Water Theory (Water 101)

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Emile Berries

For You and Planet Blue.

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BEST WATER TECHNOLOGY

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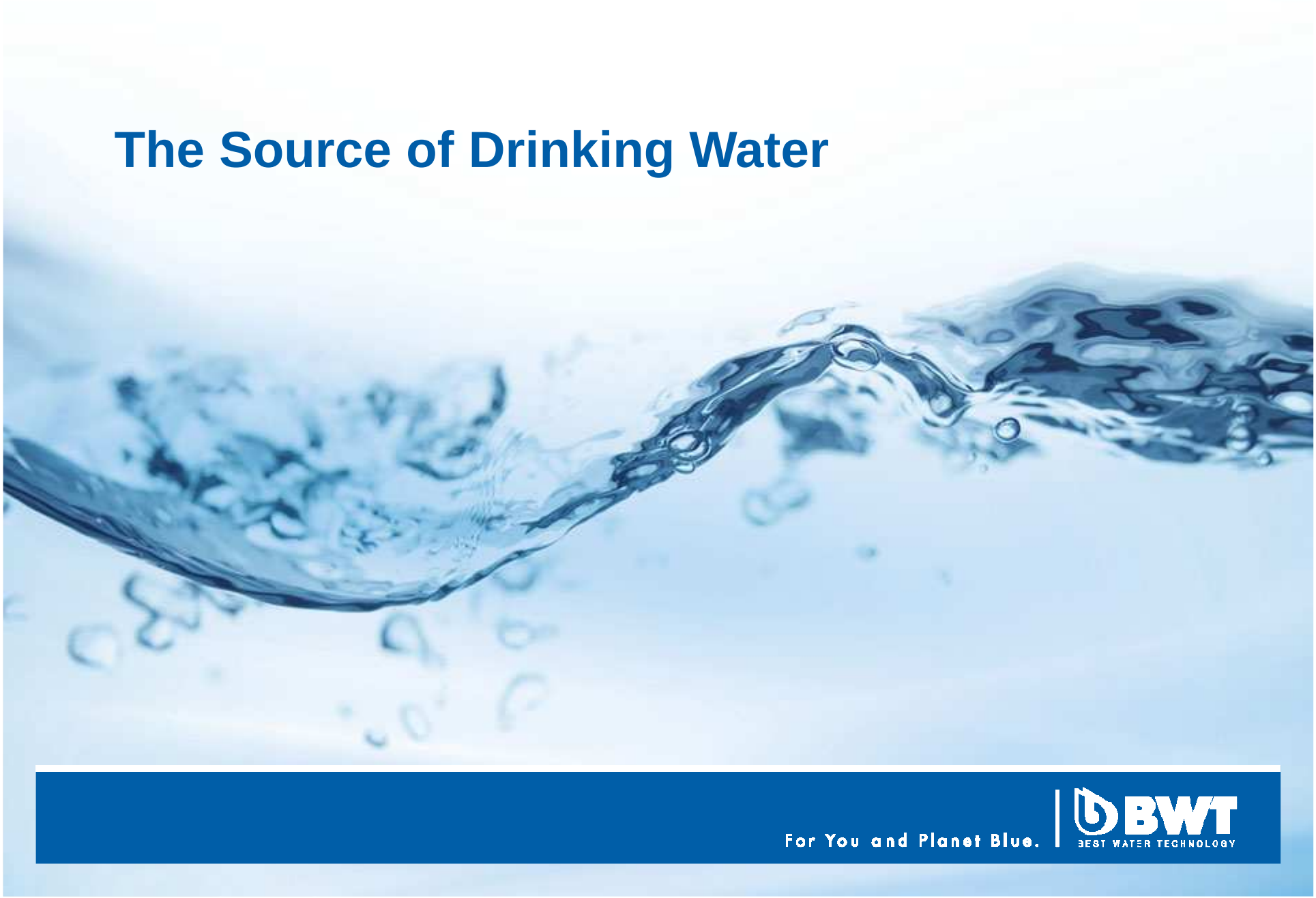
The Source of Drinking Water



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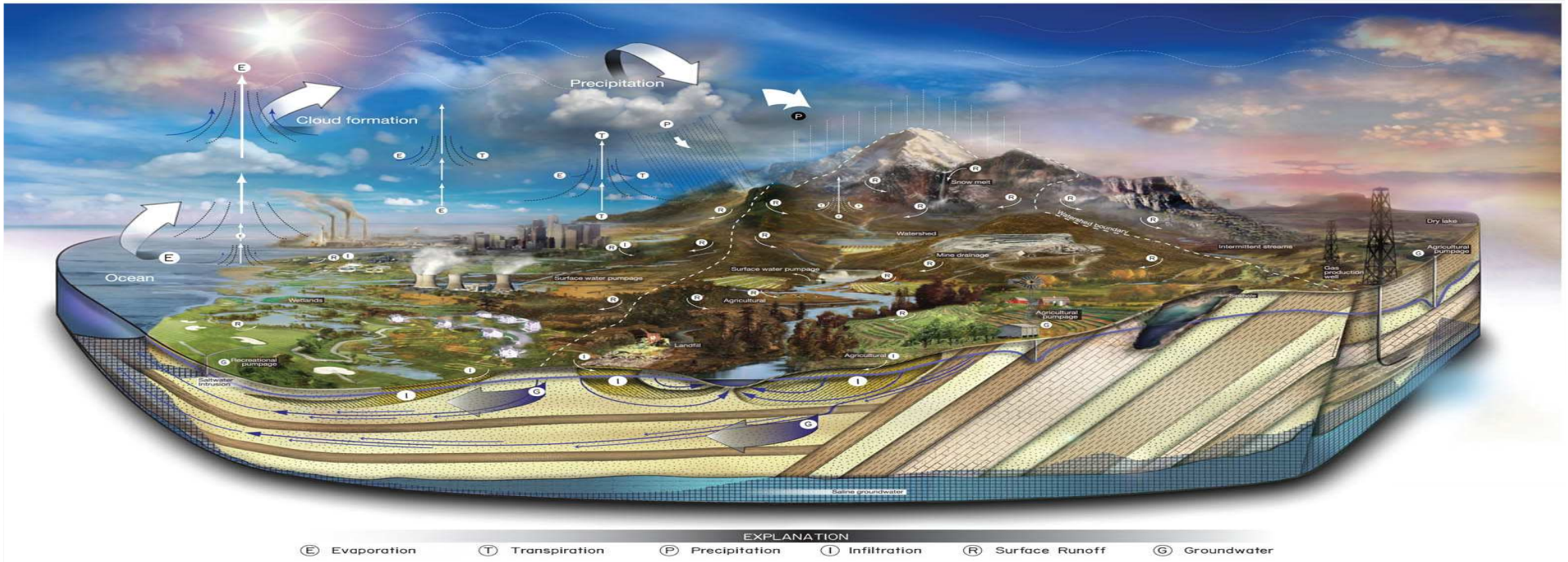
THE HYDROLOGIC CYCLE

Water is in constant movement across our planet. When we talk about water scarcity we really are just talking about distribution and treatment issues.



1. **EVAPORATION** Water evaporates or sublimates from the surface into the air due to heating from the sun or volcanic activity becoming water vapor. Water purity is at its highest.

2. **CONDENSATION** When water vapor cools down it condenses into microscopic water droplets forming clouds. Chemical contamination from gasses (in particular sulfurs and CO2) and suspended articles causes the water to become acidic, which increases water's ability to act as a solvent for various minerals.

3. **PRECIPITATION** Water returns to the surface as rain.

4. **INFILTRATION** By permeating into the soil, water dissolves metals and minerals becoming more and more basic and hard. The contact with pollutants and organic contaminants further increases its contamination, making it brackish and unsuitable for human consumption.

5. **RUNN OFF** Water enters surface streams and flows back to the oceans.

6. **EVAPORATION** As water is heated again it re-evaporates repeating the cycle.

WATER CONTAMINATION

- Contaminants: contents dissolved or suspended in water
- Pollutants: contaminants that negatively affect the biosphere
  - Natural pollutants: algae, sulfur, iron, manganese, bacteria
  - Man made pollutants: herbicides, pesticides, coolants, fracking chemicals, industrial waste products, untreated sewage, acid rain.

THE WATER SUPPLY

Sources:

- Ground water
- Surface water
- **Municipal water**

STAGES OF MUNICIPAL WATER TREATMENT



COLLECTING: Water is either diverted from the surface or pumped from underground.

Screening; water passes through filtering sluices

Storage; water is gathered into a reservoir for buffering and sedimentation

Pre-Filtration; while extracting from the reservoir water is filtered for coarse particles

PH-Adjustment; In case the water is acidic lime, soda ash, or sodium hydroxide are added to rectify the PH. Acidic water is corrected by carbon dioxide bubbling and the addition of sulfuric or hydrochloric acid.

Coagulation and Flocculation; The addition to the water of coagulants such as aluminum sulfide or iron chloride induce various chemical reactions which result in the ionization and precipitation of particles (coagulation), which subsequently aggregate in larger particles (flocculation).

Sedimentation and sludge removal; sludge created during coagulation / flocculation is removed and disposed

Filtration; water is assed through one or few stages of sand filters to remove residual particles

Chlorination; as a last step the water is disinfected by the addition of chlorine or Chloramine, a strong oxidant.

Settling tank with thick surface sludge

Slow sand filter.

Chlorine dosing for municipal water

Pressurization; achieved either pumps or gravity.

Other municipal treatment systems.

- Desalination
- Distillation

FLUCTUATIONS IN WATER QUALITY

Floods, heavy rainstorms or tropical cyclones; prevent the natural precipitation of sediments in reservoirs and might overload treatment plants, increasing turbidity and contaminant content

Increases in peak consumption; overwhelming peak consumption results in hasty and incomplete water treatment

Drought; might cause municipalities use secondary water sources off inferior quality.

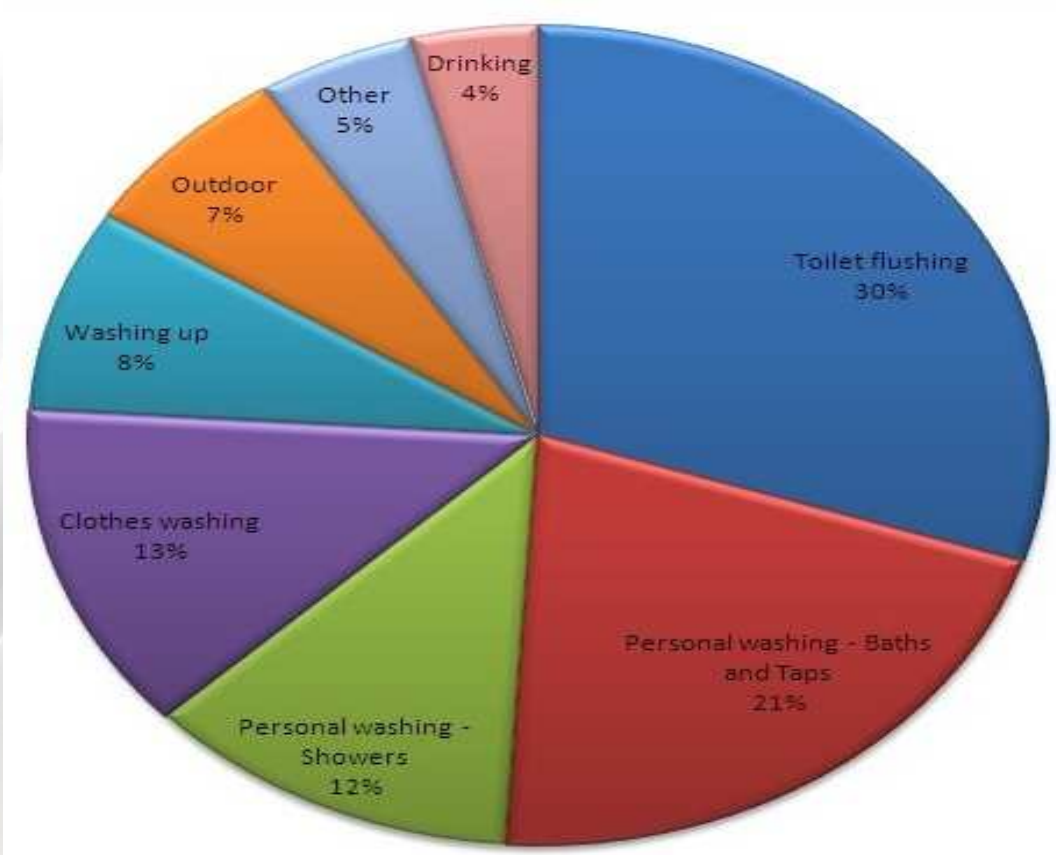
Algal Blooms; dramatically increase the amount of organic contamination

Algal bloom in pond

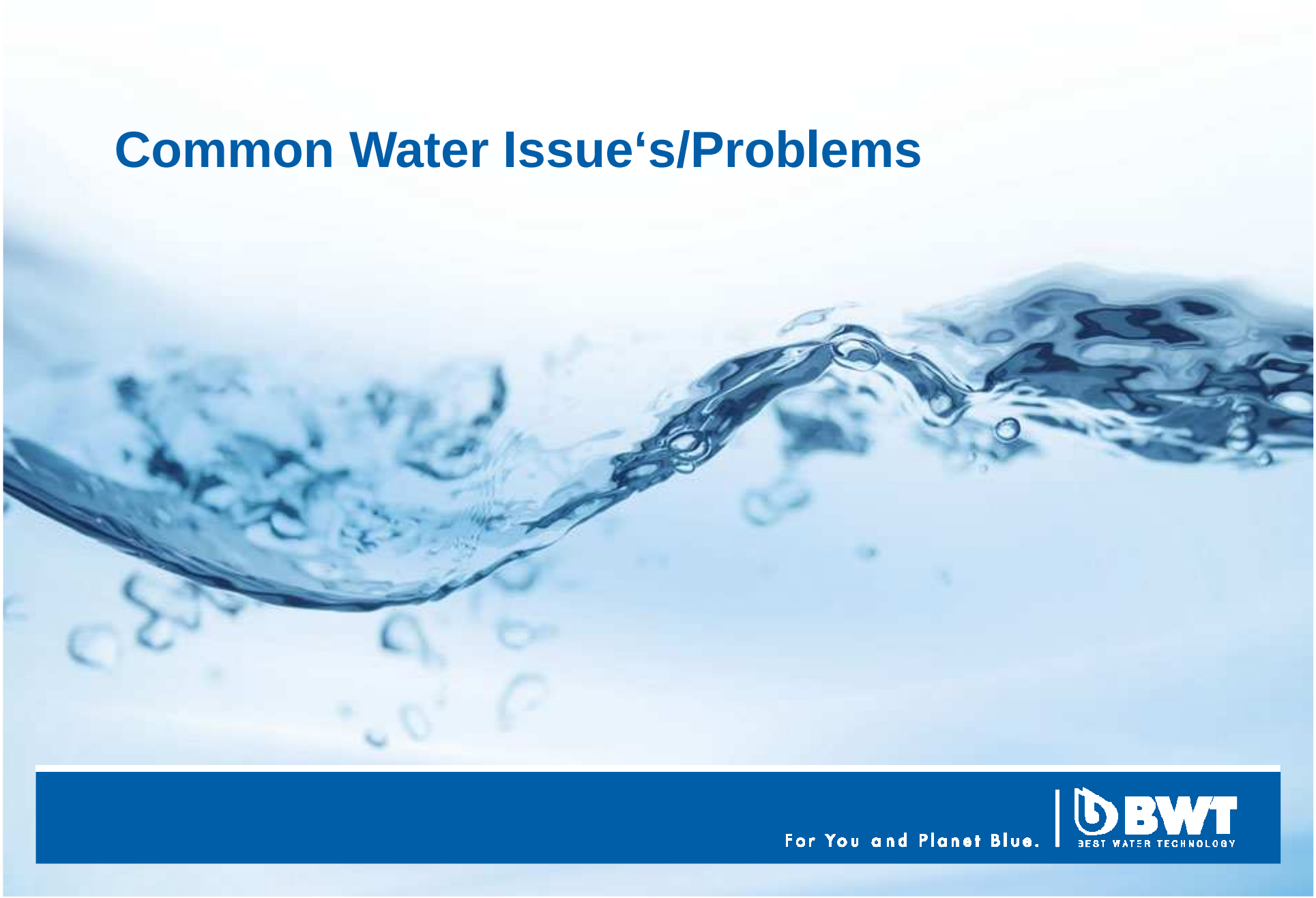
AVERAGE WATER CONSUMPTION

The average individual consumes between 160-200 liters of water a day.

About 4% is used for direct consumption (cooking and drinking)



Common Water Issue‘s/Problems



COMMON PROBLEMS AFFECTING RESIDENTIAL WATER

Every human being comes into contact with and uses water hundreds of times a day. The intimate relationship we have with water is the reason why the quality of the water we use directly affects our safety, hygiene, health and comfort.

Suspended sediments and foreign particles

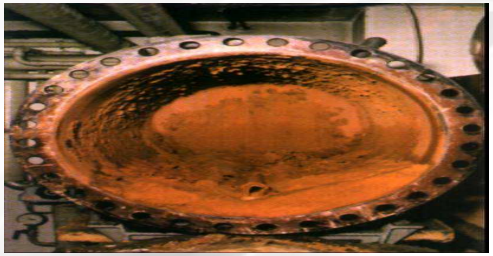
- All particles create turbidity
- Usually big enough to be seen with the naked eye
- Cause pipe rupture, natures bacteria, damage appliances

Dissolved metals and minerals

Iron dioxide (rust) might be averted as a slightly metallic taste in the water, taints red to various degrees

Copper (often from pipes) can be oxidized by acidic water, coloring the water to a light blue

Lead plumbing will also be oxidized contaminating the water that flows in it



Examples: 1) An oxidized municipal pipe, 2) Iron contamination, 3) Copper contamination

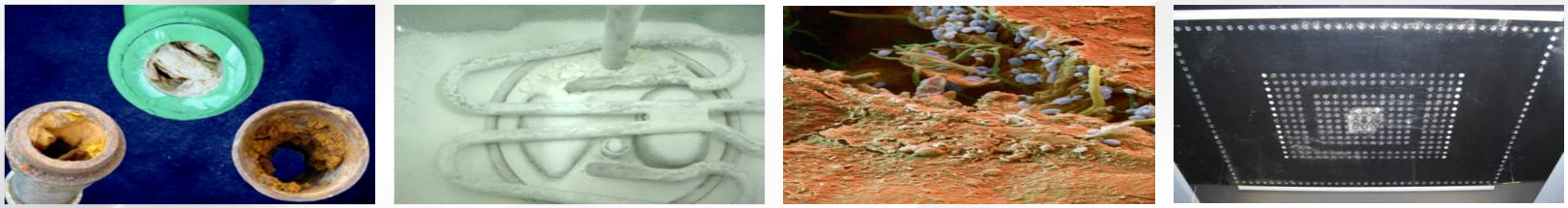
Dissolved metals and minerals

The main minerals of concern in residential water are calcium and magnesium. The quantity of dissolved calcium (Ca), magnesium (Mg) and Iron (Fe) ions constitute the water's total hardness.

Their presence is not a problem for our health

BUT

- Lime scale depositions can grow thick enough to obstruct pipes
- The rough surface of the deposits is a perfect breeding ground for bacteria
- It causes stains and shortens the life of appliances
- It decreases the efficiency of water heaters and thermal exchangers
- Forms soap scum which stains fixtures (bath tube ring)
- Discolours and weakens fabrics.



Examples: 1) Tubes obstructed by lime scale. 2) A heating element made inefficient 3) bacterial growth on lime scale 4) a high-end shower malfunctioning due to lime clogged nozzles.

Chemical contamination

Industrial waste water and pollutants might enter the water supply and can have major medical consequences in case of long-term exposure. The same can be said for chlorine

Chlorine exposure might cause:

- dry skin
- Hair damage
- Eyes irritations
- skin rushes
- allergies and acne
- sores, inflammation and worsen dermatitis

It is mainly absorbed by skin and lungs

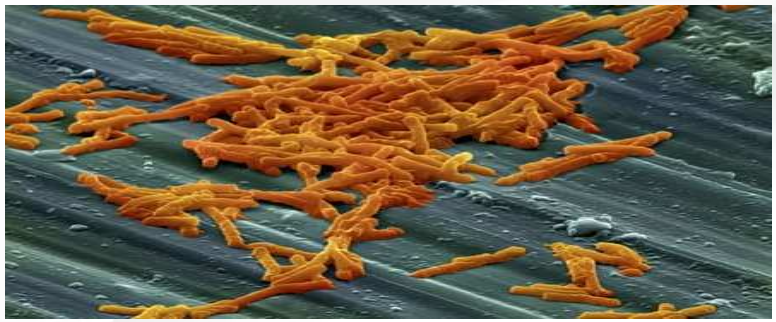
European Union's maximum chlorination limit is 0.1ppm for drinking water and 0.5ppm for pool disinfection.
In tropical countries the limit is as high as 1.2ppm!

Chlorination effects on hair

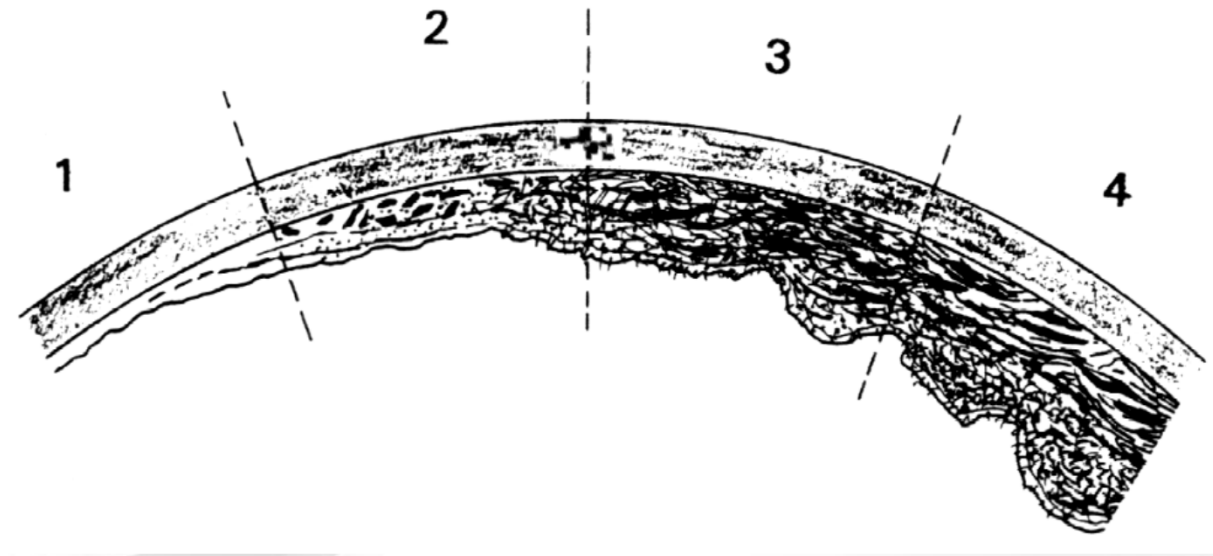
A Chlorine induced skin-rash

Bacterial and viral contamination

- Roofs water tanks are the ideal breeding ground for bacteria
- Not all bacteria or viruses are pathogens BUT all bacterial growth will spoil water's taste and smell
- Bacterial colonies create **biofilms**, which augment resistance to disinfection
- Some bacterial colonies corrode pipes
- Bacteria in the water supply are a major health hazard



Biofilm - Steps in biofilm formation

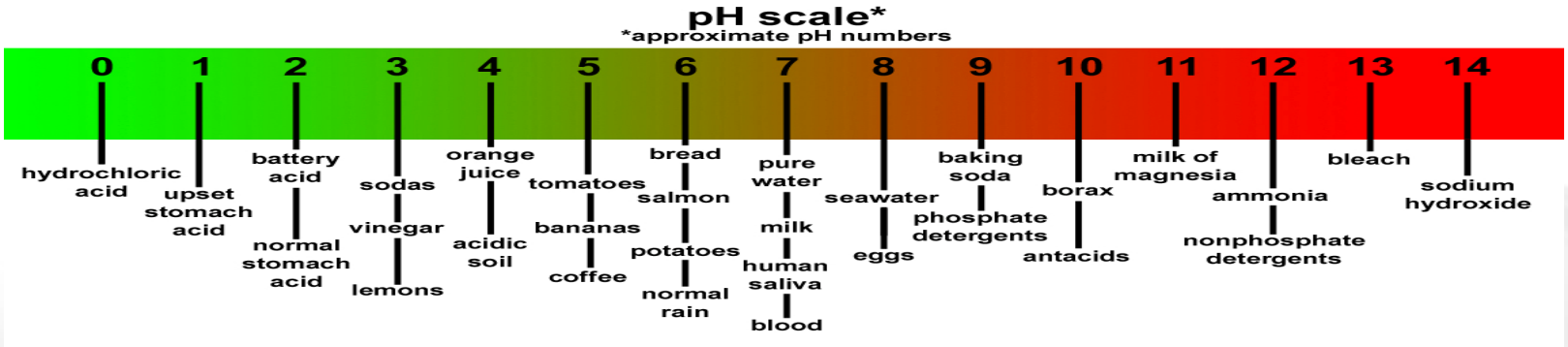


1) Initial colonization – thin film of bacteria enclosed in protein film (biofilm)
2) Sediment trapped by biofilm; bacteria secrete small individual particles of iron and manganese hydroxides
3) Filament-forming bacteria and fungi stabilize biofilm
4) Deposits harden and mineralize, forming basis for more biofilm to develop

Alkaline or acidic water

- The PH scale measures the acidity or basicity of an aqueous solution
- The scale goes from 0 (most acidic) to 14 (most basic), where pure water has a value of 7
- Physically it measures the concentration of free Hydrogen ions (protons) in the water
- Water with significant deviations from neutrality is said “aggressive” and can cause:
  - Bluish/green or gray cast to water (caused by water oxidizing and assimilating copper or lead from the pipes).
  - Blue or green stains in the proximity of copper fixtures
  - Slight metallic taste

The PH scale and the relative PH of common solutions. Acidic rain has been measured as low as PH 1.5!



PH CORRECTION (NEUTRALIZATION)

There are two ways in which it is possible to correct the PH of acidic/basic water: removing the contaminants (distillation) or neutralizing them.

To chemically correct the PH value toward neutrality is called neutralization.

For correcting acidic water we use calcium carbonate (for PH >6.5), sodium carbonate (for PH >5.5) or sodium hydroxide (for all acidities <5.5).

For basic water are acetic acid, vinegar, (for PH >8), hydrochloric acid(for PH >10), Sulfuric acid (for PH >10).

pH for Human Consumption and alkaline water

The human body carefully regulates blood's pH in the narrow 7.38-7.42 range through homeostatic mechanisms. These consist of complex buffer reactions which keep the blood at a fixed pH.

Water hardness

Water hardness is given by the presence of calcium , magnesium and iron ions in the water. Both are in solution in the form of Ca^{2+} , Mg^{2+} Fe^{2+} cations.

Measurement	Water Hardness Scales				
Classification	**mg/L**	**mmol/L**	**dGH/°dH**	**gpg**	**ppm**
Soft	0–60	0–0.60	0.3-3.00	0-3.50	less than 60
Moderately hard	61–120	0.61–1.20	3.72-6.75	3.56-7.01	60-120
Hard	121–180	1.21–1.80	6.78–10.08	7.06-10.51	120-180
Very hard	≥ 181	≥ 1.81	≥ 10.14	≥ 10.57	> 180

- Low amounts of hardness in the water is desirable. Water with hardness <1 dGH (17ppm) is considered soft and does not require treatment. Too much hardness causes:
  - Cause white halo deposits on surfaces;
  - Prevents surfactants (soap and detergents) from lathering;
  - Leads to the formation of soap scum;
  - Causes soap residues to cling to fabric;
  - Cause fabric to become weak and causes it to discolour.

Limescale in pipes and faucets

No matter what material is used

Galvanized steel tubes

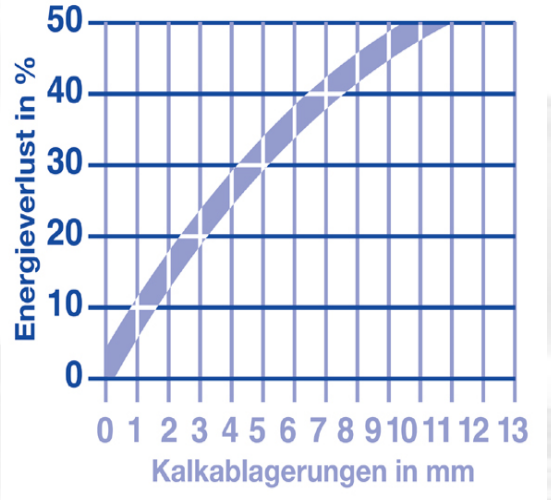
Copper pipes

Stainless steel tubes

Plastic pipes

Limescale on heat exchangers

Lime scale on heat exchangers = increased energy costs



Already 2 mm lime scale on a heat exchanger increases the energy consumption about 20 %

Corrosion

Definition:

„reaction of a metallic material with its surroundings, which causes a measurable change of the material and can lead to a corrosion damage…“

Reasons for corrosion:

- **Gases (oxygen, CO_2)**
- **Salts (conductivity)**

Particulate contamination

TOTAL DISSOLVED SOLIDS (TDS)

- Total dissolved solids TDS refers to the total combined weight of all solids dissolved in water and is reported in either mg/l or ppm.
- Water with TDS <250mg/l is labeled **natural spring water**, above 500 mg/l **mineral water** and >1000mg/l considered unfit for human consumption (sea water's TDS might exceed 37000 mg/l).
- The removal of TDS is achieved either by distillation or Reverse Osmosis.

Turbidity

Suspended media will cause water's its opacity to rise

Usually turbidity is caused by silt, sand, fine organic and inorganic particles and other suspended colloidal material.

COMMON CONTAMINANTS

Iron

- Reddish/brownish colored water
- Red/brown stains on fixtures
- Metallic taste and odor
- Water that appears clear turns red upon heating
- Discolored laundry
- Darkened beverages

Turbidity

Hydrogen Sulfide

Easily detectable by the “rotten eggs” smell and foul taste. Can be toxic in high concentrations

Manganese

- Brownish or black water
- Stains and metallic taste
- Clogged pipes
- Hosts bacteria which form corrosive colonies

Treatment Technologies

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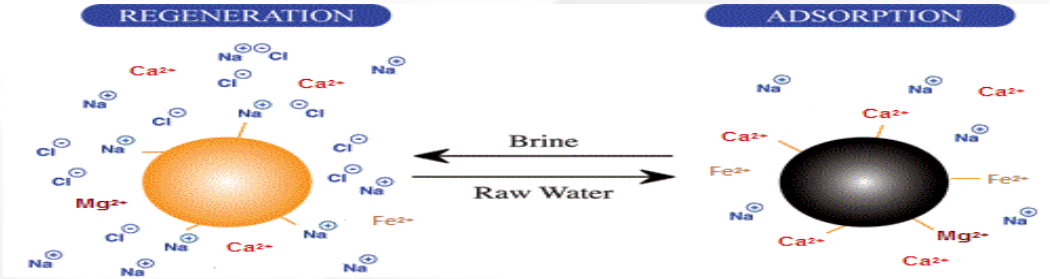
WATER SOFTENING VIA ION EXCHANGE

- In the common process of water softening a polymeric resin is used
- The resin has electrically charged active sites to which oppositely charged ions will stick
- During softening **Ca^{2+}**, **Mg^{2+}** and **Fe^{2+}** ions will stick to this sites and thus be removed from the water
- Once all the active sites have exchanged their Sodium ions for Calcium or magnesium ions it is called exhaust and will not be able to further soften any water unless it is regenerated.
- During regeneration **Na^{+}** ions will be introduced and exchanged with the **Ca^{2+}**, **Mg^{2+}** and **Fe^{2+}** ions at the active sites, this process is called the **Ion exchange process**

Ion exchange resin beads



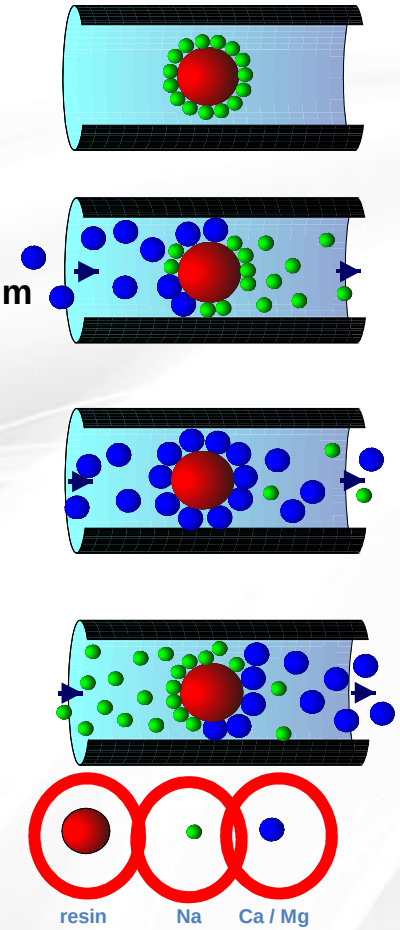
WATER SOFTENING VIA ION EXCHANGE

Ion exchange material (resin) ready for operation

Hardness is bound and exchanged against sodium

Exchange capacity consumed

Sodium solution; bound calcium is flushed into channel

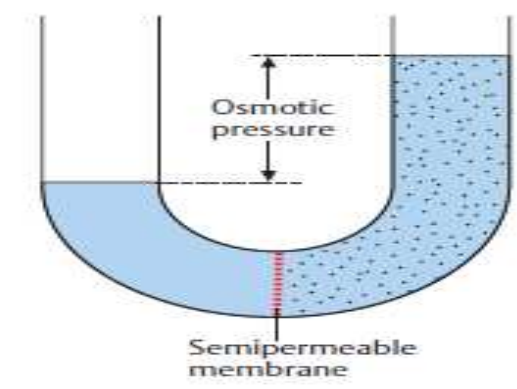


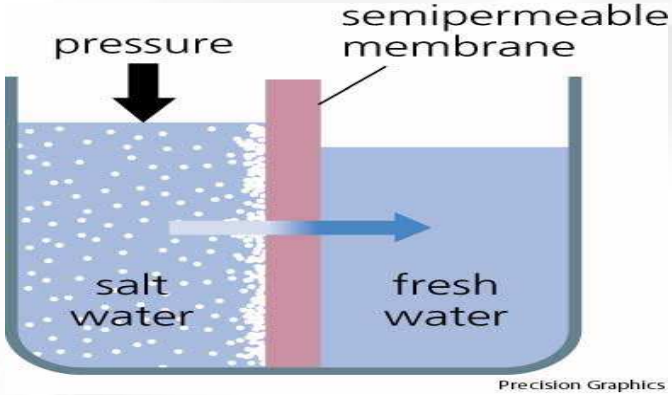
After regeneration and rinsing the process of softening can be restarted

REVERSE OSMOSIS (RO)

Osmosis is the tendency of solvent molecules to move spontaneously to areas where solute concentrations are higher. If the regions of higher/lower solute concentration are divided by a semipermeable membrane the solute will flow towards the area of higher solute concentration with a pressure defined as **Osmotic Pressure**.

Hydrostatic pressure higher than the osmotic pressure is applied & is possible to reverse the flow direction. This process is called **Reverse Osmosis (RO)** and can be exploited as a water purification or desalination procedure.





FILTRATION

Filtration is the mechanical physical removal or separation of solids from liquids

Gravel-sand-quartz filters
These force the water to pass through a granulose filter medium which physically retains particles suspended in the water. This process is termed **absorption**.

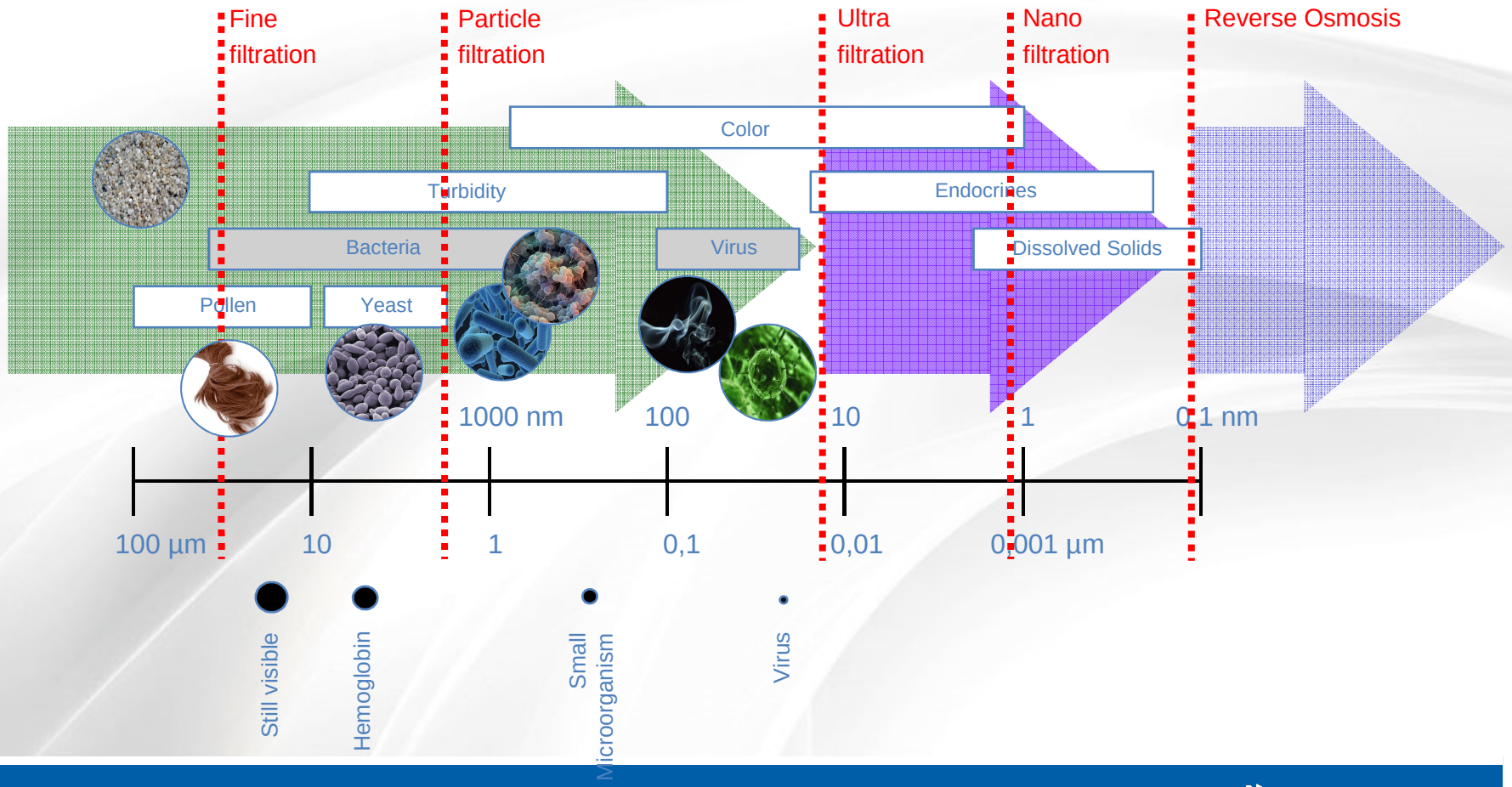
Rigid mash filters
Synthetic or metallic sheets with pores of a specific diameter called mashes. Mash sizes can vary from 300 to 30µm. They are used to remove coarse particles

Bag Filters
In bag filters the filtering medium is a soft membrane with pore diameters ranging from 500 to .5µm. These are used to remove turbidity, silt and fine sediments

Microfiltration membranes
These are used to remove bacterial contamination for the filtration of drinkable water. Mash sizes vary from .5 to .2µm.

Ultrafiltration Membranes
Membranes pore sizes small enough to filter out viruses, typically .1-.02µm.

Calcium Carbonate filters
This are used to offer limited sediment filtration combined with PH regulation properties for acidic water, but sharply increase hardness.



Adsorbtion

Adsorption is the physical adhesion of atoms, ions or molecules form a substance termed the **adsorbate**, to a surface, this defined as the **adsorbent**.

The adsorbate is captured through a chemical bond without causing a chemical reaction

The most widely used adsorbing medium, by far, is **activated carbon**.

A teaspoon of activated carbon can have the astonishingly surface area of a whole football field!

- Removal of chemicals such a Chlorine, ionized solute metals, pesticides etc.
- Correction of water's taste and odor
- Removal of organic compounds
- Removal of chromatic contaminants
- Fine sediments removal (up to 5µm)
- Removal of solute acid gasses and hydrocarbons

Disinfection

Chemical feed
This method consists in adding chemical oxidizers, usually Chlorine, to kill microorganisms.

UV
Ultra Violet radiation (UV) is highly energetic and damages irreparably DNA.

Ozone disinfection
Ozone gas is a very strong oxidizer and kills most microorganisms and viruses upon contact.

Overview Treatment Processes

TREATMENT PROCESS	DESCRIPTION	METHODS
Neutralization	The process of adding a base or acid producing a more neutral solution.	1. Magnesium Oxide - Calcium Bicarbonate
Filtration	The process of removing contaminants and suspended matter by trapping it in pores of progressively smaller diameters.	1. Sand, Quartz, Anthracite 2. Multi-media filters 3. Backwash-Bag filters 4. Micro and Ultrafiltration membranes 5. Ceramic filter
Adsorption	The process of liquid, gas or suspended matter bonding to the surface or pores of a media but causing no chemical reaction.	1. Activated Carbon
Ion Exchange	A reversible chemical process where electrically charged matter is exchanged for lesser or opposite charged matter.	1. Cation Exchange Resin 2. Anion Exchange Resin 3. Specialty exchange Resins
Disinfection	The process of adding oxidizing chemicals in solution or using radiation to kill microorganism.	1. Chlorine 2. Ultraviolet Lamp 3. Ozonation
Demineralization Desalinization Deionization	The removal of matter from a solution by a two-phase ion exchange procedure, heating or pressurized filtration.	1. Reverse Osmosis 2. Distillation 3. Mixed Ion Exchange Resin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