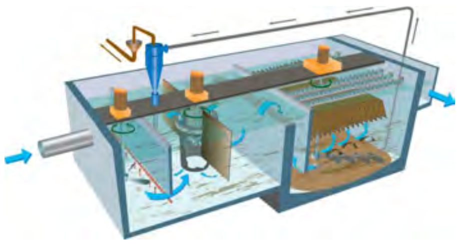
Reducing footprint of separation stage



Actiflow: from 2 hours to 10-20 mins

Polymers??

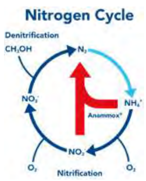
Flotation in DWT

70%

space gain compared to a conventional installation using flotation.

Advances in biological treatment

Nitrogen cycle revisited



- Short cut in N-removal
- No need for external C-source
- Must prevent $NO_2 \rightarrow NO_3$
- Slow growing organisms

Enzymology in Biological WWT

- Use of selective enzymes in biological WWT
  - Can shorten the space requirement by 50% in cold climates
  - Faster start-up
  - Less odour
  - Controlling filamentous microorganisms

Disinfection

- Safer, cheaper and more efficient..

UV disinfection

- Lifetime from 2 years to >11 years with LED technology
- Combatting reactivation
- Disinfection by-products: no THMs, but more exotic ones?

Membrane technologies

- Membrane bioreactors for wastewater treatment
- membranes for desalination
- Removal of non-traditional pollutants cheaper and more efficiently
- Seawater desalination with solar-power

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Nano technology

Nanoadsorbents
Magnetic nanoparticles
Nanofiltration
Nanocatalysts
Nanobiocides
Nanofibers

Water Reuse: a Global Trend towards **Sustained Growth** in All Continents

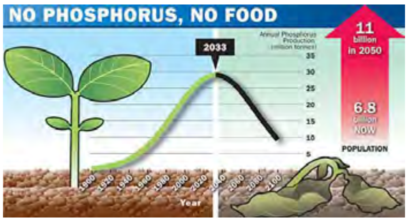
Water Harmony Erasmus+

Recovery of valuables from wastewater

Nitrogen
Phosphorous
Organic matter
Energy

Water Harmony Erasmus+

Phosphorus crisis



- Coagulation – reduces the plant availability of phosphorous
  - After treatment of sludge
  - Struvite (magnesium ammonium phosphate) production
  - Reduce Al/Fe use

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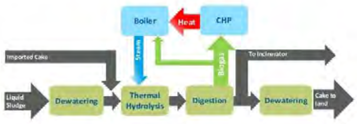
WWTPs or energy plants?

Frank Rogalla, Aqualia

Water Harmony Erasmus+

Energy from sludge

- Thermal hydrolysis



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One visit to toilet = car fuel for 350 m

En tur på toalettet, og du kan kjøre 350 meter med denne bilen

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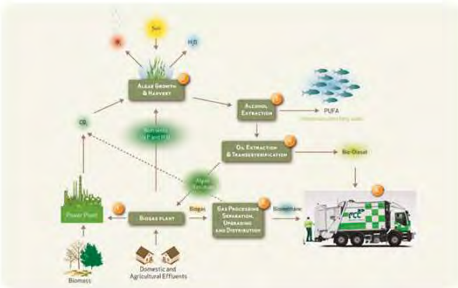
Biofuels from microalgae.



EU FP7 All-gas project

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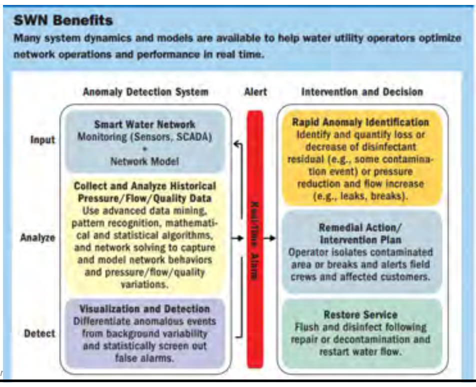
Distribution and transport systems



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Real-time surveillance and control

- Predictive network modelling and optimisation capabilities to asses the effects of operational or physical changes in system performance and integrity
  - Real-time network models
  - Real-time operational optimisation models (anomality detection)

Smart IT technologies will become an integral component of modern water networks in the 21st century
- earlier detection
- Approximate location from data simulations

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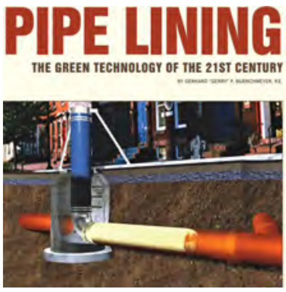
Sewer systems



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Coping with the Climate Change

- More and frequent rains
  - Overloaded sewers and WWTPs will have even more challenges.
- How to cope with the need?
  - Infrastructure expansions
  - Soft approaches: real time control of sewers and WWTPs (Regnbyge-3M)

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Novel sensors and estimation tools

- Water quantity- using weather radar and physical measurements
- Models to estimate water quality with simpler measurements (flow, etc)
- Advanced data processing
- Remote surveillance & control

- Image analysis
- Novel technologies for cheaper and faster detection
- Bioindicators

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A paradigm shift

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Novel sensors and estimation tools

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- Image analysis
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- Bioindicators

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Valuable resources in wastewater

In household wastewater:

*** 90 % of N**
*** 80 % of P**
*** 80 % of K**
*** 40-75 % of org.matter**

comes from the toilet fraction (blackwater)

Arve Heistad, NMBU

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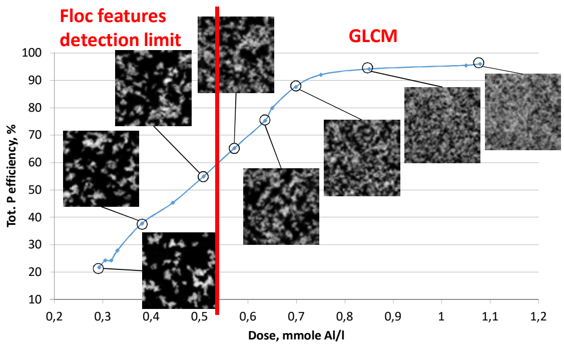
Optimal dosages and images of flocs



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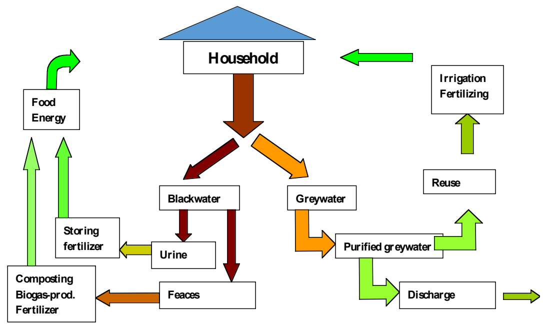
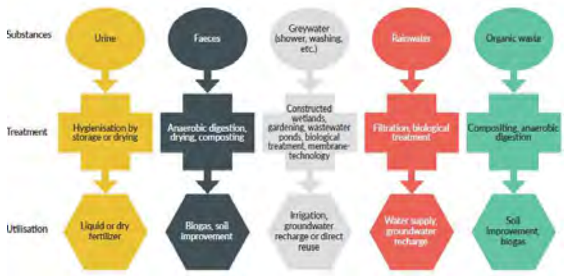
Wastewater as a resource



Arve Heistad, NMBU

Waste segregation and possible utilization options



Source: UNESCO-IHP/GTZ (2006, Fig. 4, p. 15).

Process Control

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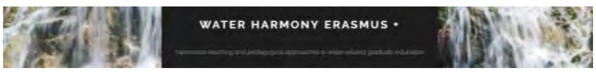


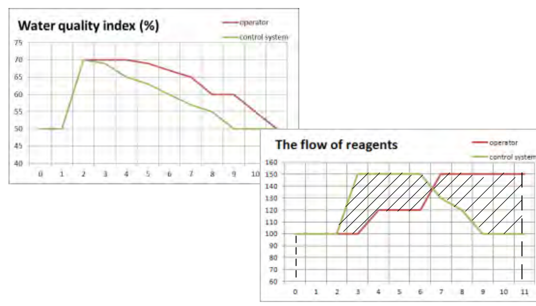
Process Control

- Activities involved in ensuring a process is predictable, stable, and consistently operating at the target level of performance with only normal variation.
- It is a deliberate influence on the process to achieve a desired performance of the given object.
- In practice Process Control is curried out by Process Control Systems (PCS)

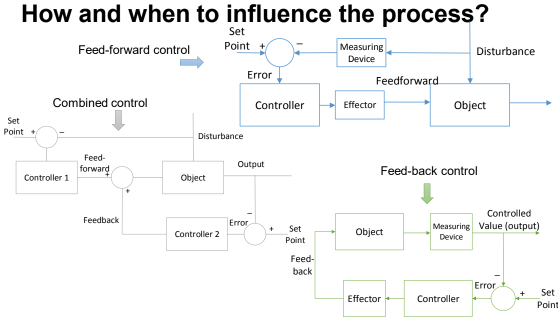
Control Strategies

- Treatment efficiency
  - turbidity, SS, pH etc.
- Chemicals saving
  - minimization of reagent consumption (coagulant, alkaline agent, flocculants) without reducing the treatment quality.
  - PCS helps plant owners/users to control advanced processes with a smaller staff of operating personnel.
- Minimum maintenance effort
  - due to communication with all kinds of equipment, checking the state of mechanical equipment such as pumps, mixers, valves etc.

Manual vs Automatic Control

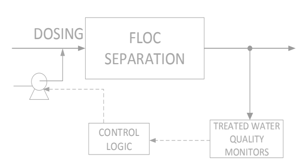


How and when to influence the process?



Feed-back control

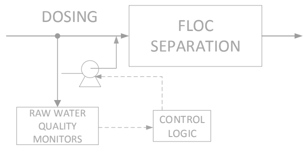
- The most useful technique of control
- Disadvantage
  - influence a process after violation detected



Feed-back control scheme
based on finished water quality

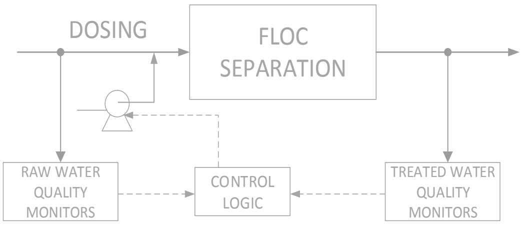
Feed-forward control

- Advantage
  - influence a process before violations occurred
- Disadvantages
  - Can keep track of one or two disturbances



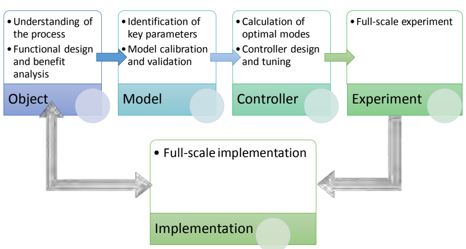
Feed-forward control scheme based on raw water quality

Combined control



combined control scheme based on finished water quality

Phases of a Typical Project



Functional design

- Define Process Control Goals
  - Economical
  - Operation
  - Instrumentation
- Specify
  - Manipulated Variables
  - Disturbance Variables
  - Controlled Variables

Control Goals

- Understand the process and its operation
- Understand the problem
- Understand operating objectives of the process (unit)
  - Unit objectives, performance criteria
  - Integration with other process units
  - Understand the process limits and constraints
- Define the control goals

Control Goals

- Control Expectations
  - What do we expect the controller to do for us?
  - What can we expect?
  - Set/Revise the control expectation
- Control Performance Indexes
  - Economical: feed, product value, consumption of the reagents, etc.
  - Technological: pH, TSS, flow rate, temperature
  - Environmental, Safety Indexes, Combined and many others.

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Process Economics

- Understanding of economics of the units is essential to designing good control
- Set the economic aim: discuss with operations, planners and schedulers

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Identification of Key Parameters

- The current mode of the object (mode parameters)
- What values influence the process?
- When the object changes the given mode and which of its states is the given one?

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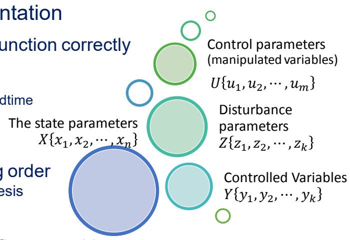
Identification of key parameters

- Process instrumentation
  - Sensors should function correctly
    - minimum noise
    - responsive
      - minimum deadtime
      - quick
    - representative
  - Valves in working order
    - minimum hysteresis
    - free moving
  - Where possible, fix any problems



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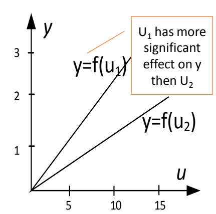
Choosing manipulated variables

- A good control parameter should have
  - Significant effects on output Y
  - Model predictable effects on output
  - Fast, strong and predictable effect
  - Should change product and heat flows
- Independent of other control schemes
- Independent of other control parameters and all disturbance variables



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Choosing manipulated variables (design issues)

- Avoid trim control and “too big” valves
- Being a part of the total moves
- Set up proper windup handling
- Be careful about discontinuities
- Check for wind-up propagation
- Check “shed-modes”

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Choosing disturbance variables (DV)

- Be careful about recycling DV’s
  - Causes many difficulties in the model identification
- DV’s often cannot be moved independently
  - What if some of them always come together?
    - Use only ONE of them
- Watch out for integrating DV’s
- DV’s must always propagate the DV value back to the DV interface point

Choosing Controlled Variables Y

- These are the parameters reflecting the control aim
- Three main classes
  - regulated
  - restrained
  - optimised
- Dependent on at least one U
  - Building the relationships between Y and U:

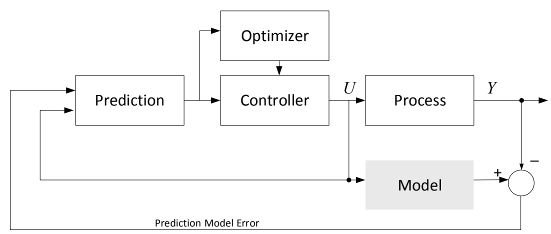
$$Y = f(U)$$

Choosing Controlled Variables Y

- For measured Y:
  - Noise
  - Precision
  - Dead-time
  - Frequency
- For inferred Y:
  - Calculation model
  - Lab update and Lab data validation
  - Be careful about calculated Y

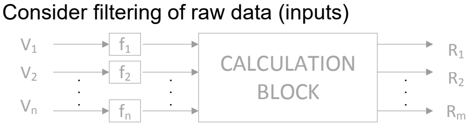
Instrumentation

Model Considerations



Building a house on good foundations

- Develop / understand the models for calculations and the assumptions behind them
  - WEAP®, STOAT®, MatLab, …
- Most models are steady state models
- Consider a lab / analyser update scheme in the model
- Consider filtering of raw data (inputs)



Model Identification

- Multivariable systems can be described in different forms, which depends on software you are planning to use

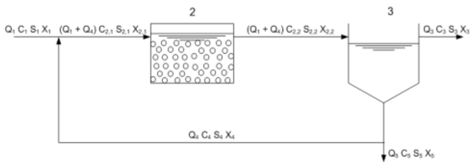
$$y = a_0 + \sum_{j=1}^{k} a_j u_j + \sum_{\substack{u,j=1 \\ u \neq j}}^{k} a_{uj} u_u u_j + \sum_{j=1}^{k} a_{jj} u_j^2 + \cdots$$

$$\dot{x}(t) = A(t) \cdot x(t) + B(t) \cdot u(t)$$
$$\dot{y}(t) = C(t) \cdot x(t) + D(t) \cdot u(t)$$

$$\Delta Y = G \Delta U$$

…

Model Identification. Example



$$(Q_1+Q_4)C_{2,1} - r_{x,s}V_2X_{2,2} = (Q_1+Q_4)C_{2,2}$$

Input Flow — Concentration Change — Output Flow

Example

- Steady State $(Q_1+Q_4)C_{2,1} - r_{x,s}V_2X_{2,2} = (Q_1+Q_4)C_{2,2}$
- Dynamics

$$\Delta V_2 C_{2,2} = (Q_1+Q_4)C_{2,1}\Delta t - r_{x,s}V_2X_{2,2}\Delta t - (Q_1+Q_4)C_{2,2}\Delta t$$

- or

$$V_2\frac{\Delta C_{2,2}}{\Delta t} + (Q_1+Q_4)C_{2,2} = (Q_1+Q_4)C_{2,1} - r_{x,s}V_2X_{2,2}$$ (1)

- where
- $C_{2,1} = \frac{Q_1C_1+Q_4C_4}{Q_1+Q_4}$ (2) $X_{2,2} = \frac{Q_1C_1}{V_2B_x}$ (3)

Example

- (2) and (3) → (1)

$$T\frac{\Delta C_{2,2}}{\Delta t} + C_{2,2} = k_1C_1 + k_2C_4$$

- *where* $T = \frac{V_2}{Q_1+Q_4}$ $k_1 = \frac{Q_1(B_x - r_{x,s})}{(Q_1+Q_4)B_x}$ $k_2 = \frac{Q_1}{Q_1+Q_4}$
- $Ty' + y = k_1 z \quad + k_2 u$

Simulation

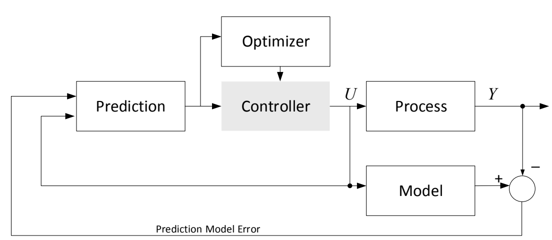
Model testing

- Model testing requires significant effort
- Minimum time for pre-step testing is given by

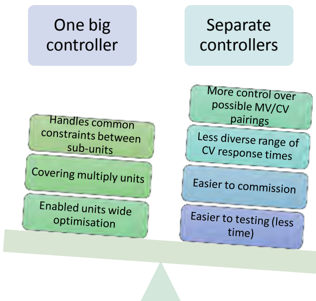
$$4 \times (n_U + n_Z) * t_{ss}$$

- where
  - n_U - number of U
  - n_Z - number of Z
  - t_{ss} - time to steady-state

Controller design and tuning



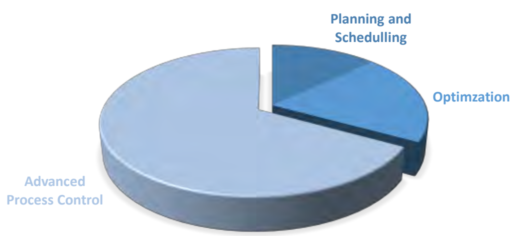
Poor controller design leads to poor performance



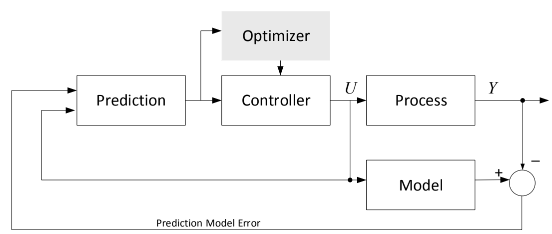
Different Technologies of Control

Optimization	Local Optimisation	Multi-Unit Optimisation	Non-linear Optimization
Model Based Control	Smith Predictors etc.	Multivariable Predictive Control	
Advanced Control	Feedforward Control	Dynamic Decoupling	Constrained Control
Regulatory Control	Single PI/PID Regulator	Cascade	

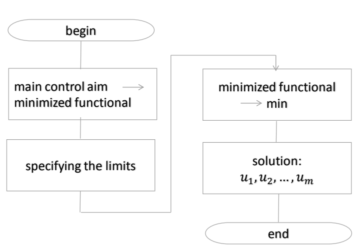
Available Economic Benefits



Consistent controller tuning leads to optimum performance



Procedure of Optimization



Choosing Objective Function

- Product Value Optimization
  - $I = \begin{bmatrix} ProductFlows \times ProductValues - \\ FeedFlows \times FeedCosts - \\ Energy/UtilityFlows \times Energy/UtilityCosts \end{bmatrix}$
- Limitations (examples)
  - Overloading
  - Flooding
  - Lack of overhead cooling

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Choosing Objective Function

- Linear Program Optimization
- $I = \sum_i \$_i^{cost} \times y_i + \sum_j \$_j^{cost} \times u_j$
  - $I = \sum_j \$_j^{cost} \times u_j$
- Use to minimise utilities or other operating variables
- Use to maximise product value

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Choosing Objective Function

- Quadratic Program (QP) Optimization
- $I = \sum_i \$_i^{cost} \times (y_i - y_i^{ss})^2 + \sum_j \$_j^{cost} \times \left(u_j - u_j^{ss}\right)^2$
  - $I = \sum_j \$_j^{cost} \times \left(u_j - u_j^{ss}\right)^2$
  - where y_i^{ss} , u_j^{ss} – "ideal operating point"
- Need to pre-calculate "ideal" U/Y values
- Difficult to specify QP U/Y costs

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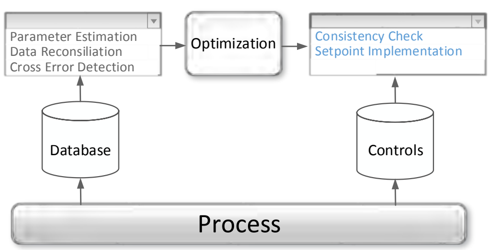
Execution Flow for Optimization



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Review of Process Control Systems

- PCS is the heart in the plant. Should it fail, the manager have to significantly increase staffing to run the plant in manual mode.
- PCS is collecting data from measuring instruments, flow- and mass-meters in our process. PCS also checks the state of mechanical equipment such as pumps, mixers, valves etc.
- PCS uses the collected process data to adjust parameters such as the speed of a pump to ensure stabile flow or the right dosage of a chemical.

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Review of Process Control Systems

- For the operator the interface to the Process Control System is the computerized SCADA-system. SCADA is a contraction for "supervisory control and data acquisition".
- PCS has a "communication module" that can communicate with all kinds of equipment through standards as 4-20 mA, standard Ethernet (TCP/IP) or different types of industry protocols (Profibus, Modbus)
- What actions to be done is determined by the PLC (Programmable logic controller), based on the program made by the automation engineer.

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ERP/MRP

- coordination of operations of separated workshops or plants
- economic planning tasks
- insuring effective control of the plant as a whole

SCADA

- data collection from measuring instruments, flow- and mass-meters in the process
- process control on the bases on collected data in order to insure maximum efficiency in process safety
- search of optimal modes of interconnected devices,
- distribution of load between separate units or machines working in parallel

LCS

- stabilize of preset technological parameters of the process
- alarming
- blocking of equipment in case of emergency

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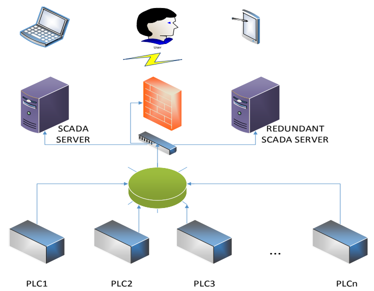
How does it work?



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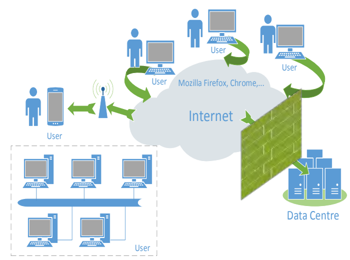
Distributed Control Systems



http://waternet.ua/

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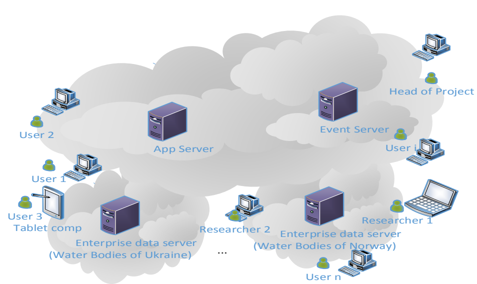
Distributed Control Systems



Bioindication of the wastewater state

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The types of bioindication

passive: InInvestigation of visible or inconspicuous lesions and abnormalities in free-living organisms which are signs of adverse effects

active or biotesting: Investigation of the impact of adverse factors in standard conditions for the most sensitive to this factor test organisms

The purpose of the lecture

- Concepts of bioindication of the state of wastewater;
- Knowledge of the aquatic indicator organisms;
- Hydrobiological characteristics of various muds.

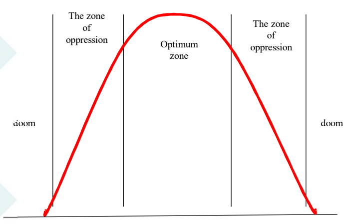
Advantage of bioindication and biotesting methods

- Reflection of the state of the environment from the biologically important data obtained
- Detection of the pollutants complex presence in the environment;
- Possibility to estimate the degree of the pollutant toxicity;
- ability to control the effect of synthesized xenobiotics
- due to the dose minimization, the ability to respond to minor fluctuations in a chronic anthropogenic press
- assistance in the regulation of the permissible load on various ecosystems, including different geographic areas
- the possibility of not using expensive equipment or labor-intensive physico-chemical methods for measuring biological characteristics
- establishment of pollution sources in ecosystem.

- **Bioindication** is the determination of biologically significant loads based on the reactions of alive organisms and their communities to them.
- **The main objective of bioindication** - development of methods and criteria for diagnosing disorders in components of natural communities.

Liebig's law of the minimum
- The relative effect of an individual environmental factor is the stronger, the more it is in comparison with other environmental factors at a minimum.

Shelford's law of tolerance
- the existence of a species is determined by limiting factors that are not only in the minimum, but also at the maximum.



The scheme of influence of the ecological factor

The existence of a species is determined by limiting factors in the region of the pessimum at the maximum and minimum values. Near the points of maximum and minimum lie sublethal values of the environmental factor, and outside the zone tolerance-lethal.

A source : Ляшенко О.А. Биоиндикация и биотестирование в окружающей среде. Schoolbook, 2012, p.15

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- Bioindicators are organisms or communities of organisms according to the presence, condition and behavior of which scientists judge about changes in the environment

Criteria for choosing a bioindicator:
- reliability (error <20%)
- monitoring capabilities
- simplicity
- fast reaction

Bioindication of the state of wastewater

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Oxidation of organic pollutants in aerotanks is due to the vital activity of aerobic microorganisms forming flocculent clusters - activated sludge.

Activated sludge is an artificially grown biocenosis during aeration of clarified wastewater, populated by bacteria, protozoa and multicellular animals that transform pollutants and purify wastewater as a result of soaking, oxidation, and eating.

Bioindication of the state of wastewater

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The types of bioindicators

Sensitive	*Accumulative*
Quickly reacts with a significant deviation of indicators from the norm	Accumulates exposure without manifest disturbances

Bioindicators are usually described by using two characteristics: specificity and sensitivity. At low specificity, the bioindicator reacts to different factors, at high specificity - only one.At a low sensitivity, the bioindicator responds only to strong deviations of the factor from the norm, while at high - to insignificant.

Bioindication of the state of wastewater

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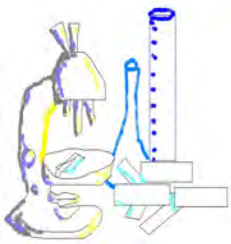
Hydrobiological analysis of activated sludge

1. Visual research of the sludge in a glass cylinder
2. identification of species, subspecies of organisms
3. determination of the number of each species
4. description of the morpho-functional state and changes in bioindicators
5. determination of the sizes of indicator organisms
6. distribution of bioindicators by environmental groups
7. final assessment of biocenosis
8. Preparation of hydrobiological conclusion



Bioindication of the state of wastewater

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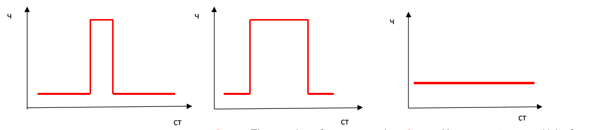
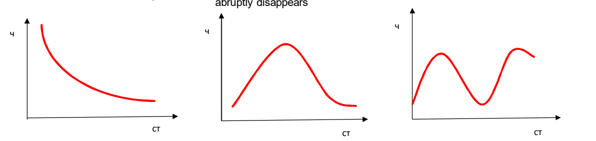
Depending on the development time of the indication reactions, there are 6 types of sensitivity



1 type. Gives a one-time reaction after some time and then loses sensitivity

2 type. The reaction of a strong and sudden, lasts for a certain time, then abruptly disappears

3 type. Keeps constant sensitivity for a long time



4 type. After an immediate, strong reaction, it is observed at first fast and then slow attenuation

5 type. When a disturbing effect occurs, the reaction increases to a maximum, and then gradually fades

6 type. The reaction is repeated repeatedly

A source : Ляшенко О.А.Биоиндикация и биотестирование в окружающей среде. Schoolbook, 2012, p.15

Bioindication of the state of wastewater

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Indicators of physiological state of aquatic organisms:
- Prevalling groups and species of biocenosis organisms.
- Degree of fatness
- Condition of contractile vacuoles
- The condition of the ciliary disk in the attached circourex ciliates (open, closed)
- Body shape
- Intensity of the ciliary apparatus (intensive, weak, complete, immobility)
- The size of organisms (normal, enlarged, small)
- The nature of reproduction
- The presence of cysts
- The presence of dead animals

Bioindication of the state of wastewater

Changes in biocenoses of activated sludge

- **Weakly disturbed biocenosis:** Less than 30% of the species of organisms disappears
- Average Violation: Disappears 50% of the species
- **Severe Violation:** More than 50% of species die

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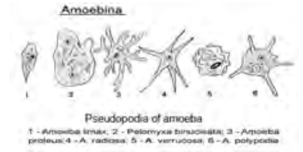
Amoeba

Amoebas are single-nucleated, less often multinucleated protozoa, that do not have a constant body shape, moving with the help of temporarily formed pseudopods and having neither a shell nor an internal skeleton. Pseudopodia may be in various different shapes amoebae, more blade or finger (A. proteus), the lancet (A. radiosa).



Pseudopodia of amoeba
1 - Amoeba limax, 2 - Pelomyxa binucleata; 3 - Amoeba proteus, 4 - A. radiosa, 5 - A. verrucosa, 6 - A. polypodia

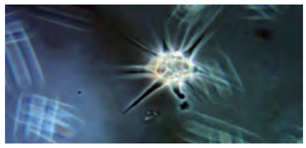


Photo: https://cf.ppt-online.org/files/slide/l/lthPVefQD5BMzl4WbYC9gHpyrwZ07qvXxs2FSm/slide-5.jpg
http://s1.dmcdn.net/MgOq-/1280x720-BFX.jpg

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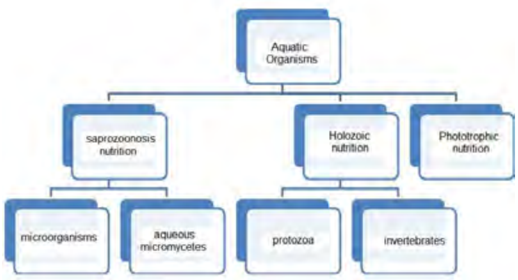
Biocenosis of activated sludge



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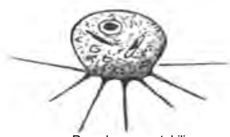
Testate amoebae

Testate amoebae are single-celled protists partially enclosed in a simple test (shell), who also move and perceive food with the help of pseudopodia. Their bare protoplasmic body is enclosed in a single-chamber shell, equipped with a hole through which pseudopods emerge.


Arcella discoides (Centropyxis)



Pamphagus mutabilis

Drawing by L.V. Rubtsova

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Zoogloea ramigera

Zoogloea ramigera, is a gram-negative, aerobic bacterium from the genus of Zoogloea which occurs in organically enriched aqueous environments like activated sludges, capable of forming so-called zooglеs, which are flake masses of cells floating in the jelly-like intercellular material and characterized by branched fingerlike morphology.

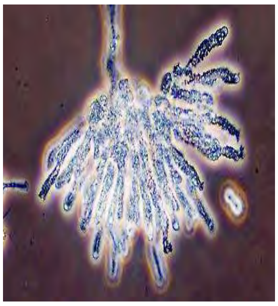

Photo: https://microbewiki.kenyon.edu/images/a/a2/Zoogloea_ramigera.jpg

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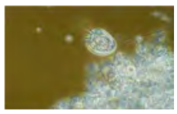
Hypotrich

Strongly flattened in the dorsoventral direction. On the dorsal side, the ciliary cover is reduced. Instead of cilia, there are long, thin threads. On the ventral side, the cilia are arranged in several rows. In addition to cilia, on the ventral side there are also groups of dense setae - cirrus, on which the infusorians rest when moving on a solid substrate.

Oxytricha spp

Euplotes spp



Aspidisca costata

Photo: http://elementy.ru/images/news/oxytricha_640.jpg
http://protist.i.hosei.ac.jp/pdb/images/Ciliophora/Euplotes/woodruffi/woodruffi.jpg
https://d3o1jlvchszf6h.cloudfront.net/wp-content/uploads/Aspidisca-e1492890905408.jpg

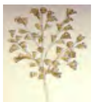
Peritrich

They are usually bell or disc shaped, with a prominent paroral membrane arising from the oral cavity and circling counter-clockwise around the anterior of the cell, accompanied by a smaller series of membranelles. The oral cavity is apical and funnel shaped, with a contractile vacuole discharging directly into it. When disturbed, the anterior of the cell can contract. The rest of the body is unciliated, except for a telotroch band circling the posterior in mobile species and stages.

Vorticella convallaria

Vorticella microstoma

Opercularia sp



Carchesium sp

Photo: https://distant-lessons.ru/wp-content/uploads/2013/11/infuzoria-trubach.jpg

http://900igr.net/datai/biologija/Prostejshie-organizmy/0018-025-Tip-Infuzorii-ili-Resnichnye.jpg

http://protist.i.hosei.ac.jp/PDB/PCD0605/D/61.jpg

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Characteristics of sludge

Satisfactory working (good) sludge

Indicator organisms::

- testate amoebaes Arcella discoides and Pamphagus mutabilis,
- tubulineas Amoeba radiosae and A. proteus,
- holotrichous from the order Cyclidium,
- hypotrichous Euplotes, Oxytricha, Aspidisca,
- peritrichous Opercularia, Epistylis,
- single copies of Carchesium. Small flagellates,
- rarely peritrichous ciliates V.microstoma and V. alba
- permanent availability of Zoogloea ramigera.

All protozoa are active, large, mobile, cilia in their working condition.

Status of sludge: sludge flakes compact, dense, silt settles quickly, the water above the silt transparent. The color of the flakes can be different (from gray-yellow to brown) and depends on the composition of the waste liquid.

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Rotifer

Multicellular organisms (from 40 microns to 2.5 mm). The rotifers are divided into a head, a trunk and a leg. Some rotifers are covered with shell, they usually develop in a low-loaded active sludge, which forms a high quality of cleaning. Spineless rotifers, such as Rotaria rotatoria, Philodina roseola, the inhabitants of the mud of ordinary aerotanks, providing complete oxidation of pollutants.

Rotaria rotatoria

Philodina roseola

Photo:
http://rotifera.hausdernatur.at/Rotifer_data/images/observation/Rotaria%20rotatoria%20(Pallas,%201766)_Ma1-PuuKukui.jpg

http://www.national-geographic.pl/media/cache/gallery_view/uploads/media/default/0001/93/736422ee775670415093262e04bdf58c0dde172a.jpeg

Bioindication of the state of wastewater

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•Nitrifying sludge

•Indicator organisms:

•in noticeable quantities of rotifers Notommata, Philodina, Cathypna, Monostyla, Callidina, Rotaria.

- quantitative predominance of attached infusorians Vorticella convallaria, Carchesium.
- there may be hypotrichous, large amoebae (A.proteus), testate amoebaes (Arcella, Centropyxis).
- possible presence in significant quantities of Aelosoma.
- lush development Zoogloea ramigera.

All of the protozoa are active, ciliary discs of peritrichous is opened.

Sludge condition. The sludge is loose, after deposition can float. The water above the sludge is transparent.

Bioindication of the state of wastewater

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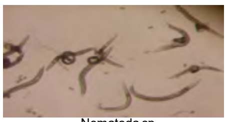
Worm

Aelosoma -characteristic worm, its body is divided into segments, between which are setae. In the body of Aelosoma, yellow droplets of fatty inclusions are usually well visible. Eyes - in the form of fairly large red spots.

The intensive development of Nematoda roundworms indicates stagnant zones in the aerotank. Excessive development of them can lead to a difficult flow of water.

Aelosoma sp



Nematoda sp

Photo:
http://www.norweco.com/html/lab/Webbugs/tech%20manual%20pictures/13.jpg

http://npc-news.ru/wp-content/uploads/2014/12/Nematode.jpg

Bioindication of the state of wastewater

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Голодающий ил

- **Indicator organisms:**
- A small variety of species of protozoa with a significant qualitative predominance of two or three of them.
- A large number of Chilodon, Colpidium colpoda.
- Presence in appreciable quantities of Vorticella microstoma andV. alba, Podophrya, Nematoda.
- Presence of Opercularia, but the ciliary disk is closed.
- Zoogloe accumulations of bacteria disappear, many individual bacterial
- cells and filamentous bacteria appear, such as Cladothrix, Sphaerotilus, Beggiatoa.

- **Sludge condition.** The sludge is contaminated with various inclusions: organic amorphous particles, muscle fibers, plant debris, garbage. Sludge flakes are dark, dense. The mud settles quickly, the water over the sludge is turbid with opalescence. The water above the sludge is turbid. At very high loads, the structure of the sludge deteriorates, loosening of the flakes.

Bioindication of the state of wastewater

Ил при недостатке кислорода

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- **Indicator organisms:**
- Rotifers motionless in the elongated state, dying off.

Vorticella convallaria swell in the form of a ball, then burst and disappear, some individuals form a freely floating form of the telotroch.
Abundantly found Vorticella microstoma.
Close cilia discs Carchesium and Opercularia.
Many small flagellates and small amoebas appear.
In a significant number develop suctoria Podophrya fixa.
Abundant develop Paramecium caundatum.

- **Sludge condition.** Flakes of sudge break up, the color of the sludge becomes whitish, it settles badly, the water over mud is muddy. In the presence of stagnant zones in aerotanks and secondary sedimentation tanks, the sludge acquires a dark color, Nematoda roundworms develop in it.

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Sludge during discharge of toxic industrial wastewater

- **Indicator organisms:**

Reducing the diversity of species of protozoa, one or two species predominate.
Small sizes of protozoa, especially Vorticella convallaria, Opercularia, Carchesium.
The stationary condition of the cilia of the infusorians, the ciliary disk of Opercularia is closed.
Rotifers motionless, compressed, dying.

- **Sludge condition.** Sludge is fine, contaminated with inclusions of industrial wastewater, can have colored particles, settles badly, the water above the sludge is turbid.

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Effect of pH variation

Indicator organisms:

At low pH (below 6.5), intensive development of the Fusarium fungus, which causes swelling of the activated sludge, is possible.
With a significant shift in pH (below 5), intensive yeast development is possible, leading to a decrease in the effect of wastewater treatment.
Significantly reduced the number of protozoa, with a strong acidification of the environment, they disappear completely.

Sludge condition.

- Claps of silt are stretched into strands, silt is crushed, its color becomes lighter.
- The sludge settles badly, in the supernatant liquid there is a lot of non-sedimenting suspension.
- Sometimes sludge floats to the surface.
- The sludge index can be increased to 200-500 mg / l.

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Intensification of the reduction-oxidation processes in the wastewater of industrial production

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- **CLASSIFICATION OF THE PROCESSES OF ELECTRICAL PROCESSING OF DISPERSE SYSTEMS WITH LIQUID DISPERSION ENVIRONMENT**
- 1. Electrodialysis is an electroprocessing method in which ion separation (dialysis) takes place with their concentration at the corresponding electrodes that change the pH of the electrode space. It is used to remove ions from dispersion media, colloid solutions and desalination of water.
- 2. Electrolysis is a method in which chemical reactions occur in the interelectrode space, as a rule, without the formation of insoluble compounds-the dispersed phase, including as well oxidation-reduction reactions at the electrode (electrooxidation-with the release of electrons at the anode and reduction-with addition electron at the cathode). It is suitable for changing the chemical composition of the dispersion medium. It is used for disinfection of water.
- 3. Electrochemical coagulation is an electroprocessing method in which cations forming sorption hydroxides are generated in the interelectrode space under the action of an external field, resulting in coagulation, sorption and disintegration of the dispersions under the action of both cations and hydroxides. It is useful for obtaining a coagulant. Used in the technology of water treatment and disinfection.
- 4. Electroflotation is an electroprocessing method in which a gas is generated that forms highly dispersed and monodisperse electrically charged bubbles that adsorb the particles of the disperse phase and transport them to the surface of the liquid. It is used in enrichment, for treatment and disinfection of water.

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- 5. Electroflotcoagulation - a method that combines successively electroflotation and electrochemical coagulation
- It is used, as a rule, for purification of natural and waste water, in enrichment.
- 6. Electrocoagulation is an electroprocessing method in which particles polarized by an external field approach and form new aggregates and particles, respectively, of a larger size. Electrocoagulation can be reversible (the aggregates break up after the removal of the field) and irreversible. It is used in the formation of coating structures of materials, coagulation in the technology of water treatment, oil purification from water and salts.
- 7. Dielectrophoresis - an electrical treatment method or a phenomenon in which the material of particles is polarized and they and their aggregates are concentrated in the region of higher field strength with the dielectric permittivity of particles of greater dielectric permittivity of the medium. In the case that the particles have a dielectric constant less than the dispersion medium, they are pushed out to a zone of lower field strength.
- Used for deep dehydration and desalting of oil, for cleaning dielectric liquids and other nonpolar media.

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- 8.Electric dehydration is a method of condensation and regulation of the rheological properties of highly concentrated hydrodispersions in an external electric field. It is applied in the utilization of precipitation of domestic, industrial and waste water.
- 9. Low-power electric discharge is an electroprocessing method in which electric discharges on the pulse front with a voltage of up to 3 kV and a length of up to 0.02 s occur in the interelectrode space created by a system of electrodes that generate an inhomogeneous electric field. This can be a high-frequency pulse discharge.
- 10. High-voltage pulse discharge is an electrical treatment method in which discharges are generated in pulses with a voltage of more than 3 kV and a length of less than 10-3 s in the interelectrode gap due to the energy stored beforehand in the storage capacitor. It is applied in the technology of electrohydraulic impact and disinfection of drinking and waste water.
- 11. A set of electrical effects - the method of electrical processing, in which a combination of the above methods is used in one combination or another.

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1. The usage of an electric discharge plasma

An alternative to chlorination is currently the methods of UV-irradiation and ozonization, which have a number of disadvantages.

The sensitivity of UV radiation to the turbidity of disinfected water and the absence of aftereffects prevent the use of this technology in wastewater treatment as an independent one.

Due to the complexity of the technology and the high power consumption, ozonation is mainly used on small volumes of water or at relatively low concentrations of pollutants.

Over the past few years, the development of electropulse methods for decontaminating liquids based on the discharge of high-voltage discharges in sewage has been carried out as the most promising from the point of view of direct introduction of oxidizing reagents: active radicals, hydrogen peroxide, ozone under the action of UV radiation into the water being treated.

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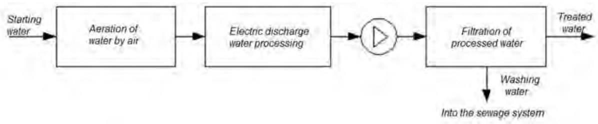
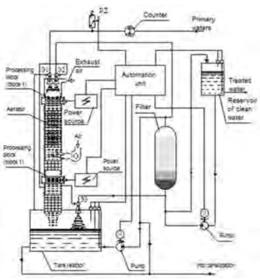
•A kind of a pulsed discharge in a liquid is a diaphragm electric discharge, in the channels of which cavitation effects arise, and also diffusion of metal ions from the surface of the electrodes.

•In the electroimpulse method (50 ... 300 ns) there are receipts in which water is processed by various radicals, electron and active ion flux, ozone, as well as ultraviolet and X-rays, local temperature increase, hydrodynamic and acoustic effects. In this case, ozone, radicals and other active oxidants affect impurities in water at the time of formation, i.e. the nonequilibrium state shifts towards the formation of OH radicals - the most active oxidants; thus, the specific energy for their formation is less than in the process of ozonation, which leads to a reduction in energy costs.

The technological process of electropulse coagulation and cavitation.



The technological process is environmentally friendly and includes aeration, electropulse treatment of water and filtration, while electroimpulse treatment of water is based on the combined action of natural oxidants (ozone, OH radicals, atomic oxygen, etc.) and UV radiation generated in water-air flow, as well as on the processes of electropulse coagulation and cavitation. The proposed electroimpulse water treatment technology is implemented in the water treatment complex.

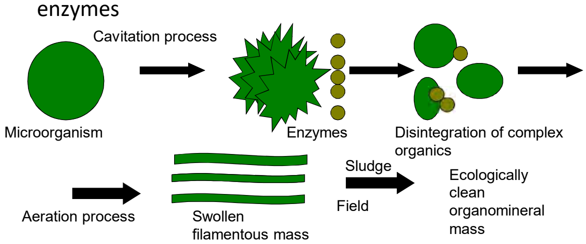


Typical technological scheme of an electric pulse installation

The main nodes of this installation are:
- column(s) complete with the device of electro-discharge water treatment and power supplies;
tank-reactor;
- transfer pumps and a pump for washing the filter;
- filters;
- block of automation with the necessary sensors and devices;
- pipelines, fittings, connecting and switching elements.

2.Cavitation and fermentation wastewater treatment

Disintegration of complex organics under the influence of enzymes



- CAVITATION BLOCK

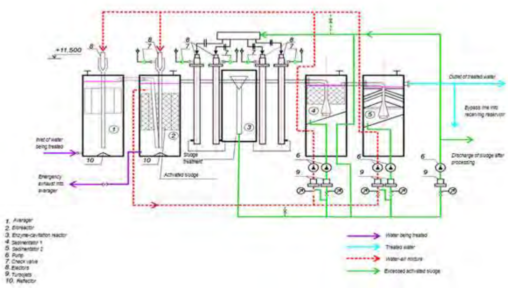
It is designed to reduce the hazard class of the treated sludge to the natural state. The process is based on the method of enzyme - cavitational oxidation of a mixture of a crude sediment with excess activated sludge, after which sedimentation, compaction and discharge of the treated sludge, its dehydration are carried out. Under the influence of cavitation in this block, dehelminthization occurs. That allows you to get an environmentally friendly product that can be used as a fertilizer.

- SEDIMENTATORS

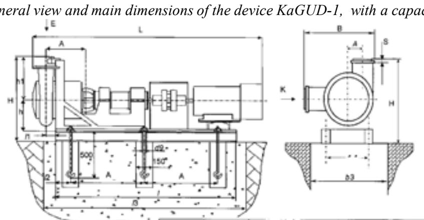
Designed for separating the solid phase from liquid, separating the activated sludge from the water to be purified, and also for further oxidation of organic contaminants. Sedimentators have in their composition active elements with a fixed charge in the form of a biological film, which ensures further efficient oxidation of contaminants

- The main work on processing (cleaning) of domestic wastewater is done by bacteria. And what if they are helped, for example, with the help of enzymes, which, as catalysts for biochemical reactions, can accelerate the decomposition of organic matter hundreds to thousands of times. Enzymes can be produced separately and then introduced into the waste water. And you can get directly into the sewage itself, if you remember that in any wastewater there is always a large number of microorganisms, which with the help of enzymes process organics.
- Cavitation-enzymatic or physico-biological technology of wastewater treatment in practice accelerates the processes of processing of contaminants in sewage.

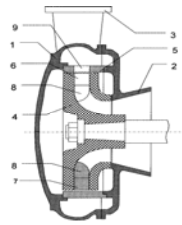
Cavitation and fermentation wastewater treatment



- *General view and main dimensions of the device KaGUD-1, with a capacity of 30 t/h*



	mm		mm		mm
A	340	D1	184	L2	135
A1	360	D2	210	L3	1840
A2	670	D3	245	S	28
A3	510	D4	150	S1	20
B	793	D5	202	H	890
B1	430	D6	225	H1	815
B	554	D7	260	H	315
B2	20	D8	15	H1	370
B3	880	D9	24	L	2090
D	125	L1	86	L	1540



The device of the KaGUD-1:
1-body; 2 - inlet branch pipe; 3 - outlet nozzle; 4 - rotor; 5 - stator; 6 - resonator chambers; 7 - narrowing channel of the resonator of rectangular section; 8 - shovels; 9 - holes of rectangular section in the stator

Advantages of cavitation-fermentation destruction during wastewater treatment and waste sludge processing

- 1. Absence of unpleasant odors.
- 2. Disposal of treatment facilities in the immediate vicinity of the residential area.
- 3. There is no need to build expensive collectors.
- 4. All treatment in a single compact building.
- 5. Reduction of area,
- 6. Solution of an important environmental problem: recycling of raw sludge and excess activated sludge.
- 7. Full automation of technological processes, which minimizes the impact of the human factor.
- 8. Absence of reagents.
- 9. Obtaining at the output of man-made humus - a product in demand by the market.
- 10. Reduction of the payback period of investments from 15-20 years to 5 years.

3. Ultrasonic wastewater treatment

- Powerful ultrasound is a unique environmentally friendly mean of stimulating physicochemical processes. Ultrasonic vibrations with a frequency of 20 000 - 60 000 Hertz and an intensity of more than 0.1 W/cm^2. can cause irreversible changes in the distribution environment. This predetermines the possibilities of practical use of powerful ultrasound in many areas of industry, including, at the stage of preliminary wastewater treatment.

Ultrasonic equipment

- Ultrasonic generators with a power of 0.1 - 10 kW, frequency of 20 - 40 kHz,
- Magnetostrictive converters with a power of 1.0 and 4.0 kW.
- Piezoceramic transducers with a power of 0.1-2.0 kW.
- Waveguide systems (including, with a developed radiating surface), providing the introduction of oscillations in gases, liquids (including aggressive and high-temperature - up to 10,000 ° C) and solids and heterogeneous systems.
- Ultrasonic instrumentation - hydrophones, instruments for measuring the amplitude of oscillations, assessing the level of development of cavitation in liquids.
- Blocks that provide the docking of ultrasonic equipment with technological processes.

3.1.Cleaning water in storage pools and sedimentation tanks

- Disinfection of water in the basin without chemistry - destruction and prevention of the formation of pathogenic microorganisms, incl. E. coli;
- Combating blue-green and filamentous algae;
- Fighting green water in the pool;
- Disinfection of water without chemicals;
- Prevention of flowering in the pool;
- Removal of bacterial plaque on the walls and bottom of the pool;
- Removal of unpleasant odor in the pool;
- Gentle skin biological treatment of water in the swimming pool;

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3.2. Disinfection of water in process tanks and storage tanks

- Cleaning and protection of the internal contour of pipes from calcium deposits and rust;
- Preparation of recycled water for recycling
- Disinfection of water in tanks, wells;
- Wastewater treatment for secondary use;
- Increase the efficiency of the septic tank;
- Destruction of a wide range of bacteria, viruses;
- Destruction of helminth eggs and protozoan cysts;
- Fighting rats, moles, mice;
- Descaling in boilers and boilers and pipelines.

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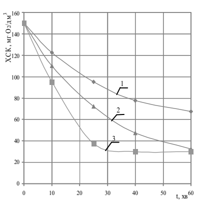
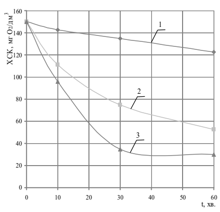
4.Insensification of oxidative processes during ozonation



In an electrocontact reactor



In a photocatalytic reactor

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. **Electro-chemical decomposition of ozone** is used in the chemodestruction of hardly decomposable compounds that have a high toxicity for the life of microorganisms, as well as traces of toxic pharmaceutical preparations

- **Example:**
- **The dose of ozone with direct ozonation of nitro compounds in wastewater was 20 ... 25 mg/m³; the time of contact of water with the ozone-air mixture is 30 ... 45 minutes.**
- **Electrochemical intensification of the ozonation stage accelerates: processes:**
- **increase transparency and reduce color - 5 ... 6 times;**
- **chemical destruction of organic compounds - in 1,5 ... 2,4 times;**
- **reduces: the required contact time of phases from 30 ... 45 to 10 ... 15 minutes and the required dose of ozone - from 20 ... 25 to 12 ... 16 mg/m³.**
- **With prolonged operation of the electrocontact ozonation reactor (up to 500 hours), a gradual decrease in the effect of electrochemical action on the decomposition of organic compounds is observed - mechanical cleaning of the electrodes is necessary.**

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5.Electro-chemical activation

Unipolar electrochemical activation is used:

-to reduce salinity in wastewater and waters of circulating cycles of industrial enterprises,
- for disinfection of sewage,
-to prevent deposition on ion-exchange resins,
- in membrane technology to protect ultrafiltration membranes before the reverse osmosis stage.

•Cathode $2H_2O+2e^- \rightarrow 2OH^-+H_2$

• $Ca^{2+}+2OH^- \rightarrow Ca(OH)_2$

•Anode $2H_2O-4e^- \rightarrow 2H^++2O_2$

▪ $2Cl^- - 2e^-+H_2O \rightarrow 2ClO^-+2H^+$

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- Content of Ca^{2+} and Mg^{2+} ions in the process of electroactivation of water is reduced by a factor of 10;
- content of dry residue - by 28-30%;
- the concentration of sulfate ions decreases by 73-75%; bicarbonate ions - by 67-69% ;
- concentration iron and heavy metals - by 67 -72%;, organic compounds - by 58 - 65%, microorganisms - by 89-94%
- distribution of electricity for demineralization and water purification is 6-12 kWh/m³.

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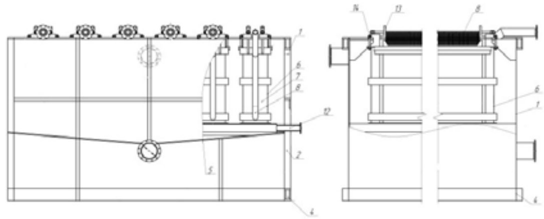
The pH and Eh values affect the various physico-chemical and biochemical processes that occur when components that contaminate it are removed from the water.
So in the process of oxidation, reduction, dissociation or complexation by the regulation of pH and Eh, it is possible to change the potential, direction and speed of chemical reactions, the oxidation-reduction activity of substances in solution, the strength of complex compounds, in the biochemical purification of water, inhibit the vital activity of bacteria, change the catalytic activity of microbial cell enzymes.



1 - body; 2- support; 3 - ribs of stiffness; 4 - support frame;5 - the tray of electrolyzer; 6 - cell of the electrolyzer; 7 - cell body (cathode); 8 - electrode central (anode);9 - gas distribution system; 10 - cathode collectorgases; 11 - the collector of anode gases; 12 - anolyte collector; 13 - 14 power supply

6.Electro flotocoagulation

- During electroflotokoagulation in water proceeds simultaneously occurs several processes: electrolysis, coagulation, sorption and flotation. .
- The combination of several processes provides a high degree of purification and recovery of SPAM from various types of sewage.
- The effect of wastewater treatment was 95% for surfactants, 72% for suspended substances, 43% for BOD.

Water treatment methods	Bacteria	Viruses	Microbial toxins	Phenols	Chlorine organic substances	Other organic substances	Heavy metal ions	Excess of mineral salts	**Amount of points**
Microfiltration	3	2	2	2	2	2	2	2	**17**
UV	4	4	2	2	2	2	2	2	**20**
Electrodialysis	3	2	2	2	2	2	2	5	**20**
Ultrafiltration	5	4	2	2	2	2	2	2	**21**
Ion exchange	2	2	2	2	2	2	5	5	**22**
Coagulation	3	2	3	3	3	3	4	2	**23**
Silvering	5	5	3	2	2	2	2	2	**23**
Iodination	5	5	3	3	2	2	2	2	**24**
Boiling	5	5	4	2	2	2	2	2	**24**
Хлорирование	5	5	3	3	2	3	2	2	**25**
Sorption	3	3	3	4	4	4	3	2	**26**
Electrolysis (without diafragm)	5	5	4	4	3	3	2	2	**28**
Ozonation	5	5	3	4	4	4	2	2	**29**
Electroactivation	**5**	**5**	**5**	**5**	**5**	**5**	**3**	**3**	**36**

Industrial Wastewater Management

WaterHarmony Erasmus+

Water and Wastewater in Industries

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Learning targets

- Understanding of water quantities and qualities of different industries
- Understanding of wastewater quantities and qualities of different industries
- Environmental, health and legal issues related to industrial water and wastewater

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WaterHarmony Erasmus+

Content

WaterHarmony Erasmus+

Industrial water: quantities and qualities

Important types of water needed in industries:

- Water for production processes
- Water for rinsing and cleaning processes
- Water for scrubbers and vacuum pumps
- Water for hydraulic transport processes
- Water for cooling systems
- Sanitary water

WaterHarmony Erasmus+

Industrial water: quantities and qualities

1. Water for production processes

Examples:

- Water as a solvent in chemical and tanning industries
- Water in solutions for the extraction of metals from ores
- Water as an essential part of process solutions in electroplating
- Water as a carrier of dyestuffs in textile industries
- Water as a portion of the product in beverages (beer, juice)
- Water as a basis for processing/cooking in food industries

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Industrial water: quantities and qualities

1. Water for production processes

Quantities: depending on the specific process and the options for multiple use and / or use of recycled water

Qualities: depending on the specific process

Exception:
For food and beverage production the process water must usually meet drinking water standards.

Industrial water: quantities and qualities

2. Water for rinsing and cleaning processes

Examples:

- Water for cleaning of raw materials in food industries
- Water for cleaning of reactors, pipes and other equipment
- Water in aqueous cooling lubricants in metal-cutting devices
- Water as a component of degreasing agents in electroplating and other surface technologies (zinc coating, painting etc.)
- Water for rinsing after chemical refinement of surfaces
- Water for washing in textile finishing

Industrial water: quantities and qualities

2. Water for rinsing and cleaning processes

Quantities: depending on the specific process and the options for multiple use and / or use of recycled water

In particular in surface technologies the reuse of rinsing water after intermediate treatment is state-of-the-art!

Qualities: depending on the specific process

→ low requirements for cleaning of raw materials

→ high requirements (use of demineralised water) for rinsing and washing of products

Industrial water: quantities and qualities

3. Water for scrubbers and vacuum pumps

Examples:

- Washing of exhaust air in scrubber devices for removal of dust and aerosols (in metal processing, chemical industries and power plants)
- Absorption of gaseous emissions from airflows in scrubber towers (in different industries)
- Water as an essential part of liquid ring vacuum pumps in chemical industries

Industrial water: quantities and qualities

3. Water for scrubbers and vacuum pumps

Quantities: depending on the specific process

The water can often be reused over a long period.

Qualities: requirements usually not very high

→ potential for multiple use of water from other applications

Industrial water: quantities and qualities

4. Water for hydraulic transport processes

Examples:

- Water as a carrier for the separation of coal and dead rock in coal processing
- Water for the preparation of paper fibre suspensions in paper mills
- Water as a component of sludge residuals

Industrial water: quantities and qualities

4. Water for hydraulic transport processes

Quantities: depending on the specific process

The solids concentration of suspensions in paper mills is about 1%, meaning that 100 L of water are needed here per kg of product. However, the water recycling rate is high.

Qualities: requirements usually low for transport processes only

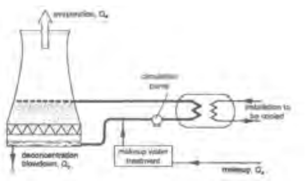
In paper mills the water must meet certain criteria, depending on the product quality.

Industrial water: quantities and qualities

5. Water for cooling systems

Examples: Water as a transport medium for excess heat

- in open-loop cooling systems
- in semi closed-loop cooling circuits
- in closed-loop cooling systems



Schematic illustration of a semi closed-loop cooling circuit (Roques, 1996)

Industrial water: quantities and qualities

5. Water for cooling systems

Quantities: depending on the specific boundary conditions (amount of heat, temperatures, type of cooling system, evaporation rate)

Qualities: requirements usually low, only turbidity removal in open-loop systems

Softening and conditioning of the make-up water; addition of antiscalants, corrosion inhibitors and biocides are necessary in semi closed-loop circuits.

Industrial water: quantities and qualities

6. Sanitary water

i.e. water for canteens, personal hygiene of the personnel, and toilett flushing

Quantities: depending on the size of the company

There are average specific demands for sanitary water that can be obtained from water suppliers.

Qualities: drinking water for canteens and personal hygiene

The use of rain water or other water with lower quality is common for toilett flushing in many companies.

Industrial water: quantities and qualities

Example: Industrial water used in Germany (2013)

➢ Cooling:	17.60 Bio. m^3/a	(Power plants and chemical industries)
➢ Production, cleaning, transport etc.	1.55 Bio. m^3/a	(all industries)
➢ Incorporation in products	0.12 Bio. m^3/a	(Food, beverages)
➢ Sanitary purposes	0.11 Bio. m^3/a	(all industries)
➢ Irrigation	0.30 Bio. m^3/a	
Sum:	19.68 Bio. m^3/a	

Industrial wastewater: sources of pollution

There are numerous sources that contribute to pollution:

- Dirt (particles) and grease from raw materials that are taken up in cleaning processes (e.g. in food and metal industries)
- Product residuals that are washed from reactors and pipes
- Dissolved organic substances and inorganic species that are released to process waters during production processes (e.g. in food and tanning companies)
- Dissolved organic substances and inorganic species that are used as process chemicals in aqueous solutions (e.g. metal-plating, paper mills, chemical and textile industries)

Industrial wastewater: sources of pollution

Sources of pollution (cont.):

- Dust (particles) and volatile substances from air scrubbing processes and vacuum pumps (e.g. in chemical industries)
- Chemicals from water treatment processes (e.g. cleaning of membranes, regeneration of ion exchange resins, oxidation and reduction processes, disinfection)
- Chemicals from conditioning of cooling waters (blow-down water from semi closed-loop cooling circuits)
- Sanitary facilities in companies

Industrial wastewater: quantities and qualities

Important types of industrial wastewater:

- Process water
- Water from rinsing and cleaning processes
- Scrubber and vacuum pump water
- Water from hydraulic transport processes
- Blow-down water from cooling systems
- Concentrates from water treatment processes
- Sanitary water
- Polluted rain water

Industrial wastewater: quantities and qualities

Quantities of industrial wastewater: General remarks

The quantity of industrial wastewater is often related to the amount of freshwater used because of an easier metering of the amount of water coming into a company.

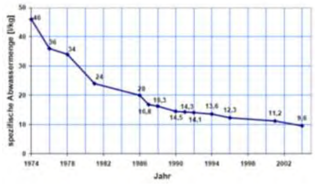
If there are larger portions of water that are either evaporated or incorporated into products, they have to be accounted for when calculating the water balance.

In chemical industries in Germany, a register of all wastewater streams with respect to origin, quantity and quality must be prepared for the authorities.

Industrial wastewater: quantities and qualities

Quantities of industrial wastewater: Example paper mills

In some industries, specific values have been derived for the water demand respective wastewater production (benchmarking values).



Development of the specific amount of wastewater (in L/kg) for the production of paper in Germany (Spörl and Wagenknecht, 2006)

Industrial wastewater: quantities and qualities

Quantities of industrial wastewater: Treatability

In companies where larger amounts of cooling water from open-loop cooling systems is produced, it is essential to collect this water in a separate sewer and not mix it with polluted wastewater.

In that case the cooling water can be discharged (after a quality control) into receiving waters without treatment.

In power plants and chemical companies, this is a prerequisite for a proper treatment of polluted wastewater.
Example: BASF company with 197 Mio. m^3/a of wastewater and 1,871 Mio m^3/a of cooling water worldwide (2010).

Industrial wastewater: quantities and qualities

Qualities of industrial wastewater: General remarks

It is **not** possible to derive general data on the quality of industrial wastewaters.

In industries where benchmarking has been done, data on specific wastewater loads related to the quantity of goods produced are available. Some examples are given in the lessons on selected industries of this course.

It is important to consider the treatment of wastewater sidestreams before mixing in order to efficiently remove hazardous substances. This issue is addressed in detail in the following treatment lessons.

Environmental, health and legal aspects

Environmental impact: Water use

Worldwide, industries account for 20% of the total water demand. Therefore a sustainable use of water, in particular in water-scarce countries, must be aimed at. This should include:

- the replacement of wet processes by dry alternatives, e.g for cleaning and in vacuum pumps
- the application of water-saving measures in all type of processes
- the utilization of multiple-use and recycle options whereever possible

Environmental, health and legal aspects

Environmental impact: Wastewater treatment

In the past, wastewater from industries has been a major source for water pollution. Thus conservation of the water resources requires:

- a proper treatment of all polluted wastewater streams including removal of hazardous substances from sidestreams
- the control of cooling water discharges in order to detect leaks that might cause pollution
- the replacement of substances that can harm the environment and that are difficult to remove, e.g. organic solvents or certain complexing agents

Environmental, health and legal aspects

Health issues: Water use

The personnel working in companies and people buying products may not be endangered by unsafe water. The risks are usually related to the hygienic quality. Attention must be paid in these areas:

- the use of clean water when producing food and beverages
- the prevention of risks from feed water when operation air conditioning systems with humidifying action
- the treatment and control of cooling water in semi closed-loop circuits with respect to legionella concentrations

Environmental, health and legal aspects

Health issues: Wastewater treatment

The personnel working in the companies' wastewater section may not be exposed to chemical or hygienic risks. Therefore some precautions should be taken:

- the treatment of wastewater with high-risk compounds, e.g. cyanide, in closed systems
- the use of protective clothing and equipment when getting in contact with wastewater
- vaccinations and frequent medical checkups of the staff

Environmental, health and legal aspects

Legal issues: Water use

As mentioned before, water getting in contact with products in food and beverage industries must have drinking water quality.

Other requirements are primarily related to the properties of water for specific purposes, but they have no legal status. Examples are:

- the quality of (demineralised) water used to produce steam
- the composition of water applied in cooling circuits and air-conditioning systems
- the quality of ultra-pure water used for the production of pharmaceuticals or electronic components

Environmental, health and legal aspects

Legal issues: Wastewater treatment

Nowadays most countries have specific legal requirements with respects to industrial wastewater treatment. This is addressed in lesson 3 of this course in more detail.

An important aspect, however, is the question which requirements apply if a company discharges its wastewater to a public sewer and thus to a domestic treatment plant.

In that case there should be requirements on a pre-treatment by the company which ensures that the emissions are not higher than with the whole treatment done by the company itself.

Final remarks

- Water and wastewater in industries is a broad area where it is difficult to obtain characteristic numbers on quantity and quality.
- A useful approach is to analyze the processes where water is used and wastewater is produced.
- During the past 20-30 years many companies have optimized their water use by developing less water-consuming processes, introducing water-saving measures and implementing multiple-use and recycling of different types of industrial water.
- Future challenges are the implementation of process-integrated measures with the ultimate aim of **clean** production processes.

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Questions

- Does the different water target have the same water quality requirement?
- What can industry do to mitigate the water scarcity?
- What can industry do to avoid water pollution?

Water Treatment Needs

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Learning targets

- Understanding the water quality requirement in specific industry
- Understanding the characteristic of different water source and the problem need to be solved
- Understanding the water saving strategies in specific industry

Content

Industries with specific water quality requirements

Production of food and beverages

- Water for pre-cleaning of raw materials, e.g. sugar beets, potatoes, vegetables
  → no specific requirements
- Water for processing of food (extraction, cooking), cleaning of vessels and other equipment, and final washing of products
  → drinking water standards
- Water for preparation of beverages, e.g. beer, soft drinks
  → drinking water standards with respect to hygienic quality, (optional) requirements on hardness and salt content

Industries with specific water quality requirements

Chemical refinement of surfaces (electroplating etc.)

- Water for pre-cleaning of raw materials and “dirty” processes like slide grinding
  → no specific requirements except low turbidity water
- Water for process solutions, e.g. cataphoretic painting baths or electrolytic baths
  → demineralised water
- Water for rinsing between process steps, and for final cleaning
  → demineralised water

Industries with specific water quality requirements

Production of chemicals, and processing of textiles and leather

- Water for pre-cleaning of raw materials
  → no specific requirements except low turbidity water
- Water for process solutions, e.g. chemical reactions, dying of textiles or tanning of hides
  → demineralised water
- Water for washing of semi-finished products between process steps, cleaning of vessels and other equipment
  → low turbidity and possibly soft water, no other requirements

Industries with specific water quality requirements

Steam generation, and production of pharmaceuticals and electronics

- Boiler feed water
  → softened, oxygen-free, pH > 9 (low-pressure systems)
  → demineralised, oxygen-free, pH > 9.2 (high-pressure systems)
  → silica < 0.02-0.5 mg/L (high-pressure systems)
- Ultrapure water for pharmaceutical solutions and electronics
  → conductivity < 0.056 µS/cm (18 MΩcm)
  → TOC < 100 µg/L
  → microbial count < 1 per 100 mL according to ASTM

Industries with specific water quality requirements

Cooling systems in power plants and petrochemical/ chemical industries

- Open-loop cooling systems
  → low-turbidity water
- Semi closed-loop cooling circuits (evaporation cooling)
  → pH = 7.5-8.5
  → TDS < 1,800-2,500 mg/L, depending on pipe material
  → softening (optional)
  → dosage of conditioning chemicals (complexing agents as antiscalants, corrosion inhibitors, dispersants, biocides)

Sources of water

Groundwater and spring water

- Characteristics
  → low turbidity, low temperature, composition almost constant, good hygienic quality
- Problems with its use
  → removal of iron and manganese, or removal of excess CO_2 (deacidification) might be necessary
  → right for water abstraction needed that might be difficult to renew if the region is affected by water stress

Sources of water

Lakes and reservoirs

- Characteristics
  → mostly low turbidity, temperature changing with season, composition might be influenced by algae blooms, moderate hygienic quality
- Problems with its use
  → in case of eutrophic conditions, elevated concentrations of organics including odorous substances, microorganisms, and dissolved iron and manganese possible
  → permit for water abstraction needed that might require an agreement with other water users

Sources of water

Rivers

- Characteristics
  → varying turbidity, seasonal temperature change, composition influenced by wastewater discharges and diffuse pollution sources (traffic, agriculture etc.), low hygienic quality
  → pre-treatment by riverbank filtration might be an option
- Problems with its use
  → treatment needed, dependant on quality requirements
  → in warm summers the temperature can be to high for cooling purposes
  → exposed to spills of hazardous substances from plants/tanks

Sources of water

Rain water

- Characteristics
  → low content of salts and fine particles (airborne components or washout from collection systems), low buffer capacity, pH often slightly acidic, moderate hygienic quality
- Problems with its use
  → amount depending on climate and weather conditions, thus storage basins required to match supply and demand, and alternative sources needed in dry weather periods
  → pH-adjustment, increase of buffer capacity or removal of particles might be necessary for certain applications

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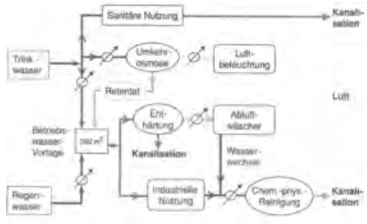
Sources of water

Rain water: Example

Utilisation of rain water for cleaning processes, for air scrubbing and for sanitary purposes by Lufthansa Technik in Hamburg/Germany



ca. 16,000 m³/a

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Sources of water

Re-used water

- Definition: Treated water that has been used before
- Characteristics
  → quality dependant on treatment applied
  → storage basins required to match production and demand
- Problems with its use
  → further treatment needed, depending on the specific quality requirements
  → components from earlier applications (e.g. salts or non-degradable organic substances) might be difficult to remove

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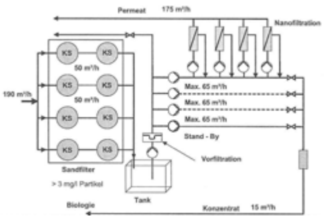
Sources of water

Re-used water: Example

Re-use of 1.65 Mio. m^3/a of biologically treated wastewater by the Palm paper factory (producing newsprint) in Eltmann/GE, after sand filtration+nanofiltration



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Challenges with quantities, water saving strategies

Production of food and beverages

- Water for pre-cleaning of raw materials
  → optimisation of washing processes, substitution of water by applying dry cleaning tools
- Water for processing of food, and cleaning of vessels and other equipment
  → mechanical pre-cleaning of equipment prior to wet cleaning
- Water for preparation of beverages
  → optimisation of cleaning stations for returnable bottles, barrels and other containers for beverages

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Challenges with quantities, water saving strategies

Chemical refinement of surfaces

- Water for pre-cleaning of raw materials and for processes like slide grinding
  → multiple use of water from other applications
- Water for process solutions
  → re-use of water from rinsing baths following the particular process
- Water for rinsing between process steps, and for final cleaning
  → multiple use of water in rinsing cascades
  → recycling of water after intermediate removal of impurities, primarily by ion exchange

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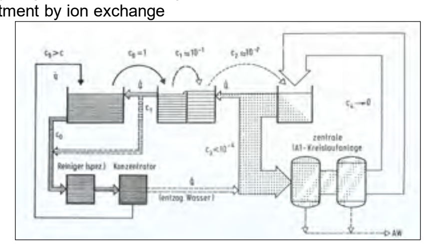
Challenges with quantities, water saving strategies

Chemical refinement of surfaces: Example

Recycling of water for rinsing purposes after a process bath with intermediate treatment by ion exchange



Courtesy: Hartinger, 1991

Challenges with quantities, water saving strategies

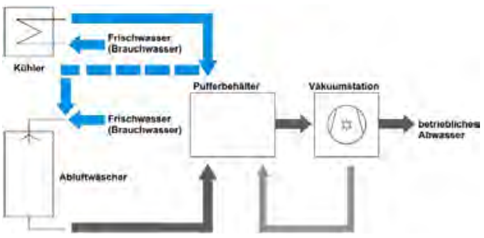
Production of chemicals, and processing of textiles and leather

- Water for pre-cleaning of raw materials
  → optimisation of washing processes
- Water for process solutions
  → re-use of water from rinsing steps following the particular process
- Water for washing of semi-finished products between process steps, cleaning of equipment, air scrubbing, vacuum stations
  → potential for multiple use of water from other applications

Challenges with quantities, water saving strategies

Production of chemicals: Example

Multiple use of water from cooling and air scrubbing in liquid ring vacuum pumps



Challenges with quantities, water saving strategies

Steam generation, and production of pharmaceuticals and electronics

- Boiler feed water
  → collection and re-use of condensate, if necessary with an intermediate cleaning step
- Ultrapure water for pharmaceutical solutions and electronics
  → no saving potentials in general, but the volumes of this type of water are usually not very large

Challenges with quantities, water saving strategies

Cooling systems in power plants and petrochemical/ chemical industries

- Open-loop cooling systems
  → conversion to semi closed-loop systems by cooling towers
  → energetic optimisation of processes, reduction of the amount of heat to be transferred
- Semi closed-loop cooling circuits
  → energetic optimisation of processes
  → reduction of blow-down water and increased thickening
  → application of closed-loop cooling systems, e.g. air coolers, for certain processes

Final remarks

- There are many different approaches for saving water in industries. However, each case must be considered carefully in order to develop the optimal strategy.
- In recent years separation processes for specific impurities have been developed further. Thus the potential for internal re-use of water after intermediate treatment has grown, and water cycles have become state-of-the-art in some areas, i.e. in electroplating.
- Industrial processes with high water demand should be evaluated with respect to a complete change of the process conditions, e.g. by applying new catalysts, or at least by regarding an introduction of process-integrated measures that reduce the water needs.

Questions

- Which of the following process need demineralised water, food and beverage, water for rinsing in electroplating industry, dying of textiles, boiler feed water?
- What is the main difference between ground water and surface water?
- How can we save cleaning water in industry?

Legal Aspects of Industrial Wastewater Discharge

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Learning targets

- Understanding of water quantities and qualities of different industries
- Understanding of wastewater quantities and qualities of different industries
- Environmental, health and legal issues related to industrial water and wastewater

Content

Structure of the wastewater legislation in Europe

Directives at EU level:

→ mandatory for member states, but national legislation necessary for their practical implementation

National legislation:

1. Laws providing guidelines for water use and **wastewater discharge**, e.g. the Federal Water Act in Germany
2. Regulations with respect to **direct discharge** of wastewater into water bodies, e.g. the Wastewater Ordinance in Germany
3. Rules for **indirect discharge** of wastewater into public sewers, e.g. the State Water Laws in Germany
4. Regulations for **monitoring** of wastewater discharges, e.g. ordinances at state level applied by regional and local authorities in Germany

EU directives

European Water Framework Directive 2000/60/EC

Establishment of a **framework** for the **protection** of inland surface waters, transitional waters, coastal waters and groundwater by

→ Coordination of administrative arrangements within river basin districts, development of river basin management plans

→ Monitoring of surface water status, groundwater status and protected areas (goal: achievement of „good“ ecological and chemical status for as many as possible water bodies)

→ **Control of point** and diffuse **emission sources**

→ Development of **strategies against pollution** of surface and ground waters (ultimate goal: elimination of initially 33 priority hazardous substances)

→ Recovery of costs for water services, including environmental costs

EU directives

European WFD 2000/60/EC, Directive on Environmental Quality Standards 2008/105/EC, amended by Directive 2013/39/EU

→ List of **45 priority substances** in the field of water policy (extension of the original list by 12 species)

→ Definition of **annual average** and **maximum allowable** concentrations in inland surface waters (rivers, lakes) and other surface waters, furthermore (only for 15 substances) **maximum contamination of biota** (fish) in µg/kg wet weight

Remark:

Originally 3 pharmaceuticals (17 alpha-ethinylestradiol (EE2), 17 beta-estradiol (E2) and Diclofenac) were also proposed, but have not been included in the list yet.

EU directives

European Urban Waste Water Treatment Directive 91/271/EEC, amended by Directive 98/15/EC

→ imposes an obligation to **collect** and **treat** wastewater from all settlements and agglomerations but the very small ones

→ sets treatment objectives for BOD_5 (25 mg/L), COD (125 mg/L), and TSS (35 mg/L) for secondary treatment (biological carbon removal)

→ sets treatment objectives for total-N (15 mg/L resp. 10 mg/L)[1)] and total-P (2 mg/L resp. 1 mg/L)[1)] in the catchment of so-called sensitive areas (either eutrophic or potentially eutrophic), thus requiring nutrient removal here

→ imposes an obligation to establish national regulations for **industrial** wastewater discharged **directly** into receiving waters, and to define sampling and monitoring routines for all treated wastewaters at the point of discharge

[1)] Depending on the size of the treatment plant

EU directives

European Urban Waste Water Treatment Directive 91/271/EEC, amended by Directive 98/15/EC

Requirements on the pre-treatment of **industrial wastewater** that is discharged into public sewers with the aim of:

- protecting the health of staff working in collecting systems and treatment plants
- ensuring that collecting systems, treatment plants and other equipment are not damaged
- ensuring that the operation of treatment plants and sludge treatment are not impeded
- ensuring that discharges from the treatment plants do not adversely affect the environment
- ensuring that sludge can be disposed of safely+acceptably for the environment

National laws

Implementation of European water law in EC member states, Example Germany: **German Federal Water Act** of 31.07.2009

Definition of the principles of water resources management, in particular:

→ Designation of river basin districts

→ Definition of **water use, permission and approval**

→ Rules for the management and maintenance of surface waters

→ Rules for the management of coastal waters

→ Rules for the management of groundwater

→ Public water supply

→ **Wastewater disposal**

→ Handling of substances hazardous to waters; appointment of water deputies

National laws

Implementation of European water law in EC member states, Example Germany: **German Wastewater Ordinance** (2004)

Purpose: Specification of the minimum requirements on wastewater for a **discharge permit directly into a water body**

→ General requirements: Pollutant load must be kept as low as the use of water-saving procedures permit; it must not be transferred to other environmental media such as air or soil, contrary to the state-of-the-art

→ Definition of analysis and measurement procedures

→ Compliance with **threshold values** given in the Appendix for **53 different sources** of wastewater generation, including domestic wastewater

Remark: For companies discharging into a public sewer, the threshold values from this ordinance apply at the point of discharge for hazardous substances.

National laws

Implementation of European water law in EC member states, Example Germany: **German Wastewater Charges Act** (2005)

Purpose: Collection of a charge (wastewater charge) for discharging wastewater into a water body

→ Determination of the **noxiousness** of wastewater based on the parameters COD, total-P, total-inorganic N, AOX, mercury, cadmium, chromium, nickel, lead, copper and the toxicity to fish eggs

→ Calculation of **noxiousness units** from these parameters and the annual amount of wastewater; one noxiousness unit equals **35.79 €**

→ Accounting for investments in improved wastewater treatment technologies via a reduction of the charge

→ Increase of the charge if the minimum requirements according to the wastewater ordinance are not met

Water use and wastewater discharge permits

In many countries, companies need a permission for abstracting water from different sources

Example Germany:

- Groundwater: Approval needed that includes the maximum amounts per hour, day and year, issued for a period of 10-30 a
  In most German states, a groundwater fee must be paid that ranges from 0.05 to 0.31 €/m^3.
- Surface water: Allowance needed that includes the maximum amounts per second, hour, day and year, issued for a period of 15-30 a
  In some German states, a surface water abstraction fee must be paid (also for cooling purposes) that ranges from 0.01 to 0.30 €/m^3.

Water use and wastewater discharge permits

In most countries, companies need an allowance for discharging wastewater into public sewers or receiving waters

Example Germany:

- Indirect discharge: Allowance needed from local water authorities that includes the maximum amounts per hour, day and year, and obligations for pre-treatment and self-monitoring. It is valid until revoked.
  For hazardous substances, the threshold values for indirect and direct discharge are identical (slide 9).
  Furthermore the by-law of the municipality is applied, where other wastewater parameters can be regulated, e.g. TSS, COD or salts like sulphate.

Water use and wastewater discharge permits

In most countries, companies need an allowance for discharging wastewater into public sewers or receiving waters

Example Germany:

- Direct discharge: Allowance needed from regional water authorities that includes the maximum amounts per second, hour, day and year, the minimum requirements for all relevant parameters, and obligations for treatment and self-monitoring
  The minimum requirements could be decreased if the quality of the receiving waters was deteriorated too much.
  The allowance must be renewed regularly, e.g. after 10 years.

Water use and wastewater discharge permits

Direct discharge: Implementation of the German Wastewater Ordinance

- The ordinance specifies the **minimum requirements** to be stipulated when granting a permit to discharge wastewater from 52 different industrial sectors (and from public wastewater systems) into water bodies.
- The requirements refer to the point at which the wastewater is discharged and also, where specified in the appendices to the ordinance, to the site of occurrence of the wastewater or the site prior to blending thereof.
- The point of discharge is synonymous with the outlet from the wastewater plant where the wastewater was last treated. The site prior to blending is also the point of discharge into a public wastewater treatment system.

Water use and wastewater discharge permits

Direct discharge: Implementation of the German Wastewater Ordinance

Example: Appendix 36 → Production of hydrocarbons

1. The following requirements apply to the wastewater at the point of discharge into the water body:

	Qualified random sample or 2-hour composite sample mg/l
Chemical oxygen demand (COD)	120
5-day biochemical oxygen demand (BOD_5)	25
Total nitrogen as the sum of ammonia, nitrite and nitrate nitrogen (N_{tot})	25
Total phosphorous	1.5
Total hydrocarbons	2

Water use and wastewater discharge permits

Direct discharge: Implementation of the German Wastewater Ordinance

Example: Appendix 36 → Production of hydrocarbons

2. The following requirements apply to the wastewater prior to blending:

	Qualified random sample or 2-hour composite sample mg/l	Random sample mg/l
Adsorbable organically bound halogens (AOX)	-	0.1
Phenol index after distillation and dye extraction	0.15	-
Benzene and derivatives	0.05	-
Sulfide sulphur and mercaptan sulphur	0.6	-

3. Requirements for wastewater for the site of occurrence:

Wastewater from the production of ethylbenzene and cumene must not exceed a level of 1 mg/L for adsorbable organic halogens (AOX) in the random sample.

Discharge fees and fines

Companies are obliged to pay for the treatment of their wastewater in public plants

Example Germany:

- According to the by-law of the municipality, each company has to pay wastewater charges in order to cover the costs for collection, treatment and final discharge.
- The scale of fees can define additional charges for high-concentrated waste-water or for certain components.
- If a public sewage treatment plant is negatively affected by an industrial wastewater stream, this may result in an individual claim for compensation, but there are no regular fines.

Discharge fees and fines

In some countries, companies are obliged to pay a charge for dis-charging wastewater into receiving waters (polluter-pays principle)

Example Germany:

- The companies have to cover the costs for own treatment and self-monitoring.
- According to the German Wastewater Charges Act (slide 10), noxiousness units are calculated from the annual amount of wastewater and the concen-trations of certain components. The regular charge is 35.79 € per unit.
- The charge is increased if the minimum requirements according to the waste-water ordinance are not met.
- If wastewater is discharged illegally, i.e. without permission or with intent at concentrations higher than permitted, responsible persons can be accused for water pollution which is a criminal offense.

Discharge fees and fines

Example: Calculation of a wastewater charge for COD

A company discharges 500,000 m^3/a of wastewater. The minimum requirement for COD according to the discharge permit is 200 mg/l (equivalent to 200 g/m^3), so the annual COD load is

500,000 m^3/a x 200 g/m^3 = 100,000 kg/a

For the parameter COD, one noxiousness unit equals 50 kg, hence the annual no. of noxiousness units is

100,000 kg/a / 50 kg/NU = 2,000 NU/a

Without discount, the charge per noxiousness unit is 35,79 EUR, resulting in an annual wastewater charge of

2,000 PU/a x 35,79 EUR/PU = 71,580 EUR/a

Final remarks

- EU's Water Framework Directive and Urban Wastewater Treatment Directive are the basis for national laws and ordinances in Europe. The compliance with the requirements in each member state is observed by the European Commission. In the event of default, warnings are sent to the states.
- The national legislations ensure that proper requirements are set for the treatment of industrial wastewater, both for indirect discharge with the option of mandatory pre-treatment by the companies, and for direct discharge.
- Water abstraction from groundwater and sometimes also from surface water must be permitted by the authorities. In Germany even abstraction fees have to be paid.
- For wastewater discharges the polluters-pay principle is widely applied nowadays. Companies have to pay fees for indirect discharge according to the by-law of the respective municipality, and for direct discharge according to national laws.

Questions

- Is there some limitation for industry to discharge waste water into water bodies directly?
- Does the industry need to pay for the wastewater discharge?

European Tools

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Learning targets

- Understanding of relevant EU-Directives
- Understanding of Best available techniques (BATs)

Content

Overview of relevant EU-Directives

- European Water Framework Directive 2000/60/EC (see lesson 3)
  - → Control of point and diffuse **emission sources**
  - → Development of strategies against pollution of natural waters
- European Urban Waste Water Treatment Directive 91/271/EEC, amended by Directive 98/15/EC (see lesson 3)
  - → Obligation to establish national regulations for industrial wastewater discharged **directly** into receiving waters
  - → Pre-treatment of industrial wastewater discharged into public sewers
- Directive 2010/75/EU on Industrial Emissions (IED)
  - → Revision of the former Directive 2008/1/EC concerning integrated pollution prevention and control (IPPC)

Directive 2010/75/EU on Industrial Emissions

General idea

- To control industrial emissions, the EU has developed a general framework based on **integrated permitting**. This means the permits must take account of a plant's complete **environmental performance** to avoid pollution being shifted from one medium - such as air, water and land - to another.
- Priority should be given to preventing pollution by **intervening at source** and ensuring **prudent use and management of natural resources**.
- The main goal is an **integrated** pollution prevention and control.

Directive 2010/75/EU on Industrial Emissions

What does the Directive do?

– It is a recast of 7 earlier pieces of legislation on industrial emissions.
– It lays down rules to prevent and control pollution into air, water and land and to avoid generating waste from large industrial installations.

Key points:

- The legislation covers the following industrial activities:

  Energy, metal production and processing, minerals, chemicals, waste management and other sectors such as **pulp and paper** production, **slaughterhouses** and the intensive **rearing of poultry** and **pigs**.

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Directive 2010/75/EU on Industrial Emissions

Key points (contd.):

- All installations covered by the directive must **prevent** and **reduce pollution** by applying the **best available techniques (BATs)**, **efficient energy use**, **waste prevention** and management and **measures to prevent accidents** and limit their consequences.
- The installations can only operate if they are in **possession of a permit**, and if they **comply** with the conditions set therein. These requirements are mandatory.

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Directive 2010/75/EU on Industrial Emissions

Key points (contd.):

- The BAT conclusions adopted by the Commission are the **reference** for setting the **permit conditions**. Emission limit values must be set at a level that ensures pollutant emissions do not exceed the levels associated with the use of BATs. However they may, if it is proven that this would lead to disproportionate costs compared to environmental benefits.
- Competent authorities need to conduct **regular inspections** of the installations.
- The **public** must be given an early opportunity to **participate** in the permitting process (obligation to access to information).

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Best available techniques (BATs)

Background:

- BATs are defined as the **most effective techniques** for preventing or reducing emissions that are **technically feasible** and **economically viable** within the sector.
- **BAT Reference documents** (BREFs) are drawn up, reviewed and updated by panels that include national experts, the respective industries concerned, NGOs and the European Commission. The activities are coordinated by the IPPC Bureau in Sevilla/Spain (http://eippcb.jrc.ec.europa.eu).
- From the BREFs, **BAT conclusions** are derived that must formally be adopted by the European Commission.

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Best available techniques (BATs)

Overview over currently*) available BREFs:

- Ceramic Manufacturing Industry
- Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector
- Emissions from Storage
- Energy Efficiency
- Industrial Cooling Systems
- Intensive Rearing of Poultry or Pigs
- Iron and Steel Production
- Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilisers Industries

*) October 2017

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Best available techniques (BATs)

Overview over currently available BREFs (contd.):

- Large Volume Inorganic Chemicals - Solids and Others Industry
- Manufacture of Glass
- Manufacture of Organic Fine Chemicals
- Non-ferrous Metals Industries
- Cement, Lime and Magnesium Oxide Manufacturing Industries
- Production of Chlor-alkali
- Production of Polymers
- Production of Pulp, Paper and Board
- Production of Speciality Inorganic Chemicals
- Refining of Mineral Oil and Gas

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Best available techniques (BATs)

Overview over currently available BREFs (contd.):

- Slaughterhouses and Animals By-products Industries
- Smitheries and Foundries Industry
- Surface Treatment of Metals and Plastics
- Tanning of Hides and Skins
- Wood-based Panels Production
- Economics and Cross-media Effects

In addition to these 24 documents, another 10 BREFs are in preparation, e.g. for

- Food, Drink and Milk Industries
- Large Volume Organic Chemical Industry

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Best available techniques (BATs)

Application and control:

- BAT conclusions shall be the **reference** for setting the permit conditions in the member states.
- If an environmental standard requires stricter conditions than those achievable by the use of BATs, **additional measures** shall be included in the permit.
- The member states shall encourage further development and application of **emerging techniques** identified in the BREFs.
- Member states shall set up a system of **environmental inspections** of installations which should include site visits and be carried out in intervals between 1 and 3 years.

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Best available techniques (BATs)

Example: Water relevant BAT conclusions, based on the Commission implementing decision (EU) 2016/902 of 30 May 2016, establishing BAT Conclusions for Common Wastewater and Waste Gas Treatment/ Management Systems in the Chemical Sector

- BAT 1: Implementation of an **environmental management system** (EMS)
- BAT 2: Establishment of an **inventory** of wastewater and waste gas streams
- BAT 3: For relevant emissions to water, monitoring of key process parameters (including continuous monitoring of wastewater flow, pH and temperature) at key locations (e.g. influent to pretreatment and influent to final treatment)
- BAT 4: **Monitoring** of emissions to water in accordance with EN standards with minimum frequencies of daily (TOC, COD, TSS, TN, N_{inorg}, TP), monthly (AOX and heavy metals) and to be decided individually (toxicity).

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Best available techniques (BATs)

Example: Water relevant BAT conclusions in the chemical sector (contd.)

- BAT 5 and 6: Related to emissions into air, not relevant for water.
- BAT 7: **Reduction** of the volume and/or pollutant load of wastewater streams, enhancement of the **reuse** of wastewater within the production process and recovering and reuse of raw materials
- BAT 8: **Segregation** of uncontaminated wastewater streams from wastewater streams that require treatment
- BAT 9: Provision of an appropriate **buffer storage capacity** for wastewater incurred during other than normal operating conditions based on a risk assessment (taking into account e.g. the nature of the pollutant, the effects on further treatment, and the receiving environment), and appropriate further measures (e.g. control, treat, reuse).

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Best available techniques (BATs)

Example: Water relevant BAT conclusions in the chemical sector (contd.)

- BAT 10: Use of an **integrated wastewater management and treatment** strategy that includes an appropriate combination of techniques in the following priority order:
  - Process-integrated techniques
  - Recovery of pollutants at source
  - Wastewater pretreatment
  - Final wastewater treatment
- BAT 11: **Pretreatment** of wastewater containing pollutants that cannot be dealt with adequately during final wastewater treatment
- BAT 12: Use of an appropriate combination of **final wastewater treatment** techniques (mechanical, biological and chemical processes)

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Best available techniques (BATs)

Example: Water relevant BAT conclusions in the chemical sector (contd.)

BAT-associated emission levels (BAT-AELs) are yearly-average values for direct emissions to a receiving water body. They comprise:

Organics and particles	Nutrients	Halogens and heavy metals
TOC = 10 – 33 mg/L	TN = 4 – 25 mg/L	AOX = 0.2 – 1 mg/L
COD = 30 – 100 mg/L	N_{inorg} = 5 – 20 mg/L	Cr, Cu, Ni = 5 – 25 (50) mg/L
TSS = 5 – 35 mg/L	TP = 0.5 – 3 mg/L	Zn = 20 – 300 mg/L

Note:
1. The values apply only if minimum annual loads are exceeded.
2. The upper and lower end of the ranges are related to certain waste-water compositions and treatment techniques applied.

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Implementation at the national level

Example Germany: State Decrees for the environmental inspection of industrial installations (including wastewater treatment plants)

Approach:

→ Authorities conduct **regular inspections** of industrial installations (every 1 – 3 years)

→ They estimate the environmental impact and check whether all **requirements are met**.

→ In case of severe problems a new inspection takes place after 6 months.

→ A **report** is prepared to the EU that is made available to the public within 4 months.

Implementation at the national level

Example Germany: **Federal Ordinance** for the **Permission** and **Monitoring** of industrial wastewater treatment plants (2017)

Content:

→ Description of the application procedure

→ Participation of the public and provision of information

→ Conditions for permission and approval

→ Monitoring conditions and monitoring plans for plants that are in operation

→ Practical execution of monitoring and control

Implementation at the national level

Example Germany: **German Wastewater Ordinance** (2004)

Purpose:

Specification of the **minimum requirements** on treated wastewater for direct discharge into a water body

→ **Pollutant load** must be kept as **low** as the use of water-saving processes permits (general requirement).

→ Effluent concentrations must comply with **threshold values** given for **52 industrial sources** of wastewater plus domestic wastewater.

→ The threshold values must be in agreement with the **BAT-associated emissions levels** given in the BREFs for the respective industry.

Final remarks

- EU's Industrial Emission Directive is based on the principle of integrated pollution prevention and control.
- It starts with defining procedures for permitting and monitoring of industrial installations, including regular inspections by authorities and reporting to the EU and to the public.
- The best available techniques (BAT) concept plays a key role in this approach because companies must comply when applying for permits.
- The respective documents (BREFs) are developed by panels where all stakeholders participate.
- The emission situation in Europe is becoming more transparent.

Water treatment methods

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Learning targets

- Understanding of general treatment process
- Mastering the principle of the typical solid-liquid separation process
- Mastering the principle of physical-chemical treatment method of dissolved in-organic compound
- Mastering the principle of biological treatment method of dissolved organic compound

Content

Treatment concepts – general remarks

Development

In the past: Treatment in a central mechanical-biological plant on-site or together with domestic wastewater (end-of-pipe)

Now: Decentralized (pre-)treatment of separate wastewater streams (point-of-source), followed by a central plant if needed

Challenges with separate wastewater streams

1. small volumetric flow rates
2. high concentrations of pollutants
3. often discontinuous flow

Treatment concepts – general remarks

Conclusions

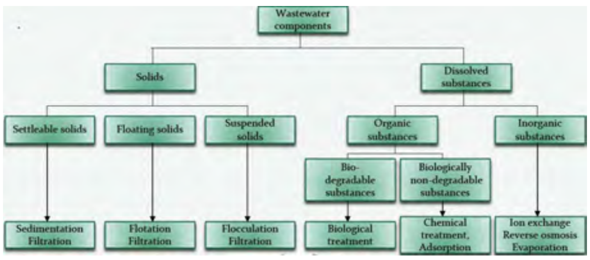
For pre-treatment purposes, biological processes are suited if

- the substances to be removed are degradable,
- the process is not affected by other toxic substances, and
- adequate adaptability to the fluctuating conditions is possible.

Therefore, physical-chemical or chemical processes must often be applied for the (pre-)treatment of separate streams.

These processes are also important as process-related measures for emission reduction.

Overview of treatment processes



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Solid-liquid separation

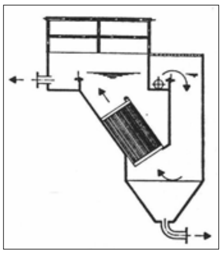
Sedimentation in inclined-plate settlers

Idea: Enlargement of the effective settling area

Important aspect: Up-flow operation

Typical design parameters:
- distance between plates: 20 -100 mm
- angle of inclination: 55 - 60°

Manufactured sizes: Q = 1 - 300 m^3/h



Inclined-plate settler
(Courtesy Vereinigte Kesselwerke)

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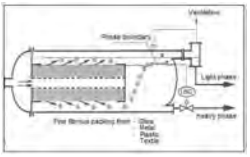
Solid-liquid separation

Oil removal by coalescence separators

Operating principle:
Formation of larger oil drops from fine oil droplets (5 - 20 µm) by hydrodynamic effects

General requirements in Germany:
Effluent concentrations < 5 mg/L HC when tested with a water/oil mixture according to DIN 1999

Limitation of mechanical oil separation:
Removal of stable emulsified oil droplets



Coalescence separator

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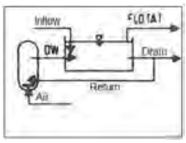
Solid-liquid separation

Dissolved air flotation (DAF)

Operating principle:
- saturation of recycled effluent with pressurized air
- formation of air bubbles in the flotation basin
- attachment of particles on air bubbles
- floating of the air-solid aggregates to the surface

Typical design parameters:
- hydraulic surface loading: 2 - 15 $m^3/(m^2 \cdot h)$
- operating pressure: 2 - 6 bar
- recycle ratio: 0.1 - 0.5 (except sludge thickening)
- air : solids ratio: 3 - 100 L_N / kg TSS



Principle of DAF

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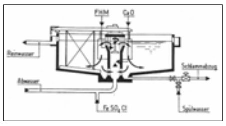
Solid-liquid separation

Flocculation in circular reactors

Principle:
- dosing of metal coagulants (iron or aluminium salts) into the inflow
- floc formation in the central part of the reactor, supported by polymer addition
- floc separation by settling in the outer volume of the reactor

Operating parameters:
- hydraulic surface loading: 2 - 6 $m^3/(m^2 \cdot h)$
- coagulant dosages: 5 - 50 mg/L Me
- pH adjustment: pH = 5.5 - 7.5



Turbo-Circulator (Courtesy Ph. Müller)

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Solid-liquid separation

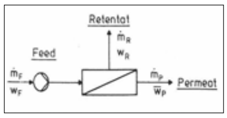
Micro- and Ultrafiltration

Operating principle:
Separation of an inflow (feed) stream into a filtrate (permeate) stream and a concentrate (retentate) stream by organic or inorganic membranes with well-defined pore sizes

Differentiation:

Microfiltration → separation size 50 - 10,000 nm
operating pressure 0.5 - 5 bar

Ultrafiltration → separation size 5 - 50 nm
operating pressure 1 - 10 bar



Principle of membrane filtration

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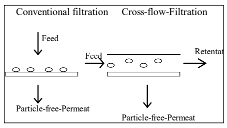
Solid-liquid separation

Micro- and Ultrafiltration

Design selection criteria:
- TSS feed concentration
- recovery
- operating mode
- energy demand
- residuals and their disposal
- fouling potential of the membrane
- rinsing and cleaning procedures

Operating mode:
→ cross-flow (applied in wastewater treatment)
→ dead-end (used for process water treatment)



Operating modes of membrane filtration

Solid-liquid separation

Typical applications in industries

Inclined-plate settlers:	Removal of particles and chemical flocs, e.g. after precipitation of heavy metals from metal-plating wastewater streams
Coalescence separators:	Pre-treatment of wastewater containing oil droplets, e.g. effluents from machine shops
Dissolved air flotation:	Removal of hydrophobic solids with low density, e.g. from wastewater streams generated in food industries and slaughterhouses
Compact flocculation:	Coagulation of fine particle and colloids, e.g. for producing process water from river water

Solid-liquid separation

Typical applications in industries

Microfiltration:	Removal of fine particles and oil droplets from all kinds of small wastewater streams
Ultrafiltration:	Separation of emulsions (e.g. drilling oils, compressor condensates) with cross-flow inorganic membranes
	Separation of proteins from whey, soya extracts etc.
	Recovery of dyes and sizing agents from dying of textiles
	Recovery of water-based paints from electrocoating processes
	Separation of activated sludge flocs from effluents in membrane bio-reactors

Removal of dissolved inorganic substances

Ion exchange

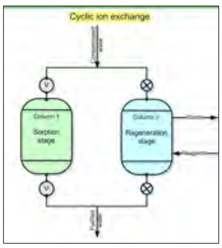
Operating principle:

Uptake of cations or anions from wastewater by porous resin beads that release a stoichiometric amount of ions (of the same charge) originally bound to the resin (sorption stage)

Desorption of these ions from the resin by applying a concentrated solution of the ions initially present on the resin (regeneration stage)

Operating mode:

→ co-current (for high ion concentrations)
→ counter-current (for high effluent qualities)



Source: http://www.ion-exchange.com.aa

Removal of dissolved inorganic substances

Precipitation of heavy metals

Principle of precipitation processes:

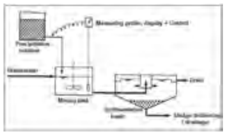
Transformation of dissolved substances by chemical reactions in components with low solubility

→ Hydroxide precipitation: Precipitation of metal ions as hydroxides or basic salts

Solubility product $L = a(Me^{z+}) \cdot a(OH^-)^z << 1$

→ Sulphide precipitation: Precipitation of divalent metal ions as sulfides

Solubility product $L = a(Me^{2+}) \cdot a(S^{2-}) << 1$



Precipitation stage

Removal of dissolved inorganic substances

Oxidation

Principle of oxidation processes:

Release of electrons, increase of the oxidation state

Oxidizing agents in industrial wastewater treatment, applied for instance for the detoxification of cyanide:

- Hydrogen peroxide H_2O_2

$$CN^- + H_2O_2 + H_2O + H^+ \Leftrightarrow NH_4^+ + HCO_3^-$$

- Ozone O_3

$$CN^- + O_3 + 2\,H_2O + H^+ \Leftrightarrow NH_4^+ + O_2 + HCO_3^-$$

- Sodium hypochlorite NaOCl

$$2\,CN^- + 5\,OCl^- + H_2O \Leftrightarrow N_2 + 5\,Cl^- + 2\,HCO_3^-$$

Removal of dissolved inorganic substances

Reduction

Principle of reduction processes:

Uptake of electrons, decrease of the oxidation state

Reducing agents in industrial water and wastewater treatment, applied for instance for the detoxification of chromate:

- Sodium hydrogen sulfite $NaHSO_3$

$$Na_2Cr_2O_7 + 3\,NaHSO_3 + 4\,H_2SO_4 \Leftrightarrow Cr_2(SO_4)_3 + 3\,NaHSO_4 + Na_2SO_4 + 4\,H_2O$$

followed by hydroxide precipitation of $Cr(OH)_3$

- Fe(II) salts, e.g. $FeSO_4$

$$Na_2CrO_4 + 3\,FeSO_4 + 4\,NaOH + 4\,H_2O \Leftrightarrow Cr(OH)_3 + 3\,Fe(OH)_3 + 3\,Na_2SO_4$$

Removal of dissolved inorganic substances

Reverse Osmosis

<u>Operating principle</u>:
similar to Micro- and Ultrafiltration

<u>Characteristic differences</u>:

- separation size 1 - 2 nm (dense membranes)
- operating pressure 10 - 200 bar
- very good removal of ions and large organic molecules
- limited rejection of dissolved gases and small uncharged molecules, e.g. silicic acid

Source:
http://www.ameriwater.com/products

Removal of dissolved inorganic substances

Evaporation

<u>Operating principle</u>:
Separation of wastewater and both dissolved and suspended substances by applying energy in order to transform the water into vapor

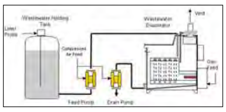
<u>Boundary conditions</u>:

→ high energy demand (ca. 800 kWh/m^3) for single-stage evaporation

→ precipitation of salts, formation of deposits

→ pollution of condensate by volatile compounds

→ corrosion and foam generation



Source:
http://www.wastewaterevaporators.com

Removal of dissolved inorganic substances

Typical applications in industries

Ion exchange:	Regeneration of process solutions in metal-plating companies
	Recovery of noble metals and non-ferrous metals from metal-plating rinsing waters
	Removal of residual heavy metals from wastewater streams after a precipitation stage
Precipitation:	Removal of heavy metals in wastewater from metal-plating industries and from flue gas washing processes
	Removal of fluoride (as CaF_2), sulfate (as $CaSO_4$ or as ettringite), phosphate (as $MePO_4$ with iron and aluminium salts, or as hydroxyl apatite with calcium hydroxide), and ammonium (as struvite) in wastewaters of different origin

Removal of dissolved inorganic substances

Typical applications in industries

Oxidation:	Detoxification of cyanide and nitrite in wastewater streams from metal-plating industries
Reduction:	Detoxification of chromate and nitrite in effluents from metal-plating processes
Reverse Osmosis:	Concentrating wastewater streams from chemical industries, electroplating, and landfills (in Germany)
	Recovery of process water in the semiconductor industry and other sectors
Evaporation:	Recovery of resources from wastewater streams
	Pre-treatment prior to combustion, e.g. in pulp production

Removal of dissolved organic substances

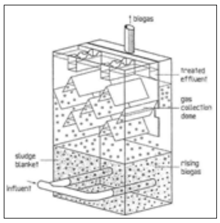
Anaerobic biological treatment

<u>Principle</u>:

- conversion of organic matter to biogas (CH_4, CO_2) that can be utilized
  → gain instead of consumption of energy
- two-stage process:
  1. pre-acidification, 2. methane production
- production of surplus sludge quite small

<u>Operating parameters</u>:

- hydraulic loading: 2 - 30 kg COD / (m^3 · d)
- temperature: 30 - 40°C (mesophilic conditions, preferred operating mode)



Scheme of an UASB-reactor
(Lettinga und Hulshoff Pol, 1991)

Removal of dissolved organic substances

Aerobic biological treatment

<u>Principle</u>:

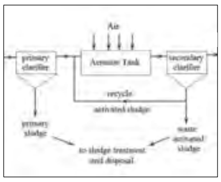
- conversion of organic matter to CO_2, H_2O and biomass; yield up to 50 %
- removal of nitrogen (nitrification/denitrification)

<u>Process realisation</u>:

- (multi-stage) activated sludge systems
- biofilm reactors

<u>Operating parameters</u>:

- sludge loading: < 0.1 - 0.5 kg BOD / (kg MLSS · d)
- hydraulic retention time: 6 - > 24 h



Flow diagram of the activated sludge process

Removal of dissolved organic substances

Application of biological processes in industries

Anaerobic treatment:	Pre-treatment of wastewater with high concentrations of biodegradable organic matter (COD = 1.5 - 40 g/L), e.g. wastewater from food industries, breweries and pulp and paper production
Aerobic treatment:	Removal of biodegradable organic matter from waste-water generated by all kind of industries, in particular by food companies, petrochemical plants, chemical industries, tanneries, textile companies, and paper mills
	Post-treatment of anaerobically treated wastewater in order to remove residual BOD and nutrients (nitrogen, phosphorous)

Removal of dissolved organic substances

Adsorption

Source: http://generalcarbon.com

Principle:
Accumulation of organic substances at the inner surface of a porous solid (adsorbent), most often activated carbon

Process configurations:
- application of powdered material in a three-step batch process that includes a) dosing, b) reaction and c) separation of the adsorbent
- use of granular adsorbent as a filter material in a continuously operated adsorption column

Removal of dissolved organic substances

Oxidation at low temperatures

... with hydrogen peroxide H_2O_2:
Activation by UV-irradiation or addition of Fe(II)-salts (Fenton's reagent) in order to generate OH radicals

$$H_2O_2 + Fe^{2+} \Leftrightarrow {}^\bullet OH + OH^- + Fe^{3+}$$

If iron salts are used, they will precipitate as hydroxides, i.e. management of residuals will be required.

... with ozone O_3:
Combination with UV-irradiation for an increased generation of hydroxyl radicals is advantageous

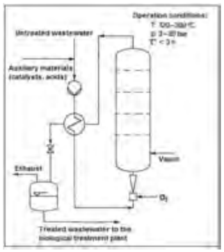
$$O_3 + H_2O \overset{h\cdot v}{\Leftrightarrow} 2\,{}^\bullet OH + O_2$$

Removal of dissolved organic substances

Oxidation at high temperatures

Operating principle of "wet oxidation":
Conversion and partial mineralization of refractory organic substances with air or oxygen

Process schemes:
→ low-pressure oxidation (p = 6 - 10 bar, T = 140 - 180 °C)
→ high-pressure process (p = 20 - 200 bar, T = 250 - 330 °C)
→ oxidation in super-critical water (still under development)



Scheme of the wet oxidation process

Removal of dissolved organic substances

Combustion

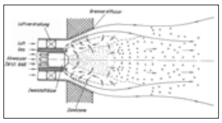
Principle:
Evaporation of water and oxidation of organic substances in a gas burner

Pre-condition:
High concentration of organic material (> 10 % by mass, or COD > 100 g/L)

Estimate of the net calorific value:

$$H_U \text{ [kJ/kg]} = 13 \cdot COD \text{ [g/kg]}$$

Operational challenge:
Handling of slag from salts in the wastewater



Gas burner for wastewater combustion (System BASF)

Removal of dissolved organic substances

Application of physico-chemical processes in industries

Adsorption:	Removal of specific components or total COD, e.g. in chemical or metal-processing industries
Low-temperature oxidation:	Pre-treatment of wastewater with refractory matter (COD concentrations of 0.5 - 5 g/L)
	Removal of chelating agents in wastewater from metal-plating industries
High-temperature oxidation:	Pre-treatment of chemical wastewater with refractory matter (COD content of 5 - 100 g/L)
Combustion:	Disposal of wastewater with very high organic content, e.g. in chemical industries and refineries

Final remarks

1. There are many technologies available to separate or eliminate pollutants from industrial wastewater streams.
2. In Europe, the "Best Available Techniques Reference Documents" (BREFs) define the state-of-the-art, also for water use, in about 30 industries.
3. Together with national laws they ensure that industrial wastewater is usually treated very efficiently.
4. Industrial wastewater treatment can be based on a central biological plant, but it often requires the application of physical-chemical or chemical processes for the (pre-)treatment of separate streams.

Final remarks

5. These processes must be selected and designed by taking all of the specific boundary conditions into account.
6. Therefore standard solutions are not the best option but individual process configurations have to be developed in order to obtain optimal removal efficiencies at reasonable costs.

Future tasks for water management in industries:

- Further reduction of water demand in processes and closing of water cycles where possible (clean technology)
- Refinement of separation techniques for refractory organic pollutants that could have a long-term effect on the environment

Questions

- Why the inclined-plate has higher removal efficiency?
- Why should the inclination angle be limited to 55-60 degree for the the inclined-plate ?
- What is the common oxidant and reductant used in industrial wastewater treatment?
- Describe the principle of three softening technologies.
- Describe the Pros and cons of the anaerobic biological treatment technology.

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Lecture 6: Industrial wastewater

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Learning targets

- Understanding of water quantities and qualities of different industries
- Understanding of wastewater quantities and qualities of different industries
- Environmental, health and legal issues related to industrial water and wastewater

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Contents

– Introduction
– Types of industrial wastewater
– Pollution loads and quantities from typical industries
– Problems associated with various industrial wastewater

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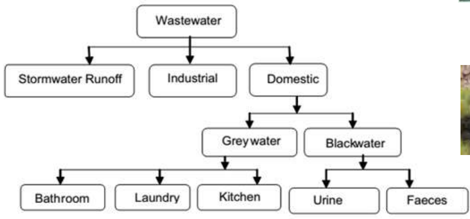
Introduction

- Types of wastewater



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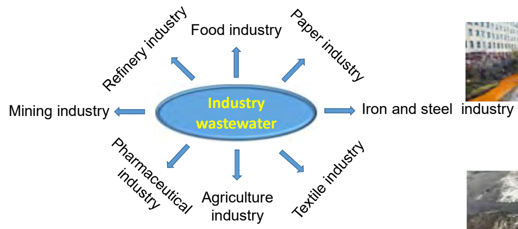
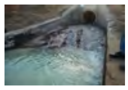
Introduction

- Sources of Industrial wastewater





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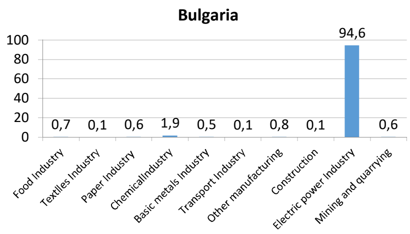
Introduction

- Water usage in industry
  - Share of water consumed in different industry (%)



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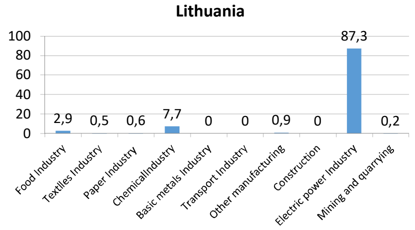

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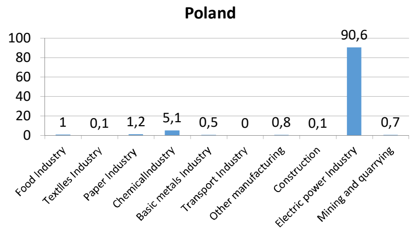

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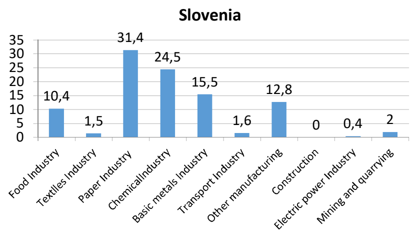

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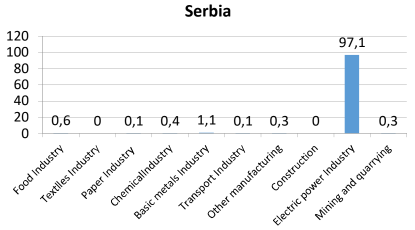
Introduction

- Water usage in industry
  - Share of water consumed in different industry (%)



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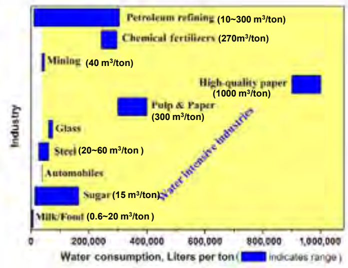
Introduction

- Water usage in industry
  - ➢ Water consumption of per ton product in water-intensive industry



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Introduction

- Characteristics of wastewater
  - ➢ Physical characteristics
    - – Electrical Conductivity (EC)
      - Indicates the salt content
    - – Total solids (TS)
      - Mass remain after evaporation at 103-105℃

Introduction

- Characteristics of wastewater
  - Physical characteristics
    - Total Dissolved Solids (TDS)
      - Comprise inorganic salts and small amounts of organic matter dissolved in water
    - Suspended solids (SS)
      - Comprises solid particles suspended (but not dissolved)in water

Introduction

- Characteristics of wastewater
  - Chemical characteristics
    - Biochemical oxygen demand (BOD)
      - Indicates the amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water in a defined time period.

Introduction

- Characteristics of wastewater
  - Chemical characteristics
    - Chemical oxygen demand (COD)
      - Indicates the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.

Introduction

- Characteristics of wastewater
  - Chemical characteristics
    - Total Organic Compound (TOC)
    - NH_4-N and NO_3-N
      - Show dissolved nitrogen.
    - Total Kjeldhal Nitrogen
      - A measurement of organically-bound ammonia nitrogen.
    - Total-P
      - Reflects the amount of all forms of phosphorous in a sample.

Introduction

- Characteristics of Industrial wastewater
  - Vary from industry to industry, vary from process to process.
  - Have too high quality of suspended solids, dissolved organics and inorganic solids, BOD, alkalinity or acidity
  - Cannot always be treated easily by the normal method of treating domestic wastewater

Types of industrial wastewater

- Inorganic industrial wastewater
- Organic industrial wastewater.

Types of industrial wastewater

- Inorganic industrial wastewater
  - Is produced mainly in the coal and steel industry, in the nonmetallic minerals industry, and in commercial enterprises and industries for the surface processing of metals.
  - Contain a large proportion of suspended matter, which can be eliminated by sedimentation.

Types of industrial wastewater

- Organic industrial wastewater
  - Is produced mainly in chemical industries and large-scale chemical works, which mainly use organic substances for chemical reactions.
  - Contain organic substances having various origins and properties.
  - Can only be removed by special pretreatment of the wastewater, followed by biological treatment.

Pollution loads and quantities from typical industries

- Important pollutants in industrial wastewater
  - Suspended solids
    - Lead to the development of sludge deposits and anaerobic conditions.
  - Organic Substances
    - Deplete DO of stream and impose great load on secondary treatment unit.

Pollution loads and quantities from typical industries

- Important pollutants in industrial wastewater
  - Inorganic substances
    - Cause eutrophication of water bodies, increase dissolved solids content and be harmful to aquatic life.
  - Acids and alkalies
    - Affect the aquatic life of receiving water body and cause serious problem in operation of treatment units.

Pollution loads and quantities from typical industries

- Important pollutants in industrial wastewater
  - Toxic Substances
    - Cause problems in the biological treatments.
  - Color producing substances
    - Impart objectionable color in the receiving water bodies
  - Oils
    - Hinder self purification and cause problem in oxygen diffusion

Pollution loads and quantities from typical industries

- Water Pollutants in the Industrial Sector

Sector	Pollutants
Iron and steel	BOD, COD, oil, metals, acids, phenols, and cyanide
Textiles and leather	BOD, solids, sulfates and chromium
Pulp and paper	BOD, COD, solids, Chlorinated organic compounds
Petrochemicals and refineries	BOD, COD, oils, , phenols, and chromium
Chemicals	COD, organic chemicals, heavy metals, SS, and cyanide
Non-ferrous metals	Fluorine and SS
Microelectronics	COD, and organic chemicals
Mining	SS, metals, acids and salts

Pollution loads and quantities from typical industries

- Food industry
  - Freshwater consumption in beverage and food industries.

Food industry	Water consumption (%)
Meat processing	24
Beverages	13
Dairy	12
Fruits and vegetables	10
Bakery and tortilla products	9
Grain and oilseeds	9

(Bustillo-Lecompte, C.F.2015.)

Pollution loads and quantities from typical industries

- Food industry
  - Freshwater consumption in beverage and food industries.

Food industry	Water consumption (%)
Sugar and confectionary	5
Animal food	5
Seafood	2
Other food	11

(Bustillo-Lecompte, C.F. 2015.)

Pollution loads and quantities from typical industries

- Food industry
  - Typical pollution loads of slaughterhouse wastewater

Parameter	pH	BOD $mg \cdot L^{-1}$	COD $mg \cdot L^{-1}$	TN $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$	TP $mg \cdot L^{-1}$
Range	4.9-8.1	150-4635	500-15900	50-841	270-6400	25-200
Mean	6.95	1209	4221	427	1164	50

(Bustillo-Lecompte, C.F.2015.)

Pollution loads and quantities from typical industries

- Food industry
  - Typical pollution loads of diary industry wastewater

Wastewater source	pH	COD $mg \cdot L^{-1}$	BOD $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$	Total N $mg \cdot L^{-1}$	Total P $mg \cdot L^{-1}$
Creamery	8-11	2000-6000	1200-4000	350-1000	50-60	--
Mixed dairy	3.35-11	1150-63100	--	304-12500	14-272	8-68
Cheese whey	--	61000-68814[a]	--	1780[a]	980-1462[a]	379-510[a]
Cheese	4.7-9.5	1000-7500	588-500	500-2500	830[a]	280[a]
Fluid Milk	5.0-9.5	950-2400	500-1300	90-450	--	--
Milk powder/butter	5.8	2.0[a]	--	--	--	--

[a]Mean concentrations

(Demirel, B.,2005 .)

Pollution loads and quantities from typical industries

- Food industry
  - Typical pollution loads of brewery wastewater

pH	COD $mg \cdot L^{-1}$	BOD $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$	Total N $mg \cdot L^{-1}$	Total P $mg \cdot L^{-1}$
4.5-12	2000-6000	1200-3600	200-1000	25-80	10-50

(Jaiyeola, A.T.2016 .)

Pollution loads and quantities from typical industries

- Oil industry
  - Typical pollution loads of oil/gas field wastewater

Wastewater source	pH	COD $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$	Total oil $mg \cdot L^{-1}$	Chloride $mg \cdot L^{-1}$	Sulfate $mg \cdot L^{-1}$	Calcium $mg \cdot L^{-1}$	Magnesium $mg \cdot L^{-1}$
Oil field	4-10	0-1200	1-1000	2-565	80-2000000	2-1650	13–25,800	8–6000
Gas field	3-7	2600-120000	8-5484	--	1400-190000	<0.1-47	<51300	0.9–4300

(Munirasu, S.2016.)

Pollution loads and quantities from typical industries

- Oil industry
  - Typical pollution loads of oil/gas field wastewater

Wastewater source	Iron $mg \cdot L^{-1}$	Aluminum $mg \cdot L^{-1}$	Boron $mg \cdot L^{-1}$	Barium $mg \cdot L^{-1}$	Lithium $mg \cdot L^{-1}$	Lead $mg \cdot L^{-1}$	Arsenic $mg \cdot L^{-1}$	Mercury $mg \cdot L^{-1}$
Oil field	<0.1–100	310–410	5-95	1.3–650	3–50	0.002–8.8	<0	<0.002
Gas field	<1100	<0.5–83	<56	<1–1740	18.6–235	<0.2–10	<151	--

(Munirasu, S.,2016 .)

Pollution loads and quantities from typical industries

- Oil industry
  - Typical pollution loads of oil/gas field wastewater

Wastewater source	Cadmium $mg \cdot L^{-1}$	Chromium $mg \cdot L^{-1}$	Copper $mg \cdot L^{-1}$	Manganese $mg \cdot L^{-1}$	Strontium $mg \cdot L^{-1}$	Zinc $mg \cdot L^{-1}$
Oil field	<0.005–0	0.02–1.	<0.002–105	<0.004–175	0.02–1000	0.01–35
Gas field	<0.02–1.2	<0.03	<5	<63	<6200	<0.02–5

(Munirasu, S.,2016 .)

Pollution loads and quantities from typical industries

- Oil industry
  - Typical pollution loads of oil refinery wastewater

Wastewater source	COD $mg \cdot L^{-1}$	SS $mg \cdot L^{-1}$	Phenols $mg \cdot L^{-1}$	Benzene $mg \cdot L^{-1}$	Sulphides $mg \cdot L^{-1}$	Ammonia $mg \cdot L^{-1}$
Desalter	400–1000	<500	10-100	5-15	<100	<100
Sour water	600–1200	<10	<200	0	<10	<100
Tank bottom	400–1000	<500	--	--	<100	--
Cooling tower	<150	<200	--	--	--	--

(Munirasu, S.,2016.)

Pollution loads and quantities from typical industries

- Pulp and paper (P&P) industry
  - Major pollutants released from P&P making process

Processes	
Raw material preparation	Suspended solids including bark particles, fiber pigments, dirt, grit, BOD, and COD.
Pulping	Color, bark particles, soluble wood materials, resin acids, fatty acids, AOX, VOCs, BOD, COD, and dissolved inorganics.
Bleaching	Dissolved lignin, color, COD, carbohydrate, inorganic chlorines, AOX, EOX, VOCs, chlorophenols, and halogenated hydrocarbons.
Paper-making	Particulate wastes, organic and inorganic compounds, COD, and BOD.

(Kamali, M.2014 .)

Pollution loads and quantities from typical industries

- Pulp and paper industry
  - Typical pollution loads of pulp and paper industry wastewater

Unit operations	pH	COD $mg \cdot L^{-1}$	BOD_5 $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$
Wood yard and chipping	7	1275	556	7150
Thermo-mechanical pulping	4.0–4.2	3343–4250	_	330-510
Chemical thermo-mechanical pulping	7.43	7521	3000	350
Kraft cooking section	13.5	1669.7	460	40
Pulping process operations	5.5	9065	2440	1309

(Kamali, M.2014 .)

Pollution loads and quantities from typical industries

- Pulp and paper industry
  - Typical pollution loads of pulp and paper industry wastewater

Unit operations	pH	COD $mg \cdot L^{-1}$	BOD_5 $mg \cdot L^{-1}$	TSS $mg \cdot L^{-1}$
Paper machine	6.5	1116	64	645
Integrated pulp and paper mill	6.5	3791	1197	1241
Recycled paper mill	6.2–7.8	3380–4930	1650–2565	1900-3138

(Kamali, M. 2014.)

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Pollution loads and quantities from typical industries

- Textile wastewater
  - The textile industry's main concern is the quantity of effluent generated and the high chemical load it contains. The most significant environmental impacts are caused by: salts, detergents and organic acids.

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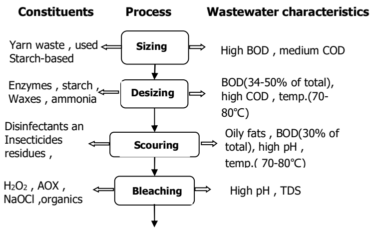
Pollution loads and quantities from typical industries

- Textile wastewater
  - Major pollutants involved at various stages of a textile manufacturing



(Sarayu, K. 2012and .)

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Pollution loads and quantities from typical industries

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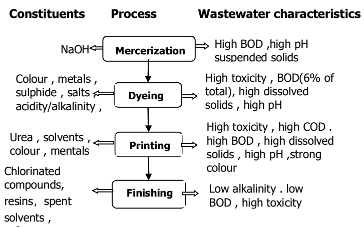

(Sarayu, K. 2012and .)

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Pollution loads and quantities from typical industries

- Textile wastewater
  - Typical pollution loads of textile wastewater

Industries	pH	COD mg·L^{-1}	BOD$_5$ mg·L^{-1}	TSS mg·L^{-1}	Chloride mg·L^{-1}	Sulfate mg·L^{-1}	Phenol mg·L^{-1}	Oil and grease mg·L^{-1}
Composites industries	5.5-11.0	600-1400	350-600	300-500	700-1200	300-700	0.5-2.0	5-15
Processing industries	7.0-8.5	470-900	230-450	300-500	300-900	200-1000	0.5-2.0	5-10
Woolen industries	7.0-11.0	220-700	160-350	160-380	-	-	-	-

(Sarayu, K.2012.)

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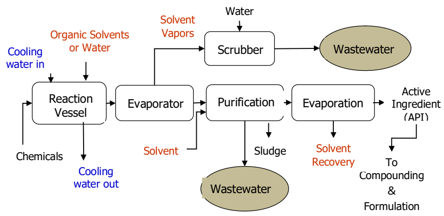
Pollution loads and quantities from typical industries

- Pharmaceutical Industry
  - Pharmaceutical Manufacturing Processes
    - Chemical Synthesis Process



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Pollution loads and quantities from typical industries

- Pharmaceutical Industry
  - Pharmaceutical Manufacturing Processes
    - Fermentation Process
      - A biochemical process involving the use of Baker's yeast, lactic acid bacillus, bacillus sp., and various other microorganisms to produce a chemical product.

Pollution loads and quantities from typical industries

- Pharmaceutical Industry
  - Typical pollution loads of pharmaceutical industry wastewater

Processes	pH	COD mg·L^{-1}	BOD_5 mg·L^{-1}	TKN mg·L^{-1}	NH_4-N mg·L^{-1}	TDS mg·L^{-1}	Chloride mg·L^{-1}	Sulfate mg·L^{-1}
Chemical processes	3.9-9.2	375–32500	200–6000	165–770	148–363	675–9320	760–4200	890–1500
Fermentation processes	3.3–11	180–12380	25–6000	190–760	65.5–190	1300–28000	182–2800	160–9000

Problems associated with various industrial wastewater

- Industrial wastewater pollution
  - Use of outdated technologies
    - Some industries still rely on old technologies to produce products that generate large amount of wastewater.
  - Presence of large number of small scale industries
    - Many small scale industries and factories often escape environment regulations and discharge wastewater without inefficacy.

Problems associated with various industrial wastewater

- Industrial wastewater pollution
  - Unplanned industrial growth
    - In most industrial townships, unplanned growth took place wherein those companies do not provide proper waste disposal sites and disregard for pollution control rules and norms, which lead to water pollution.

Problems associated with various industrial wastewater

- Industrial wastewater pollution
  - Lack of strict policies
    - Lack of effective policies and poor enforcement drive, resulted in mass scale pollution that affected lives of many people.
  - Inefficiency wastewater treatment
    - Not treated adequately before discharging it into rivers or lakes.

Problems associated with various industrial wastewater

- Difficulty to treat industrial wastewater
  - Vary characteristics
    - Characteristics of industrial wastewater highly varied from different process. And the pollutants is complex.
  - Poor management
  - Lack of investment
    - Some enterprises do not invest enough to maintain the long-term stable operation.

Problems associated with various industrial wastewater

- Design of industrial wastewater treatment processes
  - Developing the most suitable treatment processes.
  - The water allocation in order to minimize the treatment cost
  - Optimization of the wastewater treatment by enough experimental data and evaluation of the performance of the wastewater treatment units.

Questions

- What is the industrial wastewater?
- What are the types of industrial wastewater?
- What are the problems associated with various industrial wastewater?

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Thank you for your attention!

Wastewater management strategies

Learning targets

- Understanding of the principle of polluter-pays
- Understanding of the principle of cleaner production
- Understanding of the principle of end-of-pipe technology

Contents

- Polluter-Pays Principle
- Cleaner production versus end-of-pipe
- Principles of cleaner production
- Principles of end-of-pipe technology
- Discharge options

Polluter-Pays Principle

- Polluter-Pays Principle was first proposed in 1972 by the Organization for Economic Cooperation and Development (OECD).
- Polluter-Pays Principle is an environmental policy principle, which requires the costs of pollution prevention, control and reduction measures be borne by polluter to prevent damage to the environment.

Polluter-Pays Principle

- All Industrial Users proposing to connect to or discharge nondomestic wastewater to the Authority treatment works shall first obtain a Wastewater Discharge Permit issued by the Authority.

Polluter-Pays Principle

- How much must the polluters pay?
  - Base Fee:
    - This fee is based on permit type: Categorical Industrial User, Significant Industrial User, Non-Significant Industrial User, or Non-Discharging Categorical Industrial User.
  - Compliance monitoring costs:
    - These are the actual costs for Environmental Services staff to sample and analyze an industrial user's wastewater for permit compliance.

Polluter-Pays Principle

- How much must the polluters pay?
  - Enforcement costs:
    - This fee will be based on environmental services' costs to administer each enforcement action.
  - Additional fee (if applicable):
    - For categorical and significant industrial users, which discharge a large amount of wastewater to the publicly owned treatment works, have the ability to discharge toxic pollutants, or are found by the county, state or environmental protection agency to have a significant impact on the treatment plant, either alone or in combination with other contributing users.

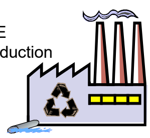
Polluter-Pays Principle

- Limitations of Polluter-Pays Principle
  - Polluter-Pays Principle has typically not been fully implemented in national and international laws and programs. For example, drinking water and sewage treatment services are subsidized and there are limited mechanisms in place to fully assess polluters for treatment costs.

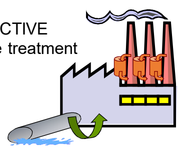
Cleaner Production versus end-of-pipe

- Many years ago, smart environmentalists already recognized two entirely different ways of handling problems associated with pollution and resource conserving.

PROACTIVE
Cleaner Production
1



CONSTRUCTIVE
End-of-pipe treatment
2

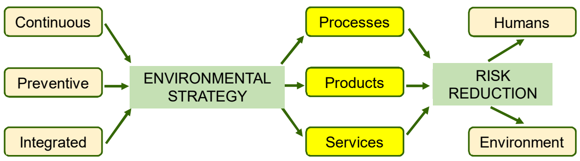


Cleaner Production vs end-of-pipe

- Cleaner Production
  - " Cleaner Production" is the pollution source reduction methods and places emphasis on pollution prevention rather than control. It is continuous application of an integrated, preventive environmental strategy towards processes, products and services in order to increase overall efficiency and reduce damage and risks for humans and the environment."

Cleaner Production vs end-of-pipe

- Cleaner Production



Cleaner Production vs end-of-pipe

- Cleaner Production
  - It applies to:
    - Production processes: conserving raw materials and energy, eliminating toxic raw materials and reducing the quantity and toxicity of all emissions and wastes.
    - Products: reducing negative impacts along the life cycle of a product.
    - Services: incorporating environmental concerns into designing and delivering services.

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Cleaner Production versus end-of-pipe

- Benefits of Cleaner Production
  - Reduce operating costs---connected with waste treatment, storage, and disposal. And material, energy and facility cleanup costs can also be reduced through cleaner production strategies.
  - Improve a company's image
  - Reduce ecological damage--- from raw material extraction and refining operations during the production, recycling, treatment and disposal operations.
  - Reduce the risk of civil and criminal liability

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Cleaner Production versus end-of-pipe

- End-of-pipe treatment
  - End-of-pipe treatment is pollution control methods used to remove already formed contaminants from a stream of air, water, waste, product or similar. These techniques are called 'end-of-pipe' as they are normally implemented as a last stage of a process before the stream is disposed of or delivered.

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Cleaner Production versus end-of-pipe

- Cleaner production versus end-of-pipe

Cleaner production	End of pipe technology
Continuous improvement	One-off solutions to individual problems
Where do waste and emissions come from?	How can we treat existing waste and emissions?
Progress towards use of closed loop or continuous cycle processes	Processes result in waste materials for disposal a pipeline with resources in and wastes out
Active anticipation and avoidance of pollution and waste	Reactive responses to pollution and waste after they are created
Elimination of environmental problems at their source	Pollutants are controlled by waste treatment equipment and methods

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Cleaner Production versus end-of-pipe

- Cleaner production versus end-of-pipe

Cleaner production	End of pipe technology
Environmental protection comes in as an integral part of product design and process engineering	Environmental protection comes in after products and processes have been developed
Environmental problems are tackled at all levels / in all fields	Environmental problems are solved from a technological point of view
Involves new practices, attitudes and management techniques and stimulates technical advances techniques for a more sustained development	Relies mainly on technical improvements to existing technologies
Everyone in the community has a role to play; partnerships are essential	Solutions are developed by experts often in isolation

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Principles of cleaner technology

- Input-Substitution
- Good Housekeeping
- Internal Recycling
- Technological Optimization/Change
- Optimization of the Product

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Principles of cleaner technology

- Input-Substitution
  - Use of less hazardous raw-, auxiliary- or operating materials
  - Use of operating materials with a longer life-time
  - Use of renewable materials
  - Material purification
- Good Housekeeping
  - Increasing the Material and Energy efficiency
  - Reducing losses due to leakage
  - Training of employees
  - Production scheduling
  - Working instructions and procedures
  - Proper maintenance and cleaning
  - Adequate process control operations

Principles of cleaner technology

- Internal Recycling
  - Closing of Material and Energy Loops (Water, Solvents,…)
  - Cascading of Material and Energy streams
- Technological Optimization/Change
  - Implementation of new technologies
  - Improved process control
  - Optimal process conditions
  - Redesign of processes
  - Equipment modification or improved equipment lay-out
  - Increased automation
  - Change in substitution of hazardous processes

Principles of cleaner technology

- Optimization of the Product
  - Increasing the life-time
  - Easier repairing
  - Easier demanufacturing , recycling or deposition
  - Reduction of harmful substances
  - More efficient, less material intensive packaging

Principles of end-of-pipe technology

- Centralized wastewater systems
  - Centralized wastewater systems are the most widely applied in well-developed urban environments and the oldest approach to the solution of the problems associated with wastewater. They collect wastewater in large and bulk pipeline networks and convey it at long distances to a single, large treatment system.

Principles of end-of-pipe technology

- Benefits of centralized wastewater systems
  - The wastewater treatment community assumes the responsibility for maintenance. For Industries, it is out-of-sight and out-of-mind. Industries do not have to check pipes;
  - The wastewater treatment community assumes the responsibility for liability caused by environmental mishaps;
  - Industries know approximately each month what their costs for wastewater treatment will be, and can budget for costs.

Principles of end-of-pipe technology

- Decentralized wastewater systems
  - Decentralized wastewater systems treat and dispose or reuse small volumes of industrial wastewater, generally originating from small communities, buildings and dwellings, individual or private properties, which are located relatively close to its source of generation.
- Benefits of decentralized wastewater systems
  - May be the most cost-effective treatment strategy for rural communities with sparse populations;
  - Is appropriate for varying site conditions including ecologically sensitive areas—treatment methods can be tailored to suit different site conditions.

Principles of end-of-pipe technology

- Benefits of decentralized wastewater systems
  - Saves money by deciding on a preventive strategy (such as assessing a industry's needs and conditions) to manage wastewater before a crisis occurs, thereby avoiding unnecessary cost;
  - Enables better watershed maintenance by eliminating the large transfers of water from one watershed to another that happens with centralized treatment;

Principles of end-of-pipe technology

- Centralized versus decentralized wastewater systems
  - The main difference between decentralized and centralized systems is in the conveyance structure. In decentralized systems the treatment and disposal or reuse of the effluent is close to the source of generation. This results in a small conveyance network, in some cases limited only to one pipeline.

Discharge options

- Direct discharge
  - Direct discharge to surface waters:
    - Such as a river, lake, ocean, estuaries or wetlands, without treatment. This includes through a storm sewer system that enters water body, a ditch or other conveyance. Industries wastewater which is less polluted than the expected effluent of the sewer wastewater treatment plants should be discharged into the waters directly.
  - Direct discharge to land that enters groundwater:
    - This involves spreading the wastewater over the surface of the ground, generally by irrigation ditches.

Discharge options

- Indirect discharge
  - Treated discharge to the waters
  - Untreated discharge to sewer system
  - Pre-treated discharge to sewer system

Discharge options

- Treated discharge to the waters
  - Industries discharge their wastewater into the waters via their own wastewater treatment plants, where specific demands (relate to harmful substances, such as heavy metals , mineral oil , chlorinated hydrocarbons , cyanides, complexion agents.) is reduced.
  - The content of industrial effluents varies from one industry to another, and therefore requires varying treatment.

Discharge options

- Treated discharge to the waters
  - Technology Description
    - Separate treatment:
      - For the purpose of separating materials that require special treatment. This is important when the wastewater contains high concentrations of BOD, COD, H_2S, NH_4 or poisonous materials.
    - Preliminary treatment:
      - It includes (1) grit removal in some cases (iron and steel foundries, rainwater and sandpits), (2) oil removal for hydrocarbons and oils, and (3) equalization of liquid flow and pollutant load.

Discharge options

- Treated discharge to the waters
  - Technology Description
    - Physical-chemical treatment:
      - An intermediate or final stage, includes settling of poisonous minerals or salts, removal of oils in emulsions, and other suspended substances, clarification and dilution of colloidal BOD and COD concentrations, floatation units for oil and fiber removal.
      - The physical-chemical treatment is preceded, or followed, by other methods, such as electric neutralization, oxidation or reduction and degassing or stripping
    - Biological treatment:
      - The biological purification process is considered on of the best methods for reducing BOD and COD resulting from decayed organic compounds of different types (solvents, aromatic materials, hydrocarbons)

Discharge options

- Untreated discharge to sewer system
  - Non-hazardous industrial wastewater is discharged to the nearest municipal sewer system (or municipal wastewater treatment plant
  - Some industries must first obtain an Industrial Wastewater Discharge Permit to discharge to a municipal sewer system. The industry wastewater meets local sewer authority standards and requirements.

Discharge options

- Untreated discharge to sewer system
  - A register of all relevant industrial polluters is the basic condition for an efficient supervision and monitoring of industrial wastewater discharges.
    - This register should contain the general data, branch of industry, daily working hours, shift system, material used, intermediate products, wastes, water consumption, general situation of sewerage, internal wastewater treatment, storage of ecologically harmful substances

Discharge options

- Untreated discharge to sewer system
  - Danger potential of industrial polluters for the sewer system:
    - Sewerage
      - Hydraulic, solid substances, grease and fat, explosive hydrocarbons
    - Wastewater treatment and sludge disposal
      - C/N/P-relation, grease and fat, mineral oil, heavy metals, AOX, biocides
    - Health protection and safety
      - Temperature, pH-value, H_2S, mineral oil, cyanide, benzoyl, phenol

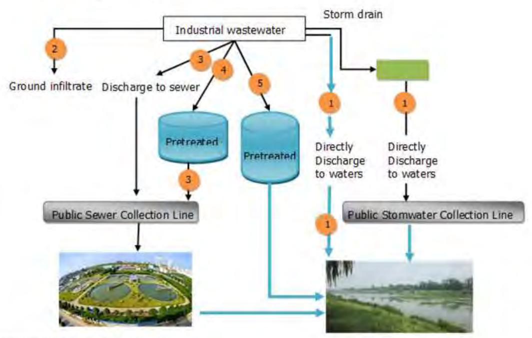
Discharge options

- Untreated discharge to sewer system
  - Danger potential of industrial polluters for the sewer system:
    - Constructions in sewerage and sewage treatment plants
      - Temperature, pH-value, H_2S, sulphate, ammonia
    - Environment of the municipal sewerage
      - Status of sewerage, utilization of sewer system, development, odor
    - Local conditions
      - Storage of dangerous substances, risk of accident

Discharge options

- Pre-treated discharge to sewer system
  - Prevent interference with the performance of sewer system
  - Prevent the introduction of pollutants that could pass through sewer system untreated and into the receiving body of water;
  - Prevent the introduction of pollutants that could cause health or safety problems to the public or the environment;
  - Improve opportunities for reusing or recycling wastewater and sludge.

Discharge options



Questions

- what is the polluter-pays principle?
- What is the cleaner production?
- What is the end-of-pipe?
- What is the discharge options?

THANKS FOR YOUR ATTENTION !

Biological wastewater treatment

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Learning targets

- Understanding of the conversion process of different pollutant in bacterial cell
- Understanding the degradation process of organic compounds, nitrogen and phosphorous
- Understanding the mechanism of anaerobic technology
- Grasp the principle of UASB

Content

1.Introduction

- Why biological treatment
  - Reduce BOD
  - Reduce SS
  - Oxidize ammonia, remove nitrogen and phosphorous
  - Oxidize sulphide
  - Remove possibly harmful organics
  - Substances which have negative impact on water quality have to be converted by simple biological processes into harmless substances.
- What is biological treatment
  - Treatment of the wastewater with adapted biomass

Biodegradability

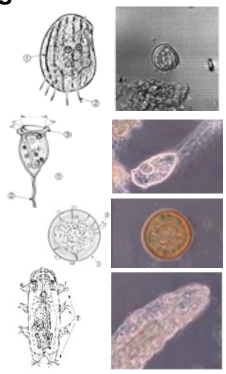
- BOD/COD ratio:
  - 0.4-0.7: readily biodegradable
  - Below 0.4: slowly biodegradable
  - -zero: not biodegradable
- Most organic compounds are biodegradable, but:
  - Several compounds needs special adapted biomass
  - Some compounds are toxic above certain levels

Main objective of biological wastewater treatment

- Substances which have negative impact on water quality have to be converted by simple biological processes into harmless substances:
  - Gases: N_2, CO_2, CH_4
  - Soluble substances: H_2O, NO_3^-, HCO_3^-
  - Solids: Biomass, flocs

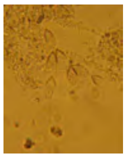
Microorganismn aerobic degradation

- **Protozoa**
  - **Ciliates**
    unicellular organism
    free swimming organism
    robust, grazing of flocs
  - **Vorticella convalaria**
    good oxygen supply
  - **Mastigophorans**
    flagellates for locomotion
  - **Rotifer**
    multicellular organism
    high generation time and sludge age



Flagellates

Small



Bicoeca petiolata

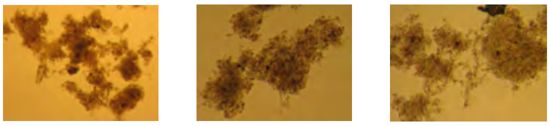
Anisonema acinus

Large

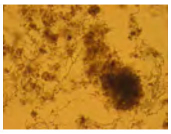
Peranema pleururum

Peranema trichophorum

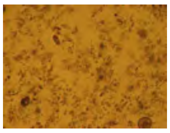
Characteristics of activated sludge



Compact flocs of activated sludge



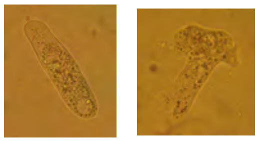
Activated sludge in conditions of filamentous swelling

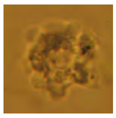


Activated sludge in conditions of gel swelling

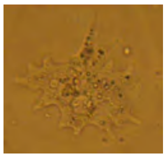
Naked amoeba

Astromoeba radiosa





Amoeba papillata



Amoeba proteus

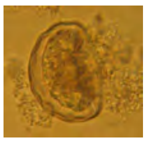
Thecamoeba sp.

Step-by-step change of populations during biocenosis development of activated sludge

Dispersed bacteria
⇩
Filamentous forms of bacteria
⇩
Zoogloeas accumulations
⇩
Colorless flagellates
⇩
Small naked amoebae
⇩
Small testate amoebae
⇩
Large testate amoebae
⇩

⇩
Free floating ciliates
⇩
Hypotrichida ciliates
⇩
Rotifer
⇩
Nematode
⇩
Fastened ciliates
⇩
Oligochaeta and gastrotrich worms
⇩
Suctoria ciliates and another hunters (water bears, rotifers, fungi)

Testate amoebae



Arcella gibbosa

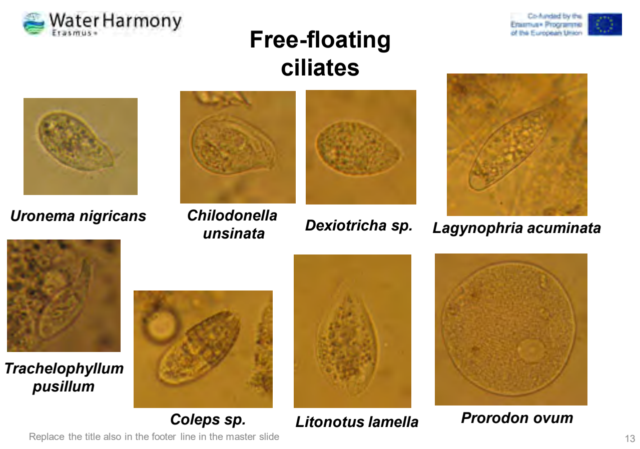
Centropyxis aculeata

Trinema enchelys

Arcella vulgaris

Centropyxis sp.

Euglypha sp.


Water Harmony
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Free-floating ciliates
Uronema nigricans
Chilodonella unsinata
Dexiotricha sp.
Lagynophria acuminata
Trachelophyllum pusillum
Coleps sp.
Litonotus lamella
Prorodon ovum
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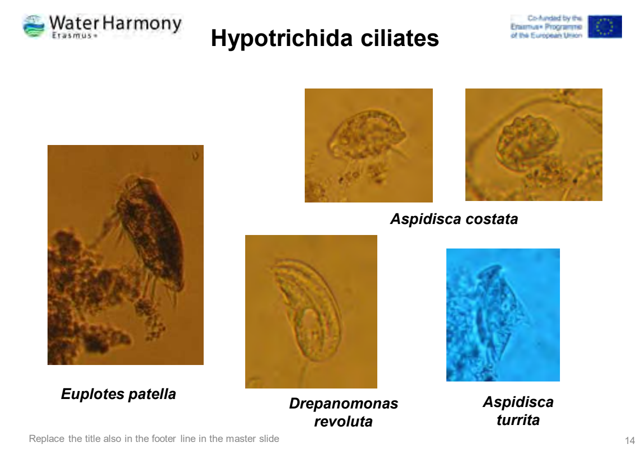
13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Hypotrichida ciliates
Euplotes patella
Aspidisca costata
Drepanomonas revoluta
Aspidisca turrita
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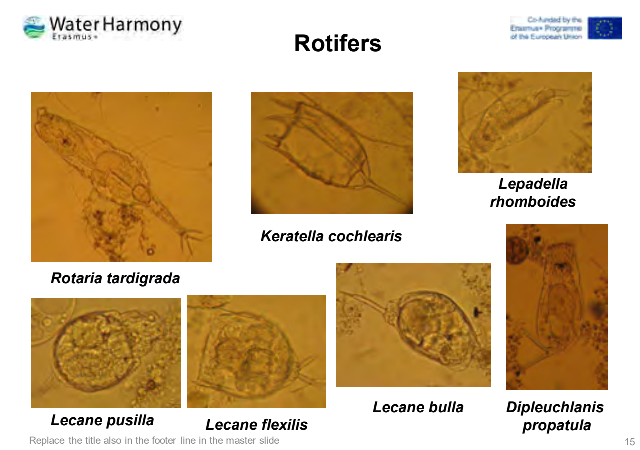
14


Water Harmony
Erasmus+
Co-funded by the Erasmus+ Programme of the European Union
Rotifers
Rotaria tardigrada
Keratella cochlearis
Lepadella rhomboides
Lecane pusilla
Lecane flexilis
Lecane bulla
Dipleuchlanis propatula
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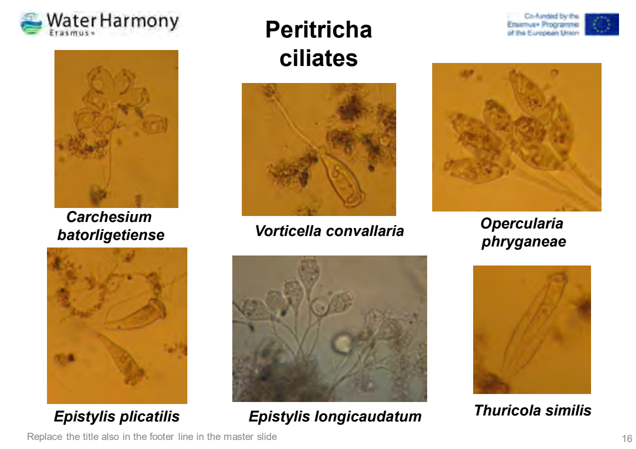
15


Water Harmony
Erasmus+
Co-funded by the Erasmus+ Programme of the European Union
Peritricha ciliates
Carchesium batorligetiense
Vorticella convallaria
Opercularia phryganeae
Epistylis plicatilis
Epistylis longicaudatum
Thuricola similis
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16


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Suctoria ciliates
Staurophria elegans
Rhabdophrya sp.
Acineta foetida
Tokophrya quadripartita
Acineta sp.
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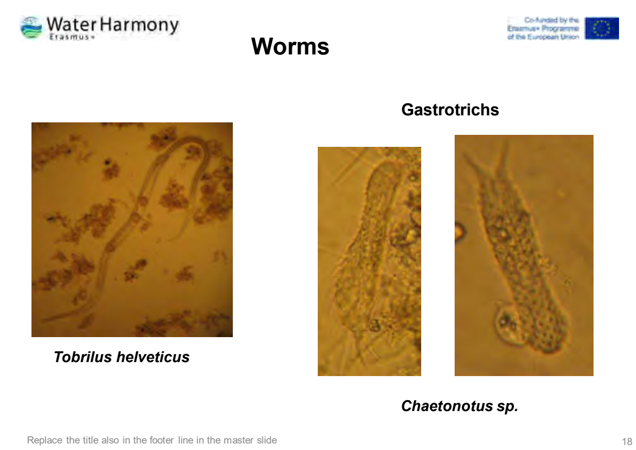
Water Harmony
Erasmus+
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Worms
Gastrotrichs
Tobrilus helveticus
Chaetonotus sp.
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18

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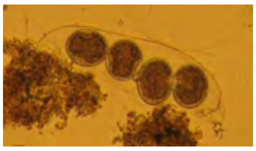
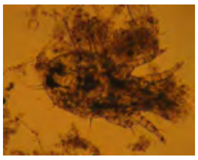
Water bears

Water mites





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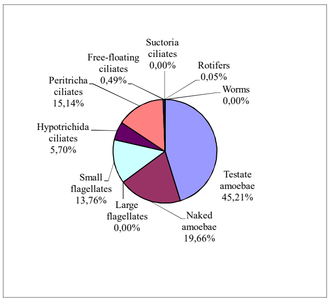
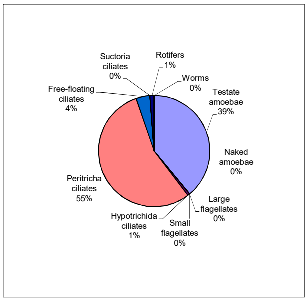
Examples of organisms distribution of activated sludge by main indication groups





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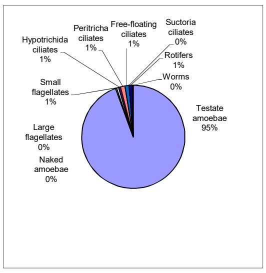
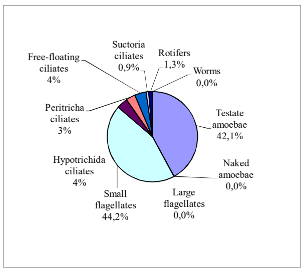
Examples of organisms distribution of activated sludge by main indication groups





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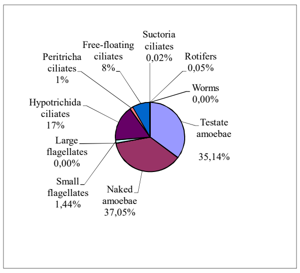
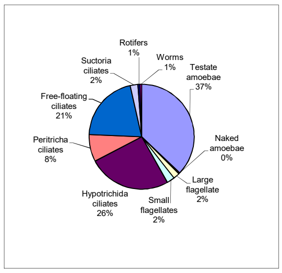
Examples of organisms distribution of activated sludge by main indication groups





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The stages of removal of contaminants from sewage

Diffusion of contaminations from the liquid phase and sorption them on the surface of activated sludge flakes

Delivery of substances into the cells (diffusion, active transport, phagocytosis, the splitting of macromolecules by exoenzymes, sorption of solid particles)

Catabolism (splitting) of pollutants to simple connections

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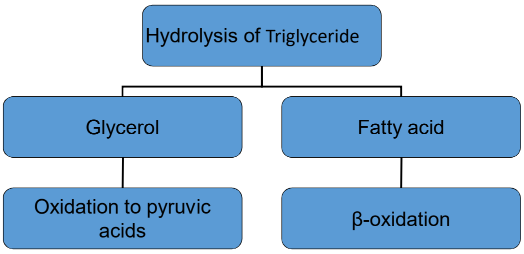
Catabolism of carbohydrates

Monosaccharides	**Most of microorganisms**
Starch	**Fungus and bacteria, having amylase**
Cellulose and hemicellulose	**Bacteria: *Cytophaga*, *Sporocytophaga*, *Sorangium*, *Cellulomonas*, myxobacteria and others. Fungus: fungus *Trichoderma viride*, *Aspergillus niger*, *Fusarium spp.***
Pectin substances	***Bacillus polymyxa*, *Clostridium felsineum* and other.**

Catabolism of Triglyceride

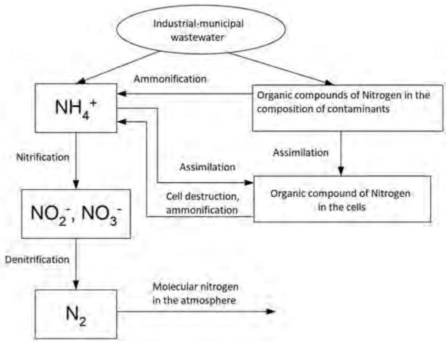


Pseudomonas fluorescens, Bacillus fluorescens, Pseudomonas liguefaciens, Achromobacter lipolyticum, **other bacteria and fungi**

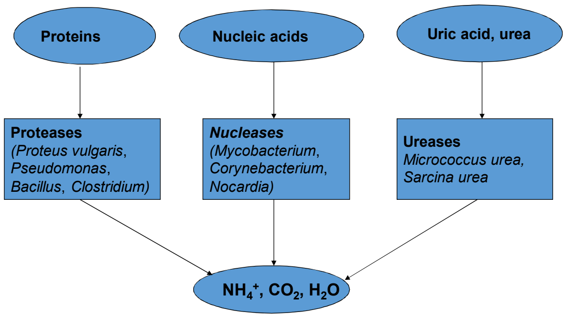
Catabolism of hydrocarbons

Methane	***Methylomonas, Methylobacter, Methylococcus***
Ethane, propane, etc.	***Pseudomonas, Acinetobacter, Arthrobacter, Mycobacterium, Micrococcus,*** **yeast of the genus Candida**
Aromatic hydrocarbons	***Pseudomonas, Mycobacterium, Bacillus, Flavobacterium, Nocardia, Aspergillus, Penicillium*** **and other.**
Lignin	***Consortium of microorganisms***

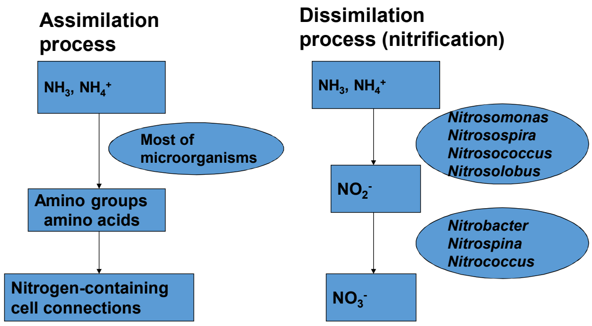
Conversation of Nitrogen compounds



Putrefaction



Consumption of reduced nitrogen compounds

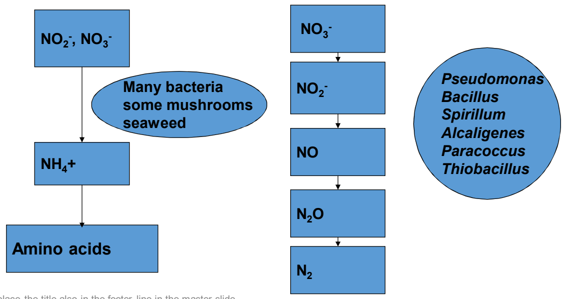


Influencing factor

- 1. temperature
- 5℃ ~ 15 ℃ ~ 30 ℃ ~ 35 ℃
- almost stop slow optimal
- 2. DO
- DO > 2 mg/L
- 3. Alkalinity
- pH: 8.0 ~ 8.4
- 4. sludge age
- SRT>10d

Nitrate reduction

Assimilation process | **Dissimilation process (denitrification)**



Denitrification

- $NO_3^- \xrightarrow[denitrifying\ bacterial]{} N_2$

- Heterotrophic bacterial
- Electron acceptor: NO_3^-
- low DO condition

Overall reaction:

$$CH_3OH + NO_3^- + H_2CO_3 \rightarrow C_5H_7NO_2 + N_2 + H_2O + CO_2 + OH^-$$

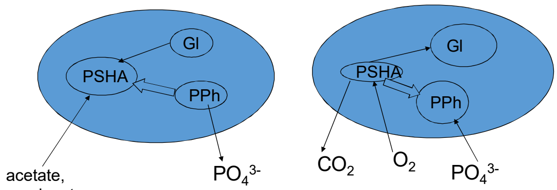
2.86g 1g 3.57g

Biological phosphorous removal

- Principle
- phosphorus accumulating organisms (PAO)
  - Heterotrophic
  - Anaerobic: PAO will release P
  - Aerobic: PAO will intake P
  - Remove P by discharging sludge
  - P releasing consume carbon source: BOD/P>17:1

Scheme of transformations of phosphorus compounds

- Anaerobic conditions
  phosphate-accumulating organisms
- Aerobic conditions
  phosphate-accumulating organisms

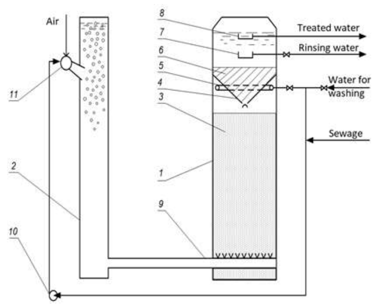


PSHA– polymeric saturated hydroxy acids; Gl –glycogen; PPh -- polyphosphates

Flow chart of biological treatment of municipal wastewater

1 – pumping station; 2 – receiving chamber; 3 – lattice; 4 – sand trap; 5 – primary clarifier; 6 – bio-reactor; 7 – secondary settler.

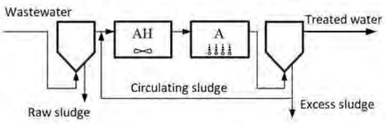
Scheme of bio-sorber



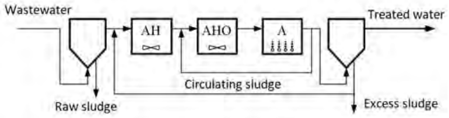
1 – bio-sorber; 2 – aeration column; 3 – fluidised bed of coal; 4 – cone; 5 – catchment; 6 – coal filtering bed; 7 – industrial water drainage tray; 8 – tray for purified water; 9 –water distributor; 10 – circulation pump; 11 – ejection chamber.

Variants of biological wastewater treatment with a deep removal of nitrogen and phosphorus compounds

Flow chart of A/O Process®

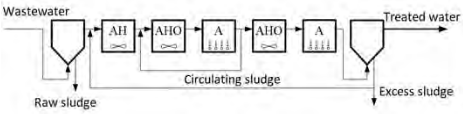


Flow chart of A2/O Process®

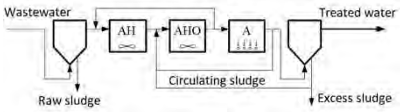


Variants of biological wastewater treatment with a deep removal of nitrogen and phosphorus compounds

Flow chart of Bardenfo

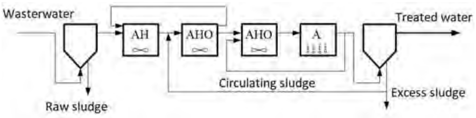


Flow chart of UCT

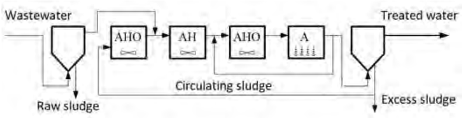


Variants of biological wastewater treatment with a deep removal of nitrogen and phosphorus compounds

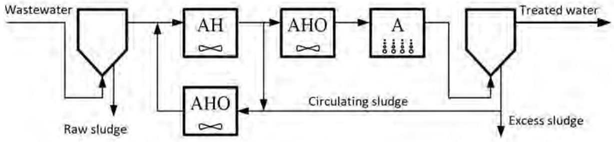
Flow chart of MUCT



Flow chart of JHB



Variants of biological wastewater treatment with a deep removal of nitrogen and phosphorus compounds



Flow chart of ISAN

Anaerobic treatment technology

- Mechanism - Four key stages
  - Hydrolysis
    - Complex organic molecules are broken down into simple sugars, amino acids and fatty acids
  - Acidogenesis
    - Remaining components are further broken down into VFAs, ammonia, carbon dioxide, and hydrogen sulfide
  - Acetogenesis
    - simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid, as well as carbon dioxide and hydrogen.
  - Methanogenesis
    - methanogens use the intermediate products of the preceding stages and convert them into methane, carbon dioxide, and water.

Anaerobic treatment technology

- Advantages of anaerobic treatment
  - Appropriate for high COD-concentrations
  - High volumetric load => small volumes required
  - Low sludge production (3-10 lower than with aerobic treatment)
  - Low energy demand, no aeration necessary
  - Yield of biogas
  - Lower cost than for aerobic treatment
  - Degradation of substances which are non-biodegradable under aerobic conditions
  - Suitable for hot climate conditions

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Anaerobic treatment technology

- Disdvantages of anaerobic treatment
  - Efficiency of degradation of organic substances only up to 70-80% => aerobic post-treatment required
  - Balance of volatile fatty acids
  - Long adaption phases necessary
  - Sensitivity towards oszillating temperature, pH-value, changing concentrations and loads
  - Detailed monitoring systems required
  - Sometimes pH-control required

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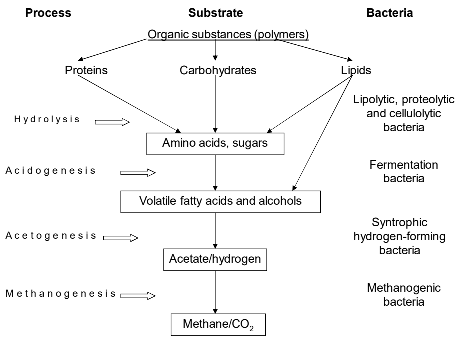
General scheme of the transformation of organic substances under anaerobic conditions



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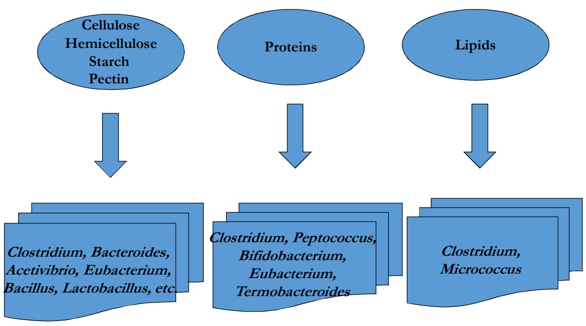
Hydrolysis



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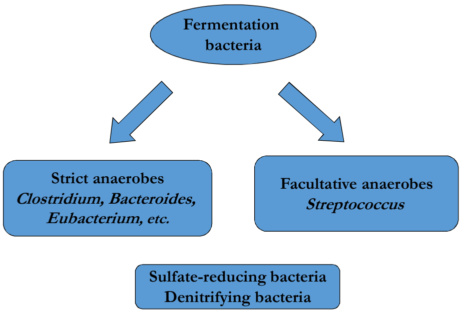
Acidogenesis



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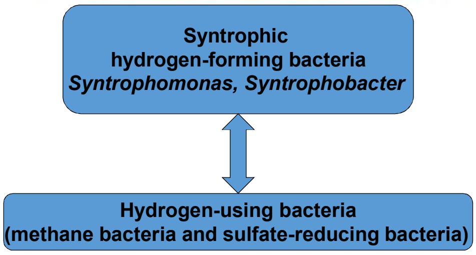
Acetogenesis

$$C_3H_7COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2$$
$$C_2H_5OH + H_2O \rightarrow CH_3COOH + 2H_2$$



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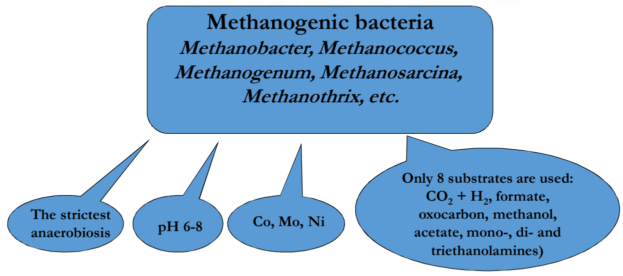
Methanogenesis

$$4CH_3COOH + 4H_2 \rightarrow 5CH_4 + 2H_2O + 3CO_2$$
$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$$



Effect of pH of waste water

ACIDIFICATION
Formation VFAs

ALKALIZATION
Consumption VFAs
Formation of ions NH_4

Overloading the reactor by pollution
pH ≤ 5
long-term destabilization work of the bioreactor

pH 6–8
buffer capacity of fermentation medium
(carbonic acid, VFAs, ammonium ions)

pH > 9
inhibition of methanogenesis
pH 6–8
resumption of the process

The rate of biomethanogenesis

- Process temperature
- Chemical composition of raw materials
- Density of bacterial association
- The degree of homogenization of the medium

Thermophilic process
40-55°C

Mesophilic process
20-40°C

Acidic stage (pH 6,0-6,5) → Methane Stage (pH 6,5-8,0)

Effect of process temperature

Mesophilic regime
30-40°C

+ A sufficiently high rate of destruction of pollution

Low energy consumption for stabilizing the temperature regime

Thermophilic regime
50-55°C

+ Higher velocity → Higher productivity of bioreactor

– Higher costs of maintaining the temperature

A lower species diversity of methanogenic biocenosis

Biogas output

1 t of fermented dry organic matter	300–600 nm³ of biogas
1 t of carbohydrates	420–470 nm³ of biogas
1 t of fat	to 1000 nm³ of biogas

The presence in the waste water of biogenic elements, inhibitors and toxic substances

BOD : N : P = 100 : 1 : 0,2

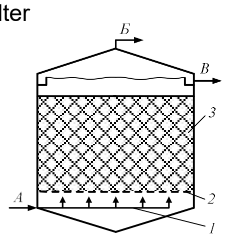
C : N from 20 : 1 to 100 : 1

Inhibitors and toxic substances

- Dissolved ammonia 50 mg/l
- VFAs 2000 mg/l
- Hydrogen 0.2-0.5% in the gas phase
- Dissolved Hydrogen sulphide 200 mg/l
- Heavy metals, antibiotics, etc.

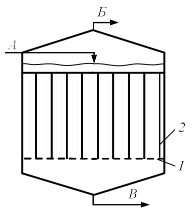
Commonly used anaerobic treatment technology

- Anaerobic biofilter



1 – distribution system; *2* – supporting grid;
3 – layer of loading material;
А – initial wastewater; Б – biogas; В – treated wastewater

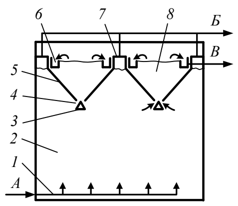
- Bioreactor with a downward flow of sewage



1 – supporting grid;
2 – layer of vertically oriented initial material;
А – initial wastewater; Б – biogas; В – treated wastewater

- UASB-reactor (Upflow anaerobic sludge blanket reactor)

  - Advantages
    - High reduction of BOD
    - Can withstand high organic and hydraulic loading rates
    - Low sludge production (and, thus, infrequent desludging required)
    - Biogas can be used for energy (but usually first requires scrubbing)

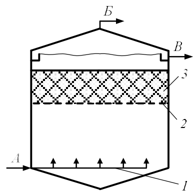


1 – distribution system; *2* – treating zone; *3* – deflector; *4* – crevice (entrance to the settling zone); *5* – gas control baffle; *6* – catchment tray; *7* – gas collecting box; *8* – settling zone;
А – initial wastewater; Б – biogas; В – treated wastewater

- UASB-reactor (Upflow anaerobic sludge blanket reactor)

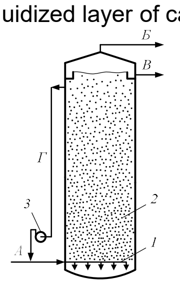
  - Disadvantages
    - Treatment may be unstable with variable hydraulic and organic loads
    - Requires operation and maintenance by skilled personnel; difficult to maintain proper hydraulic conditions (upflow and settling rates must be balanced)
    - Long start-up time to work at full capacity
    - A constant source of electricity is required
    - Not all parts and materials may be locally available
    - Requires expert design and construction
    - Effluent and sludge require further treatment and/or appropriate discharge

- Hybrid bioreactor



1 – distribution system; 2 – supporting grid;
3 – layer of loading material;
А – initial wastewater; Б – biogas; В – treated wastewater

- Bioreactor with fluidized layer of carrier particles



1 – distribution system; *2* – carrier particle layer; *3* – pump;
А – initial wastewater; Б – biogas; В – treated wastewater;
Г – wastewater recycling

Innovative Technologies Of Biological Wastewater Treatment

- Autotrophic anamox process

  - Partial nitrification, during which part of the ammonium nitrogen is oxidized to nitrite by bacteria of the first group:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O.$$

  - The autotrophic anoxidic oxidation of the remaining ammonium nitrogen by nitrite to molecular nitrogen, carried out by a second group of bacteria:

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O.$$

  - Currently, two technologies are used in the world:
    - Technology DEMON® (Austria);
    - Technology of Paques ANAMMOX® (Nederland).

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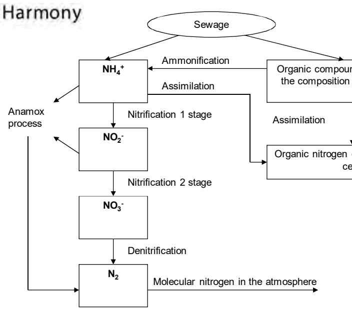

Advantages of autotrophic anoxidation:
- high efficiency (up to 90% of nitrogen is removed);
- economy (per unit of removed nitrogen is spent 60% less oxygen);
- less excess biomass is formed;
- readily oxidizable organic substances are not required.
The cost of nitrogen removal is reduced by 2-3 times.

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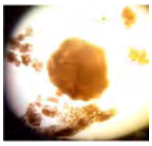
Application of aerobic granulated activated sludge

Aerobic granules of activated sludge are stratified:
- in the outer layers - aerobic heterotrophs and nitrifiers;
- inside the granules are denitrifying agents and phosphate-accumulating denitrifying bacteria.



Basic conditions for obtaining

- changing of substrate saturation and starvation conditions;
- the process of cyclic (periodic) action;
- rising flow of sewage;
- limited time for sedimentation.

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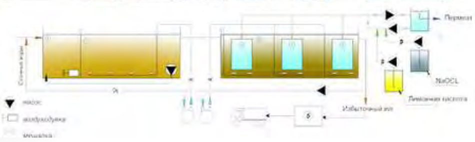
Membrane methods



http://www.saveplanet.su/tehno_590.html

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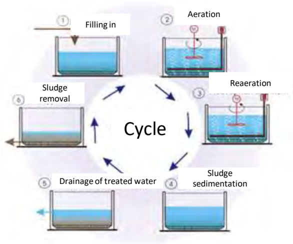
Wastewater treatment by using the SBR-reactor (Sequencing Batch Reactor)



http://www.saveplanet.su/tehno_582.html

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Questions

- Which process can reduce contaminants, assimilation or dissimilation?
- How can you judge if certain wastewater can be treated with biological process?
- Describe the four stages of anaerobic digestion
- What is the pros and cons of anaerobic treatment technology?

Bioindication of the waste water state

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The types of bioindication

passive:
Investigation of visible or inconspicuous lesions and abnormalities in free-living organisms which are signs of adverse effects

active or biotesting:
Investigation of the impact of adverse factors in standard conditions for the most sensitive to this factor test organisms

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Content

- Concepts of bioindication of the wastewater state;
- Knowledge of the aquatic indicator organisms;
- Hydrobiological characteristics of various muds.

Bioindication of the wastewater state

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Advantage of bioindication and biotesting methods

- Reflection of the state of the environment from the biologically important data obtained
- Detection of the presence of a complex of pollutants in the environment
- possibility to judge the degree of toxicity of the pollutant
- ability to control the effect of synthesized xenobiotics
- due to the dose minimization, the ability to respond to minor fluctuations in a chronic anthropogenic press
- assistance in the regulation of the permissible load on various ecosystems, including different geographic areas
- the possibility of not using expensive equipment or labor-intensive physico-chemical methods for measuring biological characteristics
- establishment of sources of pollution in ecosystems

Bioindication of the wastewater state

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Bioindication

- concept
  - Bioindication is the determination of biologically significant loads based on the reactions of alive organisms and their communities to them.

❿ The main objective of bioindication –
  - development of methods and criteria for diagnosing disorders in components of natural communities.

Bioindication of the wastewater state

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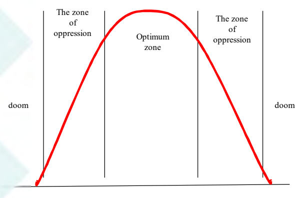
Liebig's law of the minimum
- The relative effect of an individual environmental factor is the stronger, the more it is in comparison with other environmental factors at a minimum.

Shelford's law of tolerance
- the existence of a species is determined by limiting factors that are not only in the minimum, but also at the maximum.



The scheme of influence of the ecological factor

The existence of a species is determined by limiting factors in the region of the pessimum at the maximum and minimum values. Near the points of maximum and minimum lie sublethal values of the environmental factor, and outside the zone tolerance-lethal.

A source : Ляшенко О.А. Биоиндикация и биотестирование в окружающей среде. Schoolbook, 2012, p.15

Bioindication of the wastewater state

- **Bioindicators** are organisms or communities of organisms according to the presence, condition and behavior of which scientists judge about changes in the environment

Criteria for choosing a bioindicator
- reliability (error <20%)
- monitoring capabilities
- simplicity
- fast reaction

Oxidation of organic pollutants in aerotanks is due to the vital activity of aerobic microorganisms forming flocculent clusters - activated sludge.

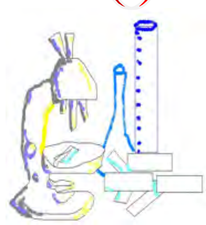
Activated sludge is an artificially grown biocenosis during aeration of clarified wastewater, populated by bacteria, protozoa and multicellular animals that transform pollutants and purify wastewater as a result of soaking, oxidation, and eating.

Bioindicators are usually described by using two characteristics: specificity and sensitivity. At low specificity, the bioindicator reacts to different factors, at high specificity - only one. At a low sensitivity, the bioindicator responds only to strong deviations of the factor from the norm, while at high - to insignificant.

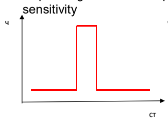
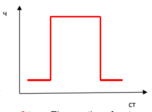
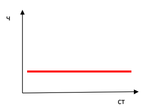
The types of bioindicators
- *Sensitive* — Quickly reacts with a significant deviation of indicators from the norm
- *Accumulative* — Accumulates exposure without manifest disturbances

Hydrobiological analysis of activated sludge

- Visual research of the sludge in a glass cylinder
- identification of species, subspecies of organisms
- determination of the number of each species
- description of the morpho-functional state and changes in bioindicators
- determination of the sizes of indicator organisms
- distribution of bioindicators by environmental groups
- final assessment of biocenosis
- Preparation of hydrobiological conclusion



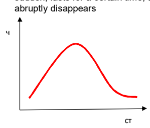
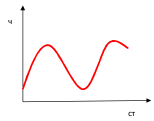
Depending on the development time of the indication reactions, there are 6 types of sensitivity

1 type. Gives a one-time reaction after some time and then loses sensitivity

2 type. The reaction of a strong and sudden, lasts for a certain time, then abruptly disappears

3 type. Keeps constant sensitivity for a long time

4 type. After an immediate, strong reaction, it is observed at first fast and then slow attenuation

5 type. When a disturbing effect occurs, the reaction increases to a maximum, and then gradually fades

6 type. The reaction is repeated repeatedly

A source : Ляшенко О.А.Биоиндикация и биотестирование в окружающей среде. Schoolbook, 2012, p.15

Indicators of physiological state of aquatic organisms
- Prevailing groups and species of organisms of biocenosis
- Degree of fatness
- Condition of contractile vacuoles
- The condition of the ciliary disk in the attached circourex ciliates (open, closed)
- Body shape
- Intensity of the ciliary apparatus (intensive, weak, complete, immobility)
- The size of organisms (normal, enlarged, small)
- The nature of reproduction
- The presence of cysts
- The presence of dead animals

Changes in biocenoses of activated sludge

- **Weakly disturbed biocenosis:** Less than 30% of the species of organisms disappears
- **Average Violation:** Disappears 50% of the species
- **Severe Violation:** More than 50% of species die

Amoeba

Amoebas are single-nucleated, less often multinucleated protozoa, that do not have a constant body shape, moving with the help of temporarily formed pseudopods and having neither a shell nor an internal skeleton. Pseudopodia may be in various different shapes amoebae, more blade or finger (A. proteus), the lancet (A. radiosa).

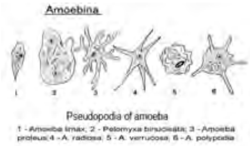
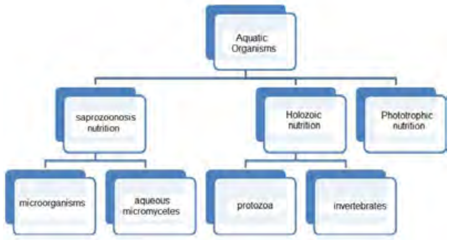


Photo: https://cf.ppt-online.org/files/slide/l/lthPVefQD5BMzl4WbYC9gHpyrwZ07qvXxs2FSm/slide-5.jpg

http://s1.dmcdn.net/MgOq-/1280x720-BFX.jpg

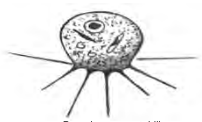
Biocenosis of activated sludge



Testate amoebae

Testate amoebae are single-celled protists partially enclosed in a simple test (shell), who also move and perceive food with the help of pseudopodia. Their bare protoplasmic body is enclosed in a single-chamber shell, equipped with a hole through which pseudopods emerge.

Arcella discoides (Centropyxis)



Pamphagus mutabilis

Drawing by L.V. Rubtsova

Zoogloea ramigera

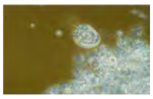
Zoogloea ramigera, is a gram-negative, aerobic bacterium from the genus of Zoogloea which occurs in organically enriched aqueous environments like activated sludges, capable of forming so-called zoogles, which are flake masses of cells floating in the jelly-like intercellular material and characterized by branched fingerlike morphology.

Photo: https://microbewiki.kenyon.edu/images/a/a2/Zoogloea_ramigera.jpg

Hypotrich

Strongly flattened in the dorsoventral direction. On the dorsal side, the ciliary cover is reduced. Instead of cilia, there are long, thin threads. On the ventral side, the cilia are arranged in several rows. In addition to cilia, on the ventral side there are also groups of dense setae - cirrus, on which the infusorians rest when moving on a solid substrate.

Oxytricha spp



Aspidisca costata

Euplotes spp

Photo: http://elementy.ru/images/news/oxytricha_640.jpg
http://protist.i.hosei.ac.jp/pdb/images/Ciliophora/Euplotes/woodruffi/woodruffi.jpg
https://d3o1jlvchszf6h.cloudfront.net/wp-content/uploads/Aspidisca-e1492890905408.jpg

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Peritrich

They are usually bell or disc shaped, with a prominent paroral membrane arising from the oral cavity and circling counter-clockwise around the anterior of the cell, accompanied by a smaller series of membranelles. The oral cavity is apical and funnel shaped, with a contractile vacuole discharging directly into it. When disturbed, the anterior of the cell can contract. The rest of the body is unciliated, except for a telotroch band circling the posterior in mobile species and stages.


Vorticella convallaria


Vorticella microstoma


Opercularia sp


Carchesium sp

Photo: https://distant-lessons.ru/wp-content/uploads/2013/11/infuzoria-trubach.jpg

http://900igr.net/datai/biologija/Prostejshie-organizmy/0018-025-Tip-Infuzorii-ili-Resnichnye.jpg

http://protist.i.hosei.ac.jp/PDB/PCD0605/D/61.jpg

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Characteristics of sludge

Satisfactory working (good) sludge

Indicator organisms:

- testate amoebaes Arcella discoides and Pamphagus mutabilis,
- tubulineas Amoeba radiosae and A. proteus,
- holotrichous from the order Cyclidium,
- hypotrichous Euplotes, Oxytricha, Aspidisca,
- peritrichous Opercularia, Epistylis,
- single copies of Carchesium. Small flagellates,
- rarely peritrichous ciliates V.microstoma and V. alba
- permanent availability of Zoogloea ramigera.

All protozoa are active, large, mobile, cilia in their working condition.

Status of sludge: sludge flakes compact, dense, silt settles quickly, the water above the silt transparent. The color of the flakes can be different (from gray-yellow to brown) and depends on the composition of the waste liquid.

Bioindication of the wastewater state

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Rotifer

Multicellular organisms (from 40 microns to 2.5 mm). The rotifers are divided into a head, a trunk and a leg. Some rotifers are covered with shell, they usually develop in a low-loaded active sludge, which forms a high quality of cleaning. Spineless rotifers, such as Rotaria rotatoria, Philodina roseola, the inhabitants of the mud of ordinary aerotanks, providing complete oxidation of pollutants.


Rotaria rotatoria


Philodina roseola

Photo: http://rotifera.hausdernatur.at/Rotifer_data/images/observation/Rotaria%20rotatoria%20(Pallas,%201766)_Ma1-PuuKukui.jpg

http://www.national-geographic.pl/media/cache/gallery_view/uploads/media/default/0001/93/736422ee775670415093262e04bdf58c0dde172a.jpeg

Bioindication of the wastewater state

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Nitrifying sludge

- **Indicator organisms:**
- in noticeable quantities of rotifers Notommata, Philodina, Cathypna, Monostyla, Callidina, Rotaria.
- quantitative predominance of attached infusorians Vorticella convallaria, Carchesium.
- there may be hypotrichous, large amoebae (A.proteus), testate amoebaes (Arcella, Centropyxis).
- possible presence in significant quantities of Aelosoma.
- lush development Zoogloea ramigera.

- **All of the protozoa are active, ciliary discs of peritrichous is opened.**

Sludge condition. The sludge is loose, after deposition can float. The water above the sludge is transparent.

Bioindication of the wastewater state

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Worm

Aelosoma -characteristic worm, its body is divided into segments, between which are setae. In the body of Aelosoma, yellow droplets of fatty inclusions are usually well visible. Eyes - in the form of fairly large red spots.

The intensive development of Nematoda roundworms indicates stagnant zones in the aerotank. Excessive development of them can lead to a difficult flow of water.


Aelosoma sp


Nematoda sp

Photo: http://www.norweco.com/html/lab/Webbugs/tech%20manual%20pictures/13.jpg

http://npc-news.ru/wp-content/uploads/2014/12/Nematode.jpg

Bioindication of the wastewater state

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Starving sludge

- **Indicator organisms:**
- A small variety of species of protozoa with a significant qualitative predominance of two or three of them.
- A large number of Chilodon, Colpidium colpoda.
- Presence in appreciable quantities of Vorticella microstoma and V. alba,
- Podophrya, Nematoda.
- Presence of Opercularia, but the ciliary disk is closed.
- Zoogloe accumulations of bacteria disappear, many individual bacterial
- cells and filamentous bacteria appear, such as Cladothrix, Sphaerotilus,
- Beggiatoa.

- **Sludge condition.** The sludge is contaminated with various inclusions: organic amorphous particles, muscle fibers, plant debris, garbage. Sludge flakes are dark, dense. The mud settles quickly, the water over the sludge is turbid with opalescence. The water above the sludge is turbid. At very high loads, the structure of the sludge deteriorates, loosening of the flakes.

Bioindication of the wastewater state

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Lack of oxygen

- **Indicator organisms:**
- Rotifers motionless in the elongated state, dying off.
  Vorticella convallaria swell in the form of a ball, then burst and disappear, some individuals form a freely floating form of the telotroch.
  Abundantly found Vorticella microstoma.
  Close cilia discs Carchesium and Opercularia.
  Many small flagellates and small amoebas appear.
  In a significant number develop suctoria Podophrya fixa.
  Abundant develop Paramecium caundatum.

- **Sludge condition.** Flakes of sudge break up, the color of the sludge becomes whitish, it settles badly, the water over mud is muddy. In the presence of stagnant zones in aerotanks and secondary sedimentation tanks, the sludge acquires a dark color, Nematoda roundworms develop in it.

Bioindication of the wastewater state

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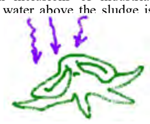
Sludge during discharge of toxic industrial wastewater

- **Indicator organisms:**
  Reducing the diversity of species of protozoa, one or two species predominate.
  Small sizes of protozoa, especially Vorticella convallaria, Opercularia, Carchesium.
  The stationary condition of the cilia of the infusorians, the ciliary disk of Opercularia is closed.
  Rotifers motionless, compressed, dying.
- **Sludge condition.** Sludge is fine, contaminated with inclusions of industrial wastewater, can have colored particles, settles badly, the water above the sludge is turbid.



Bioindication of the wastewater state

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Effect of pH variation

Indicator organisms:
At low pH (below 6.5), intensive development of the Fusarium fungus, which causes swelling of the activated sludge, is possible.
With a significant shift in pH (below 5), intensive yeast development is possible, leading to a decrease in the effect of wastewater treatment.
Significantly reduced the number of protozoa, with a strong acidification of the environment, they disappear completely.

Sludge condition.
- Claps of silt are stretched into strands, silt is crushed, its color becomes lighter.
- The sludge settles badly, in the supernatant liquid there is a lot of non-sedimenting suspension.
- Sometimes sludge floats to the surface.
- The sludge index can be increased to 200-500 mg / l.

Bioindication of the wastewater state

Questions

- What should be considered when you choose a bioindicator?
- How can you judge if an activated sludge system works well?
- How can you judge if the influent of the wastewater treatment plant contains toxic compound?

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Wastewater treatment. Removal of dissolved inorganic substances

Associate Prof. Tatyana Solodovnik
Cherkasy State Technological University
solodovniktetana@gmail.com

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Learning targets

- Understanding of neutralization, oxidation, reduction, precipitation wastewater treatment means
- Understanding of the principle of ion-exchange, reverse osmosis, and vacuum evaporation
- Understanding of electrochemical treatment technology

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Content

- Types of wastewater pollution
- Sources of contamination with dissolved inorganic substances
- Methods of sewage treatment from dissolved inorganic substances
- Methods for cleaning industrial wastewater from typical inorganic impurities

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Types of wastewater pollution

- Mechanical
- Chemical: organic and inorganic solutes
- Biological and bacteriological
- Thermal - water from thermal power plants and nuclear power plants
- Radioactive

http://rosao.ru/information/articles/205

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Sources of contamination with dissolved inorganic substances

Wastewater:

- metallurgical industry enterprises
- galvanic production
- chemical enterprises
- machine-building plants
- enterprises of instrument making
- coal mining industry
- factories for the production of building products and materials

http://www.bwt.ru/useful-info/1088

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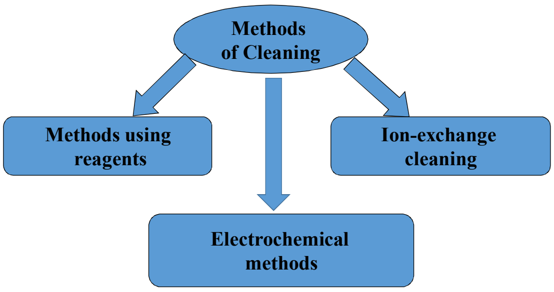
Methods of sewage treatment from dissolved inorganic substances



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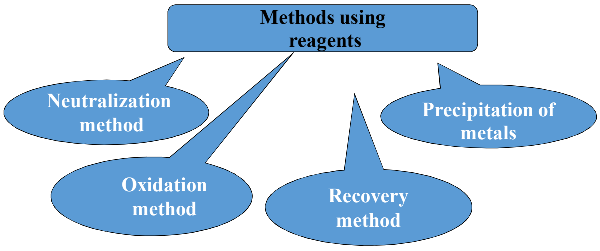
Methods of sewage treatment from dissolved inorganic substances



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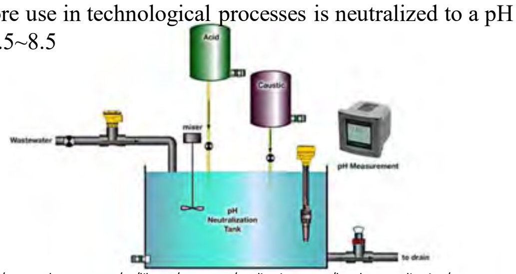
Neutralization method

Operating principle: Wastewater containing mineral acids or alkalis before being discharged into water bodies or before use in technological processes is neutralized to a pH of 6.5~8.5



https://www.yokogawa.com/us/library/resources/application-notes/batch-neutralization/

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Neutralization method

Operating mode:

- Mixing of acidic and alkaline wastewater
- Addition of reagents (solutions of acids, quicklime CaO, $Ca(OH)_2$, ammonia solution, etc.)
- Filtering of acid wastewater through neutralizing materials
- absorption of acid gases by alkaline water

The choice of neutralization method depends on the volume and concentration of wastewater, the availability and cost of reagents.

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Oxidation method

Operating principle:

- As a result of the chemical oxidation reaction, toxic contaminants become less toxic and are removed from the water.

Operating mode:

- For purification of waste water, oxidizing agents such as gaseous and liquefied chlorine, chlorine dioxide, calcium chlorate, calcium and sodium hypochlorite, potassium permanganate, potassium dichromate, hydrogen peroxide, oxygen (technical or oxygen of air), ozone are used.

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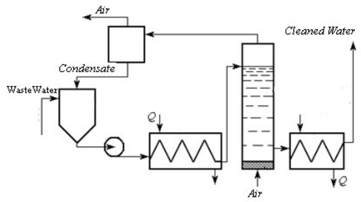
Oxidation method

Example:



Scheme of oxidation of sulfides with oxygen of air

Oxidation by oxygen in the air takes place in the liquid phase at elevated temperature and pressure.

Stages of oxidation:

$$S^{2-} \rightarrow S \rightarrow S_2O_6^{2-} \rightarrow S_2O_3^{2-} \rightarrow SO_3^{2-} \rightarrow SO_4^{2-}$$

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Oxidation method

Typical applications:

- For the neutralization of industrial wastewater, which contain:
  - toxic impurities (cyanides, complex copper and zinc cyanides)
  - chrome-containing effluent
  - compounds that are inexpedient to remove from sewage
  - compounds that are impractical to purify by other methods (hydrogen sulphide, sulfides)

Reduction method

Operating principle:

- As a result of the chemical reaction of the reduction, toxic contaminants become less toxic, and the recovered substances are removed from the water by mechanical methods: filtration, flotation or sedimentation

Operating mode:

- For the reduction reaction of inorganic compounds is used: FeS, $NaBH_4$, $NaHSO_3$, N_2H_4, iron powder, aluminum powder, hydrazine, iron sulfate, hydrogen

http://vodakanazer.ru/kanalizaciya/ximicheskaya-ochistka-stochnyx-vod.html

Reduction method

Typical applications: The reduction method is used to remove mercury, chromium and arsenic compounds from wastewater.

Example: solutions of sodium hydrosulfite for the reduction of substances containing Cr^{6+}:

$$4H_2CrO_4 + 6NaHSO_3 + 3H_2SO_4 \rightarrow 2Cr_2(SO_4)_3 + 3Na_2SO_4 + 10H_2O$$

Then Cr^{3+} is precipitated with solutions of hydroxides $Ca(OH)_2$, и NaOH:

$$Cr^{3+} + 3OH^- = Cr(OH)_3\downarrow$$

Example: A solution of hydrazine is used for the reduction of Cr^{6+} at pH = 7-8:

$$4K_2CrO_4 + 3N_2H_4 \rightarrow 4Cr(OH)_3\downarrow + 3N_2\uparrow + 8KOH$$

Precipitation of heavy metals

Operating principle:

- Wastewater treatment from heavy metal ions is carried out by precipitation of heavy metals in the form of sparingly soluble compounds. The precipitation of metals occurs when various reagents are added:

  - hydroxides of calcium and sodium,
  - sodium carbonate,
  - sulfides of sodium,
  - various wastes, for example, ferrochrome slag.

http://srjcstaff.santarosa.edu/~oraola/jartest.html

Precipitation of heavy metals

Operating mode:

- Precipitation of insoluble compounds is carried out in sedimentation tanks:

  - vertical with a descending-ascending movement of water;
  - thin-layer shelf clarifiers

http://www.tecnoidea.it/eng/linea_acque.html

Precipitation of heavy metals

Typical applications:

- Wastewater treatment of heavy industry and galvanic industries from heavy metal ions

Example: Lead ions are precipitated as one of three hardly soluble compounds:

$$Pb^{2+} + OH^- \rightarrow Pb(OH)_2\downarrow$$

$$2Pb^{2+} + 2OH^- + CO \rightarrow (PbOH)_2CO_3\downarrow$$

$$Pb^{2+} + CO_3^{2-} \rightarrow PbCO_3\downarrow$$

pH = 6.0 corresponds to the beginning of the formation of lead hydroxide precipitate

Methods using reagents

Benefits of methods

neutralization, oxidation, reduction, precipitation:

- A wide range of initial concentrations
- Versatility
- Easy operation
- Conversion of toxic pollutants into less toxic or non-toxic forms.

Disadvantages of methods

neutralization, oxidation, reduction, precipitation:

- High consumption of reagents
- Additional wastewater pollution
- Difficulty of removing heavy metals from the sludge for disposal
- The need for significant sludge storage areas
- Loss of valuable substances with precipitation

Ion-exchange cleaning

Principle of operation:

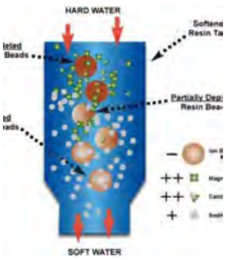
the process of exchange between ions that are in solution, and of ions that are on the surface porous resin beads.

Operating mode:

Initially, anions or cations are processed from wastewater on ion exchangers (sorption stage), and then the process of desorption of these ions from the resin (regeneration stage).

Two ion-cleaning technologies are used:

– **single-flow** and **counter-current**



http://www.globalspec.com/learnmore/manufacturing_process_equipment/filtration_separation_products/ion_exchange_resins

Ion-exchange cleaning

Typical applications:

- Wastewater treatment from heavy metal ions: zinc, copper, chromium, nickel, lead, mercury, cadmium, vanadium, manganese
- For extraction of valuable or toxic components from wastewater, and also neutralization of these waters
- Purification of industrial wastewater from compounds of arsenic, phosphorus, as well as cyanide compounds and radioactive substances

http://www.unechabros.com/Ion%20Exchange%20Plants.html

Ion-exchange cleaning

Benefits:

- High cleaning efficiency
- Obtaining, isolated from the waste water of metals, in the form of relatively pure and concentrated salts
- The possibility of selective isolation of metals

Disadvantages:

- The need for preliminary treatment of waste water from oils, solvents, organic compounds
- A large consumption of reagents for the regeneration of ion exchangers and treatment of resins
- The need for preliminary separation of washing water from concentrates
- Bulkiness of equipment, high cost of resins
- The formation of secondary waste-eluents, which require additional processing

Reverse osmosis

Principle of operation:

- filtration of solutions under pressure that exceeds osmotic pressure, through membranes that pass the solvent and retard molecules and ions of dissolved substances

http://innovativewatertreatment.com/blog/2015/04/15/the-basics-of-a-commercial-reverse-osmosis-system

Reverse osmosis

Operating mode:

- Installation of reverse osmosis is able to remove particles from the water with a size of 1-0, 1 nm, working pressure of 10-200 bar.

Typical applications:

Desalination of treated wastewater:

- in galvanic production
- in the production of printed circuit boards

http://www.degremont-technologies.com/-degremon/Reverse-Osmosis-Skids-458

Reverse osmosis

Benefits:

- High degree of purification
- The possibility of utilization of heavy metals
- Low energy costs
- Simplicity and compactness of installations
- Possibility of full automation of the process

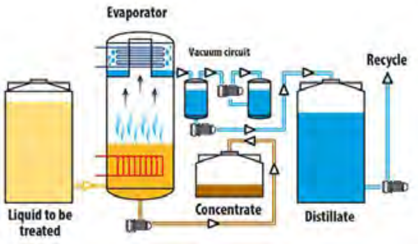
Disadvantages:

- The need for preliminary treatment of waste water from oils, solvents, organic compounds
- High cost of membranes
- The complexity of operation, high requirements for the tightness of installations
- Sensitivity of membranes to changes in the parameters of treated wastewater

Vacuum Evaporation

Principle of operation:

- concentration of liquid waste by the method of partial removal of liquid during evaporation during boiling.



http://www.pf10.com/evaporators-and-concentration-units.html

Vacuum Evaporation

Operating mode:

- Evaporation processes occur in a vacuum and the choice of pressure is determined by the properties of the waste water and the possibility of using the heat of the secondary steam.

Typical applications:

- for wastewater treatment of heavy and chemical industry enterprises containing toxic compounds of heavy metals: copper, zinc, nickel, chromium, lead.

http://galvan.ru/?q=node/303

Vacuum Evaporation

Benefits:

- Simultaneous cleaning of various effluents with a high concentration of pollutants and containing aggressive liquids
- High degree of purification
- Return of salts and water to production
- The possibility of organizing a closed cycle without discharges of harmful substances into the environment

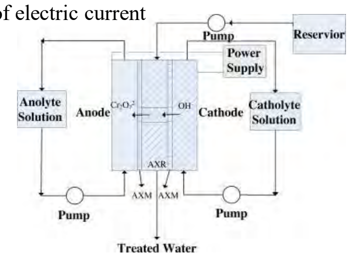
Disadvantages:

- High energy intensity
- High capital costs
- The need for multi-stage wash tanks

Electrochemical methods

Principle of operation :

- removal of dissolved inorganic pollutants from waste water due to oxidation-reduction reactions that occur as a result of the action of electric current



https://www.sciencedirect.com/science/article/pii/S0013468616301335

Electrochemical methods

Operating mode:

- The process of electrochemical cleaning is carried out using soluble and insoluble electrodes:
- **Anodes** made of graphite, magnetite, lead dioxide, manganese and ruthenium, which are applied to a titanium plate
- **Cathodes** made of molybdenum, of an alloy of tungsten with iron or with nickel
- **Main processes:**
  - anodic oxidation
  - catholic reduction
  - electrocoagulation
  - electro flocculation
  - electro dialysis

Electrochemical methods

Typical applications:

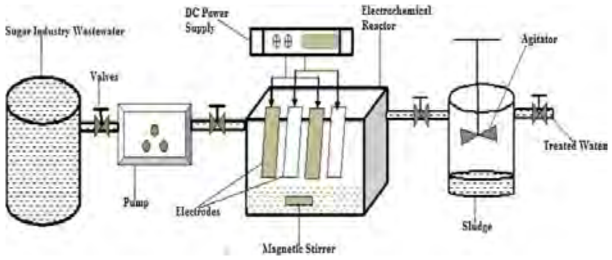
- for wastewater treatment from dissolved impurities: cyanides, amines, sulfides, heavy metal ions
- for wastewater treatment of galvanic plants
- for the electrochemical extraction of copper and other non-ferrous metals, as well as precious metals from highly concentrated and slightly concentrated wastewater

https://wholesaler.alibaba.com/product-detail/Power-plant-electrocoagulation-wastewater-treatment_60471907924.html

Electrochemical methods

Example:

- use of electrocoagulation in the technological scheme of industrial wastewater treatment



https://www.sciencedirect.com/science/article/pii/S2214714416302148

Electrochemical methods

Benefits:

- Using a simple technological scheme of cleaning without the use of chemical reagents
- Extraction of valuable metals from waste water
- Easy operation and maintenance
- High degree of purification

Disadvantages:

- High power consumption
- Possibility of formation of collateral dangerous compounds

Methods for cleaning industrial wastewater from typical inorganic impurities

Purification from heavy metal ions:

- electroflotation, sedimentation, electrocoagulation, electrodialysis, ultrafiltration, ion exchange.

Purification from ions Chromium (III):

- electroflotation, ion exchange, precipitation, ultrafiltration, filtration.

Purification from ions Chromium (VI):

- electroflotation, electrocoagulation, electrochemical reduction.

Methods for cleaning industrial wastewater from typical inorganic impurities

Purification from cyanides:

- chemical oxidation, electroflotation, electrochemical oxidation.

Purification from sulphates:

- sedimentation with reagents + filtration, vacuum evaporation, nanofiltration, reverse osmosis.

Purification from chlorides:

- reverse osmosis, vacuum evaporation, electrodialysis.

Cleaning from salts:

- nanofiltration, reverse osmosis, electrodialysis.

Questions

- How is the sulfides removed from water?
- Need the water to be pretreated before ion-exchange cleaning?
- Which of the following method can recover valuable metal from wastewater, oxidation, precipitation, electrochemical method?

Reference literature

- Physico-chemical methods of water treatment. Water resources management. *Edited by I.M. Astrelin and H. Ratnaweera* 2015
- Selected publications from the Water Harmony Project: Water Research and Technology, 2015, 323 pages

WATER AND SEWAGE MANAGEMENT IN THE FOOD INDUSTRY

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Learning targets

- Understanding the characteristic of pollution in selected food industry
- Understanding of management and treatment method of pollution in food industry
- Learn about the research trend for wastewater management in food industry

Content

- Food industry in Poland
- Water consumption of different food products
- Pollution generated by the selected branches of the food industry
- Sewage management in the food processing plants
- Example of research trends for wastewater management in the food industry

Food industry:

A. Processing of animal products
- meat processing
- poultry
- dairy industry
- fish processing

B. Processing of agricultural products
- processing of grain and pasta
- processing of potatoes
- vegetables and fruit processing
- sugar industry
- oil production

Food industry in Poland

- Approx. 15% of the whole industrial production,
- 7% contribution to the GDP (Gross Domestic Product)
- It employs more than half of million people
- About 27 thousand companies
- Only 350 large companies, and only 1400 had the status of medium-sized companies
- It provides 21% of the food products sold on the domestic market
- Many processing plants are characterized by the seasonality of production (mainly fruit, vegetable, sugar and starch industry)

Consumption of water in the food industry in Poland year 2002

Food industry branch	Water consumption [mln m^3]
Meat production	13,1
Fish processing industry	0,6
Fruit and vegetables industry	18,3
Production of oils and fats	1,7
Production of dairy products	23,3
Production of sugar	7,8
Production of beverages	15,3
Total:	82,8

Water consumption of different food products

Production	Water consumption [dm^3/kg]	Production	Water consumption [dm^3/kg]
Jam	13-25	Vegetable juices	16
Canned bean	13	Concentrated fruit juice	40
Frozen bean	12	Puree	6-12
Canned vegetables	10	Pickles	9
Frozen fruits	7		

Depends also on:
- *type of production*
- *the applied technology*
- *implementation of closed loop water systems*

Pollution generated by the selected branches of the food industry

Branch	Pollutants emitted into the atmosphere	Type of wastewater	Type of waste
Meat industry	-flue gases from coal fired boilers (CO, SO_2, NO_2), dust hydrocarbons - smoke from the smokehouse (over 250 compounds) - odor (eg. ammonia, hydrogen sulfide) coming from livestock, slaughterhouses, fertilizers, wastewater treatment burdensome for local society - ammonia from special cooling systems, typically discharged into the atmosphere	- waste water from production (technological), the storage of livestock, slaughtering and processing division, contains organic substances (fat and protein), suspension, bacteria, they get into the sewage in the form of blood, piece of meat, fat, hair, soil, fertilizer, detergents etc. - non-production waste generated during washing vehicles and equipment - sewage exceeds acceptable levels of pH, BOD_5, COD, dissolved solids and slurries	- slaughterhouse waste eg. skin, bristles, blood - used machine oils, scrap metal, etc. - manure from storage of livestock, slag, ash - sludge from sewage treatment plants, communal living waste - packaging waste

Branch	Pollutants emitted into the atmosphere	Type of wastewater	Type of waste
Fruit and vegetables industry	- carbon monoxide (CO), sulfur dioxide (SO_2), dust from the boiler - ammonia of cooling systems	- waste water resulting from washing the raw materials and blanching - waste water resulting from washing facilities and equipment - waste water from the boiler and cooling water systems - chemicals used in water treatment. - specific indicators of pollution are: variable pH value, high value of BOD_5, high concentration of suspension	- solid waste from of agricultural products - remnants of peeling vegetables and fruit - ash and slag from boilers - packaging waste - sludge from sewage treatment plants

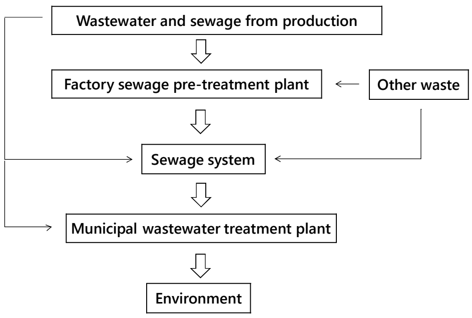
Branch	Pollutants emitted into the atmosphere	Type of wastewater	Type of waste
Dairy industry	- carbon monoxide (CO), sulfur dioxide (SO_2), solids from the coal fired boiler - dust coming from manufacturing lines of dry milk and whey - ammonia from cooling systems	- waste water from washing of floors and equipment - whey coming from cheese production - waste water from washing machines, boilers and cooling systems - chemicals precipitated during water softening - types of pollution: variable pH, high value BOD_5, fats, total suspension	- Ash and slag from boilers fired with coal - sludge from sewage treatment plants - rejects and scrap - packaging waste - municipal waste

Branch	Pollutants emitted into the atmosphere	Type of wastewater	Type of waste
Sugar industry	- carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), dust and dirt hydrocarbon from coal fired boilers and pulp dryers - dust created in lime (calcium oxide), sugar dust created during the transport, storage, packaging and briquetting of sugar - carbon dioxide (CO_2)and carbon monoxide (CO) in bulk gases generated in the saturation process - sulfur dioxide (SO_2)from the sulfur furnace	- waste in the form of plant residues, dirt, sand, oils and fats, chemicals, additives, products and detergents - cooling water - sewage usually exceeds acceptable levels of COD, BOD_5, total nitrogen, suspended solids and dissolved solids	- sludge and solid waste (beet and Packaging waste) - liquid waste (waste oils) - slag, sand, stones and contamination from beet

Concentration of pollutants in raw sewage from selected food plants

Branch	BOD5 [g O_2/m^3]	COD [g O_2/m^3]	Ether extract [g/m^3]	TSS [g/m^3]	Total phosphorus [g/m^3]	Total nitrogen [g/m^3]	pH
Potato industry	400-2500	700-4000	No data	200-1800	10-60	20-250	5-8
Sugar industry	600-1300	2500	No data	100-6500	10-70	10-200	6-9
Meat and poultry industry	200-1800	1000-3500	300-1000	400-1500	10-20	50-200	6-9
Dairy industry	100-2500	1000-5000	45-110	800-1000	5-20	55-160	6-9
Fruit and vegetable industry	200-1500	400-2800	10-1400	50-800	<1	<5	6-9
Fish industry	>7000	>10000	100-700	<3500	5-50	500	5-9
Oil industry	>5300	>8700	>6300	>2400	<100	No data	9-11

Sewage management in the food processing plants



Food wastewater in the environment

Main problems:

- organic substances (fat, oil, protein, carbohydrates)
- residues of detergents and disinfectants
- hot sewage, unfavorable pH
- microflora (pathogens, viruses etc.)

How to reduce possible threats?

- equalizing sewage
- avoiding the wave discharges
- work organization and cooperation

Basic of wastewater treatment in food industry

	Dissolved particles	Colloidal particles	Suspension	Rapidly sedimenting suspension
Size of particle, µm	<0.01	0.01-1	1-100	>100

Pre-treatment	Biological treatment	Specific
- mechanical - grates or sieves, settling tanks, flotation units, grease interceptors - mechanochemical - coagulants and polymers - fermentation of raw sewer (biogas recovery)	*including removal of biocompounds - nitrogen and phosphorus*	*ultrafiltration, reverse osmosis*

Chemical wastewater treatment process

involves application of selected chemical reagents, which due to their characteristics can be divided into:

- coagulants and flocculants
- disinfectants
- oxidizing agents
- reagents for correction of pH

Chemicals 1992	Chemicals 2012
PIX Calcium	PIX Polymers Iron blends PAX Aluminium blends Iron aluminium coagulants

Example of efficiency of sewage treatment for meat plant (slaughter and processing) with chemical treatment

[Flotation type DAF, PIX112 at a dose = 250 g/m³, flocculation with the anionic polyelectrolyte]

Parameter	Raw sewage	Sewage after treatment	Terms from municipal treatment plant
COD [mg O_2/dm³]	1954	480	1000
TSS [mg/dm³]	458	75	330
Ether extract [mg/dm3]	922	19	50
Total solutes [mg/dm³]	1083	1166	1200
Sulfur [mg/dm³]	194	292	420
Phosphates [mg/dm³]	26	0,3	Not applicable

Special consideration of chemical wastewater treatment in food industry

Branch	Strategies for wastewater treatment
Potato industry	- wastewater from washing - due to the low content of COD/BOD5 application of coagulants Fe (III) and Al is not necessary; they must be used for removal of hydrogen sulphide particularly when pH <8 iron coagulants, optionally oxidizing agents - technological sewage containing starch - the most common method is precipitation with the use of the coagulant and anionic or cationic polymer - in the biological purification iron coagulants are especially effective, which additionally eliminate hydrogen sulphide during dehydration and the storage of sludge
Spirit and yeast industry	use of Fe (III) is most commonly recommended for removing of hydrogen sulphide from the anaerobic processes
Fruit and vegetables industry	removal of suspended solids with its simultaneous compaction with the use of Fe (III) salts and appropriate polymer
Brewery industry	- due to low content of suspensions and colloids, coagulants are not used. - in the presence of hydrogen sulphide salts of Fe (III) may be used or oxidizing agents containing sulphate (VI) iron (III) and nitric acid (V)

Branch	Strategies for wastewater treatment
Sugar industry	Similarly to potato industry, but at pH<8 sewage comprising simple sugars, more easily undergoes anaerobic processes, combined with the emitting of hydrogen sulphide
Meat industry	- mechanochemical pretreatment of wastewater by means of DAF flotation system, involving salt of Fe (III) or Al and adjustment of the pH with the NaOH and the use of anionic polymer; main objective is fat removal before biological treatment or discharge to the sewage system - polyaluminum chlorides and iron (III) compounds are used to remove phosphorus, scum and swelling caused by bacteria
Dairy industry	- the pretreatment of wastewater by means of DAF flotation assisted with chemical coagulant and the polymer before discharge to sewer is used - coagulating compounds based on iron or aluminum are used during biological treatment processes
Fish industry	- mechanochemical pretreatment is frequently used; problems and methods similar to meat industry

Dairy wastewater treatment

- 11,183 million litres of milk were processed in Poland in 2011.
- milk consumption amounted 194 litres (without milk used for butter production) per capita
- water consumption was 0,7-2,5 m^3/t of processed milk
- 25.4 hm^3 of sewage was formed, of which 13.8 hm^3 waste water was treated (9.0 hm^3 biologically and 4.8 hm^3 with increased nutrient removal) and removed to the environment. The remaining 11.4 hm^3 did not require treatment or after pretreatment were discharged into the sewer
- BOD_5 value of milk is equal to 104 000 mg O_2/L

The sequence of processing used for cleaning

- pretreatment:
  - removal of the contaminants of large size – straining process
  - mineral removal – sedimentation on sand traps
  - removal of fat - flotation process,
  - averaging of wastewater
  - coagulation of colloidal particles
- treatment
  - removal of impurities easily degradable – biological processes (aerobic and anaerobic)

Flotation

- spontaneous flotation- spontaneous flow of fat to the surface
- assisted flotation- fat is taken up on the surface by means of gas bubbles (usually pressurized air)

Coagulation

- In the initial treatment of dairy wastewater process of coagulation may be used:
  - during pressurized air flotation (coagulants are dosed before the flotation chamber)
  - during biological treatment, when the precipitation will greatly reduce the pollution load

Activated sludge method

- single-use bioreactor - working with the secondary settling tank and a device for recirculation of sludge
- three-stage biological reactor - the division into three chambers: anaerobic, aerobic and hypoxic which allows for implementation of biological phosphorus removal, denitrification and nitrification
- Sequential Batch Reactor (SRB)

Example of research trends for wastewater management in the food industry

Short characteristic	Reference
Use of whey as an addition to cereals in the production of ethyl alcohol	Parashar A., Jin Y., Mason B., Chae M., Bressler D.C. Incorporation of whey permeate, a dairy effluent, in ethanol fermentation to provide a zero waste solution for the dairy industry. Journal of Dairy Science, 2015, 99: 1859-1867
The use of condensate from UHT process to provide high quality water for the boiler - purification by reverse osmosis	Suarez A., Fidalgo T., Riera F.A. Recovery of dairy industry wastewaters by reverse osmosis. Production of boiler water. Separation and Purification Technology, 2014, 133: 204-211
The possibility of using of a fat layer from dairy wastewater for production of biodiesel	Sivakumar P., Anbarasu K., Renganathan S. Bio-diesel production by alkali catalysed transesterification of dairy waste scum. Fuel, 2011, 90: 147-151
New methods for the recovery of whey proteins and lactose from the whey	Das B., Sarkar S., Sarkar A., Bhattacharjee S., Bhattacharjee C. Recovery of whey proteins and lactose from dairy waste: A step toward green waste management. Process Safety and Environmental Protection, 2016, 101: 27-33

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Thank you for your attention

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Questions

- Does the wastewater from food industry need to be pretreated before discharge into municipal wastewater treatment plant?
- What kind of method can be used to pretreat food industry wastewater?

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Puchlik M., Struk-Sokołowska J., Wołejko E., Wydro U. Problem oczyszczania ścieków z przemysłu spożywczego w małych i średnich przedsiębiorstwach. EKO-DOK 2016, VIII Konferencja Interdyscyplinarne Zagadnienia w Inżynierii i Ochronie Środowiska, 2016.

Smoczyński M. Nowe trendy w gospodarce wodno-ściekowej w przemyśle mleczarskim. Przegląd mleczarski, 2016, 7, 3-6.

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Chemicals, Oil/ Gas, Pharmaceutical, Pulp and Paper tanneries

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Water Harmony Erasmus+

Learning targets

- Understanding of oil removal method form water
- Understanding of heavy metal treatment technology
- Understanding of pharmaceutical treatment method
- Understanding of pulp and paper wastewater treatment technology

Water Harmony Erasmus+

Content

– Water purification from oil products
– Water purification from heavy metals
– Water purification in pharmaceutical industries
– Water purification in pulp and paper industries

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Water purification from oil products

Oil, incoming to oil processing plants, generally, passes pre-dehydration and desalination in industries.

Quality of pre-prepared oil depends on numerous factors and also on schemes, accepted for its preparation. Water, that contents incoming **oil**, fluctuates, in range **1 – 2 %**; **salt content** changed **from 50 until 1200 mg/L**. At high salt content the corrosion of equipment occurs, that's why, the main task of desalination installations is mostly fully removing of salt from oil.

The main pollutants of wastewaters of EDI installations are **oil products, de-emulsifiers** and **salts**.

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Water purification from oil products

Systems of oil processing plants wastewaters canalization

Volume of formed wastewaters depends on profile of the plant. So, at the plant of fuel profile it is minimal, of fuel-oil profile with oil chemistry – maximal.

Basically, at oil processing plants (OPP) following wastewaters formed, differed of pollutes composition:

polluted by **oil** and **oil products**; polluted by **chlorine salts**, **oil** and different de-emulsifiers; **sulfur hydrate** contained; contained of **ammonium sulfide** and **hydrosulfide**; contained of **phenol**, **coke breeze**, **wasted solutions of reactants**, different **dissolved organic substances**, **lead tetra ethyl**; polluted by **mineral acids**; from oil chemistry industries, polluted by different organic substances; from industries of additives and **synthetic oils**; household wastewaters. High number of wastewaters groups at OPP brings to necessity of separation it on two systems.

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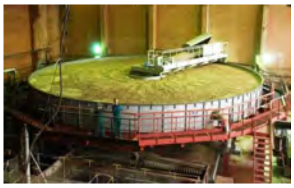
Water purification from oil products

Typical equipment

Floater (3D model)

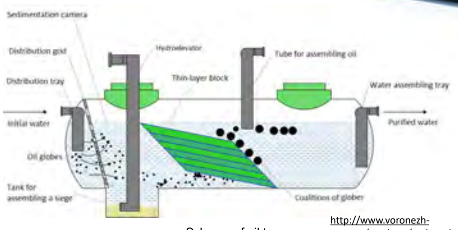


Floater (photo)

https://www.in-ekoteam.ru/krugovoj-flotator

Water purification from oil products

Typical equipment



Scheme of oil trap

http://www.voronezh-aqua.ru/products/vodopodgotovka/neftelovushki/

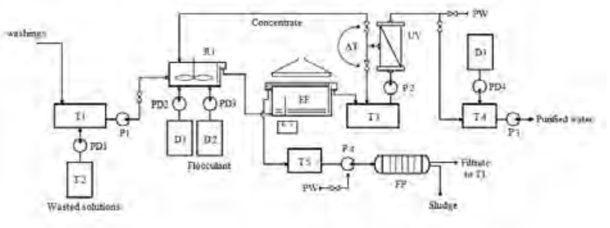
Water purification from heavy metals

The essence of reagent methods is: transferring of substances, soluble in water, into insoluble at adding of different reactants. Then reactants are removed from water as precipitate.

Disadvantage of reagent methods is: irreversible loss of raw substances with precipitates.

ЮФ17

Water purification from oil products



Typical scheme of water purification from oil products

http://www.hydropark.ru/projects/carwashing.htm

Water purification from heavy metals

Values of pH at precipitation of metal hydroxides

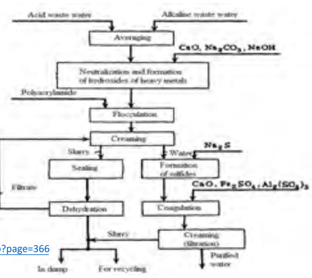
Kind of cation	Value of pH	
	Start of precipitation	Full precipitation
Fe^{2+}	7,5	9,7
Fe^{3+}	2,3	4,1
Zn^{2+}	6,4	8,0
Cr^{3+}	4,9	6,8
Ni^{2+}	7,7	9,5
Al^{3+}	4,0	5,2
Cd^{2+}	8,2	9,7

Water purification from oil products

http://vse-o-vode.ru/wp-content/uploads/2015/04/metody-ochistki-stochnyx-vod-31.jpg

3D model of water purification unit from oil products

Water purification from heavy metals



http://www.galvanicline.ru/show.php?page=366

Scheme of reagent purification of water from heavy metals

ЮФ17 Source acid-alkaline waste waters are entered into the averager T1, treated solutions of electrolytes are entered into the averager T2. Wasted solutions are dosed into T1 from T2 by the pump PD1. From the averager T1 waste water comes into the reactor R1 by the pump P1. Working solutions of reagents are dosed into the reactor 1 by pumps PD2 and PD3: sodium hydroxide for supporting of pH of formation of metals hydroxides, flocculant Superfloc A-100 for enlargement of dispersion phase and intensification of electric flotation. The reactor is set above the level of the electric floater EF for drift of liquid. From the R1 waste waters are entered into the EF, where the removing of dispersion substances takes place. From the EF clarified water is entered into the tank T3 by drifting. Clarified water from T3 is entered into the UV installation by the pump P2, where the finish purification of water from residual content of dispersion substances is occurred. From the UV purified water under residual pressure is entered into T4, the working solution of sulfuric acid is dosed by the pump PD4 for decreasing of pH.

Purified water responds of the norms of MPC for dumping into city canalization and requirements for filling into the system of reverse osmosis for desalting at organization of reversible water supply.

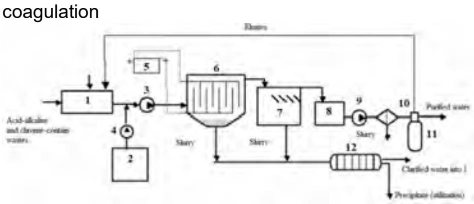
Floated sludge from the electric floater is entered into the tank T5. From T5 floated sludge is entered on the press filter FP by diaphragm pump P4, for dehydration. Dehydrated sludge (humidity 70 %) from the FP is entered for utilization.

The technology provides preliminary (T1, T2, R1) treatment of acid-alkaline, chrome- and cyanogen contained waste waters in independent technological chains.

Юра Феденко; 23.01.2018

Water purification from heavy metals

Electric coagulation

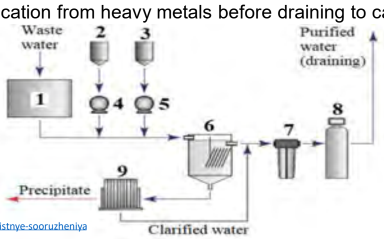


1 – Collection-drive; 2 – tank with pH corrector; 3, 4, 9 - pump; 5 – external accumulator; 6 – electric coagulator; 7 – sedimentation tank; 8 – collection-drive; 10 – filter; 11 – node of cleaning up; 12 – filter-press.

https://gsp-bmt.ru/services/1/112.html Typical scheme of electric coagulation

Water purification from heavy metals

Water purification from heavy metals before draining to canalization



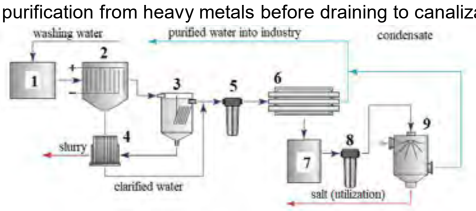
http://vskproekt.ru/ochistnye-sooruzheniya

1 – Averaging; 2, 3 – tanks for preparation of reagents; 4, 5 – dosage pumps; 6 – sedimentation tank with thin-layer module; 7 – mechanic filter; 8 – sorption filter; 9 – filter-press.

The effectivity of purification from heavy metals – to 99,5 %.

Water purification from heavy metals

Water purification from heavy metals before draining to canalization



1 – averaging; 2 – electric coagulator; 3 – thin-layer sedimentation tank; 4 – filter-press; 5 – mechanic filter; 6 – membrane module; 7 – tank for accumulation concentrate; 8 – mechanic filter; 9 – evaporation node.

The effectivity of purification from heavy metals – to 98 %.

Level of recirculation usage of water – to 95 %.

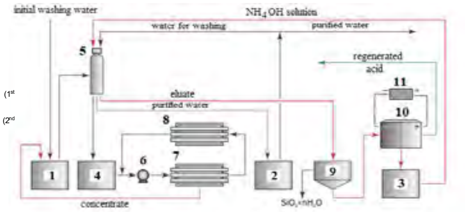
http://vskproekt.ru/ochistnye-sooruzheniya

Water purification from heavy metals

Water purification from heavy metals before draining to canalization

1 – tank for accumulation of washing water;
2 – tank for purified water;
3 – tank for ammonia hydroxide;
4 – tank for secondary washing water;
5 – ion exchange filter;
6 – pump;
7 – reverse osmosis membrane module (1st degree);
8 – reverse osmosis membrane module (2nd degree);
9 – filter-sedimentation tank;
10 – electric dialyser;
11 – rectifier.

Effectivity of purification:
Fluorides – to 99,9 %;
Silicon – to 99,95 %.

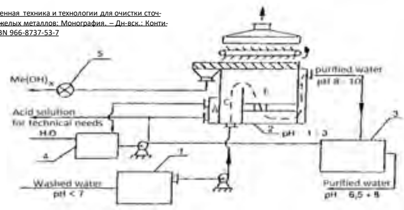


http://introsphera.ru/kompleksnye-sistemy/ochistka-stochnyx-vod-galvanicheskix-proizvodstv

Water purification from heavy metals

Water purification from heavy metals before draining to canalization

Долина Л.Ф.Современная техника и технологии для очистки сточных вод от солей тяжелых металлов: Монография. – Дн-вск.: Континент, 2008. 254 с. ISBN 966-8737-53-7



1 – averaging of washed water, 2 – electric floater with electric corrector of pH (C, A, E – cameras of cathode, anode and electric flotation, respectively); 3 – reactor of neutralization of purified solution; 4 – acid collector; 5 – vacuum-filter.

Scheme of non-reactant electrochemical module

Water purification from heavy metals

Water purification from heavy metals before draining to canalization

Indicators of purification of washed water from heavy metals

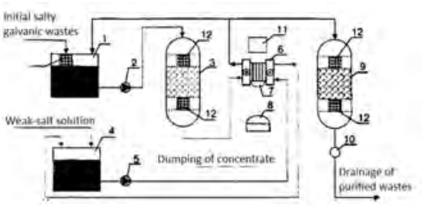
Indicator	Cu^{2+}	Ni^{2+}	Zn^{2+}	Cr^{3+}	Fe^{3+}
Concentration, mg/L initial residual	 50 – 100 0,5 – 1,6	 50 – 100 0,5 – 1,5	 50 – 100 0,4 – 1,5	 25 – 75 0,3 – 5,0	 10 – 50 0,05 – 0,15
Removal degree, %	99,4	99,4	99,3	99,3	99,8
Energy consumption, $kW \cdot h/m^3$	1,4 – 4,5	1,8 – 4,8	2,6 – 5,0	0,9 – 4,1	0,8 – 3,2

Water purification from heavy metals

Water purification from heavy metals before draining to canalization

Долина Л.Ф. Современная техника и технологии для очистки сточных вод от солей тяжелых металлов: Монография. – Дн-вск.: Континент, 2008. 254 с. ISBN 966-8737-53-7

1 – tank of initial wastes; 2 – pump of supplying of galvanic wastes; 3 – sorption reactor of pre-treatment; 4 – tank of weak-salt solution; 5 – washed pump; 6 – electroosmotic apparat of desalination – concentration; 7 – concentrate collector; 8 – container of concentrate; 9 – sorption reactor of extra-purification; 10 – counter of purified galvanic wastes; 11 – rectifier; 12 – net filter.



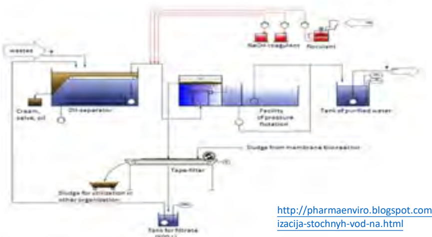
Principal technological scheme of installation of sorption-electrochemical purification of galvanic wastes

Water purification in pharmaceutical industries

- Waste waters of pharmaceutical industry are different of wide spectra of pollutants, and this raw is constantly replenished with new kinds of medical products: **for the treatment of sclerosis, oncology, mental disordered, antibiotics, insulin, veterinary products and many other.**

Methods of aerobic treatment in aerotanks are used for purification of waste waters in pharmaceutical branch. However, often this method isn't effective for removing of all potentially dangerous contamination components of waste waters. It's necessary to use other, more modern technologies.	Anaerobic technologies can be effectively used for removing of antibiotics (for example, tilozine and avilamicinum).

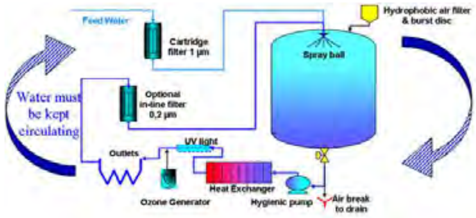
Water purification in pharmaceutical industries



http://pharmaenviro.blogspot.com/2011/12/nejtralizacija-stochnyh-vod-na.html

The example of arrangement of technological scheme of treatment of waste waters of industry of medical products

Water purification in pharmaceutical industries



Typical water storage and distribution schematic

http://www.envirochemie.ru/desisions/chemistry/

Water purification in pulp and paper industries

Pulp and paper industry is one of the most water-consuming branches of economics. Depending on quality and assortment of products, water costs for technics fluctuate in wide range. For example, 1 ton of carton and paper, produced from unbleached cellulose, responds 10 – 50 m^3 of waste water, from bleached cellulose – 150 – 250 m^3.

Waste waters of cellulose and paper enterprises, by character of pollutions, can be divided into 5 groups:

- **alkaline-containing,**
- **acid-containing (with mineral impurities);**
- **fiber-containing;**
- **bark-containing;**
- **foul-smelling (mainly, from some departments of sulfate-cellulose plant).**

Water purification in pulp and paper industries

Examples

The characteristic feature of waste water, forming at production of cellulose, is high content of different substances: **33% - inorganic (sodium sulfate, carbonate and chloride, free alkaline) and 67% - organic (including: hydroxyl acids, lactones – 33%, phenols, resin and fat acids – 23,65%, lignin – 35,7%, ant acid – 1%, acetic acid – 0.7%).**

Waste water of sulfite-cellulose enterprise contains 10% of inorganic and 90% of organic substances. Among inorganic substances, **lignosulfonic acids** are the most common **(48,4%)**, then **monosaccharides (30,4%), polysaccharides and products of saccharide degradation (15,8%), resins, proteins (2,9%), acetic acid (2,5%).**

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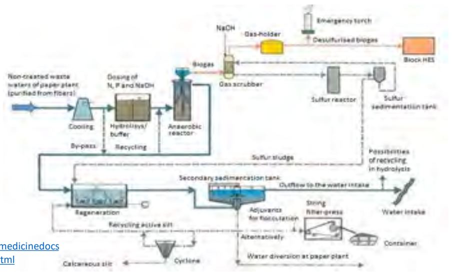
Water purification in pulp and paper industries



http://apps.who.int/medicinedocs/en/d/Js14060e/14.html

Scheme of two-stage purification of waste water with anaerobic reactor

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Questions

- What kind of technology are commonly used to remove oil from water?
- What kind of technology are commonly used to remove heavy metal from water?
- Can the anaerobic treatment process be used to treat pharmaceutical wastewater?

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Residuals Management

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Learning Targets

- Knowledge about the processes of residuals management
- Knowledge about sludge treatment like thickening, stabilisation and dewatering
- Knowledge about technologies and applications

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Origin of residuals

		Recycling	Treatment	Disposal
Mechanical Separation	Grit, Sieves			X
	Sedimentation	(X)	X	X
	Centrifugation	(X)	X	X
	Flotation	(X)	X	X
	Filtration	(X)	X	X
Chem./phys. Separation	Precipitation/Flocculation		X	X
	Ion-Exchange			X
	Vaporisation			X
	RO		X	X
Biol. Degradation	Aerobic Treatment		X	X
	Anaerobic Treatment		X	X

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Basic operation of residuals management

Sludge has to be treated before reuse or disposal.

Separation of water	Free water is removed by thickening Capillary water is removed trough dewatering Bound water can be removed by chemical or thermal means
Reduction of volume and mass	thickening dewatering Digestion drying
• Thickening	Gravity thickening Flotation thickening Centrifugation

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Thickening by sedimentation

Batch thickening

Continious thickening

Picket fence

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Thickening by machines – Disk thickener

[Huber company]

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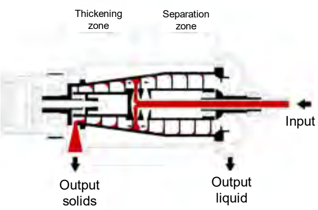
Thickening by machines – Centrifuges/Decanter



Artificial gravity field
countercurrent or current flow of sludge

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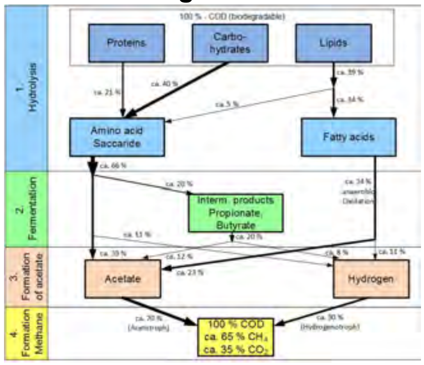
Scheme of anaerobic degradation



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Basic operation of residuals management

Sludge has to be treated before reuse or disposal.

Separation of water	Stabilisation
Reduction of volume- and mass	Partly degradation of org. matter
• Thickening	• aerobic • anaerobic (digestion)

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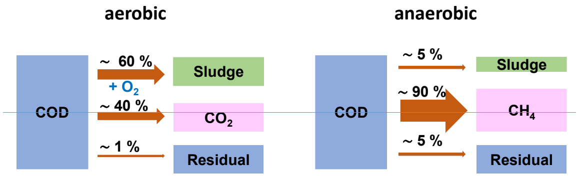
COD-Balance

- Comparison aerobic and anaerobic degradation



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Aims of sludge stabilisation

- Degradation of organic substances
  (not necessary for anaerobic wastewater treatment)

- Reduction of sludge volume
- Enhancement of dewatering
- Reduction of pathogens
- Use of biogas from digestion

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Aims of anerobic sludge stabilisation

- Degradation of organic substances
  (not necessary for anaerobic wastewater treatment)

- Reduction of sludge volume
- Enhancement of dewatering
- Reduction of pathogens
- Use of biogas from digestion

Benefits of anaerobic sludge digestion

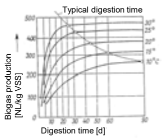
- Reduction of organic matter by approx. 50 % by sludge digestion
- mesophil: 15°C - 45°C
  thermophil: approx. 55 °C
- Degradation process:

$$2\ C_5H_7NO_2 + 8\ H_2O \Rightarrow 5\ CH_4 + 3\ CO_2 + 2\ NH_4^+ + 2\ HCO_3$$

$C_5H_7NO_2$ = organic substance (bacteria from aerobic treatment)

- Production of biogas

Biogas production by anaerobic digestion



	ratio [kg COD/kg VSS]	Specif gasvolume [NL/kg $VSS_{degraded}$]	CH_4 [Vol-%]	Energy [kWh/kg $VSS_{degraded}$]
Carbon-hydrates	1,2	830	50	4,2
Proteins	1,5	720	71	5,1
Fat/oil	2,5	1.430	70	10,0

Digestor

- Heating 30 – 37 °C
- Mixing important
- Process parameter:
  Temperature
  pH
  Gasvolume
  Gas composition
  organic acids

Gas utilisation

- **Gas engine**
  (CHPU –
  combined heat and power **unit)**
  Power: here 2 $MW_{electr.}$
  Efficiency $\eta_{electr.} \approx 39$ %

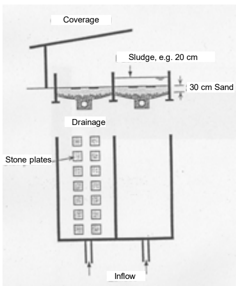
- **Gasturbine**
  Power: here 5,2 MW_{electr}
  Efficiency $\eta_{electr.} \approx 29$ %
  Gas and Steam-process $\eta_{electr.} \approx 42$ %

Basic operation of residuals management

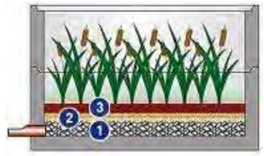
Sludge has to be treated before reuse or disposal.

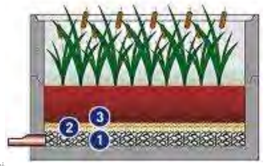
Separation of water	Stabilisation
Reduction of volume- and mass	Partly degradation of org. matter
• Thickening • Dewatering • Drying	• aerobic • anaerobic (digestion)

Dewatering in sludge beds



Dewatering in sludge humification beds





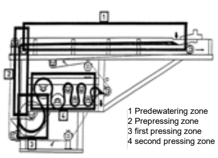
[Ekoplant GmbH]

Dewatering by machines

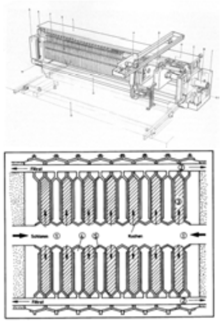
- Mechanical sludge dewatering:
  Output sludge with 18 – 30 % TSS
- Optimisation of Dewatering by use of flocculation substances for sludge conditioning
- Increase of sludge concentration up to
  20 - 45 % TSS
  (depending on sludge and ist composition).

Filtration units			artificial gravity
Belt press	Chamber filterpress	Membrane filterpress	Centrifuges (Dekanter)

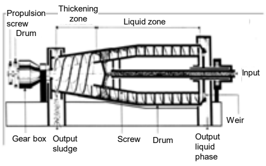
Dewatering by machines – belt press



Dewatering by machines – chamber filter press



Dewatering by machines – centrifuges (decanter)



Dewatering - suspended solids achieved

	Conditioning			TSS achieved[1]	Spec. Energy-consumption[2]
	$Ca(OH)_2$ [kg/m³]	$FeCl_3$ [kg/m³]	Polymer [g AS/kg TSS]	[%]	[kWh/m³]
Chamber filter press	15	5 – 7,5	-	28 – 40	1,5
Belt press	-	-	2,5 – 5,0	20 – 32	0,3 – 0,5
Centrifuge (Dekanter)	-	-	3,8 – 8,0	20 – 32	1,8 – 2,0
High performance centrifuge	-	-	4,0 – 8,0	28 - 40	1,8 – 2,2

[1] Depending of dewatering characterics of sludge
[2] Depending of flow [m³/h]

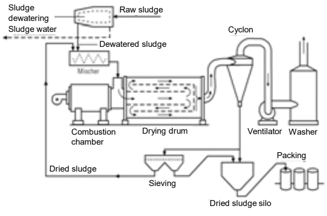
Solar sludge drying

For sludge after
dewatering
15 – 20 % TSS

Drying of sludge

- Reduction of water content by thermal drying of dewatered sludge
- Dewatering is inevitable before drying
- Sludge content after drying approx. 75 - 90% TSS
- Drying units manly on large wastewater treatment plants (> 50 000 p.e.)
- Dried sludge is hygienised and can be stored about longer times due to low water content (> 80 % TSS).

Drying of sludge



Basic operation of residuals management

Sludge has to be treated before reuse or disposal.

Separation of water	Stabilisation	Hygienisation	Mineralisation/ Inertisation
Reduction of volume- and mass	Partly degradation of org. matter	Reduction/ Killing of pathogens	Total degradation of organic matter
• Thickening • Dewatering • Drying	• aerobic • anaerobic (digestion)	• pH • Heating • Radiation	• Combustion • Gasification • Wet oxidation

Hygienisation

- External heating (pasteurisation) or self heating (addition of unhydrated lime)
- Thermal drying of sludge
- pH above 12.5
  - by adding of CaOH or unhydrated lime (CaO)

Basic operation of residuals management

Sludge has to be treated before reuse or disposal.

Separation of water	Stabilisation	Hygienisation	Mineralisation/ Inertisation
Reduction of volume- and mass	Partly degradation of org. matter	Reduction/ Killing of pathogens	Total degradation of organic matter
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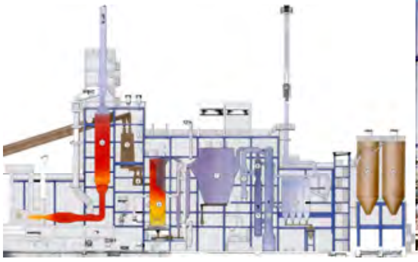
Combustion of sludge

- Inertisation of sludge by combustion



Pyrolysis

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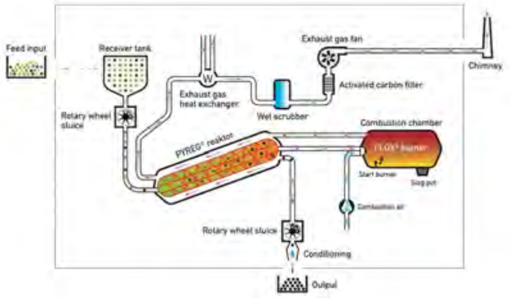
Pyrolysis of sludge



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Questions

- What are the aims of sludge thickening and dewatering?
- What is the aim of sludge stabilisation?
- Which solid concentrations can be achieved by sludge dewatering?
- When sludge has to be combusted?

Entrepreneurship

Entrepreneurship

Why you should consider becoming an entrepreneur

Prof. Harsha Ratnaweera

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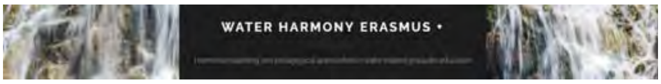


Topics covered in this presentation

- Inventions- Innovation- Entrepreneurship
- The role of entrepreneurship in education
- The hard realities
- Who are entrepreneurs?
- Encourage you to become an entrepreneur

Invention

Something new, that did not exist previously and that is recognized as the product of some unique intuition or genius. A product of the imagination; Something that has never been made before.

Innovation

- the successful implementation and adoption by society of something new. So an innovation is the successful commercialization or use (if non-profit) of an invention.

What Are Innovations?

- Innovations are new ways to achieve tasks.
- Types of innovations include:
  - Mechanical—tractors, cars.
  - Chemical—pesticides.
  - Biological—seed varieties.
  - Managerial—IPM, extra pay for work, overtime.
  - Institutional—water users' association, patents, banks, stock market, conservation districts, monks.

David Silberman, UCB

Entrepreneur

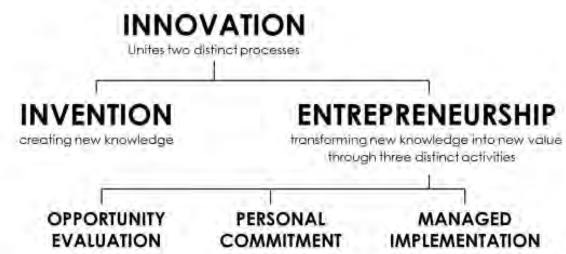
- Entrepreneurship is the pursuit of opportunity beyond resources controlled.
- Entrepreneurs are people that notice opportunities and take the initiative to mobilize resources to make new goods and services

Entrepreneurship

- They are individuals who take a concept and convert it into a reality. A product, policy or institution.
- They become the champions of a new process, and they are engines of change.
- Entrepreneurship occurs in all areas of life. In business, academy, government and Ngos.
- Entrepreneurs are everywhere, in Wall street and the Sahel.
- Entrepreneurship can be used for good and evil. The Godfather was an entrepreneur that misused his talent.

David Silberman, UCB

Invention – Innovation - Entrepreneurship



Greatest entrepreneurs of all times

- **John D. Rockefeller** was the richest man in history by most measures: Standard Oil
- **Andrew Carnegie's** steel mills were always on the leading edge of technology
- **Thomas Edison**: was an inventor and entrepreneur
- **Henry Ford** did not invent the automobile
- **Sam Walton**: WalMart
- **Bill Gates:** Microsoft
- **Steve Jobs:** Apple

These 10 succeeded by giving the customer something better, faster and cheaper than their nearest competitors

Greatest inventions

- Wheel, nail, compass, printing press, internal combustion engine, telephone, light bulb, penicillin, contraceptives, Internet…

Greatest innovations

- Robotics, genetic engineering, hypersonic transportation, free energy, artificial intelligence, nano technology, human cloning, antigravity, automation, hydrogen generated power cars

Inventors who were not entrepreneurs

In 1938, Laszlo Biro patented the **ballpoint pen**, after becoming fed up with leaky fountain pens. He sold it to Marcel Bich in 1945, whose company Bic pocketed the majority of the cash from the 100 billion that have been sold since.

Mikhail Kalashnikov invented the **AK-47** in 1947, and more than 100 million manufactured since. But while the weapon's official manufacturer did patent the design in the 1990s, Kalashnikov never did. He said he created it for the good of his country.

Why entrepreneurship education?

- Unemployment and underemployment, particularly among young people, is one of the main challenges in the fight against poverty globally. Job creation is the main road out of poverty.
- One of the most effective instruments in order to create more businesses and more jobs - and students can try it even before graduating!

The facts

- Those who receive entrepreneurship education establishes more businesses than others do, their companies are larger and they have greater turnover.
- Water Harmony projects have an ambition to introduce entrepreneurship as a subject.

The hard realities

- Most inventions never make to the market.
  - A Canadian study*:
    - 93% never make to the market
    - Only 2.8% made profits
- How many patents and inventor's certificates known to you?
- How many of them give realistic paybacks?

☹Lack of entrepreneurs (provided the invention is good)

**The economic journal, 2005*

Who are entrepreneurs?

- Original thinkers
- Risk takers
- Take responsibility for own actions
- Feel competent and capable
- Set high goals and enjoy working toward them

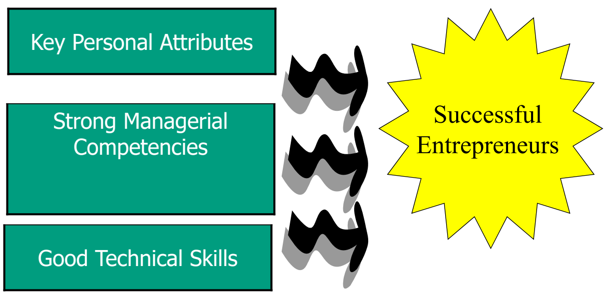
Successful and unsuccessful entrepreneurs

Successful
- Creative and Innovative
- Position themselves in shifting or new markets
- Create new products
- Create new processes
- Create new delivery

Unsuccessful
- Poor Managers
- Low work ethic
- Inefficient
- Failure to plan and prepare
- Poor money managers

English, et al

Characteristics of Entrepreneurs



English, et al

Key Personal Attributes

Entrepreneurs are made, not born!

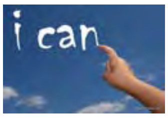
Key Personal Attributes cont.)

- Need for achievement
  - –A person’s desire either for excellence or to succeed in competitive situations
  - –High achievers take responsibility for attaining their goals, set moderately difficult goals, and want immediate feedback on their performance
  - –Success is measured in terms of what those efforts have accomplished

English, et al

Key Personal Attributes (cont.)

- Desire for Independence
  - –Entrepreneurs often seek independence from others
  - –As a result, they generally aren’t motivated to perform well in large, bureaucratic organizations
  - –Entrepreneurs have internal drive, are confident in their own abilities, and possess a great deal of self-respect



Key personal attributes (cont.)

- Self-confidence
  - –Because of the high risks involved in running an entrepreneurial organization, having an “upbeat” and self-confident attitude is essential
  - –A successful track record leads to improved self-confidence and self-esteem
  - –Self-confidence enables that person to be optimistic in representing the firm to employees and customers alike

Key personal attributes (cont.)

- Self-sacrifice
  - –Essential
  - –Nothing worth having is free
  - –Success has a high price, and entrepreneurs have to be willing to sacrifice certain things

Entrepreneurship is not for everyone!!

But it may be suitable for some (or many) among you

Technical Proficiency

- Many entrepreneurs demonstrate strong technical skills, typically bringing some related experience to their business ventures
  - –Your opportunity!

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Many good practices to proceed

- Business Plan – A step-by-step outline of how an entrepreneur or the owner of an enterprise expects to turn ideas into reality.

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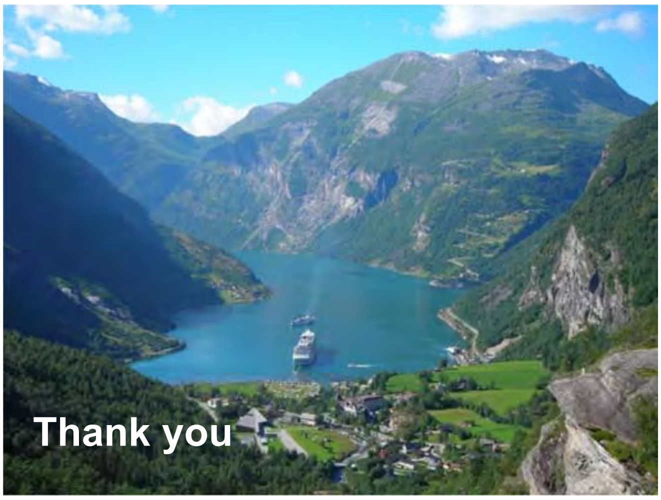
Conclusion

Entrepreneurs are made, not born!

Think what you can do for the field your are specializing in!



Entrepreneurship
Planning process

Prof. Harsha Ratnaweera

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Value proposition

- A value proposition is a promise of value to be delivered. It's the primary reason a prospect should buy from you.
- In a nutshell, value proposition is a clear statement that
  - explains how your product solves customers' problems or improves their situation (relevancy),
  - delivers specific benefits (quantified value),
  - tells the ideal customer why they should buy from you and not from the competition (unique differentiation).

- You have to present your value proposition as the first thing the visitors see on your home page, but should be visible in all major entry points of the site.
- It's not just for aesthetics, or to placate a CEO or copywriter, but ultimately, to improve your customer lifetime value.

For what?

- It's for people to read and understand
- Value proposition is something real humans are supposed to understand. It's for people to read. Here's an example of what a value proposition is NOT supposed to be like:
- *"…Revenue-focused marketing automation & sales effectiveness solutions unleash collaboration throughout the revenue cycle…"*

What the value proposition is NOT

- It's not a slogan or a catch phrase. This is not a value proposition:
  - L'Oréal. Because we're worth it.
- It's not a positioning statement. This is not a value proposition:
  - America's #1 Bandage Brand. Heals the wound fast, heals the hurt faster.
- Positioning statement is a subset of a value proposition, but it's not the same thing.

What the value proposition consists of

- The value proposition is usually a block of text (a headline, sub-headline and one paragraph of text) with a visual (photo, hero shot, graphics).
- There is no one right way to go about it, but I suggest you start with the following formula:
  - Headline. What is the end-benefit you're offering, in 1 short sentence. Can mention the product and/or the customer. Attention grabber.
  - Sub-headline or a 2-3 sentence paragraph. A specific explanation of what you do/offer, for whom and why is it useful.
  - 3 bullet points. List the key benefits or features.
  - Visual. Images communicate much faster than words. Show the product, the hero shot or an image reinforcing your main message.

Checklist

- What product or service is your company selling?
- What is the end-benefit of using it?
- Who is your target customer for this product or service?
- What makes your offering unique and different?
- Use the headline-paragraph-bullets-visual formula to structure the answers.

What makes a good value proposition:

- Clarity! It's easy to understand.
- It communicates the concrete results a customer will get from purchasing and using your products and/or services.
- It says how it's different or better than the competitor's offer.
- It avoids hype (like 'never seen before amazing miracle product'), superlatives ('best') and business jargon ('value-added interactions').
- It can be read and understood in about 5 seconds.

Growth Goals

Core growth goals, near-term/long-term:
•Xxx
•Yyy

For example: number of users, sales, revenue, signing up partners, etc.

Market expansion goals, near-term/long-term:

Near-term goals	Key barriers	Needs
•xxx		
•yyy		

Long-term goals	Key barriers	Needs
•xxx		
•yyy		

Value Proposition

Fill in the template for each of your target segments:

__________ (Our product) is a__________ that __________ (key benefit)
Unlike ___________ (key competitor), ____________ (our product) for ____________ (beachhead customer) who _______________ (key purchasing motivation)
____________ (value to customer relative to competitors) and ____________ (results).

Examples:

Our innovation is a: (customer-language)
That: (key benefit)
Unlike: (current state/key competitors)
Ours: (key differentiators)
For: (beachhead customer)
Who: (key purchase motivation insight)
At a price/value: (relative to competitors)
Value Outcomes/Results: (client deliveries)

"Autorola offers auto remarketing and sales services coupled with an online auction platform producing long tail buying power for fleet, OEM, bank, insurance and leasing companies, maximizing customer return on assets and financial outcomes, optimizing inventory, cash flow and pricing, while simplifying logistics and minimizing asset risk."

Current Business Model/Future/"Optimized" Business Model

Map out your current business model, then map out the optimized model for reaching your growth goals.

•Develop a concise description of your current business model of your venture in structured language, and a description of your proposed "optimized" model.

•Craft a diagram of your business model describing the key value-added operational functions, revenue producers and how the firm is related to customers and other providers and suppliers upstream or downstream.

•Is the business model scalable in relation to your long-term goals?

•Are there areas of the business you can "lean" out?

Market segmentation

Target segments, Product fit:

Segments	Customer pain	Alternatives (customer's proucts/status quo)	Product (feature) solution
x	Pain x (Which problem does the customer need a solution to?)	Alternative x (What are the current alternative solutions to the customer's pain?)	Product feature x (Which product/product features address the specific pain?)
y			
z			

Adjust the segmentation scheme to suit your offering and potential customers. Consider factors such as geography, industry, B2C vs. B2B, different levels and areas of decision making at the customer, etc.

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Market segmentation

Target segments, Market attractiveness:

Segments	Size	Growth	Strength of competitors	Collaboration potential	Entry barriers
x					
y					
z					

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Market segmentation

Target segments, internal capacity to address them:

Segments	Comparative strength to competitors	Own entry barriers	Competences	Resources
x				
y				
z				

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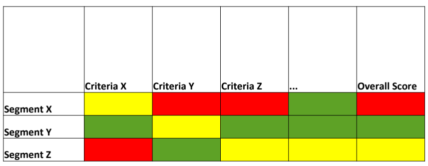
Assessment of segment strength

Example – where is your differentiation most valuable?

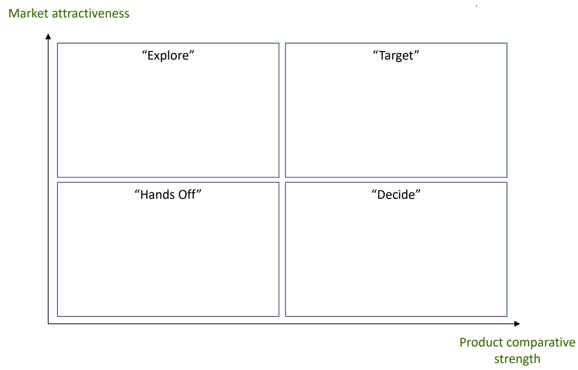
Assess the strength of your product relative to customers' pains and alternatives by assigning a score to each: green (positive) vs. yellow (neutral) vs. red (negative), which gives an indication of the attractiveness of the segment vs. your offering.

Value drivers = identified characteristics that matter in each segment



Based on the results of the assessment, establish your beachhead.

Select your beachhead



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Draft marketing plan

For your selected market (the beachhead)

Describe your segment in terms of the current ideal customer:
•Attribute x
•Attribute y
•Attribute z

Examples of such current ideal customers:
•Name of company/customer x
•...
•...

Based on the above, list your specific Business Development Goals:
•Goal x
•...
•...

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Marketing plan continued

For each of these business goals,

1.Define marketing strategy and tactics

- What is your overall purpose of marketing your product (generating leads, creating awareness, etc.)?
- Who are you targeting?
- How will you target them (what type of advertising, direct marketing, etc.)?
- Other sources of marketing (sponsorships, partnerships, etc.)?

2.Identify Sales Strategy and Tactics

- Which channels are available, which are most appropriate for you to use (direct sales, distributors, OEMs, etc.)?
- For each chosen channel, which steps must be taken to ensure efficacy.

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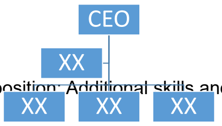
Management

1. Inventory key competences on team
   - XXXX
   - YYYY
   - ZZZZ
2. Identify core competences needed to execute on marketing plan
   - YYYY:
   - YYYY:
3. Design management organization for the venture



4. Design board composition: Additional skills and competences needed

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Financial model

- Pricing strategy:
  1. Companies should consider:
  - Company's strategic goals (for example, market penetration, sales volumeetc.)
  - Cost (fixed, variable, competitor cost)
  - Market (How are competitors pricing? What is common in the market? Can you innovate?)
  - Model (transaction, per use, upfront/installation fees, invisible fees, service fees, licensing, subscription, advertisement, upgrades, discounts, etc)
  2. Determine unit economics
  – Key revenue
  – Key cost drivers
- Estimated investment needed

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Prepare your pitch

Sales Pitch

What are the key messages your sales people need in order to communicate your value proposition:

- Need (What is your audience's need?)
- Approach (How do you solve that need?)
- Benefits (What are the benefits of your approach—top 3?)
- Competition (How are you different or better from your competitors?)

To consider:

- Internal vs. External sales pitch

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Prepare your pitch

Prepare a Venture pitch for X minutes, including the following elements:

•Opener and audience connection
•Opportunity and value proposition
•Business Model
•Market and penetration strategy
  •Market characteristics and competitors
  •Market segments
  •Positioning
  •Pricing
  •Target market and beachhead
  •Integrated business development, marketing and sales strategy
•Implementation and rollout
•Management and personnel
•Financials
•Financial opportunity/outcomes
•Closer and exit

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DOSCON – VP

- B2B: DOSCON is an intelligent dosing control system for existing and new WWTPs that supplements traditional control systems for overall automation system suppliers and results in a more economical and environmentally sustainable wastewater coagulation process. DOSCON system uses 5-20% fewer coagulants than traditional systems with improved treatment efficiencies thereby increasing the competitiveness of total automation systems. The investment and O&M costs for DOSCON is far less than annual savings

- B2C: DOSCON is an intelligent dosing control system for existing and new WWTPs that supplements traditional control systems for plant owners and consulting engineers and results in a more economical and environmentally sustainable wastewater coagulation process. DOSCON system uses 5-20% fewer coagulants than traditional systems with improved treatment efficiencies. The investment and O&M costs for DOSCON is far less than annual savings.

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Market segments

Geography	Size (given as Chem costs)	Type	State	Compliance with regulatory (customer pains)	Costs (customer pains)	Organizational type	Customer type / distribution channels ?
Observables	++, can be estimated	++	+++	No secure info, direct communication	+, lack of awareness?	Customer contact	
Norway	<100 000	Pure chem	Existing	Acceptable	Need to reduce	Cost concerned	Consulting engineers
Scandinavia	100'-250'	Bio-chem	Design/planning	Not acceptable	Acceptable	Regulatory concern	System suppliers (ABB, Siemens)
Europe	250'-500'					Both cost & regulatory concern	Service providers (Veolia, Anglian water)
China	500-2 mill						WWTP
US	>2 mill						

Target markets

Geography	Size (given as Chem costs)	Type	State	Compliance with regulatory	Costs	Organizational type	Customer type / distribution channels?	Customer
Observables	++, can be estimated	++	+++	No secure info, direct communication	+, lack of awareness ?	Customer contact		
Norway	>2 mill	Pure chem	Existing	Not acceptable	Need to reduce	Cost concerned	WWTP	Hamar LRF
Norway	> 2mill	Pure chem	Existing	Acceptable	Acceptable	Cost concerned	WWTP	Lillestrøm
Poland	500'-2 mill	Pure Chem	Existing	Not acceptable	Need to reduce	Cost concerned	WWTP	Koszalin
China	500'-2 mill	Pure Chem	Existing	Not acceptable	Need to reduce	Cost concerned	WWTP	Jiaxing

Positioning statement

- Differentiator:
  - A control system which saves >10% chemicals and sludge treatment costs and give better & even effluent quality
- PS: DOSCON is an intelligent dosing control system for existing and new WWTPs that supplements traditional control systems for plant owners and consulting engineers and results in a more economical and environmentally sustainable wastewater coagulation process. DOSCON system uses 5-20% fewer coagulants than traditional systems with improved treatment efficiencies. The investment and O&M costs for DOSCON is far less than annual savings

Business Dev Goals (relationships)

- Alliances: WWTP associations in Scandinavia + EU
- R&D partner: NIVA
- Financing partners: Innovation Norway, Nutek, Dansk industri, Polish Ecofund
- Development of DOSCON as a robust and efficient organisation

Marketing strategy & tactics

- Direct marketing, trade fares, conferences, user organizations, web ....
- Demo via reference- and pilot installations / word of mouth
- Annual recalibration to fit plant changes and increase optimizations
- Increasing reference user group?

Sales strategy & tactics

- Direct sales, special offers at trade fares & for members of user organizations,
- "try & buy", flexible pricing (stepping up with time), subscription
- Service, replacement and recalibration policies
-

Pricing strategy

- Fixed price based on selected parameters
- Low investment & subscription based on annual savings
- Fi

Core milestones

- 1Q 2009: Prototype is completed
- 1Q 2009: Agreements with 2 NO plants secured
- 2A 2009: Trade fare Poland
- 2Q 2009: Reference tests in 2 NO plants to be completed
- 2Q 2009: Agreements with 2 PL plants secured
- 3Q 2009: Web based service & calibration establishied
- 3Q 2009: Secure financing of 1 mill Euro
- 3Q 2009: Completion of prototype-II, ver 1.0
- 3Q 2009: Agreements with 2 CN plants secured
- 3Q 2009: Trade fare China + marketing
- 3Q 2009: Reference tests in 2 PL plants to be completed
- 4Q 2009: Web based installation developed & tested
- 4Q 2009: trade fare Norway + marketing
- 1Q 2010: Reference tests in 2 CN plants to be completed
- 1Q 2010: Venture capital secured
- 2Q 2010: Prototype upgraded, ver 2.0
- 2Q 2010: Product launch
- 30 customers within 3 years

Core competences

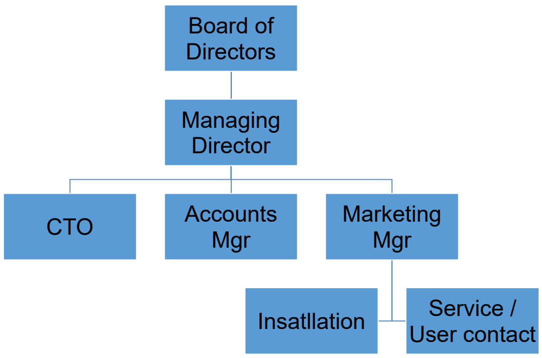
Core (next 3 years)

- Management
- Marketing
- Logistics
- Accounting
- Installation
- User support
- Product upgrading
- Modeling / control theory / PLC programming

Required:

- Financing / venture capital

Management organization



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University-Industry Collaborations

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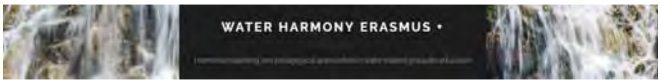

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Topics covered in this presentation

- Background and ambitions
- Different forms of UIC
- The UIC formation process
- Challenges and how to overcome
- European Best Practices

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University- Industry collaboration (UIC): why and how?

- UIC is not new, but started over 100 years ago
- UIC is increasingly a critical component of efficient national innovation systems.
- Useful to examine the experience of various countries to better understand the different types of UIC, motivations to form these agreements and barriers to cooperation, and the role of public policy in fostering such linkages
- Developing countries face even greater barriers to such alliances, calling for a differentiated approach to promoting university-industry collaboration.

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An ambition to any UIC…

- Rise of a global knowledge economy has intensified the need for strategic partnerships that go beyond the traditional funding of discrete research projects.
- World-class research universities are pioneering such partnerships. They run longer, invest more, look farther ahead and improve the competitiveness of companies, universities and regions.
- Such collaborations transform the role of the research university for the 21st century, anchoring university as a vital centre of competence to help tackle social challenges and drive economic growth.

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UIC objectives, scopes and institutional arrangements

High (Relationships)	Research partnerships	Inter-organizational arrangements for pursuing collaborative R&D, including research consortia and joint projects.
	Research services	Research-related activities commissioned to universities by industrial clients, including contract research, consulting, quality control, testing, certification, and prototype development.
	Shared infrastructure	Use of university labs and equipment by firms, business incubators, and technology parks located within universities.
Medium (Mobility)	Academic entrepreneurship	Development and commercial exploitation of technologies pursued by academic inventors through a company they (partly) own (spin-off companies).
	Human resource training and transfer	Training of industry employees, internship programs, postgraduate training in industry, secondments to industry of university faculty and research staff, adjunct faculty of industry participants.
Low (Transfer)	Commercialization of intellectual property	Transfer of university-generated IP (such as patents) to firms (e.g., via licensing).
	Scientific publications	Use of codified scientific knowledge within industry.
	Informal interaction	Formation of social relationships (e.g., conferences, meetings, social networks).

High to low intensity

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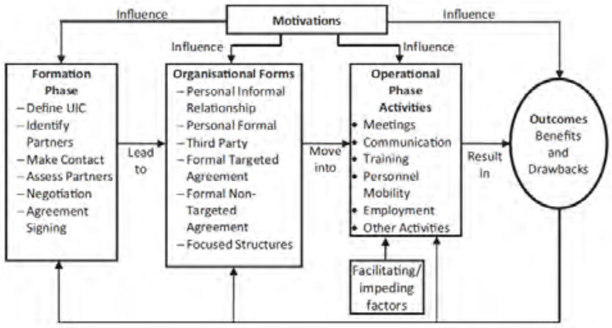
Difference between most and least developed countries

	Most developed countries	**Least developed countries**
Teaching University	• Private participation in graduate programs • Joint supervision of PhD students	• Curricula development to improve undergraduate and graduate studies • Student internships
Research University	• Research consortia and long term research partnerships to conduct frontier research	• Building absorptive capacity to adopt and diffuse already existing technologies • Focus on appropriate technologies to respond to local needs
Entrepreneurial University	• Spin-off companies, patent licensing • Entrepreneurship education	• Business incubation services • Entrepreneurship education

The process



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Motivations - I

Universities		Industry
Necessity	– Responsiveness to government policy – Strategic institutional policy	– Responsiveness to government initiatives/policy – Strategic institutional policy
Reciprocity	– Access complementary expertise, state-of-the-art equipment and facilities – Employment opportunities for university graduates	– Access to students for summer internship or hiring – Hiring of faculty members
Efficiency	– Access funding for research (Government grant for research & industrial funding for research assistance, lab equipment, etc.) – Business opportunity, e.g. exploitation of research capabilities and results or deployment of IPR to obtain patents – Personal financial gain for academics	– Commercialize university-based technologies for financial gain – Benefit financially from serendipitous research results – Cost savings (easier and cheaper than to obtain a license to exploit foreign technology) – National incentives for developing such relations such as tax exemptions and grants – Enhance the technological capacity and economic competitiveness of firms – Shortening product life cycle – Human capital development

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Motivations - II

Stability	– Shift in knowledge based economy (growth in new knowledge) – Discover new knowledge/test application of theory – Obtain better insights into curricula development – Expose students and faculty to practical problems/ applied technologies – Publication of papers	– Shift in knowledge based economy (growth in ne knowledge) – Business growth – Access new knowledge, cutting-edge technolog state-of-the art expertise/research facilities and complementary know-how – Multidisciplinary character of leading edge technologies – Access to research networks or pre-cursor to oth collaborations – Solutions to specific problems – Subcontract R&D (for example due to lack of in house R&D) – Risk reduction or sharing
Legitimacy	– Societal pressure – Service to the industrial community/society – Promote innovation (through technology exchange) – Contribute to regional or national economy – Academics' quest for recognition or achieve eminence	– Enhancement of corporate image
Asymmetry	– NA	– Maintain control over proprietary technology

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Organisational forms - I

Personal Informal Relationships	– Academic spin-offs – Individual consultancy (paid for or free) – Information exchange forums – Collegial interchange, conference, and publications – *Joint or individual lectures* – *Personal contact with university academic staff or industrial staff* – *Co-locational arrangement*
Personal Formal Relationships	– Student internships and sandwich courses – *Students' involvement in industrial projects* – Scholarships, Studentships, Fellowships and postgraduate linkages – *Joint supervision of PhDs and Masters theses* – Exchange programmes (e.g. secondment) – Sabbaticals periods for professors – *Hiring of graduate students* – *Employment of relevant scientists by industry* – *Use of university or industrial facility (e.g., lab, database, etc.)*
Third Party	– Institutional consultancy (university companies including Faculty Consulting) – Liaison offices (in universities or industry) – *General Assistance Units (including technology transfer organizations)* – Government Agencies (including regional technology transfer networks) – Industrial associations (functioning as brokers) – *Technological Brokerage Companies*

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Organisational forms - II

Formal Targeted Agreements	– Contract research (including technical services contract) – *Patenting and Licensing Agreements (licensing of intellectual property rights)* – Cooperative research projects – *Equity holding in companies by universities or faculty members* – Exchange of research materials or Joint curriculum development – *Joint research programmes (including Joint venture research project with a university as a research partner or Joint venture research project with a university as a subcontractor)* – Training Programmes for employees
Formal Non-Targeted Agreements	– Broad agreements for U-I collaborations – *Endowed Chairs and Advisory Boards* – *Funding of university posts* – *Industrially sponsored R&D in university departments* – Research grant, gifts, endowment, trusts donations (financial or equipment), general or directed to specific departments or academics
Focused Structures	– Association contracts – Innovation/incubation centers – Research, science and technology parks – University–Industry Consortia – University–Industry research cooperative research centers – *Subsidiary ownerships* – *Mergers*

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UIC formation process

Stages	Steps
Formation process	
Stage 1: Partnership Identification	– Establish the purpose – Obtain general knowledge of the capabilities of potential partners – Consider pre-existent relationships
Stage 2: Make Contact	– Identify prospective partners
Stage 3: Partner Assessment and Selection	– Objectively assess the strategic interests of the potential partners – Analyze actual versus professed capabilities of potential partners – Determine and organize the appropriate mix of partners – Choose the partners
Stage 4: Partnership Negotiation	– Define the partnership – Define and agree on the partnership's documented purpose or mission/vision – Determine the specific common goals/objectives for the particular effort – Define the organizational structure of the partnership – Define the management and administration of the partnership with clearly defined responsibilities – Agree on the plan – Specify the milestones – Identify the measures/indicators for success – Specify the interim and/or final deliverables
Stage 5: Agreement Signing	– Preparation and signing of collaboration agreement and/or intellectual property agreement

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Activities during UIC

Activities	
Meetings & Networking	– Meetings (often in a formal way) – Conferences/Workshops/Seminars/Symposia/Forums – Expositions, Trade Shows/Fairs/Exhibitions – Informal social gatherings (e.g. U-I get-togethers, breakfast meetings) – Networking activities (the process of contacting and being contacted and maintaining these relationships/links)
Communication	– Communications by voice/mail/email/conference calls (formal or informal) – Publications or co-publications of research papers, reports, newsletters, booklets, bulletins, pamphlets
Training	– Tailored educational programmes for industrial personnel – Internships in company for students – Students' involvement in industrial projects – Joint supervision of Masters degree dissertations and PhD Thesis by academic and industry personnel – Industrial fellowships for students and faculty – Industry involvement in curriculum development
Personnel Mobility	– Exchange of personnel to work at one another's research facilities – Lectures by industry members at universities and vice versa
Employment	– Employment of university researchers in the business sector – Employment of graduates particularly those related to the project – Representation on Industry Boards or University Committees

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Factors that facilitate or impede UICs- I

Main categories	The factors
Capacity and Resources	– Adequate resources (funding, human and facilities) – Incentive structures for university researchers – Recruitment and training of technology transfer staff – Capacity constraints of SMEs
Legal Issues, and Contractual Mechanisms	– Inflexible university policies including intellectual property rights (IPR), patents, and licenses and contractual mechanisms – Treatment of confidential and proprietary information Moral responsibility versus legal restrictions (research on humans)
Management and Organization Issues	– Leadership/Top management commitment and support – Collaboration champion – Teamwork and flexibility to adapt – Communication – Mutual trust and commitment (and personal relationships) – Corporate stability – Project management – Organization culture (cultural differences between the world of academia and of industry)

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Factors that facilitate or impede UICs- II

Main categories	The factors
	– Organization structure (university administrative structure and firm structure) – Firm size (size of organization) – Absorptive capacity – Skill and role of both university and industry boundary spanners – Human capital mobility/personnel exchange
Issues Relating to the Technology	– Nature of the technology/knowledge to be transferred (tacit or explicit; generic or specialized; academic rigor or industrial relevance)
Political Issues	– Policy/legislation/regulation to guide/support/encourage UIC (support such as tax credits, information networks and direct advisory assistance to industry)
Social Issues	Enhancement in reputation/prestige
Other Issues	– Low level of awareness of university research capabilities – Use of intermediary (third party) – Risk of research – Cross-sector differences/similarities – Geographic proximity

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Challenges in UIC

- Inherent mismatch between the research orientations of firms and universities, with an excessive focus on fast commercial results in firms and on basic research in universities. Collaboration is costly and the returns only accrue in the medium to long run, but firms seek short-term results and clear contributions to current business lines.
- In terms of outputs, firms are usually interested in how quickly new patents or new products can be obtained, and want to delay publications to avoid disclosing information. University researchers, in contrast, are typically motivated to publish research results as fast as possible.
- Industry is concerned about secrecy and misalignment of expectations with regard to intellectual property (IP) rights and making a profit from them. Thus agreements need to be established in a commercially timely manner that ensures the ability to commercialize with appropriate returns.
- Difficulties in negotiating a collaboration include lack of information, difficulties finding contact persons, and transaction costs of finding the right partner, among others.

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How to overcome challenges?

- Successful UIC should support the mission of each partner. Any effort in conflict with the mission of either partner will ultimately fail.
- Institutional practices and national resources should focus on fostering appropriate long-term partnerships between universities and industry.
- Universities and industry should focus on the benefits to each party that will result from collaborations by streamlining negotiations to ensure timely conduct of the research and the development of the research findings.

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European Best Practices

- University leadership is vital
- Long-term strategic partnerships with built-in flexibility work best
- Start with a shared vision and develop a strategy
- Put the right people in charge – those who cross boundaries
- Kick-start the dialogue – encourage cross-fertilisation of ideas
- Don't get hung up on intellectual property (IP)
- Promote a multidisciplinary approach to research and learning
- Don't get hung up on measuring the results of a strategic alliance
- Redefine the role of the research university as a source of competence and problem-solving for society

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Tools in entrepreneurship

IPR, NDA, Value propositions, Pitching, Business plans, Financing innovations and commercialisation process

NDA – Non Disclosure Agreement

- A formal document where parties agree and acknowledge ownership to ideas which are in various stages of realization.
- Partners will feel safer to disclose their ideas
- Although only one person signs the NDA, it will regulate the conditions of the organization
- It is not a sign of distrust, rather the opposite
- Mutual NDAs common

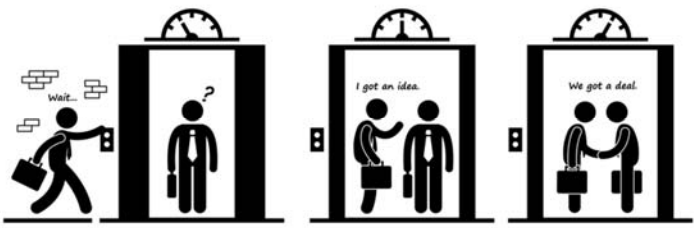
IPR – Intellectual Property Rights

- Regulated by national and international laws
- Ownership declaration, author certificates, patents or simply secrecy of know-how
- Can be used in a legal process

- Patenting could be very expensive
- Even with a patent, your IPR is not fully protected
- “Patented” and “Patent pending” reduces the chances of plagiarism but will not prevent it.

The marketing and financing

The «elevator pitch»



- Objective is to get an opportunity present your idea, not to get the offer at once.

How to get attention to you among others??

- We have limited time and access to information is exponentially increasing.
- Electronic media aggressively, unconsciously and uncontrollably access us.

- How many times we browsed webpages for less than few seconds before we leave that page?
- How many times we skipped our attention to a lecture at a conference because we thought “it was not for us”?

- Many valuable ideas, concepts might have missed ours (and other persons important for you) just because we could not “sell” our idea within a short time frame in a manner that others understood it?

Developing a Value Proposition VP

- __________ (Our product) is a__________ that __________ (key benefit)
- Unlike ___________ (key competitor), ____________ (our product) for
- ____________ (beachhead customer) who _______________ (key purchasing motivation)
- ____________ (value to customer relative to competitors) and
- ____________ (results).

Our innovation is a: (customer-language)
That: (key benefit)
Unlike: (current state/key competitors)
Ours: (key differentiators)
For: (beachhead customer)
Who: (key purchase motivation insight)
At a price/value: (relative to competitors)
Value Outcomes/Results: (client deliveries)

“Autorola offers auto remarketing and sales services coupled with an online auction platform producing long tail buying power for fleet, OEM, bank, insurance and leasing companies, maximizing customer return on assets and financial outcomes, optimizing inventory, cash flow and pricing, while simplifying logistics and minimizing asset risk.”

__________ (Our product) is a__________ that __________ (key benefit) Unlike ___________ (key competitor), ____________ (our product) for ____________ (beachhead customer) who _______________ (key purchasing motivation) ____________ (value to customer relative to competitors) and ____________ (results).

DOSCON – VP B2C

- Innovation: is an intelligent and innovative dosing control system
- Key benefit: for optimising the wastewater coagulation step (process)
- Unlike: traditional systems which omit critical parameters or require manual adjustment
- Ours: based on real-time monitoring of critical parameters
- Beachheads: WWTP plant owners with coagulations stage, System automation suppliers, WWTP builders
- Who: cost saving, secure quality, full automation, flexibility,
- At a price: costs a fraction of what you save
- Value: reducing costs by reducing coagulant consumption by 5-20% while securing better and more even treatment efficiencies.

DOSCON – VP B2C

- DOSCON is an intelligent dosing control system for optimising the wastewater coagulation process by innovating the traditional control systems by supplementing with additional critical parameters for environment & economy conscious plant managers and consulting engineers to reduce the coagulant consumption by 5-20% while securing better and more even treatment efficiencies at a cost of a fraction of what you save.

Developing a Sales Pitch

What are the key messages your sales people need in order to communicate your value proposition:

- Need (What is your audience's need?)
- Approach (How do you solve that need?)
- Benefits (What are the benefits of your approach—top 3?)
- Competition (How are you different or better from your competitors?)

Financing your idea / business

- Investor pitch

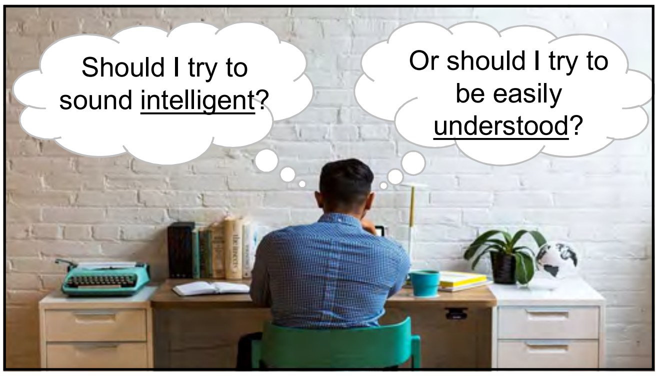
Prepare your pitch

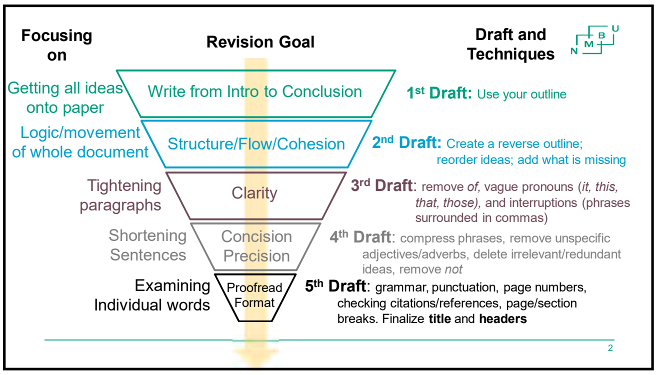
- Opener and audience connection
- Opportunity and value proposition
- Business Model
- Market and penetration strategy
  - Market characteristics and competitors
  - Market segments
  - Positioning
  - Pricing
  - Target market and beachhead
  - Integrated business development, marketing and sales strategy
- Implementation and rollout
- Management and personnel
- Financials
- Financial opportunity/outcomes
- Closer and exit

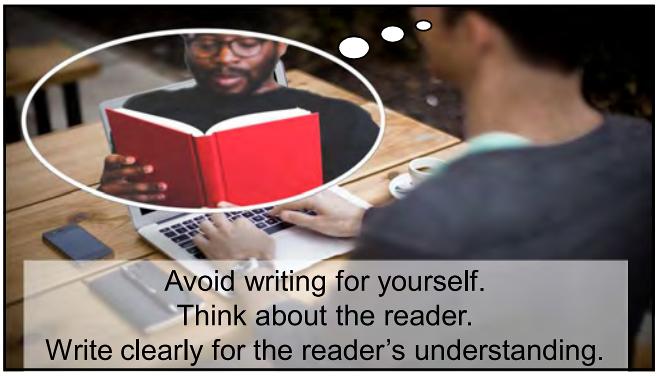
Academic Writing

The WritingCentre

Writing for Ph.D Candidates:
Clarity, Concision, Precision







Do you easily understand this?

When confronted with the challenge of articulating the core premises of symbolic interactionism, scholars generally refer, almost in the fashion of liturgical recitation, to Herbert Bulmer's conceptual distillation of the perspective into three core principles: 1) that people act towards things, including each other, on the basis of the meanings they have for them; 2) that these meanings are derived through social interaction with others; and 3) that these meanings are managed and transformed through an interpretive process that people use to make sense of and handle the objects that constitute their social worlds (Bulmer, 1969). Even though there are different varieties of symbolic interactionism, referencing this three-pronged conceptualization seems to occur as a matter of routine in discussions of the perspective with students and colleagues or in most textual discussions of its defining essence.

Snow, D. (2001). Extending and Broadening Blumer's Conceptualization of Symbolic Interactionism. Symbolic Interaction, 24(3), 367-377. doi:10.1525/si.2001.24.3.367

Causes of Unclear Writing

Professional

Replicate what we read
- Read many poor examples of writing, and we try to copy this style

Desire to use new concepts and abstract ideas we do not fully understand

Culture of writing and presenting
- Writing for supervisor, not a wider audience

Personal

We were taught *rules* in writing, not principles to write clearly

Desire to sound intelligent and academic

Writing in a vacuum – little or no peer review of our writing

Poor writing habits
- Not outlining
- Developing ideas as you write
- Poor time management
- Procrastinating and 'binge writing'

Using Characters and Actions clarifies your idea

Example

Our lack of knowledge about local conditions precluded determination of experiment action effectiveness in sample determination to those areas in greatest need of representation.

Who does what in this sentence?

…performs an Action
(verb)

A Character… (Subject noun)

…producing an Outcome (Object noun)

Subject-verb explains *Who does what.*

Using Characters and Actions clarifies your idea

Example

Our lack of knowledge about local conditions precluded determination of experiment action effectiveness in sample determination to those areas in greatest need of representation.

Who does what in this sentence?

Using Characters and Actions clarifies your idea

Example

Our lack of knowledge about local conditions precluded determination of experiment action effectiveness in sample determination to those areas in greatest need of representation.

Unclear because:

- Characters are not subjects
- Actions are not verbs

Using Characters and Actions clarifies your idea

Example

Our lack of knowledge about local conditions precluded determination of experiment action effectiveness in sample determination to those areas in greatest need of representation.

Revised Example

Since we knew nothing about local conditions, we could not determine how effectively the experiment sampled areas that needed greater representation.

Using Concepts as Characters

Because intellectual foundations of evolution are the same as so many other scienti... the falsification ... necessary for the replac... evolutionary theory with creationism.

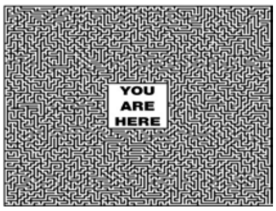
UNCLEAR

Who does what in this sentence?

Identify the Subjects and the Verbs

Remember the Reader

Abstract Writing
Unclear character-action



Specific Writing
Clear character-action

Using Concepts as Characters

Because intellectual foundations of evolution are the same as so many other scientific theories, the falsification of their foundations would be necessary for the replacement of evolutionary theory with creationism.

Who does what in this sentence?

Identify the Subjects and the Verbs

Avoid Prepositional Phrases

Common prepositions in academic writing:

- Of
- To
- For
- By
- From
- In

The purported intention of this workshop is to enhance th... ...pment of nece... ...ng, there... ...students while ...aneously clarifying the meaning of that which is to be communicated in writing from the author to the reader.

UNCLEAR

Using Concepts as Characters

Because intellectual foundations of evolution are the same as so many other scientific theories, the falsification of their foundations would be necessary for the replacement of evolutionary theory with creationism.

The theory of evolution shares intellectual foundations with other scientific theories. Evolutionary theory will remain dominant until another theory, like creationism falsifies evolution's foundations. Only then can creationism replace evolution as a scientific theory for life on earth.

Avoid Prepositional Phrases

- Of
- To
- For
- By
- From
- In

An evaluation of the program by us will allow for greater efficiency in allocation for funds.

Identify prepositions within your sentences.

Avoid Prepositional Phrases

- Of
- To
- For
- By
- From
- In

An evaluation of the program by us will allow for greater efficiency in allocation for funds.

Identify prepositions within your sentences.
Identify Subjects and Verbs in your sentences.

Avoid Prepositional Phrases

Reorder your WORDS, not your IDEAS around of:

- Of
- To
- For
- By
- From
- In

An evaluation of the program identified weakness in planning and implementation.

The program evaluation identified weakness in planning and implementation.

Avoid Prepositional Phrases

- Of
- To
- For
- By
- From
- In

An evaluation of the program by us will allow for greater efficiency in allocation for funds.

Identify prepositions within your sentences.
Identify Subjects and Verbs in your sentences.

Develop Connections to Develop Analysis

Bridge gaps for the reader.
Avoid jumping between ideas without connecting them.

The more effective presentation of needs by other parties to the UN resulted in our failure in acquiring funds, despite intensive lobby efforts on our behalf.

Who does what?
What connections or analysis exists?
Is this easy for the reader to understand?

Avoid Prepositional Phrases

- Of
- To
- For
- By
- From
- In

An evaluation of the program by us will allow for greater efficiency in allocation of funds.

Revise for clarity

We will evaluate the program so we can allocate funds efficiently.

Develop Connections to Develop Analysis

Bridge gaps for the reader.
Create logical relationships by connecting ideas.

The more effective presentation of needs by other parties to the UN resulted in our failure in acquiring funds, despite intensive lobby efforts on our behalf.

Despite our lobby efforts, we failed to acquire UN funds because other parties lobbi[illegible] more effectively.

Analysis/Reasoning **Cause/Connection**

Write Short Sentences

Long, complex and interrupted sentences REDUCE clarity and understanding

When confronted with the challenge of articulating the core premises of symbolic interactionism, scholars generally refer, almost in the fashion of liturgical recitation, to Herbert Bulmer's conceptual distillation of the perspective into three core principles: 1) that people act towards things, including each other, on the basis of the meanings they have for them; 2) that these meanings are derived through social interaction with others; and 3) that these meanings are managed and transformed through an interpretive process that people use to make sense of and handle the objects that constitute their social worlds (Bulmer, 1969).

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Avoid Unnecessary Nominalization

Nominalization:

Turning verbs (action words) or adjectives (describing words) into nouns (person/place/thing)

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Break Apart Long Sentences

Long, complex and interrupted sentences **REDUCE** clarity and understanding

When ~~confronted with the challenge~~ of articulating the core premises of symbolic interactionism, scholars generally refer, almost in the fashion of liturgical recitation, to Herbert Bulmer's ~~conceptual distillation~~ of ~~the perspective~~ into three core principles: 1) that people act towards things, including each other, on the basis of the meanings they have for them; 2) that these meanings are derived through social interaction with others; and 3) that these meanings are managed and transformed through an interpretive process that people use to make sense of and handle the objects that constitute their social worlds (Bulmer, 1969).

Subject Verb Preposition Interruption

~~Irrelevant information~~ Information for separate sentences

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Identify nominalization easily. Look for words ending in –ion, -ize/-ise, -ive, -ity

Often a word between *the…of*

Snow, D. (2001). Extending and Broadening Blumer's Conceptualization of Symbolic Interactionism. Symbolic Interaction, 24(3), 367-377. doi:10.1525/si.2001.24.3.367

Break Apart Long Sentences

Long, complex and interrupted sentences **REDUCE** clarity and understanding

Shortened sentences improve understanding without losing meaning

When describing symbolic interactionism's core premises, scholars refer to Bulmer's (1969) three core principles. First, people act towards each other and towards objects based on specific meanings towards specific people and objects. Second, these meanings are derived from social interactions with other people. Lastly, meanings are managed and transformed as a person interprets the world. Interpretation allows individuals to make sense of the people and objects that constitute their social world.

Avoid Unnecessary Nominalization

Identify **unnecessary** nominalization and revise for clarity

When confronted with the challenge of articulating the core premises of symbolic interactionism, scholars generally refer, almost in the fashion of liturgical recitation, to Herbert Bulmer's conceptual distillation of the perspective into three core principles: 1) that people act towards things, including each other, on the basis of the meanings they have for them; 2) that these meanings are derived through social interaction with others; and 3) that these meanings are managed and transformed through an interpretive process that people use to make sense of and handle the objects that constitute their social worlds (Bulmer, 1969).

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Some nominalization is useful

Excessive nominalization is not useful

Replace Abstract Concepts with Concrete Examples

Abstract concepts and **jargon** can be eliminated by:

1) Replacing the abstract concept/jargon with plain language
   Abstract: Negative environmental consequence
   Plain language: Pollution, deforestation, increased toxicity
   Abstract: Domiciled
   Plain language: Living

2) Enhance the reader's understanding by using a concrete example

Data points were **aggregated together** in the model. Gathering all points provided the opportunity to identify clusters and determine relationship patterns.

Avoid Abstraction

Abstract ideas are difficult to understand

The participatory role of stakeholders in the process of decision making surrounding negative environmental impacts of industrial activities is paramount to the creation of heightened assessments of the environmental consequences, which is an absolute necessity due to its role in livelihoods for affected non-industrial partners, prior to moving forward with the planned development of natural resources for either private-profit or state-led economic enhancement.

Excessive nominalization — Unclear Subject-Verb (Who does what?)

Excessive prepositions — Long sentence — Interruptions

Abstract ideas — Abstract pronouns

Avoid Excessive Abstract Pronouns

Excessive or unspecified pronouns cause abstraction

Common academic pronouns: It, this, that, those, those, them, their, one(s)

It was because of those results that the research decided it would use them instead of the ones that this research originally began with.

Who does what in this sentence?

Subjects and Verbs are unclear

Avoid Abstraction

Abstract ideas are difficult to understand

The participatory role of stakeholders in the process of decision making surrounding negative environmental impacts of industrial activities is paramount to the creation of heightened assessments of the environmental consequences, which is an absolute necessity due to its role in livelihoods for affected non-industrial partners, prior to moving forward with the planned development of natural resources for either private-profit or state-led economic enhancement.

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Excessive or unspecified pronouns cause abstraction

Common academic pronouns: It, this, that, those, those, them, their, one(s)

It was because of those results that the research decided it would use them instead of the ones that this research originally began with.

Identify vague pronouns

Use concrete Subjects and Verbs instead

Revise for clarity

Avoid Excessive Abstract Pronouns

Excessive or unspecified pronouns cause abstraction

Common academic pronouns: It, this, that, those, those, them, their, one(s)

It was because of those results that the research decided it would use them instead of the ones that this research originally began with. ✗

Current results proved the original data was incorrect. Therefore, the research team decided to use **this** new data instead of the original data set. ✓

Useful pronoun.
Directs reader to clear information in the previous sentence.

Past or Present Tense of Verbs?

Past Tense	Present Tense
States facts	**Generalize/Interpret facts**
Ex. The experiment results **produced**…	**Ex.** Our results **indicate**…
We **found**…	Generally speaking, we **may expect to find**…
This information cannot be debated. It is a **FACT**.	This information can be debated. We generalize, interpret and apply facts.

Using Active vs. Passive Voice

Active Voice Subject-Verb-Object	Passive Voice Object-Past Tense Verb-Subject
Emphasizes the actor's action	**Emphasizes** the object/action's outcome
Ex. The experiment created unexpected results.	Ex. The results created by the experiment were unexpected.
The hypothesis predicts increased soil pH will have an inverse effect of soil microbial concentration.	Increased soil pH has been predicted by the hypothesis to have an inverse effect on soil microbial concentration.

Shorter, clearer sentence

Using First Person

First person pronouns: I, me, my

Academic writing generally **avoids** using first person pronouns

If you must use first person in writing, limit it to:

Introductions

- Use I, me, my to establish a context for your research
- Use I, me, my to explain steps or processes you undertook

Conclusions

- Use I, me, my to express you viewpoints and opinions about your results

Using Active vs. Passive Voice

Active Voice Subject-Verb-Object	Passive Voice Object-Past Tense Verb-Subject
Emphasizes the actor's action	**Emphasizes** the object/action's outcome
Ex. The experiment created unexpected results.	Ex. The results created by the experiment were unexpected.
The hypothesis predicts increased soil pH will have an inverse effect on soil microbial concentration.	Increased soil pH has been predicted by the hypothesis to have an inverse effect on soil microbial concentration.
Shorter, clearer sentence	Longer. More prepositions

Compound Nouns Create Abstraction

Compound noun: Two or more nouns connected together

Example:

Environmental impact assessment criteria
- *-Environmental criteria of impact assessment?*
- *- Assessment criteria of environmental impact?*

Nonlinear regression aggregation error specification test
- *- Aggregation error of nonlinear regression in a specification test?*
- *- Nonlinear regression of aggregation error specification test?*

Remember the reader!

Clarify by either:
1) Connecting related words with a hyphen (-)
   Nonlinear-regression aggregation error-specification test
2) Using the passive voice (add prepositions)
   Testing error specification of nonlinear regression aggregation

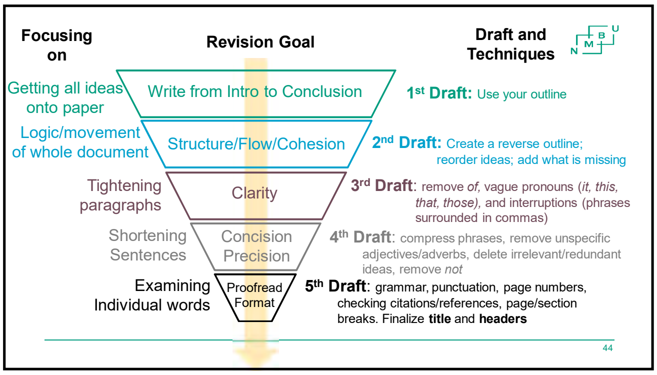
Easy Tips to Revise for Clarity

Start by removing unnecessary **prepositions**

- Use the **Find/Navigate** function in Word
- First, eliminating ***of, to*** helps
  - Remove nominalization
  - Clarify abstraction
  - Reduce unnecessary passive voice
  - Identify character and action

Remove **commas** to avoid interruptions

- Use the **Find/Navigate** function in Word
- Delete irrelevant information
- Use a period/full stop to break up sentences



Norwegian University of Life Sciences

Concision and Precision

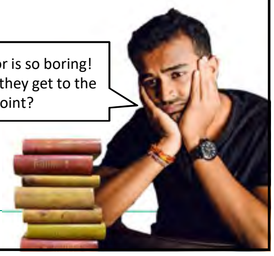
Writing shorter, clearer articles
Writing with specific language

Concise Writing: Lower Your Word Count

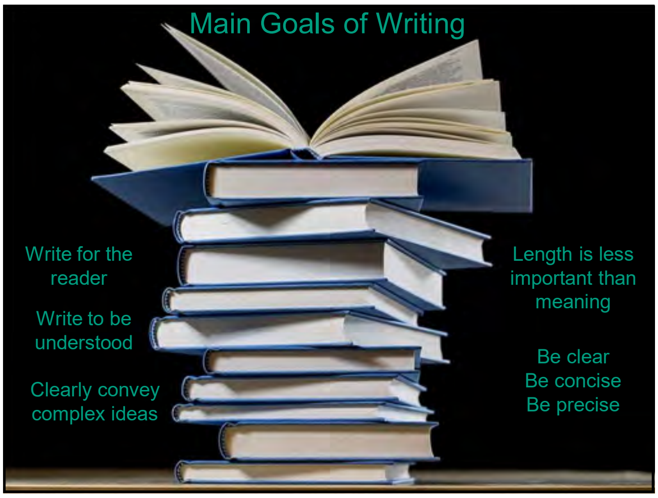
Concise: Giving a lot of information clearly, in a few words.

Most academic writing IS NOT concise because:
- Long sentences
- Tangents
- Irrelevant information
- Interruptions
- Stating obvious information
- Unclear sentences
- Takes to long to make a point

This author is so boring! When will they get to the point?



Main Goals of Writing



Concision is Editing

Reducing word count and improving clarity is the goal of concision.
Concise writing comes from editing and revising previous drafts

Steps to improve concision

1) Improve Subject-Verb with active verbs. Remove weak verbs
2) Remove redundant and less important information
3) Reduce wordiness
4) Compress phrases into a single word

The point

Concise Writing: Lower Your Word Count

Concise: Giving a lot of information clearing, in a few words.

Be Concise: Remove Weak Verbs

Weak verbs:
To be (is, are, was were) To have (have, has, had)
To get (get, gets, got)

The outcomes have demonstrated that the data our research team got from the experiment is valid.

Identify weak verbs and replace them with a subject and active verb

Be Concise: Remove Weak Verbs

Weak verbs:
To be (is, are, was were) **To have** (have, has, had)
To get (get, gets, got)

The outcomes have demonstrated that the data our research team got from the experiment is valid.

Identify weak verbs and replace them with a subject and active verb

The experiment outcomes demonstrate data validity.

Same meaning
10 fewer words

Avoid Wordiness

Remove duplicate pairs with similar meaning	Avoid redundant modifiers: Words with same meaning	Reduce redundant phrases
Ex.	**Ex.**	**Ex.**
First and foremost…	Completely finished…	In order to… = to
After the previous…	Revolve around…	Prior to…= before
Basic and fundamental…	Progress forward…	A number of…= several
Any and all…	Finally done…	In addition to… = additionally
So on and so forth…	Initialize start-up…	

Remove Less Vital Information

Find redundant, irrelevant, and less important information.
Often contained in interruptions, which reduce clarity and concision.

A sample size was not quite sufficiently large enough, although the data collection used valid methodologies, to gather enough data on the population being studied despite our best efforts to do so.

Avoid Wordiness

Remove meaningless adverbs and adjectives (modifying words)	Replace pompous language and nominalization (use plain language)	Avoid meta-discourse/meta-writing (Telling the reader what they will read)
Very… Really…	*Pursuant to the recent promulgation issued April 19, 2017, because of temporal exigencies, it is incumbent upon us all to endeavor to make maximal utilization of electronic communication vis-à-vis scripting counselors to assure visitation at the centre for improved written ~~communication.~~*	*The author will argue the benefits of increased spending on research.*
Quite… Actually…		*In this section, you will be introduced to necessary concepts…*
Rather… Basically…		
Kind of… Generally…		
Substantial(ly)…		
Interesting(ly)…		
Use **precise** language	Use **plain, clear** language	Waste of words. Lead the reader. Don't tell them what they will read.

Remove Less Vital Information

Find redundant, irrelevant, and less important information.
Often contained in interruptions, which reduce clarity and concision.

A sample size was not quite sufficiently large enough, although the data collection used valid methodologies, to gather enough data on the population being studied despite our best efforts to do so.

Remove or reorder less vital information.
Apply principles of clarity to improve concision.

Despite valid data-collection methods, the same size was insufficient to gather enough data on the study population.

Compress Phrases

because…since…**or** ***why…*** replaces
- The reason for…
- For the reason that…
- Due to the fact that…
- Owning to the fact that…
- In light of the fact that…
- This is why…
- On the grounds that…

although…even though… replaces
- Despite the fact that…
- Regardless of the fact that…
- Notwithstanding the fact that…

about… replaces
- As regards…
- In reference too
- With regards to…
- Concerning the matter of…

if… replaces
- In the event that
- If it should transpire…
- If it should happen that…

must/should… replaces
- It is crucial that…
- It is necessary that…
- There is a need for…
- It is important that…
- It cannot be avoided…

can…could…may…might… replaces
- Is able to…
- Is in a position to…
- Has the capacity for…
- Has the ability to…

Precision in Writing

Precise: Accurate and exact expression

Imprecision is caused by generalizing.

Avoid imprecise, vague words

area system situation

nature character level

structure field condition

case process problem

Words can have multiple meanings

Avoid anonymous claims

It was shown that…
It is speculated…
It has been found…
Generally speaking…
In general, everyone knows…
There are many papers written on this topic…

Where is the evidence to prove this?

Precision Avoids Doubt

If you are certain of something, take a stand

Presents uncertainty

Students can enhance their papers by revealing insight.

Additional funding may lengthen the research period.

Precision might be ranked among the most important qualities of good writing.

Certainty gives a sense of authority

Students enhance their papers by revealing insight.

Additional funding will lengthen the research period.

Precisions ranks among the most important qualities of good writing.

Use Positive Language Precisely

Double negative: a statement expressing two negatives, resulting in a positive outcome

Double negatives reduce clarity, concision and precision

It is not uncommon for experiments to fail = It is common for experiments to fail

It is unlikely that it will not succeed = It will likely succeed

Replace negative with affirmative statements

Not many = few not the same = different did not remember = forgot

Not important = unimportant/minor Did not pay attention = ignored

Not possible = impossible Did not allow for = prevented

The point

Precision Avoids Doubt

Express certainty when you are certain. Save doubt for real uncertainty.

When we cannot guarantee certainty, use:

would should could may might can

A new cancer treatment could save the lives of millions.

According to our findings, efficiency may be increased by as much as 73% if the company applied this new management approach.

Precise Words adds Analysis and Power

The patient did not want to receive additional medical support and their reason stemmed from their strong belief in religion.

Vague, unimpressive, long

The patient rejected medical treatment because of their strong religious beliefs.

Precise, powerful, accurate, analytical

Use Precise Examples to Define

Avoid defining technical terms. Place them in context for the reader instead

A binary system is desc… o astrological bodies gravitational forces interact t… o objects begin to orbit each other.

Gravitational relationships are exhibited by binary systems. When two objects with strong enough gravitational fields are close enough together, their gravity interacts. This interaction can result in a binary system if these two objects begin orbiting each other.

Easier to understand? Less boring?
You get the definition through the context

Precise Language for International Readers

Avoid slang and clichés the reader will not understand

We needed to think outside the box, to search for the holy grail. However it was neither found to be a magic bullet nor a slam dunk. So, we rolled with the punches and let the chips fall where they will. In the end, we saw the glass was not half empty. It really was a no-brainer. The team ended up being tickled pink and happier than a pig in mud.

Be professional, be precise.

Use plain language to convey intelligent thought

N M B U
Norwegian University of Life Sciences

Precision is about Style

Style is specific

Style is definite

Style is concrete

Style grabs attention

Style takes work to refine

Easy Tips for Concision/Precision

Start by removing **weak verbs**

- Use the **Find/Navigate** function in Word
    Look for the preposition ***to***
    Search for weak verbs and their various forms
    Identify the **strong verb** hidden within your sentence

Use online resources and digital tools to work smart

- **The Writer's Diet Test** (clarity, concision, precision)
- **Thesaurus.com** to improve your vocabulary and find more precise words

Understand Clarity and Concision/Precision overlap

- Working to clarify often improves concision
- Becoming more precise improves clarity

WaterHarmony ERASMUS

Structuring a manuscript

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WATER HARMONY ERASMUS •

WaterHarmony ERASMUS

Contents

- Structure of academic writing
- IMRAD standard components
  - Introduction
  - Materials and methods
  - Results
  - Discussion
- Thesis statement: argue and develop
- Tables and Figures: way to present data

WaterHarmony ERASMUS

What is academic paper?

- ➢Essay
- ➢Research Paper
- ➢Dissertation

Should have:

- ➢Clear and limited focus – thesis statement
- ➢Logical structure
- ➢Evidence-based arguments
- ➢Impersonal tone

Info from: https://www.thoughtco.com/what-is-academic-writing-1689052

WaterHarmony ERASMUS

Structure of academic writing

Basic principle	Paragraph	Manuscript
Introduction	Topic Sentence	Introduction
Body	Assertion statements	Methods
Conclusion	eXample(s)	Results
	Explanation	and
	Significance	Discussion

Move from simple to complex!

General → Specific
Known → Unknown

Info from: https://www.thoughtco.com/body-paragraphs-composition-1689032

WaterHarmony ERASMUS

IMRAD standard components

Introduction	• What are you studying and why?
Methods	• What did you do?
Results	• What did you find?
and	
Discussion	• What do your findings mean?

WaterHarmony ERASMUS

Introduction – 10-20% of whole paper

During introduction writing:

- get the reader's attention by opening sentence (**importance of the topic**)
- give your reader some info about the issue (**background of the topic**)
- **summarize** the current state of knowledge on the topic
- state the research question clearly (**thesis statement**)
- describing the scope and structure of paper

To achieve success:

- think critically
- provide facts not opinion
- use only appropriate citations

"Know your audience, keep it short, tell readers why you have done the study and explain why it's important, convince them that it is better than what has gone before, and try as hard as you can to hook them in the first line." by Richard Smith
(Norris, C. B. (2016) Academic Writing in English, University of Helsinki)

RefWorks EndNote Web MENDELEY

WaterHarmony

Methods

What to write?

✓Materials (name, chemical formula, purity, manufacturer)
✓Methods:
- How to produce?
- How to analyze?
- How to process data?

Specify:
✓ quantities of materials
✓ process maintenance parameters
✓name, model, manufacturer and company's location of equipments

Don't write well known, standardized or quite lengthy procedures, use citations.

Note: to ensure that the structure is correct, follow the instructions in Journal guide!!!

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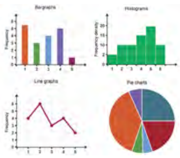
Results

Show the statistical significance of your findings!

Way to present data:
- ➢ Figure
- ➢ Table
- ➢ Text



Main rules:
- ➢Make data in figures and tables readable
- ➢Do not duplicate the data
- ➢Do not evaluate (say "NO" to strong emotional terms as greatly/ considerably/markedly or greater etc)
- ➢Do not summarize
- ➢Avoid passive voice

Lead your readers into following your thoughts by state the main findings in order relating to the used hypotheses and methods.

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Discussion

"...***answers the question posed in the Introduction and includes the main supporting evidence***..."
by Gustavii from (Norris, C. B. (2016) Academic Writing in English, University of Helsinki)

Compare...
- ➢ your own finding
- ➢ own data with other studies' findings

Do your results support or deviate previous studies?

Explain...
- ➢ how the study adds to previous knowledge
- ➢ contradictory results

To mention any possible explanations for the results

Conclusion

– as a "mirror image" to the Introduction
- ➢begin by short summarizing the main aim of paper
- ➢confirm the topic/thesis statement of paper
- ➢ end by recommendations and implications for future research

Specific → General

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Thesis statement: argue and develop

Thesis statement - is a one sentence captures ONE main idea of the paper.

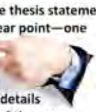
-is not a fact nor a question, but your point of view on the topic.

- is way to tell the reader about the scope, purpose, and direction of the paper.

- identifies the relationships between your evidences and argument.

imagesait.ru

An effective thesis statement makes a clear point—one that will be supported by specific details in the rest of the essay.



From https://www.thoughtco.com/exercise-in-identifying-effective-thesis-statements-1692401

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Way to write a strong thesis statement

Identify the topic
Develop your argument
Make a "guide" to your argument

Check list for strong thesis statement:

✓ Does your thesis statement reflect each paragraph of the paper?
(avoid irrelevant info or rewrite thesis statement)

✓Is your thesis statement arguable?
(Does the statement encourage a dispute?)

✓Is your thesis statement specific?
(avoid using of two statement connected by coordinating conjunction)

✓Is your thesis statement clear?
(avoid jargon, abstract or vague words)

✓Is your thesis statement original?
(avoid quoting, "to be" verbs, generic arguments and formula statements)

✓Does your thesis statement represent your position on the issue?
(*NO* facts, *NO* universal judgments, *NO* announcing the topic)

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Examples:

Arguable

"The Beverly Hills Diet is inadvisable for the typical college student." – **So what?**

"Although it does provide quick weight loss, the Beverly Hills Diet is inadvisable for the typical college student because it is inconvenient, unhealthy, and provides only temporary weight loss. " – **create a debate**

Clear

"Scholars should work to seize metacognitive outcomes by harnessing discipline-based networks to empower collaborative infrastructures" - **too complex** sentences with **special language**

"Ecologists should work to educate the U.S. public on conservation methods by making use of local and national green organizations to create a widespread communication plan." – **clear**

Specific

"World hunger has many causes and effects." – **to broad** (All over the world? What reasons? What are the consequences?)

"Hunger persists in Glandelinia because jobs are scarce and farming in the infertile soil is rarely profitable." – **specific**

Info from https://wts.indiana.edu/writing-guides/how-to-write-a-thesis-statement.html

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Tables and Figures: way to present data

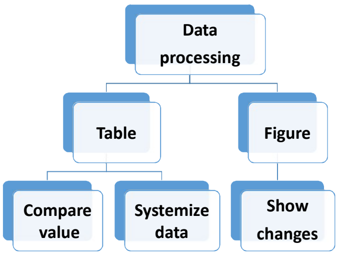

Table or Figure?

[Table]: - precise
- large volume of data

[Figure]: - complex data
- compare relative values

Note: All Tables/Figures must be referred to (as "Table 1" and "Fig. 1"):
- near the reference;
- on the next page;
- end of Results or Discussion (for IMRAD);
- in an appendix

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Table anatomy

Table title
clear content

Colum titles
info support title

Table 1 – Students' academic performance

Surname, name	Competition grade	Exam grade	Rating
Addams Luis	75.156	86	161.156
Bent Alex	62.839	88	150.839
Black Kathrin	92.152	77	169.152
Devil Bob	70.053	97	167.053
Jacobson Kevin	76.854	86	162.854
Mitchell Paul	77.660	65	142.660
Neuton Beatrice	83.028	72	155.028
Peirce Martin	78.585	83	161.585
Smith Jon	89.051	91	180.051
Wolf Scott	91.167	67	158.167

Exam grade is a score on Water treatment course exam; the competition grade is the average score for the course

Body of table
data

Footnotes
statistical differences
or data source

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How to make a Table understood?

- ✓ Table title is a description of content (object → comparison)
- ✓ Follow down the columns, not across
- ✓ Move from familiar to new
- ✓ Sort data on the most meaningful variable
- ✓ Avoid unnecessary decimal points (round)
- ✓ Avoid unnecessary lines in a table
- ✓ Add a space-filler (—) into empty table cell
- ✓ Omit repetitious items entirely

Sorbent	q, mg/g	R, %
~~Sample~~ 1	15.1	89
~~Sample~~ 2	13.4	79
~~Sample~~ 3	8.6	51

Table 1 – **Students'** academic **performance**

Surname, name	Competition grade	Exam grade	Rating
Addams Luis	75.156	86	0.805780
Bent Alex	62.839	88	0.754195
Black Kathrin	92.152	77	0.845760
Devil Bob	70.053	97	0.835265
Jacobson Kevin	76.854	86	0.814270
Mitchell Paul	77.660	?	0.388300
Neuton Beatrice	83.028	72	0.775140
Peirce Martin	78.585	83	0.807925
Smith Jon	89.051	91	0.900255
Wolf Scott	91.167	67	0.790835

Exam grade is a score on Water treatment course exam; the competition grade is the average score for the course

Artificial sense of accuracy?
(100, 10.1, 1.23, 0.123)

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Example of Table transformation

Table 1 – **Students'** academic **performance**

Surname, name	Competition grade	Exam grade	**Rating**
Addams Luis	75.156	86	0.805780
Bent Alex	62.839	88	0.754195
Black Kathrin	92.152	77	0.845760
Devil Bob	70.053	97	0.835265
Jacobson Kevin	76.854	86	0.814270
Mitchell Paul	77.660	?	0.388300
Neuton Beatrice	83.028	72	0.775140
Peirce Martin	78.585	83	0.807925
Smith Jon	89.051	91	0.900255
Wolf Scott	91.167	67	0.790835

Table 1 –Academic **performance of students (group B3) on Wastewater treatment course**

Surname, name	Competition grade	Exam grade	**Rating** ↑
Smith Jon	89.0	91	0.900
Black Kathrin	92.2	77	0.846
Devil Bob	70.0	97	0.835
Jacobson Kevin	76.9	86	0.814
Peirce Martin	78.6	83	0.808
Addams Luis	75.2	86	0.806
Wolf Scott	91.2	67	0.791
Neuton Beatrice	83.0	72	0.775
Bent Alex	62.9	88	0.754
Mitchell Paul	77.7	—	0.388

If you can not simplify the Table, maybe you should use a figure?

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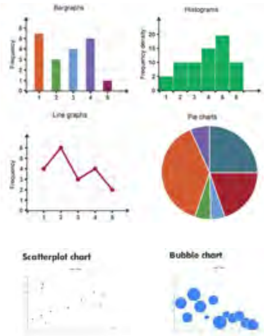
Figure as a graphic way to present data

- Line graphs compare
- Scatter plots correlate (Y) vs. (X)
- Bar graphs divide and compare single variable (Y) among groups (X)
- Pie charts compare parts of a whole

X axis – independent variable (as time)

Y axis – depended variable



MATLAB ORIGIN

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Graph structure

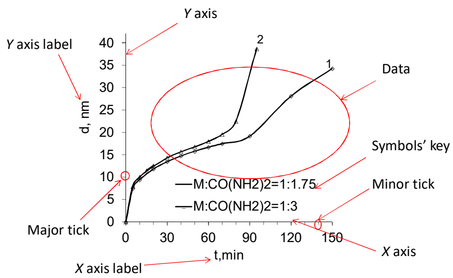
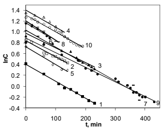


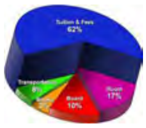
Fig. 1. Particles size vs. hydrolysis time for mixed ZOH-AOH sol with molar ratios Zr:Al=1:1 and M:carbamide: 1 – 1:1.75; 2 – 1:3.

Legend

To be understood



- In figure legends, show actual symbols or print them on the figure itself
- For overlapping curves, change the intervals on the vertical axis.
- Compound two figures one the same topic and format
- Ensure that multiple-part figures have clear numbers or letters nearby
- Be clear, not decorative; no "city skyscraper" by histogram bars
- Do not use a pie chart for black and white printing paper
- Avoid >6 lines, section on a graph.



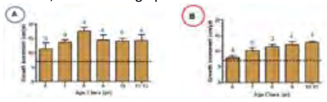
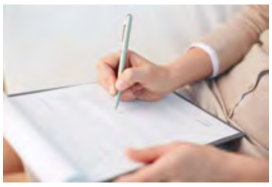


Fig.2 . Annual stem growth of white pine seedlings in 2012 (A) a selectivity harvested area, and, (B) a non-harvested area.

Summary

- follow a structure
- move from simple to complex
- think about reader
- rewrite!



What is wrong?

Which **variable goes where?**

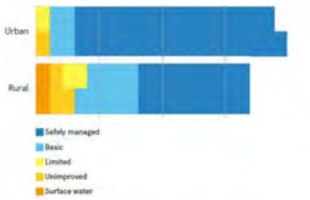


Fig 34 Number of people using different levels of drinking water services in 2015, urban and rural (each unit represents 100 million people)

Suggested citation. Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. Licence: CC BY-NC-SA 3.0 IGO.

Show your results to colleague:
- Is it necessary?
- Understandable: too simple or complex?
- Does it make sense?
- Must stand alone and be interpretable