Water

Methods of finding, purifying and storing water

"Nothing is softer or more flexible than water,
yet nothing can resist it."
Lao Tzu

Introduction

Water is essential for almost all forms of life on the planet without which we could not sustain ourselves due to the sheer amount we lose daily without realising. It's something that we all take for granted. We turn on the faucet and there it is, plentiful, clean, drinkable and seemingly endless. Without such a simple way to acquire water many people would panic out of sheer thirst and drink contaminated water from a stream, lake or worse yet - the ocean.

With an atmospheric temperature of 20°C (68°F) the average adult requires 2 to 3 litres (quarts) of water daily. The following section will inform you on multiple ways to acquire water and how to sterilize it to properly kill any viruses or pathogens that may be in it.

Purpose	The aim of WATER is to provide foundational knowledge on finding, harvest and purifying naturally occurring water until it's ready for human consumption. It also outlines how you can protect electronics from water and expounds on how the flow of water around the planet occurs by means of the ocean, rips, tides and waves.
Lost?	● For information on swimming and crossing bodies of water, see the SURVIVAL > Water Survival section. ● For ships, sailing and living on boats, see the TRANSPORT section. ● For tsunamis and flooding, see the NATURAL DISASTERS section. ● For dam failures, see the MAN-MADE DISASTERS section.

Contents

1 Types of Water

Here you can find a description of all the different types of water you may encounter, from distilled to bore water.

The distribution of water on the Earth's surface is extremely uneven. Only 3% of water on the surface is fresh; the remaining 97% resides in the ocean. Of freshwater, 69% resides in glaciers, 30% underground, and less than 1% is located in lakes, rivers, and swamps. Looked at another way, only one percent of the water on the Earth's surface is usable by humans, and 99% of the usable quantity is situated underground.

Water Distribution

- Ocean Water (96.5%)
- Ice and Snow (1.76%)
- Groundwater (1.69%)
- Lakes (0.013%)
- Atmosphere (0.00093%)
- Swamps (0.00083%)
- Rivers (0.00015%)
- Biological Water (0.000081%)

Tap Water	Water from a faucet, may or may not be suitable for drinking depending on country.	**May be Safe to Drink**
Mineral Water	Water that naturally contains minerals and is obtained from underground sources. No further minerals added and cannot be treated before packaging.	**Safe to Drink**
Spring Water	Rainwater leaking from the surface as a spring or puddle. Not passed through a community water system but is suitable for drinking.	**May be Safe to Drink**
Well Water	A well is an excavation or structure created in the ground by digging, driving, or drilling to access liquid resources, usually water. The oldest and most common kind of well is a water well, to access groundwater in underground aquifers.	**Requires Treatment**
Purified Water	Water which has been treated at a water plant removing bacteria, contaminants and dissolved solids.	**Safe to Drink**
Distilled Water	Demineralised water has been treated to remove all the minerals and salt via reverse osmosis. It's not recommended for drinking over long periods of time as it can cause mineral deficiencies.	**Safe to Drink (For a Limited Time)**
Sparkling Water	Water which has undergone carbonation (the addition of carbon dioxide) to make it fizzy. It may be spring water, purified water or spring water.	**Safe to Drink**
Bore Water	Bore water is groundwater that has been accessed by drilling a bore into underground aquifers (water storages) and pumping to the surface. Aquifers may contain chemicals and micro-organisms that are potentially harmful. Some of these chemicals are naturally occurring (such as those present in soils and rocks) while others are a result of contamination.	**Requires Treatment**
Drinking Water (Potable Water)	Drinking water, also known as potable water, is water that is safe to drink or to use for food preparation. The amount of drinking water required to maintain good health varies, and depends on physical activity level, age, health-related issues, and environmental conditions.	**Safe to Drink**

2 Water Loss

This section is about any form of water loss, from natural evaporation to water lost as sweat.

Bodily Water Loss

These are the different methods in which water can be lost from the body.

Exhaling Water Vapour	Water is lost from your body through breathing. Depending on the humidity level of the air, we lose about 300-500ml (0.3-0.5 quarts) of fluid a day through breathing.
Perspiration	You can lose up to 1.9L (2 quarts) of water per hour while exercising. Your body temperature rises about 3°C when engaged in physical activity. Sweating is your body's natural cooling system by releasing H2O in the form of perspiration.
Urine	We lose water through urination. A person typically loses 1.5 litres of water a day through urine. If your water intake is high then your kidneys produce larger amounts of water to help maintain a balance.
Bowels	Water keeps the food you eat moving through your intestines which also need water to help keep stools soft and easy to pass. All faeces contain water, causing water loss during a bowel movement. A person typically loses about 6% of their water through faeces.
Diet	Diets containing heavily processed foods could lead to water loss in your body. Heavily processed foods lack the moisture of fresh foods. Meat proteins pull water from the body to aid in digestion. Less moisture in your foods may be causing your body to pull more water from its water supply.

Water Loss Modifiers

The following list will multiply any water loss you are experiencing, so try to minimise their impact.

Heat Exposure	When an individual is exposed to very high temperatures, water lost in sweat can be increased to as much as 3.5 quarts an hour. Water loss at this increased rate can deplete the body fluids in a short time.
Exercise	Physical activity increases the loss of water by: ● The increased respiration rate causes increased water loss by evaporation through the lungs. ● The increased body heat causes excessive sweating.
Cold Exposure	As the temperature decreases, the amount of water vapour in the air also decreases. Therefore, breathing cold air results in increased water loss by evaporation from the lungs.
High Altitude	At high altitudes, increased water loss by evaporation through the lungs occurs not only as a result of breathing cooler air but also as a result of the increased respiratory efforts required.
Burns	After extensive burns, the outermost layer of skin is destroyed. When this layer is gone, there is no longer a barrier to water loss by diffusion, and the rate of water loss in this manner can increase up to 5 quarts a day.

Illness	Severe vomiting or prolonged diarrhoea can leas to serious water depletion.

Natural Water Loss

This covers any form of natural forms of water loss such as evaporation.

Evaporation	Water naturally evaporates over time but can really add up when you have large quantities of it.
Freezing	When water freezes it becomes ice. Ice is unusable in it's current form but can easily be turned back into water again by applying a low, steady heat.
Steam	Water can be lost in the form of steam. This occurs when the water reaches its boiling point. It's difficult to capture and turn steam back into water so try to keep it below boiling point.

Water Conservation

Some tips on conserving both bodily water and natural water.

Conserving Water
- Avoid exertion, rest
- Keep cool, stay in shade
- Don't lie on heated surfaces
- Don't eat, or eat as little as possible
- Don't drink alcohol which requires fluid to break down
- Don't talk and breathe through the nose, not the mouth
- Drink in small sips, even if you have an ample supply

Conserving Household Water
- Flush the toilet once a day for liquids and solids every use
- Fill a bucket for washing hands and add antibacterial elements
- Wash your clothes manually in a scrubber bag
- Use disposable cutlery and eating utensils to prevent washing up
- Take sponge baths instead of showers and especially baths
- Utilise rain, lakes or rivers for showers

Rationing Water
Try to ration water in any survival situation unless you have large amounts of it readily available. Don't drink more water than is necessary in your current situation if water is limited. Extra water will only come out as urine in a few hours and oversaturation doesn't have many additional benefits. Do not ration a limited amount of water and only take sips if you're very thirsty. It's better used early on to keep your mind and body strong so you can search for more.

3 Water Acquisition

Acquiring water is a vital skill in survival situations and should be one of the top priorities after medical needs. The section below will describe how to find water in different environments.

Minimum Water Intake
You need about 2L (64oz) of water per day to stay alive. This depends heavily on how much you are moving and the environment you're in. Find a suitable source of water that won't dry up over time such as a lake or spring.

Locating Water

The below are some tips on finding bodies of water using nature.

Animals	Animals require water regularly, grazing ones are never far from water as they drink at dawn and dusk.
Birds	Birds are never far from water. When they fly straight and low they are heading for water. They fly from tree to tree when returning from water - resting frequently.
Insects	Bees only fly 6.5km (4mi) from their hives at most. Flies keep within 90m (295ft) of water.
Valleys	Look in valley bottoms where water naturally drains. If none look for patches of green vegetation and dig.
Stream Beds	Dig in gullies and dry stream beds. Go deep enough and you should find water spilling in from the sides.
Mountains	In mountains look for water trapped in crevices.
Coast	On the coast dig above the high water line or look for lush vegetation in cliff faults - there may be a spring.
Warnings	Be wary of pools with no green vegetation around or contains animal bones. Watch out for mineral build-ups around the edges of lakes which indicate alkaline conditions. In the desert lakes with no outlets become very salty - distil to drink.

Polar Water Tips
Ice will yield more water per given volume than snow and requires less heat to do so. If the sun is shining, snow or ice may be placed on a dark surface to melt. If snow must be used for drinking water, use the snow closest to the ground. This snow is packed tighter and will produce more water. To melt snow, add it a little at a time to a pot over a fire preventing burning out the bottom of the container through insulation and airspace. All arctic water should be purified by some means. In the summer surface water may be discoloured but is drinkable when purified. You can use body heat to melt ice and snow using a waterproof container and placed between clothing layers. Do not place it directly next to the skin. Do not ingest unmelted snow or ice as it will lower the body's temperature, inducing dehydration and causing minor cold injury to lips and mouth.

Tundra Water Tips
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WATER Water Acquisition Locating Water

Northern Coniferous Forest Water Tips
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Deciduous Forest Water Tips
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Temperate Grassland Water Tips
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Mediterranean Regions Water Tips
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Tropical Forests Water Tips
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Savannah Water Tips
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Desert Water Tips
Sufficient water to last until the next water hole is reached should be on hand. Be prepared to backtrack if you cannot find your next source. Look for water before your supply is exhausted. Water canteens should be transported in such as way that they cannot be damaged or the seams split. You can drink 2.1L (2.2 quarts) of water at a time. The body sweats this amount in two hours. To maximise your water intake drink slowly and in sips. Drink as much as you can, rest and slowly drink again. Repeat this a few times until your body is saturated. To conserve water, do not travel in the heat of the day but only in the early morning, late evening or on a moonlit night. Set up a sheltered rest area for the day. The optimum drinking water temperature is between 10° - 15°C (50 - 59°F). To cool water, it can be wrapped in a wet cloth which will cause cooling when the water evaporates. Palm trees will grow where the water table is closest to the surface. Dig for water at the low point between dunes.

Ocean Water Tips
Collect rainwater in any available containers and store for future use. Collect dew on metal surfaces on foggy days. Use a Solar Still to distil the seawater. Use a desalter kit if there are no other options available.

Water Sources

WATER Water Acquisition Water Sources

Rain	Collect with a tarp and store for 7 days max without filtering. Can drink immediately.
Snow	Melt snow gradually and keep adding more to the liquid so you don't burn the bottom of the pot. It's 10% water depending on the type and isn't as efficient to collect as rain or hail. If the snow is fresh it doesn't typically require boiling.
Hail	Melt hail gradually and keep adding more to the liquid. Hail is 100% water and contains pathogens so boiling is essential.
Rivers	Filter the pathogens, viruses and particulate out. Always filter no matter how clear it looks.
Ocean	Desalinate - boil the water and recondense in a container. The average salinity of Earth's oceans is about 35 grams of salt per kilogram of sea water (3.5% salt). Most of this salt was released from volcanic activity or extracted from cool igneous rocks.
Lakes	Filter pathogens, viruses and particulate out. Ensure there's no green algae around the edges or carcasses nearby.
Evapotranspiration (Water Transpiration Bag)	Shake leaves to remove bugs. Place transparent bags over some of the fresh leaves on a medium tree or large shrub and tie at ends with a clean rock in the corner and a tube with a tap if available to prevent opening the bag. Do not use for more than three days consistently. Ensure the plant isn't toxic. Provides 3.7L/bag a day. Water may taste bitter.
Plant Condensation	Dig a shallow hole next to a plant with many leaves. Place a plastic bag over the plant and have its side slope to the lowest point which is in the hole. Tie or tighten the opening of the bag around the base of the plant. The plant will collect water with its root system. It should work for a few days as long as the plant isn't too exposed to the sun as it will be killed by overheating.
Vegetation Bag	Cut foliage from trees or herbaceous plants, sealing it in a large clear plastic bag and allow it to heat in the sun to extract the fluids contained within. The bag should be filled with about 1 cubic yard of foliage, sealed and exposed to the sun. The average yield is 320ml/bag in a 5 hour day. The water can be bitter to taste caused by leaf breakdown in the water. Use a taste test prior to consumption to test for toxins.
Dew Collection	Use clothing to mop up morning dew and wring into a cup. Dew and condensation settles on cold surfaces. These surfaces can be pieces of metal, grass, smooth rocks. Dew will evaporate at sunrise.
Fog Harvesting	Mesh netting made of nylon or polyethylene - AKA shade netting. Placed in a location with common fog on a mountain. The altitude should be 2/3rds of the stratocumulus cloud's thickness above the base - around 400-1000m. Mountain fog is denser then coastal fog. Harvests about 50L per day per m.
Atmospheric Water Generator	An atmospheric water generator (AWG) is a device that extracts water from humid ambient air. Water vapour in the air is condensed by cooling the air below its dew point, exposing the air to desiccants, or pressurizing the air. Unlike a dehumidifier, an AWG is designed to render the water potable.
Animals	In an emergency you can filter fresh animal blood for viruses and treat it for bacteria - only if you were the one to kill it. The eyes can be sucked for water as well. Large fish have a drinkable fluid along their spines. Gut the fish and keeping it flat remove the backbone being careful not to spill the liquid. In Aus desert frogs that burrow in the ground can be dug up and squeezed for their water.
Plants	Plants trap water in cavities. Shake old bamboo to find it and cut each notch to retrieve. Vines can store water but ensure sap isn't poisonous. Cut a deep notch high up and then close to the ground letting it drain, then work your way up.
Roots	Water Tree, Desert Oak, Bloodwood have roots near the surface. Pry them up and cut in 30cm lengths. Remove the bark and suck out the moisture or shave to a pulp and squeeze over mouth.
Cacti	Water is stored in the fruit and bodies but some are poisonous. Prickly pears are moisture laden in the fruit and 'ears'.
Vines	Slice the vine high up to prevent water capillary action and slice the bottom off. Water should slowly flow out. Avoid the liquid if it's cloudy, milky or has a bitter or sour taste. Do not touch the vine with your mouth. If the flow stops, cut another nick in the opposite end to drinking.

Green Bamboo	Water may be trapped within sections of bamboo. Shake it to determine if there's water inside by listening for sloshing. Cut two 45° notches on the same side and pry the piece away. Ensure the inside walls are clean and white and the water will be safe. If there are brown or black spots or any discolouration the water should be purified first.
Moss	Moss in tropical forests can be wrung of its water into your mouth.
Soil & Sand	In a muddy or damp area dig a hole one to two feet. Allow water to seep into the hole. Purify this to drink. Wet sand can be put in a piece of cloth which is then pressed or wrung to force the water out. The water will be cloudy for both methods but if left - will settle or can be filtered through a fine cloth.
Coast Water	Along coasts, water may be found by digging beach wells. Locate the wells behind the first or second pressure ridge. Wells can be dug 3-5 feet deep and should be lined with driftwood to prevent stirring up sand when procuring the water. The average well may take as long as 2 hours to produce 4 to 5 gallons of water.
Solar Still	Dig a hole 90cm across and 60cm deep in a moist area and cover with plastic sheet held by rocks then place a container in the centre. Ensure area receives lots of sunlight. Add a tube to drink from.
Sandy Beach & Salty Lakes	Along sandy beaches or salty desert lakes, dig a hole in a sand depression 30m (100ft) from the shore. Filtered water will gradually seep into the hole.
Dry Rivers	Follow a dry river bed and because of the rock structure or composition a stream might emerge. Dig a pit if the soil is moist. Follow the riverbed to the source. There might still be a trickle of water or humid soil. Dry meandering stream beds might have water deposits just below the surface at outside bends. Dig in these bends for water.
Groundwater	Groundwater is part of precipitation that seeps down through the soil until it reaches impervious rock. If the water can not find any area to flow into it saturates the area above the rock with water. It then slowly moves underground, generally at a downward angle and may eventually seep into streams, lakes and oceans. Dig deep into the earth at a low point to reveal. Filtering may be required.
Sinkholes	Sinkholes are common where the rock below the land surface is limestone, carbonate rock, salt beds, or rocks that can naturally be dissolved by ground water circulating through them. As the rock dissolves, spaces and caverns develop underground. Sinkholes are dramatic because the land usually stays intact for a while until the underground spaces get too big. If there is not enough support for the land above the spaces then a sudden collapse of the land surface can occur.
Rocky Ground	In rocky ground, look for springs and seepages.
Limestone and Lava	Limestone and lava rocks will have more and larger springs than any other rocks. Most lava rocks contain millions of bubble holes; ground water may seep through them.
Lava Flows	Look for springs along the walls of valleys that cross a lava flow.
Clay	Water moves slowly through clay, but many clays contain strips of sand which may yield springs. Look for a wet place on the surface of clay bluffs and try digging it out.
Granite	Most common rocks, like granite contain water only in irregular cracks. A crack in a rock with a bird dung around the outside may indicate a water source that can be reached by a piece of surgical house used as a straw or siphon.
Tree Spile	Requires: Drill, Bit, Mallet, taps, vinyl tube, bucket, bleach. Number of taps per tree by diameter: 12" - 1 Tap, 18" - 2 taps, 24+ - 3 taps. Drill a 12mm hole up at an angle up into the tree 5cm deep and insert spile tapping it gently. Connect the tube and run it to the bucket. Sap will collect slowly over days. Store in a cool place. Sap most likely Jul-Early Sep.
Cliffs	Find water at the leeward base (the steep side of the dune opposite the direction of the wind) of large dunes or at a very low spot between dunes.
Iceberg Water	Composed of freshwater and can be used as a source of drinking water.
Old Sea Ice	A bluish or blackish ice which shatters easily and generally has rounded corners. It's almost salt free.
New Sea Ice	Is milky or gray coloured with sharp edges and angles. This type of ice will not shatter or break easily. Snow and ice may be saturated with salt from blowing spray; if it tastes salty select a different source.
Urine	Drinking urine straight is not recommended but possible. Consume within 6 hours after urinating. Using a solar still, distillation or reverse osmosis membrane, generates pure drinking water. Boiling, water filters and purifying tablets kill bacteria but leave the waste products, but it's drinkable. Urine is 95% water, 2.5% is urea and 2.5% hormones, enzymes and salts.

Urban Water Sources

Household Water Sources

Tap	As long as there's water pressure you can get water from the tap. However this supply will run out quickly if SHTF. Use the lowest tap in your home to get every drop.
Hot Water System	A limited supply of water which can be utilised. Can give you from 125L-315L.
Fridge & Freezer	Use water melted from the freezer to purify.
Hoses	There could be residual water in outdoor hoses which you can collect and filter if required. Uncoil, lift one end and collect the water coming out.
Toilet Water	You can use the water in the tank (not the bowl) to purify. Drinking from the bowl only if desperate and you have sufficiently strong purification.
Air Conditioners	If you have a water collection tray you can use this water to distil to provide drinking water. Note: The trays are typically home to a host of various bacteria, protozoa and possibly viruses.
Fish Tank Water	If you use a strong filter (0.02 microns or less) you can filter and drink tank water. Freshwater is much easier to purify as saltwater requires distillation or desalination.
Drains	Drains will hold water for a long period of time. However it will require extreme purification methods.
Cars	You can get water from the wiper fluid container on cars which have been abandoned, but filter it prior to use.

Suburban Water Sources

Park Taps	Using a sillcock key you can turn on these taps and drain them. Some taps may have a typical handle or a lever style tap.
Water Towers	Hold large amounts of water, typically found on hills to increase the water pressure but may be difficult to access due to fences and proprietary water keys.
Fire Hydrants	Fire hydrants are very difficult to open due to having a pentagonal socket. **Signage** ● H = Potable Water ● RH = Recycled Non Potable ● P = Pathway (Location) ● R = Roadway (Location)
Wells	

Retrieving Water

Sillcock Keys

The taps - known as "Anti Vandal Taps" are used in parks, water treatment plants and other government run areas to prevent water theft. This water can be accessed by using a special key on the top of the tap to turn it on. The keys are called "Sillcock Keys" in America and "Vandal Proof Keys" generally everywhere else. A special type of key used for recycled water is called an "Anti Vandal Recycled Water Key". There a multitude of key types which should be covered in the next cells but it helps to have the four-way key for opening multiple types of taps.

Key Shape	Used For
Rectangle with convex short ends	Generally on the 4-way keys.
Reverse Cog-shaped teeth with flat sections on upper and lower areas	Generally on the 4-way keys.
Zig-Zagged Teeth	Generally on the 4-way keys. I've seen a few of these in parks, some are marked as recycled water.
Fire Hydrant Wrench Hexagonal	Allows the opening of fire hydrants for use of the water.
Square	These are rarely seen, but it seems harder to get this type of key as they aren't included in the general 4-way keys.
Zig-Zagged Circular Teeth with flat base and pointed teeth	A mid-way key shape between the cog and the zig-zagged shape. Generally on the 4-way keys.

Pumps

Pumps are used for transporting water either horizontally or vertically. They are useful for moving volumes of water over a distance or retrieving it from wells.

Wells

Wells are dug to hopefully provide a reliable and ample supply of water.

Dug Wells	Made with a pick and a shovel if the ground is soft and the water table is shallow. They are often lined with stones to prevent them from collapsing. They cannot be dug much deeper than the water table because it keeps filling up with water. During the dry season or a drought the water table will fall and the depth of the well can be increased.
Driven Wells	Built by driving a small diameter pipe into soft earth, such as sand or gravel. A screen is usually attached to the bottom of the pipe to filter out sand and other particles. They can only tap shallow water, and because the source of the water is so close to the surface, contamination from surface pollutants can occur.
Drilled Wells	Most modern wells are drilled. Drill rigs are often mounted on big trucks. Drilled wells can be drilled more than 1,000 feet deep. Often a pump is placed at the bottom to push water up from the surface.

Other Water

Bottled Water
Water stored in a bottle for consumption. Some bottles may leach chemicals into the water when heated. Water jug dispensers can also be found in some households. The jugs are generally 19L (5 gal).

Canned Water
More sustainable than bottled water and won't leach chemicals into the water. Some manufacturers started to use Nitrogen flush to remove air and bacteria from their cans to prolong shelf life to 30 years or longer, making the water suitable for long term storage. May have resealable lids or the common ring pull lid system.

Water Pouches Water Pouches are small flexible pouches of clean drinking water which you cut open to drink from. They generally hold 125ml each and have expiry dates of around 5 years. They aren't practical for anything but consumption and are often fairly expensive. Pouches are considered more durable, freeze resistant, impact resistant and heat resistant then water bottles thus giving them a unique purpose.	**Known Brands** ● Datrex ● Mainstay ● Mayday ● SOS Emergency	**Expiry** Chemicals may leak into the water over its lifetime and may be contaminated after it's expired. It's recommended to boil the water when expired. It will generally last 5 years.

4 Water Purification

This sections covers how to turn potentially dangerous water into drinking water.

In general there are 3 stages to producing drinking water from any type of water.

1. Remove Sediment	Filter out unwanted matter in the water such as dirt and sand. This makes it easier to kill pathogens.
2. Kill/Remove Pathogens	Remove the risk of pathogens by either killing them or removing them from the water. The first step can be combined with this step sometimes.
3. Remove Odour/Flavour	Remove/correct any natural bad taste lingering in the water or resulting from additives in the previous step.

Water Purification Overview

This section is a tabular description of each purification method to assist with choosing the best way to purify water. Each of the following purification methods are expanded in more detail in the sections below. Bugout convenience is how easy the purification is to accomplish on the go and how easy it is to store, use and repair. The scores signify the convenience of using this technique in a survival or bug-out situation. For more information on any of the techniques below, head to the section below entitled "Purification".

Note the difference between **Kills** and **Removes** as it could be important. **Red** text with * 's signify that only some models provide this capability. "Improves" and "Reduces" are used for a slightly less effectiveness than "Removes" or "Kills" respectively.

Filter Type	Convenience Score	Effects & Requirements	Treatment Time & Effectivity	Lifespan & Maintenance
Makeshift Water Filter A custom filter built in the field from sand, cloth, rocks and moss.	**Makeshift Water Filter** **3/5** Easy filter to build and use in the field, but won't filter pathogens.	**Effects** • Removes Larger Particulate **Requires** • Plastic Body • Filterable Materials	**Treatment Time (1L)** 2 Minutes **Not Effective On** • Viruses • Chemicals	**Effective Lifespan** Infinite **Maintenance Required** Wash thoroughly prior to first use. May become clogged over time.
Manufactured Filters Any form of manufactured water filter.	**Manufactured Filters** **5/5** Very easy to use and maintain. Slowly blocks with age.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Viruses* **Requires** • A Filter • Clean Water Container	**Treatment Time (1L)** 2 Minutes **Not Effective On** • Viruses* • Chemicals • Salts	**Effective Lifespan** 50L-1,000L Clogs as it ages **Maintenance Required** Occasional back flushing when it becomes clogged.
Bank Filtration Water is filtered naturally through a bank to remove contaminants.	**Bank Filtration** **3/5** If you're near the ocean a bank should be common. Be 100% sure the water is consumable.	**Effects** • Lowers Turbidity **Requires** • A suitable bank • Digging Utensil	**Treatment Time (1L)** o **Not Effective On** • Viruses	**Effective Lifespan** o **Maintenance Required** o
Tap Filters Filters that fit over household faucets.	**Tap Filters** **2/5** Can only be used with taps. Large and Bulky.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Chlorine • Removes Lead • Removes Asbestos • Removes Odours **Requires** • Tap Filter • Grid Water • Tap Pressure	**Treatment Time (1L)** 1 Minute **Not Effective On** • Viruses • Chemicals • Salts	**Effective Lifespan** 50L-1,000L Clogs as it ages **Maintenance Required** Occasional back flushing when it becomes clogged.
Carbon Filtering Putting water through carbon removes particulate and bad taste but leaves the bacteria and viruses.	**Carbon Filtering** **3/5** Only removes particulate and bad taste.	**Effects** • Removes Larger Particulate • Removes Bad Taste **Requires** •	**Treatment Time (1L)** 2 Minutes **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Activated Charcoal Charcoal with a large surface area for holding contaminants.	**Activated Charcoal** **3/5** Only removes particulate and bad taste.	**Effects** • Removes Larger Particulate • Removes Bad Taste **Requires** • Activated Charcoal	**Treatment Time (1L)** 2 Minutes **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Hand Filtering (Straining) Filtering water through a piece of fine clothing folded over at least 8 times.	**Hand Filtering (Straining)** **3/5** Only removes particulate. Very easy to use.	**Effects** • Reduces Protozoa • Reduces Bacteria • Reduces Turbidity **Requires** • Large Cloth or Material	**Treatment Time (1L)** 2 Minutes **Not Effective On** • Viruses • Chemicals • Salts	**Effective Lifespan** o **Maintenance Required** Rinsing out of the straining material.
Slow Sand Filter A filter using sand and a biofilm layer to kill microorganisms.	**Slow Sand Filter** **2/5** Takes a long time to set up but provides ample clean water. Removes most contaminants. Lots of maintenance and space required. Lots of resources required to build.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Viruses • Removes Turbidity • Removes Heavy Metals • Improves Odour, Taste • Reduces Iron • Reduces Manganese • Reduces Arsenic **Requires** • Lots of Space	**Treatment Time (1L)** o **Not Effective On** • Salts • Fluoride • Chemicals	**Effective Lifespan** Infinite **Maintenance Required** Have to maintain the biofilm layer to keep the filter running.

Rapid Sand Filter Rapid sand filtration is a purely physical drinking water purification method. Rapid sand filters (RSF) provide rapid and efficient removal of relatively large suspended particles.	**Rapid Sand Filter** **2/5** Takes a long time to set up but provides ample clean water. Removes most contaminants. Lots of maintenance and space required. Lots of resources required to build.	**Effects** ● Removes Turbidity **Requires** ● Lots of Space	**Treatment Time (1L)** 4k-12k Litres per Hour **Not Effective On** ● Bacteria ● Viruses ● Fluoride ● Arsenic ● Salts	**Effective Lifespan** o **Maintenance Required** ● Frequent Cleaning ● Skilled Supervision ● High Energy Input ● Backwashing
Biosand Filter Biosand filters remove pathogens and suspended solids from water using biological and physical processes that take place in a sand column covered with a biofilm.	**Biosand Filter** **2/5** Takes a long time to set up but provides ample clean water. Removes most contaminants. Lots of maintenance and space required. Lots of resources required to build.	**Effects** ● Removes Protozoa ● Removes Bacteria ● Removes Turbidity ● Removes Colour ● Removes Odour ● Removes Iron **Requires** ●	**Treatment Time (30L)** 1 Hour **Not Effective On** ● Dissolved Compounds ● Viruses	**Effective Lifespan** Has a Long Life **Maintenance Required** ● Requires Constant Use
Sedimentation Sedimentation is the process of settling or being deposited as a sediment.	**Sedimentation** **2/5** Only clumps particulate together for removal.	**Effects** ● Reduces Sediment ● Reduces Turbidity ● Reduces Viruses ● Reduces Bacteria ● Reduces Protozoa **Requires** ● Sediment Chemicals	**Treatment Time (1L)** o **Not Effective On** ● Most Things ● Chemicals	**Effective Lifespan** One Time Use **Maintenance Required** ● Careful PH control
Coagulation Coagulates the sediment so it falls out of suspension for easy removal.	**Coagulation** **2/5** Only clumps particulate together for removal.	**Effects** ● Clumps Sediment ● Reduces Turbidity ● Reduces of Protozoa ● Reduces of Bacteria ● Reduces of Viruses **Requires** ● Coagulants	**Treatment Time (1L)** 5 Minutes **Not Effective On** ● Most Things ● Chemicals	**Effective Lifespan** o **Maintenance Required** o
Boiling Boil water at high temperatures to kill pathogens.	**Boiling** **5/5** The most convenient way to purify water in the field.	**Effects** ● Kills Protozoa ● Kills Bacteria ● Kills Viruses **Requires** ● Fire ● Metal Pot	**Treatment Time (1L)** 5 Minutes **Not Effective On** ● Turbidity ● Chemicals ● Taste ● Smell ● Colour	**Effective Lifespan** Infinite **Maintenance Required** ● None
Solar Pasteurisation The heating of water to levels over 65°C (149°F) and under boiling can kill all pathogens over a longer period of time.	**Solar Pasteurisation** **3/5** Similar to SODIS and boiling but uses less energy. Harder to confirm organisms are dead.	**Effects** ● Kills Protozoa ● Kills Bacteria ● Kills Viruses **Requires** ● Heat Source ● Unmeltable Container	**Treatment Time (1L)** 6 Minutes **Not Effective On** ● Turbidity ● Chemicals	**Effective Lifespan** Infinite **Maintenance Required** ● None
Distillation Collection of the steam from boiling water recondensed back into a liquid.	**Distillation** **4/5** Guarantees water purity but takes a long time and special equipment.	**Effects** ● Removes Turbidity ● Removes Protozoa ● Removes Bacteria ● Removes Viruses ● Removes Salts ● Removes Sugars **Requires** ● Fire ● Condensation Tubing ● Funnel Section ● Boiling Container ● Collection Container	**Treatment Time (1L)** 30 Minutes **Not Effective On** ● None?	**Effective Lifespan** Infinite **Maintenance Required** ● None
Chlorination Add chlorine to water and mix to kill pathogens.	**Chlorination** **5/5** Very easy to purify water. Must to wait some time for it to work. Tiny tablets.	**Effects** ● Kills Protozoa ● Kills Bacteria ● Kills Viruses **Requires** ● Chlorine (Such as:) ○ Sodium Hypochlorite ○ Calcium Hypochlorite ○ Electrolytic Purification	**Treatment Time (1L)** 30m for Bacteria / Protozoa or 4h for Cryptosporidium **Not Effective On** ● Turbidity ● Chemicals	**Effective Lifespan** o **Maintenance Required** None
Electrolytic Water Purifier Generates chlorine from salty water to kill pathogens. (WATA) (Sodium Hypochlorite)	**Electrolytic Water Purifier** **4/5** Generates chlorine with salt easily and quick to use. Batteries Required.	**Effects** ● Kills Protozoa ● Kills Bacteria ● Reduces Viruses **Requires** ● Salt ● Chlorine Generator	**Treatment Time (1L)** 1 Minute Initial 30m or 4h Chlorination **Not Effective On** ● Cryptosporidium ● Turbidity ● Chemicals ● Taste ● Smell ● Odour	**Effective Lifespan** Infinite **Maintenance Required** Keeping the batteries charged.

UV Light Shining of a light into clear water to kill pathogens.	**UV Light** **3/5** Often requires additional filtration methods. Batteries required.	**Effects** • Kills Protozoa • Kills Bacteria • Kills Viruses **Requires** • UV Purifier	**Treatment Time (1L)** 2 Minutes **Not Effective On** • Turbidity • Chemicals • Taste • Odour	**Effective Lifespan** About 5,000 hours until the LED dies. **Maintenance Required** Keeping the batteries charged.
SODIS (Solar Disinfection) The use of the sun's UV rays to kill contaminants in water.	**SODIS** **3/5** Easy to access materials but takes a long time to purify.	**Effects** • Kills Protozoa • Kills Bacteria • Kills Viruses **Requires** • Full Sunlight for 8h	**Treatment Time (1L)** • 6 Hours • 2 Days (If Cloudy) **Not Effective On** • Chemicals	**Effective Lifespan** Infinite **Maintenance Required** None
Copper / Silver Ionization / Electrolysis Metals with antimicrobial properties that kills pathogens slowly.	**Copper/Silver Ionization / Electrolysis** **2/5** Infinite reusability but slow and hard to tell when the water is drinkable.	**Effects** • Kills Protozoa • Kills Bacteria • Kills Viruses **Requires** • Specific Metals	**Treatment Time (1L)** 2 Days **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** None
Colloidal Silver An antibacterial solution of silver that kills pathogens.	**Colloidal Silver** **2/5** Hard to obtain colloidal silver and use to treat water effectively.	**Effects** • Kills Protozoa • Kills Bacteria • Kills Viruses **Requires** • Silver • Electricity Source • Colloidal Generator	**Treatment Time (1L)** 4 Hours **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** Generation of colloidal silver solution
Ceramic Candle Filter A vertical gravity fed ceramic filter which purifies water.	**Ceramic Candle Filter** **3/5** Large and bulky but simple to use.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Most Viruses **Requires** • Filtration Device	**Treatment Time (1L)** 2 Minutes **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** Scrubbing the filter clean
Membrane Filtration A simple membrane which filters out contaminants.	**Membrane Filtration** **4/5** Generally compact, portable and easy to use.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Some Viruses **Requires** • Membrane Filter	**Treatment Time (1L)** 2 Minutes **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Reverse Osmosis An extremely fine filter membrane that removes most contaminants.	**Reverse Osmosis** **3/5** Removes virtually every contaminant but requires maintenance and parts are large and hard to get.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Viruses • Removes Salts • Removes Sugars • Removes Chemicals • Removes Pesticides • Removes Synth Dyes • Removes Heavy Metals • Removes Pharma Drugs **Requires** • RO Filter • Water Pressure	**Treatment Time (1L)** 30 Seconds **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** Replacement of the old filters when they wear down.
Hydrogen Peroxide Mix hydrogen peroxide to kill pathogens.	**Hydrogen Peroxide** **2/5** o	**Effects** • **Requires** • Hydrogen Peroxide • Mixing Container	**Treatment Time (1L)** o **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Ozonation The use of ozone gas molecules to kill contaminants.	**Ozonation** **2/5** Requires complex resources and electricity to use.	**Effects** • Removes Protozoa • Removes Bacteria • Removes Viruses • Adds Bad Taste • Adds Bad Odour **Requires** • Ozone Generator	**Treatment Time (1L)** o **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Adsorption over Metal-Organic Frameworks (MOFs) Adsorption processes with porous materials. (e.g. zeolites, activated carbon, silica gel, metal-organic frameworks)	**Adsorption over Metal-Organic Frameworks (MOFs)** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes small neutral contaminants • Removes Boron • Heavy Metals • Removes Salt **Requires** •	**Treatment Time (1L)** o **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o
Solar Desalination Solar desalination is a technique to produce water with a low salt concentration from sea-water or brine using solar energy.	**Solar Desalination** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes Salt **Requires** •	**Treatment Time (1L)** o **Not Effective On** •	**Effective Lifespan** o **Maintenance Required** o

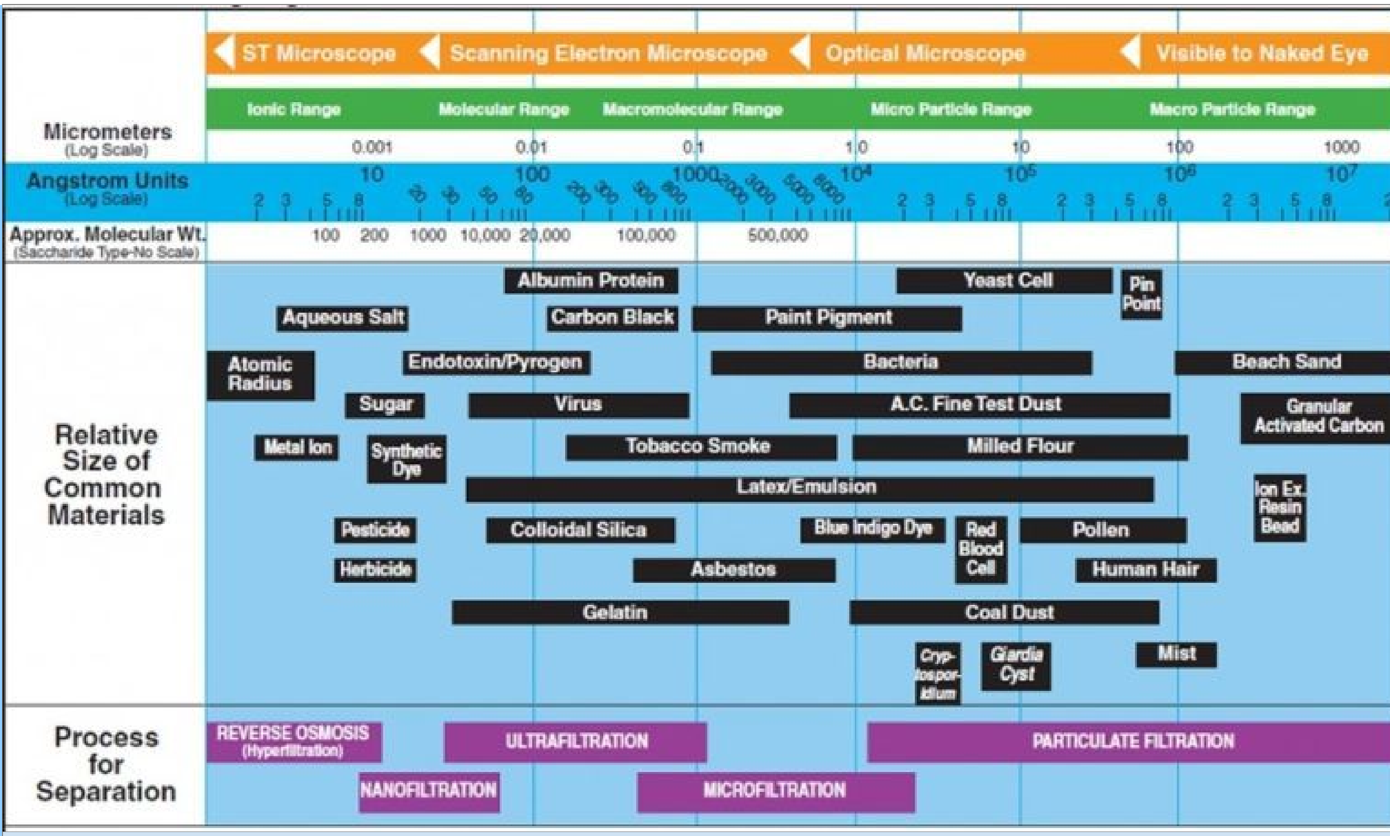
Electrodialysis Desalination Electrodialysis reversal desalination (EDR), is a water desalination process in which electricity is applied to electrodes to pull naturally occurring dissolved salts through an ion exchange membrane to separate the water from the salts.	**Electrodialysis Desalination** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes Salt **Requires** •	**Treatment Time (1L)** ○ **Not Effective On** •	**Effective Lifespan** ○ **Maintenance Required** ○
Ion Exchange Ion exchange is a water treatment process commonly used for water softening or demineralization, but it also is used to remove other substances from the water in processes such as dealkalization, deionization, and disinfection.	**Ion Exchange** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes Salt • Removes Nitrate • Removes Fluoride • Removes Sulphate • Removes Arsenic **Requires** •	**Treatment Time (1L)** ○ **Not Effective On** •	**Effective Lifespan** ○ **Maintenance Required** ○
Geothermal Desalination Geothermal desalination is a process under development for the production of fresh water using heat energy.	**Geothermal Desalination** **1/5** Not yet a functioning way to purify water.	**Effects** • Removes Salt **Requires** •	**Treatment Time (1L)** ○ **Not Effective On** •	**Effective Lifespan** ○ **Maintenance Required** ○
Freezing Desalination Freeze-thaw desalination uses freezing to remove fresh water from salt water.	**Freezing Desalination** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes Salt **Requires** •	**Treatment Time (1L)** ○ **Not Effective On** •	**Effective Lifespan** ○ **Maintenance Required** ○
Advanced Oxidation Processes Advanced oxidation processes (AOPs), in a broad sense, are a set of chemical treatment procedures designed to remove organic (and sometimes inorganic) materials in water and wastewater by oxidation through reactions with hydroxyl radicals.	**Advanced Oxidation Processes** **1/5** Extremely difficult to accomplish off-grid due to resources needed.	**Effects** • Removes Salt **Requires** •	**Treatment Time (1L)** ○ **Not Effective On** •	**Effective Lifespan** ○ **Maintenance Required** ○

Filter Membrane Size

The table below shows the sizes of various materials that are filtered from water and the type of membane required to filter them out.

Name	Filters		Filtration Material
10,000 Micron Filter (1cm)	Filters anything larger plus: • Leaves • Sticks • Plastics (bottles, caps etc.)		• Stones in a handmade filter
1,000 Micron Filter (1mm)	Filters anything larger plus: • Bugs • Insects		• Sand in a handmade filter • Fly Screen
100 Micron Filter (0.1mm)	Filters anything larger plus: • Sand • Dust Mites • Food Scraps		• Loose Clothing (folded over a few times)
10 Micron Filter (0.01mm) (10,000nm)	Filters anything larger plus: • Hair (Thin end first) • Rust • Dust	• Pollen • Fine Sand • Plant Spores • White Blood Cells	• Tightly Knit Clothing (folded over) • Activated Charcoal
1 Micron Filter (1,000nm)	Filters anything larger plus: • Protozoan Cysts • Giardia • Cryptosporidium	• Red Blood Cells • Mould • Coffee	• All Manufactured Filters (Lifestraw, Katadyn, MSR)
0.1 Micron Filter (100nm)	Filters anything larger plus: • Bacteria • Clay		• Most Manufactured Filters (Sawyer Mini, Katadyn Pocket)
0.01 Micron Filter (10nm)	Filters anything larger plus: • Asbestos • Colloidal Silica		• Specific Manufactured Filters (MSR Guardian)
0.001 Micron Filter (1nm)	Filters anything larger plus: • Viruses • Pesticides • Synthetic Dye		• Reverse Osmosis
0.00001 Micron Filter (0.01nm)	Filters anything larger plus • Hydrogen Atoms • Helium Atoms		• None Known

Filter Size Table



Size of Objects in Microns (µm)

Anthrax: 1-5	**Clay:** 0.1-50	**Lead Dust:** 0.1-0.7	**Salt:** 0.0003-0.002
Antiperspirant: 6-10	**Coal Dust:** 1-100	**Liquid Droplets:** 0.5-5	**Skin Flakes:** 0.5-10
Asbestos: 0.7-90	**Copier Toner:** 0.5-15	**Mist:** 70-350	**Natural Smoke:** 0.01-0.1
Car Emissions: 1-150	**Corn Starch:** 0.1-0.8	**Mould:** 3-12	**Spider Web:** 2-3
Colloidal Silver: 0.001-0.01	**Dust Mites:** 100-300	**Mould Spores:** 10-30	**Plant Spores:** 3-100
Bacteria: 0.3-60	**Eye of a Needle:** 1,230	**Oxygen:** 0.0005	**Starches:** 3-100
Beach Sand: 100-10,000	**Fertilizer:** 10-1,000	**Paint Pigments:** 0.1-5	**Sugars:** 0.0008-0.005
Water Molecule: 0.000275	**Fibre Insulation:** 1-1,000	**Pesticides:** 0.001	**Textile Fibres:** 10-1,000
Bromine: 0.1-0.7	**Glass Wool:** 1,000	**Pollen:** 10-1,000	**Viruses:** 0.005-0.3
Burning Wood: 0.2-3	**Hair:** 40-300	**Radioactive Fallout:** 0.1-10	**Atmospheric Dust:** 0.001-30
Carbon Dioxide: 0.00065	**Household Dust:** 0.05-100	**Red Blood Cells:** 5-10	**Synthetic Dye:** 0.001-0.005
Cement Dust: 3-100	**Iron Dust:** 4-20	**Saw Dust:** 30-600	**Water Molecule:** 0.000275

Filters vs Purifiers

This is the difference between water filters and water purifiers.

Water Filter	A water filter is a porous substance such as activated carbon which removes sediment and unwanted substances such as harmful chemicals and toxins from our water. Although filters are valuable, by themselves they are generally inadequate for turning municipal or well water into healthy drinking water. A filter improves taste and odour and reduces the level of many chemical contaminants in drinking water.
Water Purifier	A water purifier is defined as a system that removes 90-95% of all contaminants in water. There are three recognized purifier technologies known today: reverse-osmosis, deionization, and distillation. Because of their powerful capabilities, purifiers must form the foundation of any drinking water system to have a chance at creating truly pure water.

Membrane Classifications

These are the different classifications of water filter membranes. These are useful when purchasing a filter and you don't understand the terms used.

Microfiltration (MF) **Pore Size: ~0.1µm** **(±0.05-5)**	● High effectiveness in removing protozoa ● Moderate effectiveness in removing bacteria ● Not effective in removing viruses ● Not effective in removing chemicals
Ultrafiltration (UF) **Pore Size: ~0.01µm** **(±0.001-0.05)**	● Very high effectiveness in removing protozoa ● Very high effectiveness in removing bacteria ● Moderate effectiveness in removing viruses ● Low effectiveness in removing chemicals.
Nanofiltration (NF) **Pore Size: ~0.001µm** **(±0.008-0.01)**	● Very high effectiveness in removing protozoa ● Very high effectiveness in removing bacteria ● Very high effectiveness in removing viruses ● Moderate effectiveness in removing chemicals.
Reverse Osmosis (RO) **Pore Size: ~0.0001µm**	● Very high effectiveness in removing protozoa (for example, Cryptosporidium, Giardia); ● Very high effectiveness in removing bacteria. ● Very high effectiveness in removing viruses ● Removes common chemical contaminants (metal ions, aqueous salts), including sodium, chloride, copper, chromium, and lead; may reduce arsenic, fluoride, radium, sulphate, calcium, magnesium, potassium, nitrate, and phosphorous.

WATER | Water Purification | Filter Membrane Size | Micron Ratings

Micron Ratings

The micron Absolute, Nominal and Mean Filter ratings can vary significantly in purchased water filters. Knowing which you are buying will give you the best quality.

Absolute Micron Rating (International Rating)	The absolute rating, of cut-off point, of a filter refers to the diameter of the largest spherical glass particle, normally expressed in micrometres (mm), which will pass through the filter under laboratory conditions. It represents the pore opening size of the filter medium. Filter media with an exact and consistent pore size or opening thus, theoretically at least, have an exact absolute rating.
Nominal Micron Rating (US Rating)	The nominal rating refers to a filter capable of cutting off a nominated minimum percentage by weight of solid particles of a specific contaminant (usually glass beads) greater than a stated micron size, normally expressed in micrometres (mm). I.e. 90% of 10 micron.
Mean Filter Rating	The mean filter rating refers to the measurement of the average pore size of a filter element. It establishes the particle size above which the filter starts to be effective. It is determined by the bubble point test and it is more meaningful than a nominal rating and, in casa of filter elements with varying pore size, more realistic than an absolute rating.

Water Filter Pore Size in Microns

Following is a list of popular water filters and their 'claimed' micron rating. The actual rating may differ due to the testing methods stated above.

3 Micron Filters
- Aquamira Frontier

0.2 Micron Filters
- Lifestraw
- Katadyn Pocket
- Lifestraw Family
- MSR Trailshot
- MSR Miniworks EX
- Katadyn Hiker
- Katadyn Hiker PRO

0.2 Micron Filters (cont)
- Katadyn Vario
- Katadyn Expedition
- Katadyn BeFree
- Platypus GravityWorks
- MSR Sweetwater
- Black Berkey
- MSR HyperFlow
- MSR AutoFlow Gravity

0.1 Micron Filters
- Sawyer Filter
- Sawyer Squeeze
- MSR Miniworks
- Survival Hax Filter
- First Need XL
- Miniwell Filter
- Berkey Ceramic
- Versa Flow

0.05 Micron Filters
- Survivor Filter

0.02 Micron Filters
- Etekcity Portable
- MSR Guardian

0.01 Micron Filters
- AquaPura Premium
- Survivor Filter PRO
- Etekcity 1500L

WATER | Water Purification | Filter Membrane Size | Water Filter Testing

Water Filter Testing

You can test a water filters provided micron rating without specialist equipment at home using typical household items. Each material will be dissolved in water and will allow a certain filter type to remove it or not. The following are the items and the micron size that filters them out.
(Ordered Smallest to Largest) This was developed by myself (Fluidic Ice) but hasn't been tested yet so use at your own discretion.

Filter Method	Particle Size	Description	Filters
Salt	0.0003-0.002	Mix salt with pure water until fully diluted. Filter the mixture and if you can't taste salt at the end the filter is smaller than 0.0003-0.002 microns.	All Viruses +
Sugar	0.0008-0.005	Mix sugar with pure water until fully diluted. Filter the mixture and if you can't taste sugar at the end the filter is smaller than 0.0008 - 0.005 microns.	All Viruses +
Synthetic Dye	0.001-0.005	Mix a synthetic dye with pure water until fully diluted. Filter the mixture and if it isn't coloured at the end the filter is smaller than 0.001-0.005 microns.	All Viruses +
Colloidal Silver	0.001-0.01	Filter colloidal silver and if you can't taste the mixture at the end the filter is smaller than 0.001-0.01 microns.	Most Viruses +
Corn Starch	0.1-0.8	Mix corn starch with pure water until fully diluted. Filter the mixture and if you can't taste corn starch at the end the filter is smaller than 0.1-0.8 microns.	Most Bacteria +

WATER | Water Purification | Purification Methods

Purification Methods

A study by Rob Reed using brass jugs showed a major reduction of bacteria with containers made of brass. "In brass vessels, the live E. coli levels fell and after 48 hours they were at undetectable levels." Brass sheds copper particles into the water that kill the bacteria. The levels of the metal in the water is less then the daily recommended dose.

WATER | Water Purification | Purification Methods | Oligodynamic Effect (Copper)

Oligodynamic Effect (Copper)

Oligodynamic Effect
The oligodynamic effect is a biocidal effect of metals, especially heavy metals, that occurs even in low concentrations. Brass doorknobs and silverware both exhibit this effect to an extent. The oligodynamic effect was discovered in 1893 as a toxic effect of metal ions on living cells, algae, moulds, spores, fungi, viruses, prokaryotic, and eukaryotic microorganisms, even in relatively low concentrations. This antimicrobial effect is shown by ions of copper as well as mercury, silver, iron, lead, zinc, bismuth, gold, and aluminium. In 1973, researchers at Battelle Columbus Laboratories conducted a comprehensive literature, technology and patent search that traced the history of understanding the "bacteriostatic and sanitizing properties of copper and copper alloy surfaces", which demonstrated that copper, in very small quantities, has the power to control a wide range of moulds, fungi, algae and harmful microbes.

Copper Inhibits
Actinomucor elegans, Aspergillus niger, Bacterium linens, Bacillus megaterium, Bacillus subtilis, Brevibacterium erythrogenes, Candida utilis, Penicillium chrysogenum, Rhizopus niveus, Saccharomyces mandshuricus, and Saccharomyces cerevisiae in concentrations above 10 g/L. Candida utilis (formerly, Torulopsis utilis) is completely inhibited at 0.04 g/L copper concentrations. Tubercle bacillus is inhibited by copper as simple cations or complex anions in concentrations from 0.02 to 0.2 g/L. Achromobacter fischeri and Photobacterium phosphoreum growth is inhibited by metallic copper. Paramecium caudatum cell division is reduced by copper plates placed on Petri dish covers containing infusoria and nutrient media. Poliovirus is inactivated within 10 minutes of exposure to copper with ascorbic acid. A subsequent paper probed some of copper's antimicrobial mechanisms and cited no fewer than 120 investigations into the efficacy of copper's action on microbes. The authors noted that the antimicrobial mechanisms are very complex and take place in many ways, both inside cells and in the interstitial spaces between cells. The 3-dimensional structure of proteins can be altered by copper, so that the proteins can no longer perform their normal functions. The result is inactivation of bacteria or viruses. Copper may disrupt enzyme structures, and functions by binding to sulphur- or carboxylate-containing groups and amino groups of proteins.

Copper facilitates deleterious activity in superoxide radicals. Repeated redox reactions on site-specific macromolecules generate HO radicals, thereby causing "multiple hit damage" at target sites. Copper can interact with lipids, causing their peroxidation and opening holes in the cell membranes, thereby compromising the integrity of cells. This can cause leakage of essential solutes, which in turn, can have a desiccating effect. Copper damages the respiratory chain in Escherichia coli cells. and is associated with impaired cellular metabolism. Faster corrosion correlates with faster inactivation of microorganisms. This may be due to increased availability of cupric ion, Cu^{2+}, which is believed to be responsible for the antimicrobial action.

In inactivation experiments on the flu strain, H1N1, which is nearly identical to the H5N1 avian strain and the 2009 H1N1 (swine flu) strain, researchers hypothesized that copper's antimicrobial action probably attacks the overall structure of the virus and therefore has a broad-spectrum effect. Microbes require copper-containing enzymes to drive certain vital chemical reactions. Excess copper, however, can affect proteins and enzymes in microbes, thereby inhibiting their activities. Researchers believe that excess copper has the potential to disrupt cell function both inside cells and in the interstitial spaces between cells, probably acting on the cells' outer envelope.

Efficacy on Copper Surfaces
Recent studies have shown that copper alloy surfaces kill E. coli O157:H7. Over 99.9% of E. coli microbes are killed after just 1–2 hours on copper. On stainless steel surfaces, the microbes can survive for weeks. Results of E. coli O157:H7 destruction on an alloy containing 99.9% copper (C11000) demonstrate that this pathogen is rapidly and almost completely killed (over 99.9% kill rate) within ninety minutes at room temperature (20°C, 68°F).

At chill temperatures (4°C, 39.2°F), over 99.9% of E. coli O157:H7 are killed within 270 minutes. E. coli O157:H7 destruction on several copper alloys containing 99%–100% copper (including C10200, C11000, C18080, and C19700) at room temperature begins within minutes.

At chilled temperatures, the inactivation process takes about an hour longer. No significant reduction in the amount of viable E. coli O157:H7 occurs on stainless steel after 270 minutes. Studies have been conducted to examine the E. coli O157:H7 bactericidal efficacies on 25 different copper alloys to identify those alloys that provide the best combination of antimicrobial activity, corrosion/oxidation resistance, and fabrication properties. Copper's antibacterial effect was found to be intrinsic in all of the copper alloys tested.

As in previous studies, no antibacterial properties were observed on stainless steel (UNS S30400). Also, in confirmation with earlier studies the rate of drop-off of E. coli O157:H7 on the copper alloys is faster at room temperature than at chill temperature. For the most part, the bacterial kill rate of copper alloys increased with increasing copper content of the alloy. This is further evidence of copper's intrinsic antibacterial properties.

Oligodynamic Effect (Brass, Bronze, Copper-Nickel Alloys)

Efficacy on Brass, Bronze, Copper-Nickel Alloys
Brasses, which were frequently used for doorknobs and push plates in decades past, also demonstrate bactericidal efficacies, but within a somewhat longer time frame than pure copper. All nine brasses tested were almost completely bactericidal (over 99.9% kill rate) at 20°C (68°F) within 60–270 minutes. Many brasses were almost completely bactericidal at 4°C (39.2°F) within 180–360 minutes. The rate of total microbial death on four bronzes varied from within 50–270 minutes at 20°C (68°F), and from 180 to 270 minutes at 4°C (39.2°F).

The kill rate of E. coli O157 on copper-nickel alloys increased with increasing copper content. Zero bacterial counts at room temperature were achieved after 105–360 minutes for five of the six alloys. Despite not achieving a complete kill, alloy C71500 achieved a 4-log drop within the six-hour test, representing a 99.99% reduction in the number of live organisms.

Oligodynamic Effect (Stainless Steel)

Efficacy on Stainless Steel
Unlike copper alloys, stainless steel (S30400) does not exhibit any degree of bactericidal properties. This material, which is one of the most common touch surface materials in the healthcare industry, allows toxic E. coli O157:H7 to remain viable for weeks. Near-zero bacterial counts are not observed even after 28 days of investigation. Epifluorescence photographs have demonstrated that E. coli O157:H7 is almost completely killed on copper alloy C10200 after just 90 minutes at 20°C (68°F); whereas a substantial number of pathogens remain on stainless steel S30400. Copper alloys kill more than 99.9% of MRSA within two hours. Subsequent research conducted at the University of Southampton (UK) compared the antimicrobial efficacies of copper and several non-copper proprietary coating products to kill MRSA.

At 20°C (68°F), the drop-off in MRSA organisms on copper alloy C11000 is dramatic and almost complete (over 99.9% kill rate) within 75 minutes. Stainless steel S30400 did not exhibit any antimicrobial efficacy. After incubation for one hour on copper, active influenza A virus particles were reduced by 75%. After six hours, the particles were reduced on copper by 99.999%. Influenza A virus was found to survive in large numbers on stainless steel.

Oligodynamic Effect (Silver)

The metabolism of bacteria is adversely affected by silver ions at concentrations of 0.01–0.1 mg/L. Therefore, even less soluble silver compounds, such as silver chloride, also act as bactericides or germicides, but not the much less soluble silver sulphide. In the presence of atmospheric oxygen, metallic silver also has a bactericidal effect due to the formation of silver oxide, which is soluble enough to cause it. Bactericidal concentrations are reduced rapidly by adding colloidal silver, which has a high surface area. Even objects with a solid silver surface (e.g., table silver, silver coins, or silver foil) have a bactericidal effect.

Silver drinking vessels were carried by military commanders on expeditions for protection against disease. It was once common to place silver foil or even silver coins on wounds for the same reason. Silver sulfadiazine is used as an antiseptic ointment for extensive burns. An equilibrium dispersion of colloidal silver with dissolved silver ions can be used to purify drinking water at sea. Silver is incorporated into medical implants and devices such as catheters.

Surfacine (silver iodide) is a relatively new antimicrobial for application to surfaces. Silver-impregnated wound dressings have proven especially useful against antibiotic-resistant bacteria. Silver nitrate is used as a haemostatic, antiseptic and astringent. At one time, many states required that the eyes of newborns be treated with a few drops of silver nitrate to guard against an infection of the eyes called gonorrhoeal neonatal ophthalmia, which the infants might have contracted as they passed through the birth canal.

Silver ions are increasingly incorporated into many hard surfaces, such as plastics and steel, as a way to control microbial growth on items such as toilet seats, stethoscopes, and even refrigerator doors. Among the newer products being sold are plastic food containers infused with silver nanoparticles, which are intended to keep food fresher, and silver-infused athletic shirts and socks, which claim to minimize odours.

Purification By Effect

This section groups purification methods with the same effect together so you can quickly find which one you need to achieve the desired results such as needing to remove the salt from water or only the viruses from water. Some purification methods are mentioned more than once which fit into multiple categories such as distillation in Kills/Filters Contaminants and desalination.

Filters Particulate Only

These are types of water purification methods which removes the particulate only while leaving the viruses and bacteria.

DIY Water Filter	● Cloth ● Rocks ● Coarse Sand ● Fine Sand ● Charcoal ● Moss ● Sphagnum ● Cheesecloth ● Fine Cloth
Water Filter	All manufactured water filters almost entirely eliminate particulate in water.
Carbon Filtering	Heat dense wood/cloth in a pot without access to oxygen until black and crumbly. Charcoal removes contaminants and impurities using chemical adsorption. Removes chlorine, sediment, volatile organic compounds, taste and odour from water. Not effective at removing minerals, salts, and dissolved inorganic compounds.
Activated Charcoal	Powder charcoal, 25% (weight) solution of Calcium Chloride to water, add charcoal to make paste, spread paste, bake at 107°C (224.6°F) for 30m. 454g of activated charcoal contains a surface area of approximately 404k m2.
Hand Filtering	Pour water into an alternative container through a piece of fine fabric folded over about 8 times to catch particles.
Rapid Sand Filter (RSF)	Filters particulate from water.
Sedimentation	Leave water for 2 hours until particles drop to the bottom of the container. Over 1-2 days of settling will remove larger microbes such as some parasites, and some microbes. Viruses and bacteria will not be removed as they are too small.
Coagulation	Clumps sediment together which then drop out of suspension. Add coagulants to the water to quicken the sedimentation process. Coagulants: Aluminium sulphate, polyaluminium chloride (liquid alum) and ferric sulphate. Natural Coagulants: Prickly Pear Cactus, Moringa seeds, broad beans, fava beans.

Kills/Filters Contaminants

These are types of water purification which kills the viruses and bacteria only while leaving particulate such as dirt in the water.

Boiling	Altitudes under 2km - 1 Minute Rolling Boil. Altitudes over 2km - boil for 3 minutes. Prevent recontamination by ensuring flames engulf the whole bottle and threads before pouring it out.
Distillation	Boil water in a pot with a cold convex lid to collect the moisture into a container below. Has a ratio of 200:1 - 450:1 to create one litre.
Solar Pasteurisation	Heating water to 65°C (149°F) for 6 minutes, or to a higher temperature for a shorter time, will kill all germs, viruses, and parasites. Above 50°C (122°F), time decreases at roughly a factor of 10 for every 10°C (50°F) increase in pasteurisation temperature. Viruses appear the hardest to kill and essentially set the boundary for acceptable time-temperature processes.
Chlorination	Chlorine kills viruses and bacteria in water. 30m for most bacteria, 4 hours for Cryptosporidium. Types: ● Chlorine ● Iodine ● Chlorine Dioxide ● Calcium Hypochlorite (70%) ● Bleach (6%) Some chlorine formulations can be used for cleaning wounds.
UV Light	Ensure water isn't too turbid and use the UV light for 1 minute every litre for 0 NTU. If water is turbid stir the light around.
SODIS	<50% cloud - 6 hours. >50% cloud - 2 days. Temp >50°C (122°F) - 60 min. Temp >60°C (140°F) - 1 min. Use bottles less then 5cm wide. Use reflective surface to maximise light. Requires less then 30 NTU water. Shake a 3/4 bottle to oxygenate it prior to placing then fill the rest and do not touch it again.
Copper / Silver Ionization / Electrolysis	Colloidal Silver and Copper act as antimicrobials and slowly ionize the water and purify it. They destroy biofilms slowly.
Electrolytic Water Purifier	Creates chlorine (Sodium Hypochlorite) from a brine solution. (Salty water) Mix the solution into the water to be purified. Potable Aqua - Pure Use any semi pure non-salty water. Generates from 1-20L. 1L - 20s, 10L - 3m. Reduces all bacteria and viruses by 99.99%. Lasts 60k Litres. 150L per charge. 1h Solar Charge = 2L. 30m mixture time for bacteria and viruses, 4h for crypto. 37g salt storage. 2.22kg's for 60k L. Can use any type of sodium chloride, food grade recommended.

Filters Particulate & Kills/Filters Contaminants

These purification techniques remove both the particulate and the bacteria and viruses from water, leaving potable water.

Reverse Osmosis	Removes most contaminants by filtering through a semi permeable membrane. 0.0001 micron filter size, Does not filter chlorine, radon, pesticides, benzene, toluene and trihalomethanes. Filters out salt. Requires a lot of filter replacement and maintenance.
Water Purification: Adsorption over Metal-Organic Frameworks	Experimental Prototypes Only.

Slow Sand Filter (SSF)	Removes turbidity and pathogenic organisms. High reliability and low lifecycle costs. Biological process vs RSF. Removes sediment and biologically filters via the biofilm. Microbes are sourced from water source and establish within a few days (3 weeks for full community). The predatory bacteria feed on water-borne microbes passing through the filter. Requires Filter Chamber, Reservoir and pipes. Order: Water inlet flows to the top of the SSF leaving 1-1.5m water on top, Schmutzdecke / microbial community, Sand bed - 0.6-1.2m deep, 50cm gravel, drainage layer and pipes last. The total height of the filter is between 2.5-4m. Requires slow filter time at 0.1-0.3 m3/h per 1sq m. Water remains several hours prior to being filtered. Water requires pressure (or weight) to push it through the sand. No bacteria present at the outlet. Turbidity < 1 NTU = 90-99% bacteria and viruses. Highly effective for: Bacteria, Protozoa, Viruses, Turbidity, Heavy Metals (Zn, Cu, Cd, Pb), Somewhat effective for: Odour, Taste, Iron, Manganese, Organic Matter, Arsenic. Not effective for: Salt, Fluoride, Chemicals. Chlorination may be used as a final treatment step to kill remaining bacteria. Flow rate = 0.1-0.3 m/h for microorganism nutrients and oxygen. Organism build up may occur and clog filter - so scrape the top layer off.
Biosand Filter	0.9m tall cylinder and 61cm wide. Filled with: water (10%), washed sand (70%), gravel (20%). Water 5cm deep adjusted from outlet pipe coming from the bottom then U turns at the top allowing the biofilm layer. Diffusion layer avoids disruption of biofilm layer maturing in 20-30 days. Kills pathogens via: Mechanical Trapping (Sieve), Adsorption (Pathogens become attached to each other), Predation (Pathogens absorbed by microorganisms) and Natural Death (Not enough food or oxygen for the pathogens). Removes: Bacteria 87-98%, Viruses 70-90%, Protozoa > 99%, Turbidity 85%, Iron 90-95%.
Ozone Water Filter	Infuses incoming water with highly reactive ozone molecules. Starts with an ozone generator chamber where a high intensity UV light is used to break the bonds of oxygen molecules and create the unstable ozone molecule. The ozone air is forced into through the generator chamber into the recycling tank. Once the ozone enters the water it oxidizes biological components including almost all bacteria and viruses. It also bonds with many dissolved minerals, causing them to precipitate to the bottom of standing water. Ozone has been found to effectively remove 99% of all biological pathogens including Giardia and Cryptosporidium. It also is effective at removing iron and manganese as well as freeing up chlorine to kill even more microbes if used in a multiple step system. The ozone has a half-life of only a few minutes, so after it has purified the water any remaining molecules break down into standard oxygen. This creates an environment that highly oxygenates the water.

Desalination

These purification techniques remove salt in the water and can be used for purifying seawater.

Distillation	
Solar Desalination	
Reverse Osmosis	
Electrodialysis Desalination	
Ion Exchange Desalination	
Geothermal Desalination	
Freezing Desalination	

Removes Bad Taste/Odour

These filtration materials remove bad taste and odours from water.

Charcoal	
Activated Charcoal	

Filtering Info

Bacteria / Virus Sizes Giardia: 8-12 microns Cryptospor: 4-6 microns Bacteria: 0.2-4 microns Viruses: 0.004-0.1 microns	**Filter Sizes** Guardian: 0.02 Microns Sawyer: 0.1 Microns Miniwell: 0.1 Microns RO: 0.0001 Microns	**Water Pollutants** **(Micron Size which stops the Particles)** **10 Micron** - Rust, Pollen, Fine Sand, Plant Spores **1 Micron** - Protozoan Cysts **0.1 Micron** - Bacteria **0.01 Micron** - Asbestos, Colloidal Silica **0.001 Micron** - Viruses, Synthetic Dyes **0.0001 Micron** - Dissolved Solids, Radioactive Substances, Heavy Metals, Pharmaceutical Drugs	**Cloth Filter** Using clothing or a cloth can remove fine particulate from water sources but leaves the smaller bacteria and viruses intact.

Water Additives

These are compounds that can be added to water to help clean, purify or kill pathogens present.

Potassium Permanganate ($KMnO_4$)
Expiry: Never
Mix 3-4 crystals per Litre of water until light pink (background colour) and wait 2 hours before drinking. Store solution and crystals out of sunlight and in a cool place.

AKA: Condy's Crystals

Calcium Hypochlorite
Expiry: 10 Years
Mix 1g (70%+) into a 1L solution with water, then use to treat 100L as a 1:100 ratio, filtering the sediment out. Wait 1 hour before drinking or 2h if below 15°C (59°F) or water is cloudy. A faint chlorine odour should be present. Store chlorine solution in a sealed container out of direct sunlight and discard after 2 weeks. Corrosive at pH (14-16) - Therefore can't be used on wounds. May require sodium bicarbonate to decrease alkalinity.

Water/Wound Disinfection: 1g/L (1000ppm or 0.1%)
General Disinfection:
- Clean - 1g/L - 0.1%
- Med. Clean - 2g/L - 0.2%
- Dirty - 5g/L - 0.5%
- Blood - 10g/L - 1%

WATER | Water Purification | Purification Methods | Water Additives

Bleach
Expiry: 1.5 Years
Use two drops per Litre, only unscented bleach.

Chlorine
Expiry: 5y.
Each 1.67g tablet of NaCC releases 1g chlorine - in 1L (0.1% solution or 1000ppm) pH of 6-7 and therefore can be used for cleaning wounds.

Tablet Formulations
Sodium Dichloroisocyanurate (NaDCC, sodium troclosene)

Water Treatment
1g/200L (Unless pre-packaged)

Troclosene Sodium (Chlorine)
Expiry: 2 Years
One tablet/L if clear, wait 30m before drinking or 4h for cryptosporidium. Two tablets if high turbidity.

AKA: Sodium Dichloroisocyanurate

Chlorine Disinfection
Water/Wound Disinfection
1g/L (1000ppm or 0.1%)

General Disinfection
- Clean - 1g/L - 0.1%
- Med. Clean - 2g/L - 0.2%
- Dirty - 5g/L - 0.5%
- Blood - 10g/L - 1%

Sodium Dichloroisocyanurate (Troclosene Sodium)
Used in most of the water purification tablets manufactured today. Some may contain silver.
Use: 1 Tablet in 1L
Expiry: 10 Years
Storage: Cool, dark, dry area
Brands: Aquatabs.

Chlorine Dioxide
Expiry: Forever < 24°C (75.2°F)
Most effective treatment. One tablet per litre, wait 30m before drinking or 4h for cryptosporidium.

Chlorine Dioxide
Used in a few brands of water purification tablets.
Use: 1 Tablet in 1L
Expiry: Infinite if kept cool
Storage: Cool, dark, dry area
Brands: Katadyn Micropur MP1, Lifesystems, Potable Aqua.

Created by mixing 28% sodium chlorite solution with an acid such as citrus juice.
AKA: MMS

Iodine
Expiry: 7 Years
Treat water with two drops per litre. Avoid using for extended periods.
AKA: Tetraglycine Hydroperiodide

Iodine can come in liquid, powder or granular forms. Not to be confused with iodide which is used to saturate the thyroid gland during radiation.

Colloidal Silver
Expiry: 10 Years ~ 20-29°C (68°F-84.2°F) in a dark glass jar.
.05 microns to .0008.
1ppm = 1mg Silver.
Combine with Hydrogen Peroxide for more effectiveness. 100 Drops a day of 15ppm is safe.
50ml/L to treat water.
Treats IBS.
Antibacterial / Antifungal / Antiviral.

Hydrogen Peroxide
Expiry: 1y Unopened, 1m opened.
1-2ppm (1-2mg/L - 11drops/L) stir and leave for 10m.

Slaked Lime
Used to adjust water pH.
White powder (calcium hydroxide)

Aluminium Sulphate
Sedimentation agent for turbid water. Flocculation creates flocs of a higher density by agglomerating fine particles in suspension in the water.

WATER | Water Purification | Treatment Plant Set-up

Treatment Plant Set-up

Centralised drinking water treatment plants treat large amounts of water from many households in one single spot and consequently most often require more operation and maintenance and the construction of a water distribution system. Semi-centralised drinking water treatment plants are middle-scaled units e.g. on community level. These systems are most often designed to remove several types of contaminants from anthropogenic or natural origin: suspended and dissolved solids, ions (metals, fluorine, phosphates, nitrates), organic compounds (organic micropollutants, natural organic matter), and microorganisms (bacteria, viruses).

As there is no water treatment method able to remove all these contaminants in one step semi-centralised and centralised treatment often needs multistep plants, which combine several techniques to purify water. Here a general overview of plant set-up for drinking water production is given.

	Working Principle	Capacity/Adequacy	Performance	Costs	Self-Help Compatibility
Summary	Combines several processes (e.g. aeration, coagulation-flocculation, filtration, disinfection) to remove a wide variety of contaminants present in water.	Sophisticated combination of water treatment processes. Skilled labour required to guarantee the performance of each process.	Efficient for all kinds of water when treatment plants are adequately designed and set up.	Relatively high implementation and operation costs because of high inputs of labour, chemicals and electricity.	The incoming water and treated water quality has to be monitored to optimise each step of the plant.

	O&M	Reliability	Main Strength	Main Weakness
	O&M Continuous operation and maintenance staff is required.	**Reliability** Highly reliable if the treatment plant is well maintained.	**Main Strength** Very efficient for any kind of water.	**Main Weakness** The whole system has to be controlled on a regular basis to be efficient, hence the system is sophisticated and requires skilled labour, energy, technical equipment and chemicals.

Advantages	• Very efficient and reliable for purifying water	• Can be adapted to any kind of water	• Relatively low cost for drinking water production
Disadvantages	• Skilled labour, technical equipment, electricity and chemicals required to design and operate the plant	• Plant has to be continuously controlled and maintained	• High initial investment costs to build infrastructure

Introduction
Drinking water treatment plants involve several consecutive processes, which remove solids, organic and inorganic pollutants, some metals and pathogenic microorganisms. The treatment plant set-up should be designed to take into account the quality of water being treated. In general, water treatment can be divided into: primary treatment to remove solids; secondary treatment to remove organic compounds as well as nitrogen and phosphorous; and tertiary treatment for disinfection. Different sizes of treatment plants exist like centralised plants for big cities requiring a developed distribution system and semi-centralised plants adapted to provide drinking water to smaller communities at the point of use (POU).

Treatment Plants
There is no precise method for treating surface water because of the various qualities of water that exists. Groundwater typically requires less treatment than water from lakes, rivers and the sea. Nevertheless, a series of conventional processes can be identified; they are presented in the figures below. In general the treatment of fresh water involves the following key steps:

Step 1	**Primary Steps** Aeration: The water is mixed to liberate dissolved gases and to suspend particles in the water column. Sometimes a pre-oxidation step is also performed at this stage. Coagulation-Flocculation: In this step coagulants are added to remove the suspended particles (clay, organic material, metals, microorganisms), which stick to the coagulants forming heavy particles. Sedimentation: The heavy particles (flocs) settle to the bottom leading to clear water.
Step 2	**Secondary Step** Filtration: The water is run through a series of filters, which trap and remove particles still remaining in the water column. Typically, slow or rapid sand filtration and more recently membranes or reverse osmosis are used to accomplish this task. Due to growing concerns regarding micro-pollutants, additional treatments such as advanced oxidation processes, activated carbon adsorption alone or combined with ozonation or H_2O_2 are sometimes used to remove these trace organic compounds.
Step 3	**Tertiary Step** Disinfection: The water is now largely free of particles, organics and microorganism and is now treated to destroy any remaining disease-causing pathogens. This is commonly done with chlorination, ozonation, hydrogen peroxide, or UV radiation (similar to the point of use UV tubes). The water is then sent to the pumping station for distribution to homes and businesses. Chlorination is the most widely used disinfection method because it permits maintaining residual chlorine at a level efficient enough to guarantee the absence of microorganism until the water has reached its point of use. When drinking water is produced from the sea, the water is desalinated by electrolysis or membranes such as reverse osmosis or by a solar process desalination.

Operation and Maintenance
Drinking water treatment plant operation and maintenance includes the following tasks:

- Operate and adjust equipment controls to purify and clarify water.
- Inspect equipment and monitor operating conditions, meters, and gauges to determine load requirements and detect malfunctions.
- Add chemicals, such as ammonia, chlorine, and lime, to purify and disinfect water and other chemicals, such as ferric chloride, peroxide, and polymers, to enhance water treatment.
- Collect and test water samples, using test equipment.
- Record operational and laboratory data, observations of processes, and meter and gauge readings on specified forms.
- Clean and maintain tanks, basins and filter beds, using hand tools and power tools.
- Maintain, repair, and lubricate equipment, using hand tools and power tools.

Many of these tasks can be automated in modern treatment plants but trained operators and engineers are still required to control and maintain the system. Moreover, operation of the treatments also requires a significant amount of chemicals, which might not be available in little industrialised or remote areas. Required energy input is significant. In Switzerland, required energy input for treatment and distribution of drinking water, including abstraction, is relatively low (around 0.4kWh/m3) due to the excellent quality of groundwater. In case of polluted or seawater treatment in semi-centralised plants, the required input is higher (around 1-2 kWh/m3). Smaller drinking water treatment plants may be installed at semi-centralised level or point of use in order to minimise energy requirements for distribution.

Average Costs
The cost of high quality municipal drinking water including transport is between less than 1 $/m3 in the US and more than 2 $/m3 in Denmark and Germany. The cost of drinking water from semi-centralised treatment plants operating in developing countries depends on water source quality and capacity. In the case of seawater and polluted sources it is typically around 1-2 $/m3. An important initial investment is required to build the treatment plant, which should be designed properly taking into account water composition to minimise the costs.

Applicability
Centralised drinking water treatment plants are useful when water is supplied from a source containing natural or anthropogenic contaminants such as lakes, rivers, seas or groundwater. Many different types of raw water can be purified in treatment plants as processes are designed for each case considering water quality and desired capacity. The treatment plants need to be maintained by skilled labour to regularly control water quality and optimise processes. Smaller drinking water treatment plants may be installed at semi-centralised level or point of use in order to minimise energy requirements for distribution.

5 Purification Methods

This is a more detailed explanation of the purification methods in the section above. Keep in mind that you may have to combine two methods to make water drinkable as some only do half the job.

Subheadings

		5. Carbon Filtering	6. Activated Charcoal	7. Hand Filtering	8. Slow Sand Filter		
		9. Rapid Sand Filter	10. Biosand Filter	11. Sedimentation	12. Coagulation		
		13. Bank Filtration	14. Solar Pasteurisation	15. Distillation	16. Chlorination		
		17. Electrolytic Purification	18. UV Light	19. SODIS	20. Silver Ionization		
		21. Colloidal Silver	22. Ceramic Candle Filter	23. Membrane Filtration	24. Reverse Osmosis		
		25. Hydrogen Peroxide	26. Ozonation	26. Solar Desal.	28. Electrodialysis Desal.		
		29. Ion Exchange	30. Geothermal Desal.	31. Freezing Desal.	32. Advanced Oxidation		

1 Makeshift Filter

Makeshift Filter

A crude water filter made from easily obtainable materials such as rocks, sand and cloth.

Construction Start with a container that has a narrow neck and cut the base off. Collect and wash a variety of easily found materials such as:	**Materials** ● Tiny Rocks ● Coarse Sand ● Fine Sand ● Charcoal Dust ● Fine Cloth	● Wrap and tie the fine cloth over the nozzle of the bottle. ● Fill the bottle in layers of materials, starting with the charcoal, fine sand, then coarse sand and finally the rocks. ● The bottle should be basically full and split evenly into the different fillings. ● Add another piece of cloth over the top of the bottle so it's capped at both ends. ● Filter a few litres through the filter to flush anything remaining out. ● The filter is ready and should remove most particulate.

2 Manufactured Filters

Manufactured

Portable water purification devices are self-contained, easily transported units used to purify water from untreated sources (such as rivers, lakes, and wells) for drinking purposes. Their main function is to eliminate pathogens, and often also of suspended solids and some unpalatable or toxic compounds. These units provide an autonomous supply of drinking water to people without access to clean water supply services, including inhabitants of developing countries and disaster areas, military personnel, campers, hikers, and workers in wilderness, and survivalists. See Filter Membrane Size for more information on filters.

Household Purifiers

Manufactured Filters Household Purifiers

These are some household purification systems.

Big Berkey Water Filter	Filters water through a charcoal medium and drips into the chambers below to generate safe drinking water. Sizes range from 1.5Gal (5.6L) to 6Gal (22.7L) with varying flow rates from 2.75G/h (10L) to 26G/h (98L). Some filters have 1 charcoal filter with up to 8 for the largest. For more information on these types of filters, have a look at #22 below titles "Ceramic Candle Filter".
Non-Electric Distiller	Excellent water purifier that works over a gas stove, campfire or electric hotplate. Produces about 3.2 quarts (3L) of 100% steam distilled water in 1.2 hours using 8900 Btu/hr gas burner or 2600 watt electric burner. Waterwise 1600 distiller model.
Berkefeld Water Filter	Similar to the big Berkey but uses ceramic filters.
LMS Water Filter	A commercial and large water filter used by governments during disasters and usually mounted on a skid for easy trailer or ute transport. Generates 4,000L of drinking water per hour.

3 Boiling

Boiling

Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point, the temperature at which the vapour pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding atmosphere. There are two main types of boiling: nucleate boiling where small bubbles of vapour form at discrete points, and critical heat flux boiling where the boiling surface is heated above a certain critical temperature and a film of vapour forms on the surface. Transition boiling is an intermediate, unstable form of boiling with elements of both types. The boiling point of water is 100°C (212°F) but is lower with the decreased atmospheric pressure found at higher altitudes. Boiling water is used as a method of making it potable by killing microbes that may be present. The sensitivity of different micro-organisms to heat varies, but if water is held at 70°C (158°F) for ten minutes, many organisms are killed, but some are more resistant to heat and require one minute at the boiling point of water.

Boiling

Boiling Water
As a method of disinfecting water, bringing it to its boiling point at 100 °C (212 °F), is the oldest and most effective way since it does not affect the taste, it is effective despite contaminants or particles present in it, and is a single step process which eliminates most microbes responsible for causing intestine related diseases. Water's boiling point rests at around 100 °C (212 °F), when at an elevation of 0. In places having a proper water purification system, it is recommended only as an emergency treatment method or for obtaining potable water in the wilderness or in rural areas, as it cannot remove chemical toxins or impurities.

The elimination of micro-organisms by boiling follows first-order kinetics—at high temperatures, it is achieved in less time and at lower temperatures, in more time. The heat sensitivity of micro-organisms varies, at 70 °C (158 °F), Giardia species (causes Giardiasis) can take ten minutes for complete inactivation, most intestine affecting microbes and E. coli (gastroenteritis) take less than a minute; at boiling point, Vibrio cholerae (cholera) takes ten seconds and hepatitis A virus (causes the symptom of jaundice), one minute.

Boiling

Boiling does not ensure the elimination of all micro-organisms; the bacterial spores Clostridium can survive at 100 °C (212 °F) but are not water-borne or intestine affecting. Thus for human health, complete sterilization of water is not required. The traditional advice of boiling water for ten minutes is mainly for additional safety, since microbes start getting eliminated at temperatures greater than 60 °C (140 °F) and bringing it to its boiling point is also a useful indication that can be seen without the help of a thermometer, and by this time, the water is disinfected. Though the boiling point decreases with increasing altitude, it is not enough to affect the disinfecting process.

Summary
Boiling drinking water with fuel is the oldest and most commonly practiced household water treatment method. The water needs to be heated until the appearance of the first big bubbles to ensure that it is pathogen free. Many organizations recommend boiling both for water treatment in developing countries and to provide safe drinking water in emergency situations throughout the world - though it is quite laborious and uses a lot of energy. Boiling only kills pathogens and does not remove turbidity or chemical pollution (e.g. arsenic) from drinking water. So prior to boiling, water can be purified by settling or filtration method.

Advantages	• Effectively kills most pathogens.	• Easy, simple and widely accepted method of disinfection (particularly in tea-consuming cultures)	• Biogas cooking stoves can be used for the cooking stove (e.g. biogas linked toilet)		
Disadvantages	• Can be costly due to fuel consumptions	• Use of traditional fuel (firewood, kerosene/gas) contributes to deforestation and indoor air pollution	• Potential user taste objections • Time consuming	• Does not remove turbidity, chemicals, taste, smell, colour	• Water needs to cool down before use unless for hot drinks
	• Risk of injuries (especially when children are around)				

Boiling
Boiling is oldest and most effective household drinking water treatment. It is promoted in both developing countries where water is routinely of uncertain microbial quality and in developed countries when conventional water treatment fails or water supplies are interrupted as a result of disasters or other emergencies. 21.2% of the population in South-east Asia report boiling their water before drinking it. The WHO recommends bringing water to a rolling boil as an indication that a disinfection temperature has been achieved. If practised correctly, boiling is one of the most effective water treatment methods to kill or deactivate all classes of waterborne pathogens, including bacterial spores and protozoan cysts that have shown resistance to chemical disinfection and viruses that are too small to be mechanically removed by microfiltration. Heating water to even 55°C (131°F) has been shown to kill or inactivate most pathogenic bacteria, viruses, helminths and protozoa that are commonly water borne. A clean container should be used for the boiling and after boiling, water should be stored in a clean and covered container, and handled carefully (no utensils should be brought in contact with the water, thus water needs to be poured in another clean recipient for consumption) to minimise the recontamination. Despite its effectiveness and simplicity, boiling has the disadvantage to require affordable and sufficient fuel to have properly boiled water for a regular drinking purpose, and is quite labour intensive.

Effectiveness
If the boiling point is reached, boiling is effective in killing bacteria, viruses, protozoa, helminths and most pathogens from drinking water. Incomplete inactivation of pathogens in boiled water is attributed to users not heating the water to the boiling point and/or recontamination of boiled water in storage. Boiling does not remove turbidity, chemicals (e.g. arsenic), taste, smell or colour from water. Therefore, settling or even filtration (by cloth or slow sand or biosand filter) is often needed prior to boiling.

Bacteria Lab: 100%	**Protozoa** Lab: 100%
Viruses Lab: 100%	**Helminths** Lab: 100%

Applicability
Chemical pollution such as arsenic is not removed by boiling. Also water with high amounts iron (with reddish colour), calcium or chlorine is not suitable for boiling. White scales may deposit in container bottom after boiling if calcium is high in waters. In such case, the container should be washed properly after every use. Boiled water tastes flat and people may not like that. Thus, boiled water can be chilled in freezer or cooled down to room temperature to have good taste. Boiling is suitable where enough fuel sources (e.g. wood, kerosene, electricity, gas, charcoal etc.) are locally available all the time in affordable cost. Especially in densely populated areas, boiling with fuel wood is not appropriate to the overexploitation of the wood resources and the subsequent environmental damage such as desertification and soil erosion. Boiled water may cause burn injuries if not handled properly. Long term exposure in fire or stove smoke of the person boiling the water may cause associated respiratory diseases. For this indoor cooking space should be made well ventilated.

4 Tap Filters

Tap filters are filters that can be fitted directly onto a faucet. They are easy to handle and quite effective since they remove pathogens (e.g. Cryptosporidium and Giardia), contaminants (e.g. chlorine, lead, asbestos), sediments and bad odours. The user can turn the filter on and off by switching a small handle. Most often, these filters are based on activated carbon (see also adsorption). The filter medium should be changed frequently (following providers' requirements) to ensure its effectiveness. Costs vary between 20 and 40 US$ (depending on country and provider). The filters should not be used without assessing their performance and the water quality to treat.

5 Carbon Filtering

Carbon filtering is a method of filtering that uses a bed of activated carbon to remove contaminants and impurities, using chemical adsorption. Each particle, or granule, of carbon provides a large surface area, or pore structure, allowing contaminants the maximum possible exposure to the active sites within the filter media. One gram of activated carbon has a surface area in excess of 3,000 m2 (32,000 sq ft). Activated carbon works via a process called adsorption, whereby pollutant molecules in the fluid to be treated are trapped inside the pore structure of the carbon substrate. Carbon filtering is commonly used for water purification, air filtering and industrial gas processing, for example the removal of siloxanes and hydrogen sulphide from biogas. Active charcoal carbon filters are most effective at removing chlorine, particles such as sediment, volatile organic compounds (VOCs), taste and odour from water. They are not effective at removing minerals, salts, and dissolved inorganic substances. Typical particle sizes that can be removed by carbon filters range from 0.5 to 50 micrometres. The particle size will be used as part of the filter description. The efficacy of a carbon filter is also based upon the flow rate regulation. When the water is allowed to flow through the filter at a slower rate, the contaminants are exposed to the filter media for a longer amount of time.

Activated Carbon Filtering
Activated carbon filters normally have a pre-filter to remove sediments and avoid damage of the carbon unit. They are well suited to sediment and particulate removal as well as the reduction of chlorine, chlorine disinfection bi-products, a wide range of volatile organic compounds, and other contaminants responsible for bad tastes and odours. The filter system WH3, for example, is a good choice for well water, lake water, stream water, and municipal (city) water treatment applications. These filter systems are expensive (up to 200 US$ and more) and require periodic maintenance (change of filter components).

6 Activated Charcoal / Carbon

Activated carbon filtration is a commonly used technology based on the adsorption of contaminants onto the surface of a filter. This method is effective in removing certain organics (such as unwanted taste and odours, micropollutants), chlorine, fluorine or radon from drinking water or wastewater. However, it is not effective for microbial contaminants, metals, nitrates and other inorganic contaminants. The adsorption efficiency depends on the nature of activated carbon used, the water composition, and operating parameters. There are many types of activated carbon filters that can be designed for household, community and industry requirements. Activated carbon filters are relatively easy to install but require energy and skilled labour and can have high costs due to regular replacement of the filter material.

Overview	**Working Principle** The pollutants are removed from water through adsorption on the surface of the activated carbon. Use at the POE or POU (e.g. advanced filters).	**Capacity/Adequacy** Simple technique using abundant raw material (e.g. petroleum coke, bituminous coal, lignite, wood products, coconut shell or peanut shell). Skilled labour required at least occasionally.	**Performance** Efficient for pollutant having high affinity with activated carbon surface (non-polar compounds).	**Costs** Relatively low operation costs.	**Self-Help Compatibility** Initial analysis of water is required to choose proper adsorbent (type of activated carbon).
	O&M Regular replacement or regeneration of carbon cartridge.	**Reliability** Reliable if the water composition is taken into account when choosing the type of activated carbon used as filter material.	**Main Strength** Activated carbon can be produced relatively easily everywhere in the world.	**Main Weakness** Filter has to be replaced on a regular basis.	

Advantages	● Easy to install and maintain	● Can be used at the point-of-entry (semi-centralised drinking water treatment plants, wastewater treatment plants) or at the point-of-use (household / community filters)	● Efficient to remove certain organics, chlorine, radon	● Based on materials available everywhere
Disadvantages	● Filter has to be replaced regularly	● Skilled labour required, at least occasionally	● Water analysis is required to choose the most adapted type of activated carbon	● Contaminants are separated from water but not destroyed

Introduction
The use of carbon in the form of charcoal has been used since antiquity for many applications. In Hindu documents dating from 450 BC charcoal filters are mentioned for the treatment of water. Charred wood, bones and coconut charcoals were used during the 18th and 19th century by the sugar industry for decolourising solutions. Activated carbon is a material prepared in such a way that it exhibits a high degree of porosity and an extended surface area. During water filtration through activated carbon, contaminants adhere to the surface of these carbon granules or become trapped in the small pores of the activated carbon. This process is called adsorption. Activated carbon filters are efficient to remove certain organics (such as unwanted taste and odours, micropollutants), chlorine, fluorine or radon, from drinking water or wastewater. However, it is not effective for microbial contaminants, metals, nitrates and other inorganic contaminants. Activated carbon filtration is commonly used in centralised treatment plants and at household level, to produce drinking water and in industries to treat effluents. It is also an upcoming treatment applied for the removal of micropollutants both in drinking water production and for the purification of treated wastewater before disposal.

Treatment Principles
There are two basic types of water filters: particulate filters and adsorptive/reactive filters. Particulate filters exclude particles by size, and adsorptive/reactive filters contain a material (medium) that either adsorbs or reacts with a contaminant in water. The principles of adsorptive activated carbon filtration are the same as those of any other adsorption material. The contaminant is attracted to and held (adsorbed) on the surface of the carbon particles. The characteristics of the carbon material (particle and pore size, surface area, surface chemistry, etc.) influence the efficiency of adsorption. The characteristics of the chemical contaminant are also important. Compounds that are less water-soluble are more likely to be adsorbed to a solid. A second characteristic is the affinity that a given contaminant has with the carbon surface. This affinity depends on the charge and is higher for molecules possessing less charge. If several compounds are present in the water, strong absorbers will attach to the carbon in greater quantity than those with weak adsorbing ability.

Preparation
The medium for an activated carbon filter is typically petroleum coke, bituminous coal, lignite, wood products, coconut shell or peanut shell. The carbon medium is “activated” by subjecting it to stream (a gas like water, argon or nitrogen) and high temperature (800-1000°C) usually without oxygen. In some cases, the carbon may also undergo an acidic wash or be coated with a compound to enhance the removal of specific contaminants. The activation produces carbon with many pores and a high specific surface area. It is then crushed to produce a granular or pulverised carbon product.

Use
Activated carbon units are commonly used to remove organics (odours, micropollutants) from drinking water at centralised and decentralised level. At centralised level, they are generally part of one of the last steps, before the water is fed into the water distribution network. At decentralised level, activated carbon filtration units can either be point-of-use (POU) or point-of-entry (POE) treatment. A POE device is recommended for the treatment of radon and volatile organic compounds because these contaminants can easily vaporise from water in showers or washing machines and expose users to health hazards. POU devices are useful for the removal of lead and chlorine. The structure of POU devices can either be in-line, line-bypass faucet mounted (see also advanced filters) or pour-through (similar to the design of ceramic candles, colloidal silver or biosand filters). Activated carbon filters can also be used as a tertiary treatment in wastewater treatment plants to remove micropollutants from municipal effluents or recalcitrant contaminants from industrial effluents.

Combination
Activated carbon is often used as pre-treatment to protect other water treatment units such as reverse osmosis membranes and ion exchange resins from possible damage due to oxidation or organic fouling. The combination of ozonation with activated carbon is a very efficient technique for eliminating organic matter including micropollutants. Besides, the lifetime of activated carbon filters is extended drastically when used in combination with ozone, deceasing operation costs substantially.

Cost
Installation costs are moderate but additional technical equipment is required. Operating costs are usually limited to filter replacement. Depending on the type and concentration of the contaminant being removed, some carbon filters may require special hazardous waste handling and disposal, which can be costly.

Operation
Carbon filters are relatively easy to install and maintain but skilled labour is required at least occasionally for monitoring the removal performance over time of both POU and POE equipment. Activated carbon filters have a limited lifetime. After long-term use, their surfaces are saturated with adsorbed pollutants and no further purification occurs. The filter material therefore has to be replaced at regular intervals, according to manufacturer's instructions. Replacement intervals should be calculated based on the average daily water use through the filter and the amount of contaminant being removed. Cartridge disposal depends on usage. A carbon cartridge can be backwashed and then reused or discarded if non-toxics have been adsorbed.

Applicability
Activated carbon filters are widely used to produce drinking water at household and community level (to remove certain organics, chlorine or radon from drinking water) and to treat industrial or municipal wastewaters. It is not efficient for disinfection and nitrates removal. Adsorption on activated carbon is a simple technology based on materials such as fossil fuels (petroleum coke, lignite...) and even agricultural waste (e.g. coconut shell, wood, etc.). To choose the most applicable type of activated carbon for a given application it is important to analyse the composition of the influent water previously. The carbon filter has to be replaced or regenerated regularly to remain efficient. Activated carbon can also be used as a pre-treatment to protect other water treatment units.

7 Hand Filtering (Straining)

Straining is a very simple method of filtration. In this process, water is poured through a piece of cloth, which removes some of the suspended silt and solids and destroys some pathogens. After straining, water may not be perfectly safe for drinking but it can be a drinking water improvement step for people with no other treatment options. It is very important to use a clean cloth, as a dirty cloth may introduce additional pollutants into the water.

Advantages	• Simple, low cost and easy technique	• Consumes little time	• Reduces turbidity from drinking water	• Known to reduce the risk of cholera if used correctly	• No particular equipment needed
Disadvantages	• Requires extra washing of sari after use	• Not completely effective for removal of bacteria	• Not effective for removal of viruses and chemical		

Effectiveness
Straining water through a piece of clean cloth is an extremely simple, low- resource method and widely used for household water treatment. Cloth filters have been used in many cultures for centuries. Typically in South Asia, a sari or saree (a strip of unstitched cloth ranging from four to nine meters in length that is draped over the body of women (it is also a traditional garment) is folded 7 to 8 times and used as a filter. In laboratory experiments using electron microscopy, it was found that an inexpensive sari cloth, folded four to eight times provides a filter of about 20 µm mesh size, was small enough to remove all zooplankton, most phytoplankton, all Vibrio Choleraeattached to the plankton and other particulates larger than 20 µm. The risk of cholera is therefore reduced of about 50%. Water is poured through the folded sari cloth and collected in a pot underneath. The efficiency of straining depends on the weave of the cloth and the number of times it has been folded. Specific monofilament filter cloths are very efficient where guinea worm disease is prevalent. Such cloths remove organisms known as copepods, which act as intermediate hosts for the guinea-worm larvae. Dracunculiasis, more commonly known as guinea worm disease, is caused by drinking water hosting a parasite called Dracunculus medinensis.

Very Effective • Helminths • Protozoa	**Fairly Effective** • Turbidity • Bacteria • Taste • Colour • Smell	**Not Effective** • Viruses • Chemicals	In a laboratory experiments, it was found that an old sari cloth made up of cotton is most effective in removing V. Cholerae. After several launderings, threads of an old sari become soft and loose, reducing the pore size compared to a new sari cloth. Cloth filters do not remove chemical contaminants or dissolved compounds from water. After straining, additional treatment methods can further improve the safety of drinking water.

Applicability
Though the water collected from cloth filter is not perfectly safe, it is a drinking water improvement step for people with limited options. This procedure can be used as the first stage of treatment. Then water can be treated through available methods like sand filtering (see also biosand filter) or treated further with disinfection methods such as SODIS, boiling, chlorination and others. Both cotton and nylon cloths are suitable for filtration. It is very important to use clean and dry cloth, as a dirty cloth may introduce additional pollutants or pathogens into the water.

8 Slow Sand Filter

Slow sand filters are used in water purification for treating raw water to produce a potable product. They are typically 1 to 2 metres deep, can be rectangular or cylindrical in cross section and are used primarily to treat surface water. The length and breadth of the tanks are determined by the flow rate desired by the filters, which typically have a loading rate of 200 to 400 litres per hour per square metre (or 0.2 to 0.4 cubic metres per square metre per hour). Slow sand filters differ from all other filters used to treat drinking water in that they work by using a complex biological film that grows naturally on the surface of the sand.

The sand itself does not perform any filtration function but simply acts as a substrate, unlike its counterparts for UV and pressurized treatments. Although they are often preferred technology in many developing countries because of their low energy requirements and robust performance, they are also used to treat water in some developed countries, such as the UK, where they are used to treat water supplied to London. Slow sand filters now are also being tested for pathogen control of nutrient solutions in hydroponic systems.

Method of Operation
Slow sand filters work through the formation of a gelatinous layer (or biofilm) called the hypogeal layer or Schmutzdecke in the top few millimetres of the fine sand layer. The Schmutzdecke is formed in the first 10–20 days of operation and consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. As an epigeal biofilm ages, more algae tend to develop and larger aquatic organisms may be present including some bryozoa, snails and Annelid worms.

The surface biofilm is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. As water passes through the hypogeal layer, particles of foreign matter are trapped in the mucilaginous matrix and soluble organic material is adsorbed. The contaminants are metabolised by the bacteria, fungi and protozoa. The water produced from an exemplary slow sand filter is of excellent quality with 90-99% bacterial cell count reduction.

Slow sand filters slowly lose their performance as the biofilm thickens and thereby reduces the rate of flow through the filter. Eventually, it is necessary to refurbish the filter. Two methods are commonly used to do this. In the first, the top few millimetres of fine sand is scraped off to expose a new layer of clean sand. Water is then decanted back into the filter and re-circulated for a few hours to allow a new biofilm to develop. The filter is then filled to full volume and brought back into service.

The second method, sometimes called wet harrowing, involves lowering the water level to just above the hypogeal layer, stirring the sand; thus precipitating any solids held in that layer and allowing the remaining water to wash through the sand. The filter column is then filled to full capacity and brought back into service. Wet harrowing can allow the filter to be brought back into service more quickly.

Features

- Unlike other filtration methods, slow sand filters use biological processes to clean the water, and are non-pressurized systems. Slow sand filters do not require chemicals or electricity to operate.
- Cleaning is traditionally done by use of a mechanical scraper, which is usually driven into the filter bed once the bed has been dried out. However, some slow sand filter operators use a method called "wet harrowing", where the sand is scraped while still under water, and the water used for cleaning is drained to waste.
- For municipal systems there usually is a certain degree of redundancy, since it is desirable for the maximum required throughput of water to be achievable with one or more beds out of service.
- Slow sand filters require relatively low turbidity levels to operate efficiently. In summer conditions with high microbial activity and in conditions when the raw water is turbid, blinding of the filters due to bioclogging occurs more quickly and pre-treatment is recommended.
- Unlike other water filtration technologies that produce water on demand, slow sand filters produce water at a slow, constant flow rate and are usually used in conjunction with a storage tank for peak usage. This slow rate is necessary for healthy development of the biological processes in the filter.

While many municipal water treatment works will have 12 or more beds in use at any one time, smaller communities or households may only have one or two filter beds. In the base of each bed is a series of herringbone drains that are covered with a layer of pebbles which in turn is covered with coarse gravel. Further layers of sand are placed on top followed by a thick layer of fine sand. The whole depth of filter material may be over 1 metre in depth, the majority of which will be fine sand material. On top of the sand bed sits a supernatant layer of unpurified water.

As they require little or no mechanical power, chemicals or replaceable parts, and they require minimal operator training and only periodic maintenance, they are often an appropriate technology for poor and isolated areas. Slow sand filters, due to their simple design, may be created DIY. DIY-slow sand filters have been used in Afghanistan and other countries to aid the poor. Slow sand filters are recognized by the World Health Organization, Oxfam, and the United States Environmental Protection Agency as being superior technology for the treatment of surface water sources.

According to the World Health Organization, "Under suitable circumstances, slow sand filtration may be not only the cheapest and simplest but also the most efficient method of water treatment." Due to the low filtration rate, slow sand filters require extensive land area for a large municipal system. Many municipal systems in the U.S. initially used slow sand filters, but as cities have grown they subsequently installed rapid sand filters, due to increased demand for drinking water.

Summary

Slow sand filtration is a type of centralised or semi-centralised water purification system. A well-designed and properly maintained slow sand filter (SSF) effectively removes turbidity and pathogenic organisms through various biological, physical and chemical processes in a single treatment step. Only under the prevalence of a significantly high degree of turbidity or algae-contamination, pre-treatment measures (e.g. sedimentation) become necessary. Slow sand filtration systems are characterised by a high reliability and rather low lifecycle costs.

Moreover, neither construction nor operation and maintenance require more than basic skills. Hence, slow sand filtration is a promising filtration method for small to medium-sized, rural communities with a fairly good quality of the initial surface water source. As stated by the WHO, slow sand filtration provides a simple but highly effective and considerably cheap tool that can contribute to a sustainable water management system.

Advantages	● Very effective removal of bacteria, viruses, protozoa, turbidity and heavy metals in contaminated fresh water	● Simplicity of design and high self-help compatibility: construction, operation and maintenance only require basic skills and knowledge and minimal effort	● If constructed with gravity flow only, no (electrical) pumps required	● High reliability and ability to withstand fluctuations in water quality	● Easy to install in rural, semi-urban and remote areas, Simplicity of design and operation
	● Local materials can be used for construction	● No necessity for the application of chemicals	● Long lifespan (estimated >10 years)		
Disadvantages	● Minimal quality and constant flow of fresh water required: turbidity (<10-20 NTU) and low algae contamination. Otherwise, pre-treatment may be necessary	● Cold temperatures lower the efficiency of the process due to a decrease in biological activity	● Very regular maintenance essential; some basic equipment or ready-made test kits required to monitor some physical and chemical parameters	● Possible need for changes in attitude (belief that water that flows through a green and slimy filter is safe to drink without the application of chemicals), Chemical compounds (e.g. fluorine) are not removed	● Natural organic matter and other DBPs precursors not removed (may be formed if chlorine is applied for final disinfection)
	● May require electricity	● Loss of productivity during the relatively long filter skimming and ripening periods	● Requirement of a large land area, large quantities of filter media and manual labour for cleaning, Low filtration rate		

Introduction

Slow sand filtration has been an effective water treatment process for preventing the spread of gastrointestinal diseases for over 150 years, having been used first in Great Britain and later in other European countries. SFFs are still used in London and were relatively common in Western Europe until recently and are still common elsewhere in the world.

The move away from slow sand filtration in industrialised countries has largely been a function of rising land prices and labour costs, which increased the cost of SSF produced water. Where this is not the case, SSFs still represent a cost-effective method for water treatment. Since these conditions prevail in many developing countries, it is a very promising technique for water purification and, therefore, the development of a sustainable water system.

Design Principles

The basic principle of the process is very simple. Contaminated freshwater flows through a layer of sand, where it not only gets physically filtered but biologically treated. Hereby, both sediments and pathogens are removed. This process is based on the ability of organisms to remove pathogens. In this context, it is important to distinguish slow and rapid sand filtration.

The difference between the two is not simply a matter of the filtration speed, but of the underlying concept of the treatment process. Slow sand filtration is essentially a biological process whereas rapid sand filtration is a physical treatment process (WHO n.y.). To learn more about rapid sand filtration have a look at the factsheet: rapid sand filtration.

Although the physical removal of sediments is an important part of the purification process, the relevant aspect is the biological filtration. The top layers of the sand become biologically active by the establishment of a microbial community on the top layer of the sand substrate, also referred to as 'schmutzdecke'. These microbes usually come from the source water and establish a community within a matter of a few days. The fine sand and slow filtration rate facilitate the establishment of this microbial community.

The majority of the community are predatory bacteria that feed on water-borne microbes passing through the filter. Hence, the underlying principle of the SSF is equivalent to the bio-sand filtration. While the former is applied to semi-centralised water treatment, the latter mainly serves household purposes.

WATER WATER Purification Methods Slow Sand Filter

Structure
As the process itself, the basic structure is very elementary. Essentially, only the filter chamber, a type of reservoir and pipes are required. The filter chamber can either be constructed as an open or as a closed box. Depending on climatic and other factors, the one or the other is more reasonable (e.g. cold climate requires a closed box since low temperatures decrease the performance of the process).

Once a SSF facility is built, only clean sand is required for occasional replacement. The sand layers are put in gradually according to their grain sizes: rather coarse grains at the bottom and fine grains at the top. The sand-bed is usually covered with one meter of supernatant water.

As the process of biological filtration requires a fair amount of time in order to purify the water sufficiently, SSFs usually operate at slow flow rates between 0.1 – 0.3 m3/h per square metre of surface. The water thus remains in the space above the medium for several hours and larger particles are allowed to separate and settle (see also sedimentation).

It then passes through the sand-bed where it goes through a number of purification processes. The water requires some kind of physical pressure in order to pass the drag created by the sand layers. In terms of construction, two different types are feasible. The pressure can be built up either by pumps or gravity. While pump systems need some type of engine and a more elaborate construction, gravity systems work without any highly technological means.

Health Aspects
Slow sand filtration is an extremely efficient method for removing microbial contamination and will usually have no indicator bacteria present at the outlet. SSFs are also effective in removing protozoa and viruses. If the effluent turbidity is below 1.0 nephelometric turbidity units (NTU), a 90 to 99% reduction in bacteria and viruses is achieved. Yet, slow sand filtration is generally not effective for the majority of chemicals.

However, it can be argued that chemical standards for drinking water are of secondary concern in water supply subject to severe bacterial contamination. Although SSFs are very effective for the removal of microbiological pathogens, disinfectants (e.g. chlorination) are often used in treatment facilities as a step subsequent to the SSF unit.

Firstly for the purpose of inactivating any remaining bacteria as the final unit of treatment, and secondly, for the provision of a residual disinfectant that will remove any bacteria introduced during storage and/or distribution. Chlorine is generally added after the filter unit in order to not affect the biological process.

If the water contains high amounts of natural organic matter (NOMs), e.g. surface waters in tropical regions, chlorination should be avoided due to the risk of the formation of disinfection by-products (DBPs). When attacked by chlorine radicals, NOMs form trihalomethane (THM) and other organic DBPs, which are known to be carcinogenic.

Effectiveness	**Highly Effective** ● Bacteria ● Protozoa ● Viruses ● Turbidity ● Heavy Metals	**Fairly Effective** ● Odour ● Taste ● Iron ● Manganese ● Organic Matter ● Arsenic	**Not Effective** ● Salts ● Fluoride ● Trihalomethane Precursors ● Most Chemicals		

Construction
A SSF consists of a box, often made of concrete in which a bed of sand is placed over a layer of gravel and perforated pipes. These pipes collect the treated water. For community use, filter chambers can also be made out of brick or ferro-cement. Recently, also plastic boxes have been used as filter chambers. The simple design of SSFs makes it easy to use local materials and skills in their construction. Due to the simplicity of construction, SSFs can be built by experienced contractors, or by communities with external technical assistance. Basic hydrological equipment like valves and measurement devices become necessary only if the facility is rather large.

Operation / Maintenance
For a SSF to be effective, it must be operated and maintained properly. If topographic circumstances allow the water to flow through gravity during the whole process, no pumps and thus no electricity is required. However, the flow of water must be maintained at a rate between 0.1–0.3 metres per hour. This provides a stable flow of nutrients and oxygen to the microorganisms in the filter and gives them time to treat the water. After several weeks to a few months, the population of microorganisms may get too dense and start to clog the filter.

If flow rates are too low, the filter must be drained and the top layer of the sand scraped off, washed, dried in the sun, and stored. After several scrapings, the cleaned and dried sand is added back to the filter, together with new sand, to make up for losses during washing. Every two months, all the valves must be opened and closed to keep them from becoming stuck, and any leaks in the system must be repaired immediately.

SSFs can be operated and even monitored by communities, provided the caretakers are trained well. It takes a caretaker less than one hour a day to check whether the filter is functioning properly and to adjust flow rates. Several people can clean a filter unit in only one day, but it is important that hygienic measures are observed constantly. If the filter is well-designed and constructed, hardly any repairs of the filter tanks and drainage system will be necessary, although the valves and metal tubing may need occasional attention.

If water test kits are available, water quality can be easily monitored without special training. Nevertheless, a SSF for community use requires considerable organisation for scraping and re-sanding the filter units. A local caretaker will have to be trained. Apart from extra sand, some chlorine and test materials, very few external inputs are needed. With proper external assistance, water organisations can manage their water treatment independently.

Costs
Construction costs strongly depend on local conditions. Since SSFs demand rather large land areas but low input of construction materials, the capital costs primarily consist of wages and costs for land acquisition. The cost of imported materials and equipment may be kept to almost negligible proportions. Therefore, water purification through a SSF is very economical in areas where labour costs are low and land is not a limiting factor. Operational costs are incurred almost solely from the cleaning of the filter beds. No chemicals or other materials are needed for the process. No compressed air, mechanical stirring, or high-pressure water is needed for backwashing. There is thus a saving not only in the provision of plant but also in the cost of fuel or electricity.

9 Rapid Sand Filter

Rapid sand filtration is a purely physical drinking water purification method. Rapid sand filters (RSF) provide rapid and efficient removal of relatively large suspended particles. Two types of RSF are typically used: rapid gravity and rapid pressure sand filters. For the provision of safe drinking water, RSFs require adequate pre-treatment (usually coagulation-flocculation) and post-treatment (usually disinfection with chlorine).

Both construction and operation is cost-intensive. It is a relatively sophisticated process usually requiring power-operated pumps, regular backwashing or cleaning, and flow control of the filter outlet. Rapid sand filtration is common in developed countries for the treatment of large quantities of water where land is a strongly limiting factor, and where material, skilled labour, and continuous energy supply are available.

WATER Purification Methods Rapid Sand Filter

Overview	**Working Principle** After being pre-treated (coagulation-flocculation), freshwater flows through a sand- and gravel bed. Hereby, particles are removed through a physical filtering process	**Capacity/Adequacy** Large urban areas where land area is limited and chemicals, electricity and skilled labour are easily available	**Self-Help Compatibility** Rather low, highly technical facilities, chemicals and energy required	**Costs** In general, construction, operation and maintenance costs for rapid sand filters are significantly higher than costs for slow sand filters	**Performance** 4'000 – 12'000 litres per hour per square metre of surface; generally only removes solids and suspended particles; requires pre-treatment (coagulation-flocculation) and post-treatment (disinfection)
	O&M Very frequent cleaning (every 24 - 72h) and skilled caretakers required	**Reliability** Highly reliable if properly operated	**Main Strength** Rapid and efficient in removing turbidity	**Main Weakness** Not effective for the removal of bacteria, pre-treatment (e.g. coagulation/flocculation) and final disinfection (e.g. chlorine) are therefore needed	

Advantages	• Highly effective for removal of turbidity (usually < 0.1-1 NTU)	• High filter rate (4'000 – 12'000 litres per hour per square metre of surface), small land requirements	• No limitations regarding initial turbidity levels (if coagulant or flocculant is available and correctly applied)	• Cleaning time (backwashing) only takes several minutes and filters can be put back into operation instantly	
Disadvantages	• Not effective in removing bacteria, viruses, fluoride, arsenic, salts, odour and organic matter (requires pre- and post-treatment)	• High capital, energy input and operational costs	• Frequent cleaning (backwashing) required (every 24-72h)	• Skilled supervision essential (e.g. for flow control and dosage of disinfectant)	• Backwashing water and sludge needs treatment; sewage system or stabilisation ponds required

Introduction

Rapid sand filters evolved at the end of the 19th century in the United States and quickly gained popularity. By the 1920s, they were widely used as a major water purification method, since necessary facilities required less land area compared to slow sand filters. Today, a combination of flocculation and coagulation, sedimentation, filtration and disinfection (e.g. chlorination, ozonation) is the most widely applied water treatment technology for treating large quantities of drinking water in industrialised countries. Rapid sand filtration, in contrast to slow sand filtration, is a purely physical treatment process. As the water flows through several layers of coarse-grained sand and gravel, relatively large particles are held back safely. However, RSFs never provide safe drinking water without adequate pre-treatment and final disinfection. Usually, coagulation and flocculation and chlorination are applied for that purpose.

Treatment Process

The filter chamber is usually made out of reinforced concrete, filled with sand and gravel to the height of 1.5-2 metres. The water is supplied to the top of the sand-bed and filtered as it flows through the layers of graded sand and gravel. A system of perforated pipes on the bottom drains the chamber.

The filter chamber can be constructed as open tanks (rapid gravity filters) or closed tanks (pressure filters). This filtering process is determined by two basic physical principles. First, relatively large suspended particles get stuck between the sand grains as they pass the filter medium (mechanical straining). Second, smaller particles adhere to the surface of the sand grains caused by the effect of the van der Waals forces (physical adsorption).

The major parts of a gravity rapid sand filter
- Chamber: filter tank or filter box
- Filter media (sand)
- Gravel support
- Under drain system
- Wash water troughs

A chemical filter-aid (i.e. coagulant or flocculant) might be added to promote additional adhesion. In the course of these processes, more and more particles accumulate in the filter medium, increasingly causing clogged filters and decreased performance. Initial filtering performance can be re-achieved through a cleaning of the filter bed. This is usually conducted through backwashing: the flow of water is reversed, so that treated water flows backwards through the filter. The sand is re-suspended and the solid matter is separated in the surface water.

Often, air is injected additionally to support the cleaning process (WHO 1996). As soon as most particles are washed out and the backward flowing water is clear, the filter is put back to operation. Clearly, relatively large quantities of sludge are generated through backwashing and require some form of treatment before discharge into the environment.

Health Aspects

Rapid sand filtration is a highly effective method to remove turbidity if it is correctly applied. Equally, solids formed during pre-treatment, i.e. coagulation-flocculation, are filtered. A well-operated RSF reduces turbidity to less than 1 NTN and often less than 0.1 NTU. Regarding the removal of most other contaminants, the RSFs are ineffective. If combined with adequate pre-treatment measures and final disinfection, rapid sand filtration usually produces safe drinking water. Typical treatment performance of rapid sand filters if freshwater has been pre-treated with coagulation-flocculation.

Effectiveness	**Moderately Effective** • Turbidity • Iron • Manganese	**Somewhat Effective** • Odour • Taste • Bacteria • Organic Matter	**Not Effective** • Viruses • Fluoride • Arsenic • Salts		

Construction

The construction of a RSF requires the supervision of a competent engineer and highly skilled workers. It involves the construction of reinforced concrete fundaments and walls and many technical installations. Only a very precise realisation guarantees a functioning water treatment. Operation of a rapid sand filter consists of flow control, regular backwashing and cleaning. The period between backwashes depends on the quality of the influent water and normally lies between 24 – 72 hours (UNEP 1998). The cleaning process requires an interruption of the purification process of 5 - 10 minutes per filter bed. Several parallel filter units are required to guarantee constant water supply. The backwash process must be observed carefully; in particular the rate of flow must be controlled to avoid erosion of the filter medium. Periodic repacking of the filter bed may be required at infrequent intervals to ensure efficient operation (UNEP 1998). Operation and maintenance thus requires skilled and highly reliable workers.

Costs

The construction cost of rapid sand filters is determined primarily by the cost of materials such as cement, building sand, gravel, reinforcing steel, filter media, pipes, and valves. However, the cost of land and transport of materials could add substantially to the total cost. The cost of energy required to operate a rapid sand filter and the costs for treatment of generated sludge during backwashing may add significant costs. Although operation is usually conducted automatically, frequent inspection by a well-educated worker is necessary to ensure proper treatment. Maintenance costs will include repairs of the filters and replacement of equipment. In general, construction, operation and maintenance costs for rapid sand filters are significantly higher than costs for slow sand filters.

Applicability
Rapid sand filtration requires very complex technical installations, highly skilled workers for construction and operation as well as large energy inputs. Unless pre-treatment and disinfection is applied, the filtered water is not safe for drinking. Its application is hence reserved for industrialised countries or urban areas where land is a limiting factor. RSF can provide a very efficient method in larger urban water supply systems if preconditions are met. For any other areas, RSFs are usually economically unreasonable.

10 Biosand Filter

A biosand filter (BSF) is a point-of-use water treatment system adapted from traditional slow sand filters. Biosand filters remove pathogens and suspended solids from water using biological and physical processes that take place in a sand column covered with a biofilm. BSFs have been shown to remove heavy metals, turbidity, bacteria, viruses and protozoa.

BSFs also reduce discoloration, odour and unpleasant taste. Studies have shown a correlation between use of BSFs and a decrease in the occurrence of diarrhoea. Because of their effectiveness, ease of use, and lack of recurring costs, biosand filters are often considered appropriate technology in developing countries.

It is estimated that over 200,000 BSFs are in use worldwide. Biosand filters are typically constructed from concrete or plastic. At the top of the filter, a tightly fitted lid prevents contamination and unwanted pests from entering the filter. Below this, the diffuser plate prevents disturbance of the biofilm when water is poured into the filter.

Water then travels through the sand column, which removes pathogens and suspended solids. Below the sand column, a layer of gravel prevents sand from entering the drainage layer and clogging the outlet tube. Below the separating layer is the drainage layer consisting of coarser gravel that prevents clogging near the base of the outlet tube.

Filtration Process
Pathogens and suspended solids are removed by biological and physical processes that take place in the biolayer and the sand layer. These processes include:

Mechanical Trapping	Suspended solids and pathogens are trapped in the spaces between the sand grains.
Predation	Pathogens are consumed by microorganisms in the biolayer.
Adsorption	Pathogens are absorbed into each other and to suspended solids in the water and sand grains.
Natural Death	Pathogens finish their life cycles or die because there is not enough food or oxygen.
Running	The high water level (hydraulic head) in the inlet reservoir zone pushes the water through the diffuser and filter, then decreases as water flows evenly through the sand. The flow rate slows because there is less pressure to force the water through the filter. The inlet water contains dissolved oxygen, nutrients, and contaminants. It provides the oxygen required by the microorganisms in the biofilm. Large suspended particles and pathogens are trapped in the top of the sand and partially plug the pore spaces between the sand grains. This causes the flow rate to decrease. Idle time typically comprises greater than 80% of the daily cycle; during this time, microbial attenuation processes are likely to be significant. Most removal occurs where water is in contact with the biofilm. The processes that occur in the biofilm have not been identified. When the standing water layer reaches the level of the outlet tube, the flow stops. Ideally, this should be high enough to keep the biofilm in the sand layer wet and allow oxygen to diffuse through the standing water to the biolayer. The pause period allows microorganisms in the biolayer to consume the pathogens and nutrients in the water. The rate of flow through the filter is restored as they are consumed. If the pause period is too long, the biolayer will consume all of the pathogens and nutrients and will die, reducing the efficiency of the filter when it is used again. The pause period should be between 1 and 48 hours. Pathogens in the non-biological zone die from a lack of nutrients and oxygen.
Maintenance	Over time, particles accumulate between the filter's sand grains. As more water is poured, a biofilm forms along the top of the diffuser plate. Both of these occurrences cause a decrease in flow rate (clogging and bioclogging). Although slower flow rates generally improve water filtration due to idle time, it may become too slow for the users' convenience. If flow rates fall below 0.1 litres/minute, it is recommended by CAWST to perform maintenance. The "swirl and dump", or wet harrowing cleaning technique, is used to restore flow rate. About 1 US gallon (3.8 L) is poured into the filter before cleaning (assuming the filter is empty). The upper layer of sand is then swirled in a circular motion. Dirty water from the swirling is dumped out and the sand is smoothed out at the top. This process is repeated until flow rate is restored. Cleaning the diffuser plate, outlet tube, lid, and outside surfaces of the filters regularly is also recommended. Long-term sustainability and efficacy of biosand filters depends on education and support from knowledgeable support personnel.

Contaminant Removal

Turbidity	Results for turbidity reductions vary depending on the turbidity of the influent water. Turbid water contains sand, silt and clay. Feed turbidity in one study ranged from 1.86 to 3.9 NTU. In a study water was obtained from sample taps of water treatment plants from three local reservoirs. It poured through a slow sand filter and results showed that turbidity decreased to a mean of 1.45 NTU. In another study using surface water a 93% reduction in turbidity was observed. As the biofilm above the sand ripens, turbidity removal increases. Although biosand filters remove much turbidity, slow sand filters, which have a slower filtration rate, remove more.
Heavy Metals	There is limited research on the removal of heavy metals by biosand filters. In a study conducted in South Africa, the filter removed about 64% of iron and 5% of magnesium.
Bacteria	In laboratory studies, the biosand filter has been found to remove about 98-99% of bacteria. In removal of Escherichia coli it was found that the biosand filter may increase due to biofilm formation over about two months. The removal after this time ranged from 97-99.99% depending on the daily water volume and percent primary effluent added. The addition of primary effluent or waste water facilitates growth of the biofilm which aids bacterial die-off. Research shows that biosand filters in use in the field remove fewer bacteria than ones in a controlled environment. In research conducted in 55 households of Bonao, Dominican Republic, the average E. coli reduction was about 93 percent.

Viruses	Lab tests have shown that while the filters reduce significant quantities of E. coli, they remove significantly fewer viruses because viruses are smaller. In a study using bacteriophages, virus removal ranged between 85% and 95% after 45 days of usage. A recent study has suggested that virus removal increases significantly over time, reaching 99.99% after approximately 150 days.
Protozoa	In one lab test the biosand filter removed more than 99.9% of protozoa. In tests for one type of protozoa, Giardia lamblia, the filter removed 100% over 29 days of use. It removed 99.98% of the oocysts of another protozoa, Cryptosporidium sp., possibly due to their smaller size. This removal was comparable with that of the slow sand filter.

Advantages	● High removal of pathogens	● Removal of turbidity, colour, odour and iron (water tastes and looks good)	● Relatively high flow-rates can be achieved (over 30 L per hour)	● One-time installation with few maintenance requirements and negligible operation costs	● Can be fabricated from locally available materials generating an opportunity for local businesses
	● Long life	● Easy to operate and maintain			
Disadvantages	● Biological layer takes 20 to 30 days to develop to maturity	● Low rate of virus inactivation	● High turbidity (> 50 NTU) will cause filter to clog and requires more maintenance	● Requires that the filter be used on a regular basis	● Cannot remove dissolved compounds
	● Lack of residual protection (risk of re-contamination)	● Can be difficult to move or transport (due to weight)	● Requires that the filter be used on a regular basis		

How it Works
The biosand filter is an innovation on traditional slow sand water filters (which have been used for community water treatment for hundreds of years CAWST 2009), specifically designed for intermittent or household use. The BSFs was developed by Dr. David Manz in the 1990s at University of Calgary, Canada. The filter is simple to use and can be produced locally anywhere in the world because it is built using materials that are readily available. Their capital costs depend on the local material and labour costs. However, they require no consumables and the operating costs are negligible. BSFs consist of a simple container with a lid, enclosing layers of sand and gravel, which traps physically sediments, pathogens and other impurities from the water. A biofilm, which forms as a shallow layer of water, sits atop the sand column and contributes to the elimination of pathogens.

The filter container can be made of concrete, plastic or any other water-proof, rust-proof and non-toxic material. The most widely used version is however the concrete container, approximately 0.9 m tall and with a surface of 0.3 m2 (LANTAGNE et al. 2006). The concrete filter box is cast from a steel mould or made with a pre-fabricated pipe. The container is filled with layers of sieved and washed sand and gravel, also referred to as filter media (CAWST 2009). There is a standing water height of 5 cm above the sand layer, which is maintained by adjusting the height of the outlet pipe. It is this design feature that allows the formation of a biofilm layer and distinguishes the BSF from other slow sand filters, allowing for small-scale construction and intermittent use.

A diffusion layer avoids that water reaches the sand surface too fast, which could disturb the biofilm layer. The filter operation is very simple. Water is poured onto the top of the filter as needed. Then the water will travel slowly through the sand and gravel bed. At the base of the filter the water is collected in a pipe and is drained through plastic piping out of the filter for be collected and stored in a clean water container. Concrete filters have the outlet pipe embedded in the concrete, protecting it against breaks and leaks. The treated water should be collected by the user in a safe storage container placed on a block or stand, so that the container opening is just under the outlet, minimising the risk for recontamination.

Pathogens and suspended solids are removed through a combination of biological and physical processes that take place in the biofilm layer and within the sand layer. These processes include mechanical trapping, predation, adsorption, and natural death.

- Mechanical trapping and sieving: Suspended solids and pathogens are physically trapped in the spaces between the sand grains.
- Adsorption and attachment: Pathogens become attached to each other (and thus more easily sieved), suspended solids in the water, and the sand grains.
- Predation: Pathogens are consumed by other microorganisms in the biological layer. This biological layer matures over one to three weeks, depending on volume of water put through the filter and the amount of nutrients and micro-organisms in the water.
- Natural death: Pathogens finish their life cycle or die because there is not enough food or oxygen for them to survive.

Effectiveness
The biosand Filter is a proven technology, which removes pathogens such as bacteria, protozoa and helminth. BSFs are also somewhat effective for the removal of virus (CAWST 2009). Physical parameters such as turbidity and iron are also eliminated from drinking water.

However, dissolved chemicals (such as organic pesticides or arsenic) are not removed. The treated water generally has an agreeable colour, taste and odour. The table below shows the biosand filter treatment efficiency in removing pathogens, turbidity and iron.

Bacteria
Lab: Up to 96.5%
Field: 87.9 to 98.5%

Viruses
Lab: 70 to >99%
Field: N/A

Protozoa
Lab: >99.9%
Field: N/A

Turbidity
Lab: 95%
Field: 85%

Iron
Lab: N/A
Field: 90-95%

Operation & Maintenance
The flow rate through the filter will slow down over time as the pore openings between the sand grains become clogged. For turbidity levels greater than 50 NTU (Nephelometric Turbidity Units), the water should first be strained through a cloth or sedimented before using the BSF. When the flow rate drops to a level that is inadequate for the household use the filter needs to be cleaned. This is done by a simple 'swirl and dump' procedure performed on the top of the sand, and only takes a few minutes. The swirl and dump process consist in agitating the surface sand, thereby suspending captured material in the standing layer of the water (see cawst.org). The dirty water is than removed and dumped away. The process can be repeated as many times as necessary to regain the desired flow rate. The need for cleaning depends on the amount and quality of water being put through the filter. If the water is relatively clean (turbidity less than 30 NTU), the filter can likely run for several months without this maintenance procedure. When a BSF is used for the first time, there is no biofilm yet. The biological layer typically takes 20 to 30 days to develop to maturity in a new filter depending on inlet water quality and usage (CAWST 2009). Removal efficiency and the subsequent effectiveness of the filter increase throughout this period. After cleaning, a re-establishment of the biological layer takes place, quickly returning removal efficiency to its previous level.

Applicability
BSF are suitable for the treatment of water at household-, school- or community-level. BSF can efficiently and directly treat contaminated surface or ground water since it also removes turbidity and iron. However, it is recommended not to use water with turbidity more than 50 NTU. Further, dissolved chemicals (e.g. organic pesticides or arsenic) are not removed. Chlorinated water should not be poured into this filter as chlorine kills microorganisms presented in biofilm resulting in low pathogen removal performance. Nevertheless, the water can be chlorinated after filtration in order to improve the security for elderly or infant members of the household/community. A BSF should be constructed only by trained technicians. Though the construction and installation look very simple, incorrect filter design and installation can lead to poor filter performance. However, materials are generally locally available and the construction by trained local staff may create opportunities for local business.

11 Sedimentation

Sedimentation is a physical water treatment process using gravity to remove suspended solids from water. Solid particles entrained by the turbulence of moving water may be removed naturally by sedimentation in the still water of lakes and oceans. Settling basins are ponds constructed for the purpose of removing entrained solids by sedimentation. Clarifiers are tanks built with mechanical means for continuous removal of solids being deposited by sedimentation.

Sedimentation is recommended as simple pre-treatment of water prior to application of other purification treatments such as filtration and disinfection methods. It removes undesirable small particulate suspended matters (sand, silt and clay) and some biological contaminants from water under the influence of gravity. The longer the water is sedimented, the more the suspended solids and pathogens will settle to the bottom of the container. Adding special chemicals or some natural coagulants can accelerate sedimentation.

Three common chemicals used are aluminium sulphate, polyaluminium chloride (also known as PAC or liquid alum) and ferric sulphate. 'PUR' is a powder product containing both coagulants and disinfectant. Some native plants like prickly pear cactus, Moringa seeds, broad beans and Fava beans have all been traditionally used as natural coagulant to help sediment water in a number of countries in Africa and Latin America.

Advantages	• Simple and low cost water pre-treatment technology. • Certain contaminants such as lead and barium can be also effectively removed by coagulation	• Coagulants reduce the time required to settle out suspended solids.	• Natural coagulants can sometimes be obtained for free or at a low cost.	• Coagulation can also be effective in removing protozoa, bacteria and viruses, particularly when polyelectrolyte is used. Some bacteria and viruses can attach themselves to the suspended particles in water that cause turbidity. Thus, reducing turbidity levels through coagulation may also improve the quality of water.	
Disadvantages	• If only settling or plain sedimentation is practised, it removes only partially turbidity and some microorganisms	• Maximum effectiveness requires careful control of coagulant dose and pH, and consideration of the quality of the water being treated, as well as mixing	• Costs are variable depending on coagulant; some coagulants like polyelectrolyte are expensive to buy. Effectiveness of coagulants varies from one to another	• Without using coagulants, a long sedimentation time is needed	• Training is required for coagulant dosage, jar testing and frequent monitoring
	• Except with the use of specific coagulants, it is not effective for removing dissolved chemicals from the water	• May be toxic if used improperly	• Natural coagulants are not available in a usable form and need to be prepared		

Sedimentation
The suspended particles in water vary considerably in source, composition, charge, particle size, shape and density. The smaller particles present in water are kept in suspension by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilisation results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and since they have the same charge sign, repel each other when they come close together. Therefore they will remain in suspension rather than clump together and settle out of the water. Sedimentation is a simple, low cost pre-treatment technology to reduce settable solids and some microbes from water under the influence of gravity prior to application of other purification methods. It also improves the visual qualities of the water and increases its acceptance by consumers. The longer the water is stored, the more the suspended solids and pathogens will settle to the bottom of the container. Adding chemical or natural coagulants to the water can quicken the sedimentation process. Aluminium sulphate, polyaluminium chloride (also known as PAC or liquid alum) and ferric sulphate are three common types of chemicals used for the coagulation. Some examples of natural coagulants are prickly pear cactus, Moringa seeds, broad beans and Fava beans. Some products like “PUR” contain both coagulants and disinfectant. Coagulants are dosed in solution at a rate determined by raw water quality. After sedimentation, the water should be filtered to further remove suspended materials and pathogens.

Working Mechanism
Much of the suspended material can be removed by simply allowing the water to stand and settle for some time. This retention time (from one hour up to two days, the longer the better) is required to settle particles in the bottom. Storing water for at least one day will also promote the natural die-off of some bacteria. Coagulants enhance sedimentation because they neutralise the surface charge of suspended particles. Particles that cause turbidity (e.g. silt, clay) are generally negatively charged, making it difficult for them to clump together because of electrostatic repulsion.

But chemical coagulant particles are positively charged, and they chemically attracted to negative turbidity particles, neutralising the latter’s negative charge and accumulate to form larger particles (flocs), which settle faster. Natural coagulants contain significant quantities of water-soluble proteins, which carry an overall positive charge when in solution. The proteins bind to the predominantly negatively charged particles that cause turbidity and form flocs. The flocs can be settled out or removed by filtration. Bacteria and viruses can attach themselves to the suspended particles in water. Therefore, reducing turbidity levels through coagulation may also improve the microbiological quality of water.

Effectiveness
Plain sedimentation often is effective in reducing water turbidity, but it is not consistently effective in reducing microbial contamination. Storing water for as little as a few hours will sediment the large, dense particles like inorganic sands and silts, large microbes and any other. Overnight or 1-2 days longer settling times will remove larger microbes, including Helminth ova and some parasites, some microbes, such as certain algae, and the larger clay particles. Most viruses and bacteria and fine clay particles are too small to be settled out by simple gravity sedimentation. Sedimentation by using coagulant reduces the time required to settle out suspended solids and is very effective in removing fine particles. Some bacteria and viruses can also attach themselves to suspended particles. Therefore, reducing turbidity level through coagulation may also improve some microbiological quality (bacteria, viruses, protozoa and helminths) of water. The use of Moringa Oleifera seeds for water treatment is efficient in reducing 80% to 99.5% of turbidity accompanied by 90% to 99.99% bacterial reduction.

Bacteria - Lab: >90-99%
Viruses - Lab: >90-99%
Protozoa - Lab: >90-99%
Helminths - Lab: >90-99%
Turbidity - Lab: 80-99.5%

The effectiveness of the coagulants has a complex dependence on the type of coagulant used, the nature of the raw water, being affected by such things as temperature, pH and especially the specific proportions of organic, inorganic and biological particles that constitute the suspended solids as well as mixing. The best approach for determining the treatability of a water source and determining the optimum parameters (most effective coagulant, required dose rates, pH) is by use of a jar tester. Plain sedimentation or settling is not effective for removing dissolved chemicals from the water.

Applicability
Sedimentation is used to remove solids from water. It is suitable for water with high sediment content. It is easy to perform and requires a minimum of materials and skill. It can be done with as little as two or more simple storage vessels such as pots and buckets by manual transfer. Typically, at least two containers are needed to settle water: one to act as the settling vessel and another to be the recipient of the supernatant water after the settling period. Care must be taken to avoid disturbing the sedimented particles when recovering the supernatant water by decanting or other methods. Staffs need to be adequately trained to carry out jar tests to determine coagulant dosage. For better results, the coagulants should be rapidly and thoroughly mixed in water. Coagulants can be expensive to buy (particularly polyelectrolyte) and need accurate dosing equipment to function efficiently. When water is sedimented in vessel, the sediment should be removed and the vessel should be cleaned after each use. More rigorous physical or chemical cleaning is needed to avoid the microbial colonization of the vessel surface. Some communities have opted not to use aluminium based coagulants because of unsubstantiated reports that claim that the aluminium in drinking water poses a risk to public health despite of scientific evidences. Based on the WHO (2008), there is no evidence of health risk. Studies have been carried out to determine the potential risks associated with the use of M. Oleifera seed in water treatment but there is no evidence to suggest any acute or chronic effects on humans, particularly at the low doses required for water treatment.

12 Coagulation (Flocculation)

In water treatment, coagulation flocculation involves the addition of polymers that clump the small, destabilized particles together into larger aggregates so that they can be more easily separated from the water. Coagulation is a chemical process that involves neutralization of charge whereas flocculation is a physical process and does not involve neutralization of charge. The coagulation-flocculation process can be used as a preliminary or intermediary step between other water or wastewater treatment processes like filtration and sedimentation. Iron and aluminium salts are the most widely used coagulants but salts of other metals such as titanium and zirconium have been found to be highly effective as well.

Coagulation is affected by the type of coagulant used, its dose and mass; pH and initial turbidity of the water that is being treated; and properties of the pollutants present. The effectiveness of the coagulation process is also affected by pre-treatments like oxidation. In a colloidal suspension, particles will settle very slowly or not at all because the colloidal particles carry surface electrical charges that mutually repel each other. A coagulant (typically a metallic salt) with the opposite charge is added to the water to overcome the repulsive charge and "destabilize" the suspension. For example, the colloidal particles are negatively charged and alum is added as a coagulant to create positively charged ions. Once the repulsive charges have been neutralized (since opposite charges attract), the van der Waals force will cause the particles to cling together (agglomerate) and form micro floc.

Introduction
Coagulation-flocculation is a chemical water treatment technique typically applied prior to sedimentation and filtration (e.g. rapid sand filtration) to enhance the ability of a treatment process to remove particles. Coagulation is a process used to neutralise charges and form a gelatinous mass to trap (or bridge) particles thus forming a mass large enough to settle or be trapped in the filter. Flocculation is gentle stirring or agitation to encourage the particles thus formed to agglomerate into masses large enough to settle or be filtered from solution.

Overview	**Self-Help Compatibility** Skilled operators required	**Capacity/Adequacy** Relatively simple technology	**Performance** High efficiency in removing charged suspended and dissolved particles	**Costs** Relatively low cost	**Working Principle** Suspended particles are destabilised by addition of a clarifying agent leading to the neutralisation of their charges. Particles thus agglomerate (flocs formation) and are able to decant.
	O&M Continuous consumption of chemicals and electricity	**Reliability** Reliable if operating conditions are optimised taking into account wastewater content	**Main Strength** Removes solids and improves filtration	**Main Weakness** Continuous input of chemicals required	

Advantages	• Simplicity and cost-effectiveness	• Separates many kind of particles from water	• Enhances filtration process	• Uses abundant and low cost chemicals	
Disadvantages	• Input of chemicals required	• Qualified personnel required for design (e.g. construction of chambers and dosage of chemicals) and system maintenance	• Transfer of toxic compounds into solid phase and formation of sludge that has to be treated subsequently	• Relatively time consuming process	

Introduction
Dissolved and suspended particles are present in most of natural waters. These suspended materials mostly arise from land erosion, the dissolution of minerals and the decay of vegetation and from several domestic and industrial waste discharges. Such material may include suspended, dissolved organic and/or inorganic matter, as well as several biological organisms, such as bacteria, algae or viruses.

This material has to be removed, as it causes deterioration of water quality by reducing the clarity (e.g. causing turbidity or colour), and eventually carrying pathogenic organisms or toxic compounds, adsorbed on their surfaces. To separate the dissolved and suspended particles from the water coagulation and flocculation processes are used. Coagulation and flocculation is relatively simple and cost-effective, provided that chemicals are available and dosage is adapted to the water composition.

Regardless of the nature of the treated water and the overall applied treatment scheme, coagulation-flocculation is usually included, either as pre-treatment (e.g. before rapid sand filtration) or as post-treatment step after sedimentation (see also centralised water purification plants). Most solids suspended in water possess a negative charge; they consequently repel each other. This repulsion prevents the particles from agglomerating, causing them to remain in suspension.

Coagulation and flocculation occur in successive steps intended to overcome the forces stabilising the suspended particles, allowing particle collision and growth of flocs, which then can be settled and removed (by sedimentation) or filtered out of the water. Coagulation-Flocculation is also a common process to treat industrial and domestic wastewater in order to remove suspended particles from the water.

Coagulation Principles
Coagulation destabilises the particles’ charges. Coagulants with charges opposite to those of the suspended solids are added to the water to neutralise the negative charges on dispersed non-settable solids such as clay and organic substances. Once the charge is neutralised, the small-suspended particles are capable of sticking together.

The slightly larger particles formed through this process are called microflocs and are still too small to be visible to the naked eye. A high-energy, rapid-mix to properly disperse the coagulant and promote particle collisions is needed to achieve good coagulation and formation of the microflocs. Over-mixing does not affect coagulation, but insufficient mixing will leave this step incomplete. Proper contact time in the rapid-mix chamber is typically 1 to 3 minutes.

Flocculation
Following coagulation, flocculation, a gentle mixing stage, increases the particle size from submicroscopic microfloc to visible suspended particles. The microflocs are brought into contact with each other through the process of slow mixing. Collisions of the microfloc particles cause them to bond to produce larger, visible flocs. The floc size continues to build through additional collisions and interaction with inorganic polymers formed by the coagulant or with organic polymers added. Macroflocs are formed.

High molecular weight polymers, called coagulant aids, may be added during this step to help bridge, bind, and strengthen the floc, add weight, and increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the separation process (sedimentation, floatation or filtration). Design contact times for flocculation range from 15 or 20 minutes to an hour or more.

Coagulation Flocculation Separation
In water treatment, coagulation and flocculation are practically always applied subsequently before a physical separation. The Coagulation-Flocculation process consists of the following steps:

1. Coagulation-flocculation: The use of chemical reagents to destabilise and increase the size of the particles; mixing; increasing of flog size
2. A physical separation of the solids from the liquid phase. This separation is usually achieved by sedimentation (decantation), flotation or filtration.

The common reagents are: mineral and/or organic coagulants (typically iron and aluminium salt, organic polymers), flocculation additives (activated silica, talcum, activated carbon…), anionic or cationic flocculants and pH control reagents such as acids or bases. Certain heavy metal chelating agents can also be added during the coagulation step.

Jar Test
The jar test is used to identify the most adapted mix of chemical compounds and concentrations for coagulation-flocculation. It is a batch test consisting of using several identical jars containing the same volume and concentration of feed, which are charged simultaneously with six different doses of a potentially effective coagulant. The six jars can be stirred simultaneously at known speeds. The treated feed samples are mixed rapidly and then slowly and then allowed to settle. These three stages are an approximation of the sequences based on the large-scale plants of rapid mix, coagulation flocculation and settling basins. At the end of the settling period, test samples are drawn from the jars and turbidity of supernatant liquid is measured. A plot of turbidity against coagulant dose gives an indication of the optimum dosage (i.e. the minimum amount required to give acceptable clarification).

The criteria thus obtained from a bench jar test are the quality of resultant floc and the clarity of the supernatant liquid after settling. The design of the full-scale plant process is then done based on the bench-scale selection of chemicals and their concentrations. Unfortunately, the jar test suffers from a number of disadvantages, despite its widespread application. It is a batch test, which can be very time-consuming. And the results obtained from a series of jar tests might not correspond to the results obtained on a full-scale plant.

Operation and Maintenance
The operation of coagulators, flocculators and clarifiers requires trained operators. Maintenance work should be undertaken regularly. The key aspects of operation and maintenance of coagulators, flocculators and clarifiers are:
● Chemical stock: There should be a good stock (at least sufficient for one month of operation).
● Plant layout: The flocculator and clarifiers should be located close to one another and water should flow slowly between them so as to not break up the flocs.
● Dosing control: Correct dosing of coagulant chemicals is very important for efficient and effective removal of suspended solids. Samples of raw water should be taken regularly, and tested with a range of coagulant concentrations to determine the optimum dose rate of coagulant. The results should be used to adjust the coagulant dose.
● Flocculation should be achieved by gentle mixing so as to maximise the number of collisions between suspended particles and flocs, without breaking the flocs up through rapid mixing.
● Rapid mixing of the water and coagulant chemicals at the point where the chemicals are added is essential.

During the course of coagulation-flocculation treatment, a substantial amount of sludge coming from the settling process is generated. This sludge can be reused as fertiliser for agriculture when no toxic compounds are present. In the presence of toxic sludge the solid waste has to be treated or disposed of in an environmentally proper manner.

Applicability
Coagulation-flocculation is a conventional pre-treatment method (typically in combination with sedimentation] and rapid sand filtration) used to separate the suspended and dissolved compounds (turbidity) from the water in (semi-)centralised drinking water treatment plants. Many charged species such as suspended mineral, organics, pathogens, and dissolved species such as metal ions, phosphates, fluoride, and radionuclides can be separated by these processes. Chemicals reactants (flocculants and coagulants) concentration must be adjusted properly to the exact composition of the water. The operation of coagulators, flocculators and clarifiers requires trained operators. Maintenance work should be undertaken regularly to guarantee an efficient treatment. Coagulation-flocculation is also often used to remove suspended solids in domestic and industrial wastewater treatment plants.

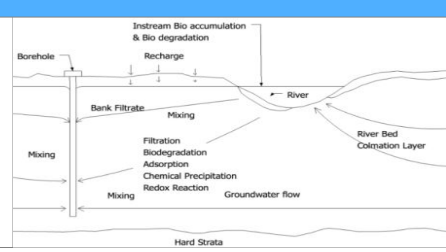
Determining Coagulant Dose
Jar Test
The dose of the coagulant to be used can be determined via the Jar Test. The jar test involves exposing same volume samples of the water to be treated to different doses of the coagulant and then simultaneously mixing the samples at a constant rapid mixing time. The microfloc formed after coagulation further undergoes flocculation and is allowed to settle. Then the turbidity of the samples is measured and the dose with the lowest turbidity can be said to be optimum.

Microscale Dewatering Tests
Despite its widespread use in the performance of so-called "dewatering experiments", the jar test is limited in its usefulness due to several disadvantages. For example, evaluating the performance of prospective coagulants or flocculants requires both significant volumes of water/wastewater samples (litres) and experimental time (hours). This limits the scope of the experiments which can be conducted, including the addition of replicates. Furthermore, the analysis of jar test experiments produces results which are often only semi-quantitative. Coupled with the wide range of chemical coagulants and flocculants that exist, it has been remarked that determining the most appropriate dewatering agent as well as the optimal dose "is widely considered to be more of an 'art' rather than a 'science'". As such, dewatering performance tests such as the jar test lend themselves well to miniaturization.

Limitations
Coagulation itself results in the formation of floc but flocculation is required to help the floc further aggregate and settle. The coagulation-flocculation process itself removes only about 60%-70% of Natural Organic Matter (NOM) and thus, other processes like oxidation, filtration and sedimentation are necessary for complete raw water or wastewater treatment. Coagulant aids (polymers that bridge the colloids together) are also often used to increase the efficiency of the process.

13 Bank Filtration

Bank filtration (BF) is a drinking water pre-treatment step, where river water is induced to percolate in subsurface passage through a river bed and mix with ambient (or natural) groundwater, before being extracted through a pumping well adjacent to the river bed. It can be applied as first step within a multi-barrier approach in an overall treatment chain where groundwater quantity is insufficient or of poor quality (e.g. geogenic pollution).



Advantages	● Can dampen pollution peaks and buffer extreme climatic conditions (quality and quantity).	● Huge freshwater storage capacity.	● Can reduce costs of supplementary treatment steps.	● Low requirements for skilled labour, chemicals and energy use (depending on purpose of output water).	
Disadvantages	● Prone to clogging/colmation at high levels of suspended solids.	● Permeability can be influenced by high (seasonal) temperature amplitude.	● High organic pollution and high mean temperatures can lead to lowered treatment efficiency.		

Design
During subsurface passage in biologically active soil layers (with aerobic, anaerobic and anoxic milieus), water quality of surface water can be improved before being mixed with groundwater and extracted for use. BF systems involve several physical, chemical and biochemical processes and are particularly known for the efficient reduction/removal (or even elimination) of suspended solids, organic pollutants, microorganisms, heavy metals, nitrogen, toxic algae as well as organic trace compounds (e.g.: pharmaceutical products), salinity or taste- and odour causing compounds. Relying on natural processes, design and treatment capacity (and efficiency) of BF systems strongly depends on local circumstances such as quality and quantity of available river- and ground water, hydraulic residence times of the water in the soil, the porosity of the soil, the hydraulic potential of the aquifer, temperature, pH values and oxygen concentrations as well as underlying redox processes. Depending on the bank filtrate quality, disinfection or even supplementary treatment steps are necessary to achieve drinking water quality. Besides its polishing function, BF also provides huge fresh water storage capacity for buffering extreme climatic conditions and shock loads, but also represents an artificial groundwater recharge technique preventing the overuse of aquifers, saltwater intrusion and land subsidence.

Operation
Basic requirements for the operation of a BF system are the availability of surface water as primary water source and a detailed consideration of the groundwater level in the surroundings of the abstraction well. Water abstraction should not result in adverse effects on the aquifer or the river downstream of the site. Depending on the BF site's characteristics and purpose of the output water, operation of a BF system is easy and only little maintenance is needed. Compared to high-end technologies, requirements for skilled labour and energy & chemical use are very low. However, more requirements may arise in relation to design, operation and maintenance of the water abstraction well. One challenge in relation to well operation is the prevention/handling of colmation of the infiltration path.

Cost
Costs for establishing riverbank filtration systems depend on many factors, including aquifer characteristics, type of well-screen installation, facility design, and distance to the population served. However, costs can be classified as moderate. Using natural treatment processes, BF system can be considered as cost-effective system, which ideally can reduce costs for subsequent treatment steps. Additional costs can arise in dependency of raw-water quality and continuative treatment steps for diverging intended purpose (e.g. drinking water use). Investment costs are costs for the abstraction well (construction, pump, main, control system etc.) as a minimum, as well as costs for groundwater monitoring of BF processes and water quality. Operational costs are primarily costs for pumping electricity for abstraction well operation. For abstraction (and treatment) facilities skilled personal is required.

14 Solar Pasteurisation

Contrary to belief, it is not necessary to boil certain water to make it safe to drink. Heating water to 65°C (149°F) for 6 minutes, or to a higher temperature for a shorter time, will kill all germs, viruses, and parasites. This process is called pasteurisation. Solar pasteurisation has proven to be a very low-cost disinfection method to produce drinking water out of non-turbid fresh water.

However, solar pasteurisation is not that easy to implement and monitor, thus it is not a wide spread method for point-of-use water treatment. Pasteurisation is one of many techniques to disinfect drinking water and is applicable to developing countries. Other techniques such as chlorination, ozonation or operation of wells may be more suitable particularly if a large amount of water is needed.

Conversely, if a relatively small amount of water is needed, pasteurisation systems, like other HWTS methods have the advantage of being able to be scaled down with a corresponding decrease in cost. In other words, if only little money is available, you can use pasteurisation to get a little clean water, perhaps enough for a family, but not a village.

Today, throughout the world, beverages such as milk, fruit juice, beer and wine are disinfected through pasteurisation on an industrial scale. Consumers are familiar with and trust the process of pasteurisation. Apart from water, milk can also be pasteurised at home, a procedure used to make it more durable. In case of milk, pasteurisation is reached when heated above 63°C for 30 minutes.

Solar Pasteurisation
Pasteurisation is the process of disinfecting water by heat or radiation without boiling. Typical water pasteurisation achieves the same effect as boiling, but at a lower temperature (usually 65-75°C/ 149-167°F), over a longer period of time. A simple method of pasteurising water is to put blackened containers with water in a solar cooker. The solar cooker reflects sunlight onto the container, which heats up the content.

The cooker may be an insulated box made of wood, cardboard, plastic, or woven straw, with reflective panels to concentrate sunlight onto the water container. It may also be an arrangement of reflective panels, or a reflective "satellite dish", on which the water pot sits. The box cooker should be frequently repositioned to ensure it is catching all available sunlight (and never in shade). A thermometer or indicator is needed to tell when the required temperature is reached for pasteurisation to monitor the required exposure time of six minutes.

Common devices for monitoring the water temperature use either beeswax, which melts at 62°C (143.6°F), or soybean fat, which melts at 69°C (156.2°F). A simple device known as the Water Pasteurisation Indicator (WAPI) has been developed at the University of California. Water may take one to four hours or more to heat to those temperatures. Heating the water to the pasteurisation temperature rather than the boiling point reduces the energy required by at least 50%.

However, solar pasteurisation is only effective if treated water is protected from post-treatment contamination during storage. The Water Pasteurisation Indicator (WAPI) indicates when water is safe to drink. When the soybean wax inside a small tube melts at about 70°C (158°F), the wax changes from solid (left) to liquid (right) state. An iron ring ensures that the tube is staying in the same position while in the solar cooker.

Advantages	● The system requires no additional inputs (electricity, chemicals or fossil fuels) after installation.	● Simple designs are available at very low cost, and this device may be built with parts available in most countries.	● Anyone can be trained to construct a solar cooker and there are no specific manufacturing hazards.	● Solar pasteurisation boxes can also be used as solar cookers for cooking meals.	● Compared to boiling, the pasteurisation process does not consume wood, charcoal or other biomass as energy supply (environmentally more sustainable) and does not take time and energy for its procurement.
Disadvantages	● Requires sunny weather and does not work during continuous rainfall, on very cloudy days, or under freezing conditions.	● Recontamination is possible after the water has cooled because it contains no residual disinfectant; subsequent safe storage is essential.	● Does not reduce turbidity, odour, taste or colour and does not remove chemical pollutants from water.	● While construction is low-cost, the life-cycle costs (chlorination, sand filters, UV treatment) are relatively high compared to competition.	● Users require a thermometer or pasteurisation indicator device.

	● Users need to keep track of containers to know which ones have been treated and to ensure that they always have treated water (batch process).	● Users may need to wait for water to cool prior to use. Cookers are made from lightweight and easily breakable materials.	● Boiling is sometimes preferred because it provides a visual measure of the water reaching sufficient temperature without requiring a thermometer.		

How it Works
Boiling or heating with fuel is perhaps the oldest means of disinfecting water at the household level and is also one of the most effective. It kills or deactivates all classes of waterborne pathogens, including protozoan cysts that have shown resistance to chemical disinfection and viruses that are too small to be mechanically removed by microfiltration.

As the water heats due to radiation from the sun, the increased temperature will kill or inactivate an important part of commonly waterborne pathogenic bacteria, viruses, helminths, and protozoa at a temperature between 65° and 75°C (149-167°F). But, spores are more resistant to thermal inactivation than vegetative cells; treatment to reduce spores requires a thermal treatment up to boiling point and must ensure sufficient temperature and time.

Furthermore, solar pasteurisation does not improve turbidity, odour, taste, colour or chemical contamination. As temperatures reach 50°C or greater, pathogenic microbes are inactivated. The temperatures which cause approximately a 1-log decrease in viability within 1 min are 55°C for protozoan cysts; 60°C for E. coli, enteric bacteria, and rotavirus; and 65°C for hepatitis A virus (3, 5, 7–9, 16).

When the WAPI wax melts at about 70°C, the cumulative lethal effect is determined by the gradual increase in temperature, often at least 30 min from 50 to 70°C, as well as the gradual cooling once the water is removed. In addition, the water at the bottom of the black jar is often 5 to 10°C cooler than the water at the top of the jar. Microbes in the upper portion will have been inactivated before those in the bottom portion, where the WAPI is located.

Temperature
Pasteurisation time decreases exponentially with increasing temperature. Above 50°C, time decreases at roughly a factor of 10 for every 10°C increase in pasteurisation temperature. Viruses appear the hardest to kill and essentially set the boundary for acceptable time-temperature processes. In rural Kenya, a simple thermo indicator which changes colour at 70°C was applied to show household members when pasteurisation temperature had been reached. This increased the number of households whose drinking water was free of coliforms from 10.7 to 43.1% and significantly reduced the incidence of severe diarrhoea compared to a control group.

Temperature Safety Zone
● 72°C at 6m
● 70°C at 8m
● 68°C at 15m
● 66°C at 25m
● 64°C at 40m

● 100% E.coli killed in 1.5 hours at 60°C
● 100% Viruses killed in 1.5 hours at 70°C
● 100% Protozoa killed in 45 seconds at 70°C

Solar Pasteurisation Devices
Literature distinguishes between batch devices and flow-through solar devices. Batch devices are used to heat water on a home scale with a simple solar cooker. While potentially inexpensive, durability of the solar box needs further investigation. Compared to other energy sources it can save fuel costs, but not labour costs, which are still relatively high. A portable version is the AquaPac, a low cost polyethylene plastic with UV inhibitors added, and air-filled bubble pack sheeting. An example for an enhanced batch device is the solar puddle, which essentially is a puddle in a greenhouse. A combination of (black) plastic sheeting is put in a shallow pit and then filled with water to be pasteurised by the solar heat. On days with good sunshine the required temperature with a water depth of up to 62 mm (2 1/2 inches) can be reached. Another way to pasteurise water is to use flow-through pasteurisation devices. They can be enhanced with a heat exchanger by recycling heat from the outgoing pasteurised water. Flow-through devices have several advantages over the simpler batch processes.

First, potable water becomes available throughout the day as new increments of treated water are added to the clean storage vessel. Second, this type of unit can adapt to variable solar conditions and is an automatic process, also decreasing the likelihood of an accident occurring when transferring water in and out of a batch unit e.g. a solar cooker jar. Flow-through devices can make use of wasted heat like the one generated in traditional clay ovens, so called "chullis". The main drawback of flow-through solar pasteurisation devices is the difficulty of ensuring safe storage, as the water needs to be transferred to a new recipient before consumption. The Solar Pasteuriser with Integral Heat Exchanger (SPIHX) collects and converts solar energy to heat energy to bring water to pasteurisation levels. Once pasteurised, the thermostat valve opens and the water flows through the bottom channel. The middle aluminium sheet facilitates heat exchange between the hot outgoing pasteurised water and cold incoming contaminated water.

Applicability
The solar pasteurisation method is effective to remove bacteria, viruses, protozoa and helminths from raw fresh water. It cannot produce drinking water from raw water with high turbidity and dissolved matter. While the removal capacity has predominantly been proved in laboratory tests, the solar pasteurisation method seems more suitable on household level rather than for producing high quantities of drinking water. Because it relies on solar energy its effectiveness depends on the daily hours of sunshine in the area of application. Solar pasteurisation might be an option on both, the village and household level. But household usage is more competitive because village-scale alternatives have much lower treatment cost. Existing solar devices have water disinfection costs that are an order of magnitude less than boiling. Solar thermal pasteurisation with existing manufactured devices costs more than the remaining alternatives but is highly effective and lowest in maintenance. Quite some solar pasteurisers that have been developed are an educational tool or curiosity rather than practical methods of producing safe water applicable in developing countries on a large scale.

15 Distillation

Distillation of the water to remove most contaminants and salts.

16 Chlorination

Water disinfection by chlorination was massively introduced in the early twentieth century. It set off a technological revolution in water treatment and complemented the known and used process of filtration. In addition to destroying harmful microorganisms, chlorination also reduces the amount of iron, manganese and hydrogen sulphide in water. Chemical disinfection using chlorine has the benefits of being relatively quick, simple, and cheap and allows a residual amount of chlorine to remain in the water to provide some protection against recontamination.

Advantages	● Simple, inexpensive and reliable technique	● Effectively kills bacteria and viruses	● Provides residual chlorine for some protection against re-contamination	● Widely available in different countries	● Easy to use
Disadvantages	● Requires that users purchase chlorine on a continuous basis and may not affordable by very poor people	● Does not deactivate parasites like Giardia, cryptosporidium and worm eggs	● Taste is unacceptable to some users	● Dose is product specific	● Availability may be restricted in rural and remote areas

WATER Purification Methods Chlorination

	• Requires clear water to be most effective	• Chlorination of water with high organic matter leads to the risk of toxic disinfection by-products formation			

Chlorination
The disinfection of drinking water by adding chlorine is called chlorination. Chlorine was used for the first time in 1850 when John Snow used it in London's water distribution system to combat cholera. Similarly, American cities like Chicago and New Jersey started to use chlorination around 1908, a step which brought a significant decrease in the number of deaths caused by cholera, typhoid, diarrhoea and hepatitis A. Today, chlorination is used to treat most of drinking water in the world since it is easy, inexpensive and reliable. Chlorine is widely available in different countries with different brand and names. Chlorination can be achieved by using liquefied chlorine gas, sodium hypochlorite solution or calcium hypochlorite granules and on-site chlorine generators (e.g. WATA). Chlorine is widely applied for the centralised disinfection of drinking water in municipal water supply systems. International agencies have also been promoting chlorination at household level as effective and simple drinking water treatment option in developing countries. Chlorine as a household level point of use treatment is available either a solution which is added at doses of one to several drops per litre of water to treat, or as tablets, which will dissolve in the treated water. Aside from these commercial products, water can also be treated at the community level by mixing chlorine in water tanks, wells and household vessels.

How it Works
When chlorine is added to water, the chemical element dissolves and forms radicals. These kill pathogens such as bacteria and viruses by breaking the chemical bonds in their molecules or by attacking the cells of the microorganisms. The different radicals and ions formed during chlorination destroy many bacteria and viruses, but also oxidise some organic matter, dissolve colours and destroy chloramines, toxic products derived from ammonia. It takes about 30 minutes to make water safe to drink.

Chlorine Use
The correct amount of chlorine solution must be used. If the concentration of chlorine is inadequate the solution may fail to destroy all the harmful micro-organisms and if in excess, health may be adversely affected. Only an appropriate amount of chlorine can destroy most of harmful micro-organisms and provide a safe amount of residual chlorine. Chlorine that does not combine with other components and remains in the water is called "Free Residual Chlorine" (FRC). FRC makes sure that water which has been treated by chlorination will not get recontaminated when being transported or stored. According to WHO guidelines, the FRC concentration in drinking water should be between 0.2 to 0.5 mg/L.

Effectiveness
Chlorine disinfection of drinking water is limited for the protozoan pathogens (in particular cryptosporidium) and some viruses (WHO 1996). Turbidity can protect microorganisms from disinfection. Further, when the natural organic matter (NOM) of the water is high, this can lead to the formation of disinfection by-products (DBPs) such as halogenated organic molecules, mainly trihalomethanes (THM), some of which are potentially hazardous.

However, the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection, and disinfection should not be compromised in attempting to control DBPs.

In 1991, the International Agency for Research on Cancer evaluated the carcinogenic potential of chlorinated drinking water. IARC concluded, that "there is inadequate evidence for the carcinogenicity of chlorinated drinking-water in humans".

However, for water containing large amounts of organics, the formation of carcinogenic halogenated disinfection products derived from the organic matter attacked by the chlorine is extremely high – it is therefore recommended to use pre-filtration (e.g. slow sand filtration or bio-sand filtration).

Very Effective
- Bacteria

Fairly Effective
- Viruses
- Most Protozoa
- Helminths

Not Effective
- Cryptosporidium
- Turbidity
- Chemicals
- Taste
- Smell
- Colour

Clear Water
1 Tablet

Turbid Water
2 Tablets

Applicability
Chlorination is very suitable for places where people are directly drinking water from bacterial contaminated water sources but where other contamination (e.g. natural organic matter, arsenic) are not of concern. It is socially acceptable by general public for purifying water because of easy handling, cost effectiveness as well as good removal of microbial organism in drinking water. It is most commonly used for water disinfection during emergencies. However, a constant supply of chlorine must be guaranteed.

17 Electrolytic Purification

WATER Purification Methods Electrolytic Purification

Chlorination, which means adding active chlorine (Sodium Hypochlorite) to water, is the most common method used for disinfecting of drinking water. Active chlorine destroys or inactivates most pathogenic microorganisms, including parasites, bacteria and viruses with a very high reliability. The WHO estimates that chlorination is the most secure, effective and economic option. Yet, generally speaking, chlorine is not produced in low-income countries, but imported in the form of tablets or bleach, at relatively high cost. WATA is technology and approach developed by Antenna Foundation which integrates health education with the local production of chlorine by electrolysis (through the WATA device) in a sustainable supply chain, making safe water treatment a profitable activity.

Advantages	• Local production (avoids most storage and transportation problems and environment impacts)	• Generation of income for local communities (e.g. water kiosk)	• Especially suitable for humanitarian response or war-thorn areas, where for example chlorine gas is banned.	• Quality control is possible at every stage of production and use	• Disinfectant can be used for a large range of applications (e.g. disinfecting laboratory equipment, wounds, cleaning latrines, disinfecting surfaces etc.)
	• Solar versions available for autonomous use	• Low Cost	• Easy to use		
Disadvantages	• Reaction time of 30 min required before consumption after treatment	• Education and training for operators are essentials, especially when using Maxi-WATA®	• Only clear water can be used to produce WATA® solution and the solution only effective to treat clean water	• Electricity required (but can be run with solar energy)	• Chlorination can cause the generation of a very low concentration of toxic disinfection by-products (DBPs) in the case of disinfecting water with a high organic matter content
	• Dosage might be more difficult than with tablets	• Chlorine taste and smell			

Electrolytic Water Purifier
To prevent waterborne diseases it is fundamental to deliver safe water at the point of use. The 2017 published Joint Monitoring Programme (JMP) report from WHO and UNICEF shows that recontamination occurs very often between the point of collection and the point of use and thus leads to an increase in waterborne diseases. It is thus fundamental to find a solution to enable populations to address their drinking water problem in a self-sufficient and perennial way. To respond to the need of BoP communities to have access to simple and affordable water treatment methods at the household level, Antenna Foundation has developed a range of WATA devices (Mini-WATA, WATA-Standard, WATA-Plus, Midi-WATA and Maxi-WATA), and control reagents (the WataBlue & WataTest). Until today WATA kits have been used in over 100 countries.

WATA Devices The WATA is a handy, robust device designed specifically for the production of active chlorine through the electrolysis of salted water under conditions in developing countries. The resulting solution can be used for drinking water disinfection (1 Litre of chlorine per 4,000 Litres of contaminated water) since the strong oxidising power of the chlorine will destroy most of the pathogenic germs and the water will be drinkable after 30 minutes.	**Mini-WATA** 1 (g/h) active chlorine 0.5L or active chlorine in 3h **WATA-Standard** 4.8 (g/h) active chlorine 1L of active chlorine in 2h 30m	**WATA-Plus** 22.5 (g/h) active chlorine 15L of active chlorine in 4h **Midi-WATA** 45 (g/h) active chlorine in 4h	**Maxi-WATA** 80 (g/h) active chlorine 60L of active chlorine in 4h 30m

		10L	20L	100L				
Indicative dosages for chlorinating drinking water by concentration Active chlorine concentration using the WataTest.	**3 g/L** **4 g/L** **5 g/L** **6 g/L** **7 g/L**	5.0ml 3.8ml 3.0ml 2.5ml 2.1ml	10.0ml 7.5ml 6.0ml 5.0ml 4.3ml	50.0ml 37.5ml 30.0ml 25.0ml 21.4ml	Volume of water to be disinfected in Litres.			

WATA
This sodium hypochlorite solution can also be used as a disinfectant for home use. The WATA® system is extremely adaptable to meeting the disinfectant needs of larger institutions such as health facilities also. Additionally, the sodium hypochlorite solution is similar to Dakin's solution, a neutral disinfectant, and can be used directly for cleaning wounds.

Use of WATA
The device requires only water, salt and electricity to function. It is important to note that clear water is a requirement for both the production process and as an input for the disinfection process. For the production process, highly turbid water will interfere with the electrolysis process and the resulting solution may not be at 6g of active chlorine per litre. If the turbidity (a measure of the suspended solids in the water) of the water to be disinfected exceeds 5 units of turbidity (NTU), it could diminish the treatment's efficiency and not guarantee adequate inactivation of microbes. If highly turbid water is the only source available, the suspended solids need to be removed, for example by (cloth) filtration, sedimentation or flocculation. The WATA is appropriate for urban and rural areas and foster people's autonomy where the technology is implemented. Since the WATA devices need a reliable electricity supply to operate, the Mini-WATA, WATA-Standard and the WATA-Plus are designed to be easily powered with solar energy.

Sodium Hypochlorite Production
The user first prepares salt water at 25g NACl/Litre. The WATA device needs to be immersed in the salt water and connected to a reliable source of electricity. The salt water is converted into sodium hypochlorite solution with a 6 g/L concentration of active chlorine through a process known as electrolysis. Potentially contaminated water can be made potable by adding a small dose of chlorine (5 mL chlorine per 20 L water). Despite the simplicity of operating a WATA device, the production of active chlorine and disinfection of potable water for a community is a responsibility, and thus requires skilled people as operators, specially trained and dedicated for that purpose.

Testing
WataTest and WataBlue reagents are part of the WATA kits and allow the user simple onsite water quality control. WataTest and WataBlue are non-toxic and inexpensive reagents which are used to measure the active chlorine concentration of sodium hypochlorite and free residual chlorine in the water, respectively. Free residual chlorine (FRC) is important because sufficient levels are required to ensure adequate inactivation of microbes and to guarantee the residual effect that chlorine has of preventing the recontamination of water during handling or consumption. Since increasing levels of FRC makes the water taste and smell unappealing, the WHO recommends a level of FRC between 0.2 and 0.5 ppm in order to strike a balance between disinfection and water taste and smell. 0.5 ppm is the level of FRC that the WHO recommends as striking the balance between effective disinfection and acceptability in terms of taste and smell. The WataBlue allows the user to carry out a safe and systematic quality control of the treated drinking water to ensure that this level is reached.

Maintenance
Devices need to be rinsed after each procedure with clean water. If after several uses you notice white marks on the WATA, prepare a solution of 50% white vinegar (or lemon juice) and 50% clean water. For the Mini-WATA and WATA-Standard, leave the device to soak for several hours (overnight for example) and then rinse it with clear water. Never scrub the titanium plates. WATA-Plus, Midi-WATA and Maxi-WATA need to be soaked for at least 24 hours and be completely immersed in the 6 – 10 L solution.

Storage
Properly used, well maintained and carefully stored after each use, WATA devices are designed to operate for 10,000 operating hours, or around 5 years of use. Active chlorine is very sensitive to light. It is therefore very important to store the solution produced with the WATA devices in closed and opaque, non-metallic recipients and label it with the production date. Place the container in a cool place, out of reach of children. Do not expose it to sunlight. The sodium hypochlorite should be used within 24 hours as the concentration of active chlorine will decline if the solution is not stabilized.

Potable Pure Aqua
The Potable Pure Aqua PURE Electrolytic Water Purifier is an example of one of these purifiers which is lightweight, small and can easily be fit into a BOB.

Electrolysis FAQ
- **White Blobs:** Adding too much salt to the brine solution causes white globs to form in the mixture.
- **Colour Change:** If the water is too "hard" it may alter the colour of the water during electrolysis.
- **Electrode Rust:** This is due to not washing the cathode and anode off after use and continual use will add rust to the water.

18 UV Light

The bactericidal effect of concentrated ultraviolet (UV) light is used in many areas and in many set-ups. For drinking water treatment, simple, commercially available UV tubes can be used to kill pathogenic microorganisms in the drinking water. Such UV tube water disinfection devices are an effective, low-cost and simple mean for a very rapid disinfection. They generally consist of a pipe, through which water slowly flows, and in which an UV light bulb is installed, which can be run on electric or solar power. There are many ways to design UV tubes devices and they can be used at household, community or institutional level. Even though very effective, however, chemical or physical pollution (e.g. salinity, heavy metals turbidity) cannot be treated and in opposition to chlorine, there is no residual disinfection effect.

Advantages	• Large quantities of disinfected water can be obtained quickly	• Minimum behaviour change required	• Can be constructed with locally available material	• Highly effective on broad range of pathogens, including E. Coli, Guardia and Cryptosporidium	• No risk for DBP formation (e.g. trihalomethanes)
	• Inactivation independent of pH and temperature	• No transportation, storage or handling of chemicals	• No unpleasant taste or odour (as it can appear for chemical treatments)		
Disadvantages	• Higher cost of equipment when compared with chlorine solution	• Requires regular power source for operation	• Lamp tube needs replacement every 6-12 months	• Some investment for installation is required	• UV lamp needs to be cleaned regularly and handled with care because of their mercury content
	• Only effective for microbial pollution	• No residual disinfection effect and risk of re-growth or recontamination			

UV Light
The bactericidal effect of concentrated ultraviolet (UV) light has been known over many years and is used in many areas and set-ups. The first use of UV light for drinking water disinfection has been reported to be in France in 1910. With the recent development of the UV tube, using locally available components, this technology is now a viable household water treatment method (CAWST 2009).

Facing the challenge that disinfection by-products (DBPs) are formed during chlorination of water containing high organic contents, simple physical instead of chemical disinfection methods, such as UV tubes have gained in interest. A typical UV system provides a flow path surrounding a UV lamp, structured to provide close proximity of the water flow along the length of the UV lamp all by preventing direct contact.

UV Radiation Disinfection Mechanism
The UV tube is basically the same as a commercial fluorescent bulb, except that it lacks the phosphor coating and the glass exterior is replaced by fused quartz. This means the bulb emits mostly UV light. UV light is generally defined to be wavelength of electromagnetic radiation shorter than 400 nm and is further divided into UV-A (315-400nm), UV-B (280-315nm) and UV-C (200-280 nm). UVA and UVB are responsible for sun tanning and sunburning. UVB is partly filtered out by the atmosphere and only a few percent reach the earth surface.

This is good, because UVB light can be directly absorbed by DNA, where it would induce cellular damage. UVC also penetrates cells and damage the DNA, but it is almost entirely filtered out by the ozone layer. The UV tubes used for disinfection do contain the whole spectrum of UV light, including the UVB and UVC. The light, when it reaches microbial cells leads to damage of the genetic material (DNA), rendering them unable to replicate.

The bulbs are suspended inside a larger tube in a covered channel. Water enters at one end and flows through the outlet at the other end. While the water flows through the tube, the UV light emitted from the bulb inactivates the microorganisms. The inactivation is directly related to continuous UV dose and depends on the intensity of the UV light and the duration of UV exposition. The height of the outlet determines the depth of the water in the tube and thus the hydraulic retention time.

In theory, the hydraulic retention time is equal to the exposure time of the microorganisms and should be designed, depending on the bulb intensity, to achieve a sufficiently long contact time for all microorganisms to be inactivated. For the calculations of the HRT, the intensity of the bulb may be adjusted according to the water depth of the farthest point away from the light source as the UV light is attenuated as it penetrates the water.

Effectiveness
UV tubes are effective in inactivating most pathogens, including bacteria, viruses, and cyst forming protozoa such as cryptosporidium (CAWST 2009). Yet, the effectiveness depends strongly on the UV dose. UV tubes are not effective for all pollution other than microbial (chemical and physical pollution) and there is now residual disinfection effect during storage of the treated water. The efficiency of UV light for bacterial inactivation is lowered by the presence of organic matter, iron, sulphites, and nitrites. Turbidity can also interfere with UV radiation, protect microorganisms from inactivation and serve as a food source for re-growth after the disinfection step. Therefore, it is common for UV tubes to incorporate a pre-filtration step, such as a settling unit.

Effective For
- Bacteria
- Viruses
- Protozoa
- Helminth Eggs

Not Effective For
- Turbidity
- Chemicals
- Taste
- Odour
- Colour

Operation
Operation and maintenance of UV tubes is generally low, provided that there is a more or less continuous source of electricity to run the bulb. Once the system is installed, the user needs to make sure that the theoretical flow rate of the water and the corresponding HRT are respected and that the bulb is working correctly. If the bulb becomes dirty, it needs to be taken out and cleaned to maintain the light emission intensity. The systems have generally a long life spam, but bulbs should be replaced at least once every 12 months. During any maintenance activity, however it is important that operators or users protect their skin and eyes from the UV radiation as it is also damaging for human cells.

Applicability
Ultraviolet is being widely used in the water supply systems for disinfection and has a potential to kill most bacteria, viruses, protozoa or helminths. Though, a more or less continuous energy supply is required and the system is not suitable for removing chemical contaminants or turbidity. There is also possibility of re-contamination during distribution or storage of the treated water as there is no residual disinfection effect. However, as it is only a physical treatment, there is low risk for the formation of toxic disinfection by-products (DBP). The UV tubes can be produced with locally available material and be installed at household, community or institutional level, as long as electricity is provided.

19 SODIS (Solar Disinfection)

When microbially polluted water is exposed to solar light in transparent PET bottles, bacteria, virus and some parasites are inactivated by the solar UV-A radiation. 1 to 2 litres of water are filled into clean bottles and exposed to the sun for at least 6 hours if the sky is bright. UV-A radiation is strongly attenuated by clouds; furthermore, turbidity or water depth protects the pathogens from UV-A radiation. Hence the process depends strongly on the local climate, and only low volumes with relatively low turbidity can be treated at a time. SODIS is extremely low-cost and simple and is one of the WHO recommended household level water treatments. However, chemical pollution (e. g. arsenic, fluoride, agricultural residues) cannot be removed by solar disinfection (SODIS).

Advantages	• Improves the microbiological quality of drinking water and therefore health	• Extremely low-cost	• Easy to understand and simple to use	• Relies on locally available resources, plastic bottles and sunlight, a renewable energy source	

Disadvantages	● Does not treat chemical pollution	● Is strongly climate and weather dependent	● Needs large efforts in terms of promotion and information to have an impact	● Requires the availability of PET bottles (or plastic bags)	● Only small volumes can be treated at a time and regardless the simplicity, it is relatively time-consuming to cover the entire water consumption of a household with SODIS

SODIS
Solar Water Disinfection (SODIS) is a simple water treatment technology that can be used at household level. As a point-of-use water purification method, SODIS improves the microbiological quality of drinking water with solar radiation at almost zero investment and maintenance costs. Today, SODIS is one of the recommended household level water treatment technologies by the World Health Organisation (WHO). PET (Polyethylene terephthalat) bottles or plastic bags with a volume of 1 to 2 litres are filled with water of low turbidity and exposed to the sun for a certain time, depending on the local weather conditions. The SODIS reference centre (www.sodis.ch) recommends, that 6 hours are sufficient under bright to 50% cloudy sky, whereas 2 days of exposure are required for 100% cloudy sky. The treatment efficiency can be improved if the plastic bottles are exposed on sunlight-reflecting surfaces such as aluminium- or corrugated iron sheets. During periods of continuous rainfall, SODIS does not perform satisfactorily and rainwater harvesting is recommended during these days.

- Use clean bottles
- Fill bottles
- Close the lid
- Expose to sunlight
- Water can be stored in the bottles

Process
UV-B light (280 to 320 nm) can directly be absorbed by DNA, leading to damage, but only 1% of natural solar light is of this type. Hence, sunlight used during the SODIS process consists mainly of UV-A light (320 to 400 nm), which makes 6% of the total solar light. This light can be absorbed by molecules, which are naturally present in the water. When these molecules (called photosensitizers) have absorbed the energy, they can pass it to the oxygen in the surrounding water, leading to the formation of reactive oxygen species (ROS). ROS include free radicals such as the superoxide anion as well as non-radicals such as hydrogen peroxide. ROS damage the membranes proteins, enhancing the oxidative stress of the cell and accelerating their aging process. But ROS can also lead to some DNA damage, such as single strand breaks and nucleic base modifications, which may be lethal and mutagenic. This type of pathogen inactivation Is called photooxidative stress. Photo- because it is the light which generates ROS, and oxidative stress, because these reactive oxygen species (ROS) lead to stress.

When the water temperature reaches more than 45°C, a synergistic effect of UV-A radiation (optical inactivation) and infrared light (thermal inactivation) is observed. At increased water temperatures, the exposure time needed to disinfect the water is reduced. But during cloudy weather conditions, the solar infrared light is reduced and bottles need to be exposed for 2 days to guarantee that the radiation dose received is sufficient to disinfect the water. In contrast to infrared light (heat), UV-A radiation is only slightly attenuated by clouds. But turbidity in the water reduces the amount of UV radiation that penetrates the water. Therefore, the containers used for SODIS should be relatively flat (i.e. not exceed a depths of 10 cm). Water turbidity can easily be determined: Place the full bottle on a newspaper headline (the letters should have a size of about 1.5 cm) and look through the bottle from top to bottom. Water turbidity is less than 30 NTU if you can read the letters through the water. If not, the water must be filtered first so that SODIS will work.

Suitable Containers
Suitable containers for SODIS are PET or glass bottles. Ordinary window glass is almost opaque to UV light and cannot be used to construct SODIS containers. The use of PVC bottles is not recommended. It is normally marked on the bottle whether it is PET or PVC, however, the labels vary from country to country. PET and PVC bottles are normally marked accordingly. The labels can vary from country to country, though. If the bottles are not marked, you can only tell the difference between the bottles by setting fire to them. PET burns quickly and easily when it is held in a flame. When it is taken out of the flame, the fire goes out slowly, or it may keep burning. The smoke smells sweet. PVC does not burn easily. The material does not burn at all when not in the flame. PVC smoke smells acrid. Heavily scratched or old PET bottle should be replaced regularly as the scratching makes them opaque.

Applicability
SODIS is not a replacement of the access to safe drinking water, as it is required to reach the millennium development goals, but a simple and extremely low cost method to improve the microbial quality of drinking water at household levels. Large volumes cannot be provided with the use of this method. SODIS can be used in both rural areas and urban slums, but PET bottles are generally more available in urban regions. SODIS cannot treat water that is chemically polluted (e.g. arsenic, fluoride or industrial and agricultural organic contaminants). SODIS is very well adapted as a secondary treatment of water coming from an improved source (e.g. well water), which does not meet the microbial quality standards. As SODIS requires a consistently sunny climate and solar irradiation, it is most suited for regions within latitudes of 15°N/ S and 35°N/ S. Turbidity can deteriorate the effect and if the latter is higher than 30 NTU, pre-filtration is required.

As SODIS is extremely low cost, it is adapted for population with little income. However it should not be sold as a method for the poor as this could lower the attractivity of SODIS as people don't like to be labelled as 'poor'. To distribute PET bottles for free will not result in a sustainable application. The integrated promotion together with other household-level drinking water treatments (e.g. chlorination, filtration) to give people the option to make a choice, seems the most promising. It is also recommended to combine SODIS with other interventions to improve the health, sanitation and hygiene situation. This approach allows also working in close collaboration with governmental or other large-scale interventions.

20 Copper/Silver Ionization

21 Colloidal Silver

Colloidal Silver Filters (CSF) are simple household water treatment devices based on a physical treatment, which does not require energy supply. CSFs use a clay candle, pot or disc made of porous ceramic materials similar to traditional ceramic filters. But in CSFs, colloidal silver is used to enhance the inactivation of bacteria and other germs. A filter set consists of two containers: the upper unit holds the ceramic coated with colloidal silver, filtering the water and killing microorganisms, while a lower unit stores the treated water. CSFs remove pathogens and turbidity from drinking water. They can be constructed with locally available material, which can contribute to the development of local commerce.

Advantages	● High removal of bacteria and protozoa; moderate removal of viruses	● Simple to install, operate and maintain	● Local production can create an opportunity small business	● Removes turbidity	● Water tastes and looks good
	● Portable container	● Easy to operate and maintain			

Disadvantages	● Does not removal chemical pollution (e.g. organics, arsenic, fluoride)	● Does not remove all viruses	● Needs to be cleaned regularly especially when using turbid water or water containing iron	● Relatively low flow rate	● Ceramic parts are fragile and are difficult to transport
	● Not applicable for extremely turbid water	● No residual disinfection effect (risk of recontamination)	● Small fissures and cracks may lead to reduced removal of pathogens		

Locally produced ceramics have been used to filter water for hundreds of years. Water is poured into a porous ceramic filter pot or in a pot containing a ceramic candle or disc, filtering the water. The filtered water is collected in another container. The filter removes turbidity and traps and kills pathogens from drinking water (see also ceramic candle filters). To enhance ceramic candle filters, colloidal silver can be added. Colloidal silver helps in pathogen removal and prevents the growth of microorganisms within the filter itself.

These enhanced forms of ceramic filters are called colloidal silver filters (CSF). CSFs were developed at the Central American Industrial Research Institute (ICAITI) in Guatemala in 1981 and are extensively promoted today. Currently, the most widely distributed ceramic filter is the Potters for Peace (PFP) colloidal silver filter, which is shaped like a flowerpot (see also pottersforpeace.org). The filters are designed in particular for simple household use and are a recommended household water treatment and safe storage (HWTS).

They can be produced locally by attending simple technical training. Ceramic filters consist of a set of two containers. The upper unit contains the ceramic unit, which filters the water and the lower unit collects filtered and safe water. A tab device allows the users to withdraw the water for consumption while preventing recontamination by contact with hands or other objects that could bear bacteria. The porous ceramic devices can be either one or two candles, a disc or a pot.

During use, tiny silver particles (colloidal silver) are suspended in the liquid acting as a disinfectant, preventing bacterial growth in the ceramic filter and enhancing inactivation of the bacteria in the filter. The colloidal silver is either added to the clay mixture before firing or impregnated on the fired ceramic pot.

How it Works
Pathogens and suspended material are removed from water through physical processes such as mechanical trapping and adsorption. Colloidal silver breaks down the pathogens' cell walls causing them to die. The filter operation is simple. First, the filter needs to be cleaned with clean water and left aside to dry naturally. Then, the filter units need to be assembled and the upper unit should be filled with water. Then, one has to wait until the water has passed the filter fort he first time. For security, the water filtered for the first time should not be used for consumption. Then, the filter can be refilled and the now filtered water collected in the lower storage unit can is ready to drink. To prevent clogging, water with a high turbidity (levels greater than 50 NTU) should first be strained (through a cloth) or settled before using the filter. The filter pot should be regularly cleaned using a cloth or soft brush to remove any accumulated material. It is recommended that the filter pot, candle or disc be replaced every 1-2 years. Cleaning prevents the formation of a biofilm and protects against fine invisible cracks, which may have developed over time. Any cracks will reduce the effectiveness since water can short-circuit without being filtered through the ceramic pores. However, make sure not to remove all the silver when using a brush for cleaning.

Treatment Efficiency
Candle filters and disc filters normally have a lower contact surface for the water and therefore the filters produce less treated water per day than pot filters. However, the effective treatment rate (or flow rate) depends on the design). A typical pot filter can produce up to 1-3 L/hour while a candle filter produces only 0.1 to 1 L/hour. The effectiveness of ceramic filters at removing bacteria, viruses and protozoa depends on the pore size of the ceramic material and the production quality of the filter unit. Most ceramic filters are effective at removing the majority of the larger protozoan and bacterial organisms and helminths, but not the smaller viral organisms. Laboratory testing has shown that although the majority of the bacteria are removed mechanically through the filter's small pores, colloidal silver is necessary to inactivate almost 100 % of the bacteria. The effectiveness of colloidal silver on viruses is not well known but estimated to be lower due to the smaller size of virus compared or silver particles. Turbidity (solids) is efficiently removed by physical straining (filtration) and also taste, odour and colour of filtered water by CSF is generally improved. Iron is partially removed but other dissolved chemical pollutions are not removed. The effectiveness of CSF colloidal filter has been proven in many studies, where the reduction of diarrhoeal disease incidence among users has been documented. For lack of residual protection, however, it is important for users to be trained on proper operation and maintenance of the ceramic filter and receptacle.

Applicability
CSFs are suitable for households using turbid and contaminated water. However, ceramic filters do not remove arsenic, fluoride, pesticides or other dissolved chemicals. Due to the limited flow rate and storage capacity, CSFs are suitable for households with small families, organisations or school classes. As iron is only partially eliminated, it is recommended to use raw water with little iron only (< 0.3mg/L). Chlorinated water should not be filtered in CSFs. Due to the risk of clogging, water with a turbidity above 50 NTU should be pre-settled or strained to avoid frequent cleaning of the filter.

Creating Colloidal Silver
Distilled water is a fairly good insulator, with a constant voltage connected to silver electrodes in distilled water, the initial current flow is very low because the water has high resistance to electron flow. However, as the silver ions and particles finally do start to accumulate in the water, the resistance in the water drops from the conductive silver building up. The silver comes off the positive electrode as ions (single atoms, missing an electron) carrying a positive electrical charge due to the lack of an electron. As silver particles build up the resistance decreases creating more faster. Silver ions build up and keep gaining size, reflecting yellow light and falling out of suspension. Mechanical stirring solves this problem and uniformity of size is very important. Do not use salt in the reaction. Thicker wire = lower gauge. 14 gauge - 1.63mm, 12 gauge - 2.06mm and 10 gauge - 2.59mm. Thicker gauge silver wires have more surface area and because the size of particles made is directly related to the amount of electrical current per unit area, the thicker gauge wires will make smaller colloidal silver particles for the entire processing run. If you want to skew the range of particle sizes to smaller particles, use 12 and even better, 10 gauge wire, rather than 14 gauge. 1-100nm is a typical size for colloidal silver.

22 Ceramic Candle Filter

Ceramic candle filters (or Berkey Filters) are simple devices made out of clay and used to filter drinking water in order to removes turbidity, suspended materials and pathogens. Removal takes place by physical process such as mechanical trapping and adsorption on the ceramic candles, which have micro-scale pores. Water is poured into the upper of two container and flows through a candle situated in the bottom. Once the water has passed through the candle, it is collected in the lower container. This system both treats the water and provides safe storage until it is used. The filters are easy to assemble and no energy is required. Maintenance includes frequent scrubbing with a brush and proper care during transport and its use. They can be constructed with locally available material, which can contribute to the development of local commerce.

Advantages	● Cheap, simple and easy to use and clean	● Can be constructed with locally available material	● Somewhat effective for the removal of viruses and iron	● Improves taste, smell and colour of water	● Removes pathogens, turbidity and suspended solids
	● Keeps water cold and safe	● Durable, easy to move and transport (except clay pot)			
Disadvantages	● Does not remove all the pathogens	● Does not remove chemical contaminants and colour	● Highly turbid or iron containing water plugs candle pores	● Low flow rate	● Ceramic candle and clay container is not easy to transport due to its fragility and heavy weight

	• Quality control difficult to ensure in local production				

Ceramic Candle Filter
The use of ceramic material for the filtration of drinking water is one of the oldest drinking water treatments. Nowadays, the ceramic candle filters and the colloidal silver filter (see also the colloidal silver filter factsheet) are the most widely used. The devices consist of two compartments, which allow simultaneous treatment and save storage of the drinking water. Candle filters are used in various countries and produced by a range of manufacturers around the globe. Ceramic candle filters basically consist of an upper and a lower container, one or more ceramic candles in between, a tap and a lid. Usually the containers have a diameter of about 30 by 25 cm depth for a treatment capacity of about 8 L and a flow rate of 1-2 L per hour per candle. The ceramic candles are screwed into the base of the upper container. To the lower container is attached a tap that allow to withdraw safe water without risking recontamination. A lid is placed on top of the upper container to prevent contamination. Candles can have very slow flow rates, so it is common to use two or more candles in one filter. The candles are made up of clay and the container can be made from plastic, aluminium, copper, steel or clay material. Though clay containers keep water cold and tasty, due to its fragile nature other materials nowadays replace it.

How It Works
Water is poured into the upper container and flows through the candle and collects in lower container. Turbidity, suspended materials and pathogens are removed from water through mechanical trapping and adsorption in micro-scale pores of ceramic candles. Colloidal silver is sometimes used in candle for more effective pathogen removal.

Operation and Maintenance
Water should be poured slowly into the container, not above the candle as regular water pressure may damage fragile candle. Candle needs to be replaced if any cracks are found: cracks will reduce the effectiveness since water can pass through that crack without being filtered through the ceramic pores. Candle needs regular cleaning, particularly when the flow rate slows down. The candle is cleaned by (slightly) scrubbing the candle surface with a soft scrubber brush or cloth to remove any accumulated dirt. Only clean water (no soap, chlorine or other chemicals!) should be used for cleaning. The candle should not be touched with dirty hands, and not placed on a dirty surface during cleaning. Storage containers, tap and lid should be cleaned on a regular basis using soap and water.

Effectiveness Ceramic candle filters are effective in removing bacteria, protozoa, helminths and turbidity from water. It also removes some viruses and iron and taste, smell and colour of water are improved. The effectiveness of the filter also depends on the production quality, the initial water quality, and the handling practices of users. Highly turbid or iron containing water may plug candle pores easily so that container and candle need to be cleaned more frequently. In this case, the water should be pre-settled before pouring it into filter. It is recommended to use raw water with less iron (<0.3mg/L) and turbidity (<5NTU).	**Bacteria** Lab: >99% Field: >99.95% **Viruses** Lab: >90% Field: N/A **Protozoa** Lab: >100% Field: >100%	**Helminths** Lab: >100% Field: >100% **Turbidity** Lab: 88-97% Field: 97-99%

Production
Candle filters can be manufactured at a local level and contribute to the development of local commerce. Local production process provides financial supports to household and voluntary labours. However, the production of ceramic filters is a lengthy process and a quality control process is required to ensure candle filter's effectiveness. Quality can be affected by variations in clay composition across geographic regions. Variability in weather conditions also makes long-term production planning difficult, and lack of storage can complicate storage of filters. The fragility of ceramic filters can make their transport difficult. A supply chain and market availability for replacement of candles and taps is required. Filters typically come with illustrated instructions in market.

Applicability
Ceramic candle filters are easy to set up and operate, cheap and effective in removing bacteria, protozoa, helminths and turbidity from water. It also removes some viruses and iron and taste, smell and colour of water are improved. But due to the limited flow rate (i.e. 1-2liter/hour) and storage capacity, filters are only suitable for small families, organisations or school classroom. It is suitable where drinking water is little turbid (<5NTU) and contaminated and with little iron (<0.3mg/L). In the case of too high turbidity, water can be presettled. Chlorinated water should not be used in candle filters! Except for clay, filter containers of other materials are easy to transport and handle.

23 Membrane Filtration

Membranes are thin and porous sheets of material able to separate contaminants from water when a driving force is applied. Once considered a viable technology only for desalination, membrane processes are increasingly employed in both drinking water and wastewater treatment for removal of bacteria and other microorganisms, particulate material, micropollutants, and natural organic material, which can impart colour, tastes, and odours to the water and react with disinfectants to form disinfection by-products (DBP). As advancements are made in membrane production and module design, capital and operating costs continue to decline.

Membranes emerged as a viable means of water purification in the 1960s with the development of high performance synthetic membranes. Implementation of membranes for water treatment has progressed using more advanced membranes made from new materials and employed in various configurations. An increasing scarcity in fresh water sources fuelled a push towards alternative resources such as ocean water. Membranes are becoming increasingly popular for production of potable drinking water from ground, surface and seawater sources, as well as for the advanced treatment of wastewater and desalination.

Overview	**Working Principle** Pollutants are separated as water is forced to pass through the membrane.	**Capacity/Adequacy** Simple but high-tech.	**Performance** Excellent separation capacity.	**Costs** Relatively low operation costs.	**Self-Help Compatibility** Process can be automatized but operators required for the control.
	O&M Membranes have to be backwashed on a regular basis to avoid fouling and to increase their lifetime.	**Reliability** Reliable when membranes are maintained properly (backwashing).	**Main Strength** High performance and simple.	**Main Weakness** Membrane fouling, which implies backwashing operation or membrane replacement.	

Advantages	• High performance	• Compact units: less space needed than conventional treatment schemes	• Simple operation	• Membranes available can be used to separate many kinds of contaminants	• Disinfection can be performed without chemicals
Disadvantages	• Membrane fouling	• Production of polluted water (from backwashing)	• Membranes have to be replaced on a regular basis		

Membranes
There are four main types of modules: plate-and-frame, tubular, spiral wound, and hollow fibre. The plate-and-frame module is the simplest configuration, consisting of two end plates, the flat sheet membrane, and spacers. In tubular modules, the membrane is often on the inside of a tube, and the feed solution is pumped through the tube. The most popular module in industry for nanofiltration or reverse osmosis membranes is the spiral wound module. This module has a flat sheet membrane wrapped around a perforated permeate collection tube. The feed flows on one side of the membrane. Permeate is collected on the other side of the membrane and spirals in towards the centre collection tube. Hollow fibre modules used for seawater desalination consist of bundles of hollow fibres in a pressure vessel. They can have a shell-side feed configuration where the feed passes along the outside of the fibres and exits the fibre ends. Hollow fibre modules can also be used in a bore-side feed configuration where the feed is circulated through the fibres. Hollow fibres employed for wastewater treatment and in membrane bioreactors are not always used in pressure vessels. Bundles of fibres can be suspended in the feed solution and the permeate is collected from one end of the fibres.

Water treatment processes employ several types of membranes. They include microfiltration (M-F), ultrafiltration (U-F), reverse osmosis (R-O), and nanofiltration (N-F) membranes. Microfiltration membranes have the largest pore size and typically reject large particles and various microorganisms. Ultrafiltration membranes have smaller pores than microfiltration membranes and therefore, in addition to large particles and microorganisms, they can reject bacteria and soluble macromolecules such as proteins. Reverse osmosis membranes are effectively non-porous and, therefore, exclude particles and even many low molar mass species such as salt ions, organics, etc. Nanofiltration membranes are relatively new and are sometimes called "loose" reverse osmosis membranes. They are porous membranes, but since the pores are on the order of ten angstroms or less, they exhibit performance between that of reverse osmosis and ultrafiltration membranes.

Membrane Materials
Most membranes are synthetic organic polymers (e.g. polysulfone, cellulose acetate). Microfiltration and ultrafiltration membranes are often made from the same materials, but they are prepared under different membrane formation conditions so that different pore sizes are produced. Membranes can also be prepared from inorganic materials such as ceramics or metals. Ceramic membranes are microporous, thermally stable, chemically resistant, and often used for microfiltration. However, disadvantages such as high cost and mechanical fragility have hindered their widespread use. Metallic membranes are often made of stainless steel and can be very finely porous. Their main application is in gas separations, but they can also be used for water filtration at high temperatures or as a membrane support. The current tendency on membrane development is to use nanofunctionalised membranes. Polymer membranes doped with silver nanoparticles to avoid biofouling is an example of such modern membranes.

Membrane Fouling
Membrane fouling is a process where solute or particles deposit onto amembrane surface or into membrane pores in a way that degrades the membrane's performance. It is a major obstacle to the widespread use of this technology. Membrane fouling can cause severe flux decline and affect the quality of the water produced. Severe fouling may require intense chemical cleaning or membrane replacement. This increases the operating costs of a treatment plant. There are various types of pollutants: colloidal (clays, flocs), biological (bacteria, fungi), organic (oils, polyelectrolytes, humics) and scaling (mineral precipitates). Fouling can be divided into reversible and irreversible fouling based on the attachment strength of particles to the membrane surface. Reversible fouling can be removed by a strong shear force of backwashing. Formation of a strong matrix of fouling layer with the solute during a continuous filtration process will result in reversible fouling being transformed into an irreversible fouling layer. Irreversible fouling is the strong attachment of particles, which cannot be removed by physical cleaning.

Operation
Raw water quality must be reviewed frequently and operational parameters of the membrane treatment train should be continually trended and compared to original start up conditions. Pre-treatment efficiencies and post treatment works should also be monitored closely. These tasks can alert operators of pending problems in time for corrective action to occur before production capabilities are impacted. While some changes in the treatment process may not significantly impact plant productivity or finished water quality, they may result in membrane degradation, more frequent cleaning, and generally higher operating costs over time if not properly addressed. When treatment or equipment failures become apparent, it is critical that adequate maintenance resources are made available. As with any industrial facility, routine preventive maintenance activities should be performed prudently as scheduled, while responsiveness to unforeseen repairs also needs to be timely. Unlike other treatment technologies, which produce lower quality product as the raw water quality degrades, membrane systems produce consistent water quality while the systems themselves degrade. Therefore, early detection of raw water changes and making adjustments to the operational parameters to accommodate the changes are the key to successful plant operation. A well-designed plant should include the necessary "tools" and have proper and adequate provisions for conducting routine tests and inspections. Such provisions include a well-equipped laboratory, tools and provisions for testing, and sample points for profiling.

Costs
Membrane filtration systems' capital costs, on a basis of dollars per volume of installed treatment capacity, do not escalate rapidly as plant size decreases. This factor makes membranes quite attractive for small systems. In addition, for groundwater sources that do not need pre-treatment, membrane technologies are relatively simple to install, and the systems require little more than a feed pump, a cleaning pump, the membrane modules, and some holding tanks.

Applicability
Membrane processes have become more attractive for potable water production and advanced wastewater treatment in recent years due to the increased stringency of regulations, water scarcity, and decreasing costs of membranes. Membrane processes have excellent separation capabilities and show promise for meeting many of the existing and anticipated drinking water standards. Membrane processes are very versatile: for example ultrafiltration and microfiltration are efficient for turbidity suspended particles and microbial removal, nanofiltration and ultrafiltration membranes for organics (e.g. DBP precursors, micropollutants) and viruses separation, and reverse osmosis process for desalination and removal of small size organic contaminants.

24 Reverse Osmosis

Reverse osmosis has become the water purification method of choice for drinking water in many households and bottling plants throughout the world. It is a very efficient method to purify water from even very small molecules. There are many providers of reverse osmosis filter devices but, in general, the treatment stages are the same. It is possible to combine reversed osmosis filters with UV, infrared technology, or ozonation for disinfection (see also UV tubes and ozonation). Most reverse osmosis filters have 4 to 6 filter stages in different combinations.

Stage 1	(5 Micron Sediment Filter): Removes dirt, rust and sand particles.
Stage 2	(Granular Activated Carbon Filter or Carbon Block Filter): Takes out 99% of the chlorine and organic chemicals and provides enhanced reduction of taste, odour, and colour.
Stage 3	(1 Micron Sediment Filter): Provides effective filtration to protect the membrane.
Stage 4	(Reverse Osmosis (RO) Membrane): A thin film composite (TFC) high quality membrane processes 80 gallons (300 litres) per day. It removes the following hard water contaminants that may be present in the water: lead, cooper, barium, chromium, mercury, sodium, cadmium, fluoride, nitrite, nitrate, and selenium.
Additional Filter Stages	Some systems may use these additional filters below.
Stage 5	(Post Carbon Filter): Removes objectionable tastes and odours to enhance the quality of drinking water.

Stage 6a	(Deionisation (DI) Filter): Produces 99.99% pure water by simply attaching this convenient deionisation filter with RO unit. A convenient post RO filtration DI unit (RO/DI unit) provides crucial supplemental filtration to remove most impurities for pure polished product water. Excellent in areas with hard water.
Stage 6b	(Mineral Filter): This filter improves the qualities of clean water by adding minerals which are necessary for proper human development and health, such as calcium, magnesium, sodium, potassium and others readily found in many natural mineral waters.
Stage 6c	(Ultraviolet Water Steriliser): Ultraviolet light (UV), a natural part of sunlight is widely accepted as a reliable, efficient & environmentally friendly solution for water disinfection. The UV lamp destroys 99.99% of bacteria and viruses.

Reversed osmosis filter systems might be too expensive for some parts of the world. They also need a power supply (pump) and should not be used for water which is over 45°C (113°F). The filter system should not be frozen and an ideal water pressure should be provided. The three pre-filters should be changed every 6 months.

25 Hydrogen Peroxide

Hydrogen peroxide (H2O2), a colourless water-like liquid, is one of the most versatile, reliable and environmentally friendly oxidising agents. The relative safety and simplicity of its uses has led to the development of a number of applications in water treatment such as odour removal, disinfection or metal removal. Hydrogen peroxide is also used in advanced oxidation processes (AOP) and can be combined with catalysts or other oxidisers to produce reactive oxygen species (ROS) able to attack a wide range of organic compounds and microorganisms. The production of hydrogen peroxide is usually performed at industrial scale but can also be done directly in drinking water (or pre-treated wastewater) by electrolysis.

Overview	**Working Principle** H2O2 s breaks down (spontaneously or with a catalyst) into water producing reactive species that react with microorganisms and pollutants	**Capacity/Adequacy** Relatively high-tech equipment required for “catalysed” H2O2 treatments	**Performance** High efficiency	**Costs** Relatively high operation costs for “catalysed” H2O2 treatments	**Self-Help Compatibility** Engineers are required for the design
	O&M Continuous input of H2O2 required	**Reliability** Reliable if the treatment is designed according to each application	**Main Strength** Very versatile and environmentally compatible oxidising agent	**Main Weakness** Continuous input of H2O2 required	

Advantages	• Destroys toxic organic compounds without pollution transfer to another phase	• Does not produce harmful residues	• Can be combined with catalysts and other oxidisers	• Works for water disinfection (destruction of microorganisms)	• Efficient in treating almost all organic pollutants and in removing some toxic metals
Disadvantages	• Relatively high operation costs due to input of H2O2	• Engineers, additional power and/or chemicals are required for the design of “catalysed” H2O2 treatment systems			

Hydrogen Peroxide
Hydrogen peroxide (H2O2) is a powerful oxidiser that decomposes into an environmental compatible product (water and oxygen). H2O2 is formed under the action of sunlight in natural surface waters due to the presence of natural organic constituents. This mechanism contributes to water purification within the environment. H2O2 is widely used as a bleaching agent for paper and textiles as well as in industrial applications to manufacture or process products. H2O2 can be used for water treatment alone or combined with UV light, a catalyst and/or other oxidants like ozone (see also ozonation). The hydrogen peroxide-based processes are versatile and can treat organics, microbial contamination as well as some inorganic compounds. H2O2-based treatments can be used both for drinking water purification (e.g. to remove bacteria, odour, micropollutants, etc.), and for municipal or industrial wastewater treatment (effluent disinfection, organics degradation, see also advanced oxidation).

Process
The active part of hydrogen peroxide is the peroxide group, which is an oxidant similar to ozone (see ozonation) or chlorine (see chlorination). When dissolved in water, H2O2 spontaneously breaks down into water and oxygen. This decomposition leads to the formation of reactive oxygen species (ROS), which can oxidise certain organics and metal ions and can also kill pathogens. Optimisation of conditions using H2O2 to destroy these pollutants can involve control of pH, temperature and reaction time. No additional additives are required.

“Catalysed” Hydrogen Peroxide
H2O2 can be used in combination with catalysts: UV light and/or other oxidants. The UV light allows the production of an oxidising agent (ROS) called hydroxyl radical (.OH). .OH is one of the strongest oxidants known, much more efficient than hydrogen peroxide alone and is therefore much more efficient in killing microorganisms and degrading organics in water.

H2O2 + UV light --> 2 .OH

Another way of generating hydroxyl radical from H2O2 is the use of a catalyst. The use of iron ions as a catalyst is a common approach and is referred to as Fenton process.

Fe2+ + H2O2 --> Fe3+ + OH- + .OH

This reaction is enhanced by the use of solar light (photo-Fenton).

The addition of both hydrogen peroxide and ozone (peroxone) to wastewater accelerates the decomposition of ozone and enhances the production of hydroxyl radical.

Hydrogen Peroxide Generation
The classical manufacturing process involves the catalytic reaction of Hydrogen (H2) with atmospheric oxygen (O2) to give H2O2. Anthraquinone (Q) is used as a hydrogen carrier. Palladium catalyses the reaction between H2 and Q to create H2Q in solution. Then the solution is oxidised by blowing air producing H2O2 (H2Q + O2 --> H2O2 + Q). Hydrogen peroxide can also be produced directly in wastewater by water electrolysis using electrodes. The required oxygen can be supplied by transfer from the atmosphere.

Cost Considerations
Costs depend on the specifics of the requirement (e.g. H2O2 strength and grade, volume per year, packaging and delivery volumes, and location/proximity to production plant, etc.). For large amounts of technical grade 30% H2O2, the price is roughly a few dollars per kg.

Applicability
The strong oxidising power of H_2O_2 makes it suitable for the destruction of a variety of pollutants such as bacteria, toxic organic compounds and some metals. The process has many applications in drinking water production: taste and odour control, hydrogen sulphide removal, metal removal, ozone enhancement and disinfection. H_2O_2has also been used for many years to degrade organics in industrial or municipal wastewater. It can also be used for the disinfection of wastewater treatment plants. When H_2O_2 is combined with UV light, catalyst or other oxidants, the resulting treatment is more efficient in destroying organics present in high strength wastewaters. When H_2O_2 is used on its own, the operational costs are limited to input of H_2O_2. In case of "catalysed" H_2O_2 treatments, the design is more complex and additional power and/or chemicals input is required.

26 Ozonation

Ozonation (also referred to as ozonisation) is a chemical water treatment technique based on the infusion of ozone into water. Ozone is a gas composed of three oxygen atoms (O_3), which is one of the most powerful oxidants. Ozonation is a type of advanced oxidation process, involving the production of very reactive oxygen species able to attack a wide range of organic compounds and all microorganisms. The treatment of water with ozone has a wide range of applications, as it is efficient for disinfection as well as for the degradation of organic and inorganic pollutants. Ozone is produced with the use of energy by subjecting oxygen (O_2) to high electric voltage or to UV radiation. The required amounts of ozone can be produced at the point of use but the production requires a lot of energy and is therefore costly. Ozone (O_3) has been used in water treatment since the late 19th century. Today it is applied for the disinfection of drinking water, for the removal of effluents from wastewater treatment plants in a process called ozonation (or ozonisation) as well as for the degradation of organic and inorganic pollutants in wastewater (see also advanced oxidation process).

Overview	**Working Principle** Infusion of ozone, a gas produced by subjecting oxygen molecules to high electrical voltage, which reacts with microorganisms and pollutants	**Capacity/Adequacy** High tech equipment required	**Performance** High efficiency	**Costs** Relatively high operation costs	**Self-Help Compatibility** Engineers are required for the design
	O&M Continuous input of electrical power required	**Reliability** Reliable if operating conditions are scaled taking into account wastewater content	**Main Strength** Very efficient and fast method for disinfection and as a AOP	**Main Weakness** Requires complicated equipment as well as large amounts of energy and qualified operators	

Advantages	• Rapidly reacts with bacteria, viruses and protozoa over a wide pH range	• Stronger germicidal properties than chlorination	• No chemicals are added to water	• Also efficient for organics degradation and inorganics removal	• Removes colour, taste and odour
Disadvantages	• Relatively high equipment costs	• Requires large amounts of energy	• Qualified professionals required for design and system maintenance	• Formation of potentially harmful disinfection by-products (DBPs) in the case of brome existence in water	• No residual effect is present in the distribution system
	• Potential fire hazard and toxicity associated with ozone generation				

Disinfection with Ozone
Ozone is an excellent disinfectant and can even be used to inactivate microorganisms such as protozoa, which are very resistant to conventional disinfectants. However, ozone is an unstable gas that transforms to oxygen hence no residual disinfection effect takes place with ozonation.

Degradation of Pollutants
Ozonation is an efficient treatment to reduce the amounts of micropollutants released in the aquatic systems by wastewater treatment plants. Although no residual by-products are generated by ozone itself, some concerns are raised regarding oxidation by-products when water containing both organics and ions, such as bromide, iodide and chlorine ions, are treated with ozonation. A typical ozonation system consists of an ozone generator and a reactor where ozone is bubbled into the water to be treated.

Ozone Effect
The effectiveness of ozone results from its powerful oxidising effect on chemicals and microorganisms caused by the generation of reactive oxygen species during ozone transformation to oxygen. Ozone directly attacks the surface of microorganisms and destroys their cell walls. The cells thus loose their cytoplasm and can no longer reactivate themselves. Ozone can induce an oxidative degradation of many organics and leaves more biodegradable compounds. Besides, ozone can oxidise metallic ions such as Fe(II), Mn(II) or As(III) producing insoluble solid oxides that can be easily separated from water by filtration or sedimentation.

Ozone Production
Because of its relatively short half-life, ozone is generated on-site by an ozone generator. The conventional ways to produce ozone are UV-light and corona-discharge. Ozone generation by corona-discharge is most common nowadays and has many advantages such as longer lifespan of the unit, higher ozone production and higher cost efficiency. Production with UV-light is an option where only small amounts of ozone are required. Other ozone generators that are available involve electrolysis of water and the use of membranes. With this method, the ozone is dissolved in the process water as soon as it is formed resulting in ozonation using minimum equipment.

Technical Aspects
Whilst ozone is the most effective disinfectant overall and is more effective than chlorine in inactivating viral agents, there are significant disadvantages to its use. Ozone does not provide residual protection against recontamination during distribution and as ozone affects biological stability, it may encourage re-growth of bacteria. However, given the concerns about the use of chlorine in many countries because of the formation of toxic disinfection by-products (DBP), the use of ozone is increasingly investigated and the lack of residual may be dealt with by employing regular booster ozonation during distribution.

Cost
The cost of ozone disinfection systems depends on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Ozonation costs are generally high in comparison to other disinfection techniques. For the removal of micropollutants in wastewater, the additional operation costs for ozonation combined with sand filtration are around 3-4 Swiss cents/m^3.

Operation
Ozone generation uses a significant amount of electrical power. Constant attention must thus be given to the system to ensure that power is available. Moreover, ozone should not be released from the system and connections in or surrounding the ozone generator should not be leaking. The operator must monitor the appropriate subunits on a regular basis to ensure that they are not overheated. Therefore, the operator must check for leaks routinely since a very small leak can cause unacceptable ambient ozone concentrations.

Health
There are significant health and safety concerns for operators regarding the production and application of ozone. However, far less is known about ozonation and the effect of ozone on human health. There are also concerns regarding by-product formation during the disinfection of drinking water containing bromide ions.

Applicability
Ozonation has been successfully applied for water disinfection and can kill most bacteria viruses and protozoa. However, there is no residual disinfection effect and ozonation is more expensive than chlorination. Ozonation is a suitable process to degrade organic pollutants (e.g. for micropollutants removal and landfill leachate pre-treatment) and oxidise metallic ions (e.g. iron manganese). Design and construction needs skilled staff and high-tech equipment. Sophisticated generators consuming high-amounts of electricity are required to produce ozone. Although operation and maintenance costs are relatively low, precise monitoring and dosing adjustment of ozone is needed to ensure the efficiency of the treatment.

27 Solar Desalination

28 Electrodialysis Desalination

29 Ion Exchange

Ion exchange is a water treatment method where one or more undesirable ionic contaminants are removed from water by exchange with another non-objectionable, or less objectionable ionic substance. Both the contaminant and the exchanged substance must be dissolved and have the same type of electrical charge (positive or negative). A typical example of ion exchange is a process called "water softening" aiming to reduce calcium and magnesium content. Nevertheless, ion exchange is also efficient in removing toxic metals from water.

Overview	**Working Principle** Undesirable ionic contaminants are removed from water by exchange with another non-objectionable, or less objectionable ionic substance.	**Capacity/Adequacy** Relatively simple technology.	**Performance** Efficient technology to remove ionic substances from water and to soften water.	**Costs** Relatively low costs.	**Self-Help Compatibility** Monitoring is necessary to manage the regeneration process.
	O&M Ion exchange resin must be regenerated regularly.	**Reliability** Reliable if ion exchange resin regenerated properly.	**Main Strength** Efficient to remove dissolved inorganics.	**Main Weakness** Do not remove particles or bacteria.	

Advantages	• One of the most appropriate technologies to removes dissolved inorganic ions effectively	• Possibility to regenerate resin	• Relatively inexpensive initial capital investment
Disadvantages	• Does not remove effectively bacteria	• High operation costs over long-term	• The process of regenerating the ion exchange beds dumps salt water into the environment (regeneration)

Introduction
In 1850, Thomas and Way performed some of the first scientific research that indicated the existence of an ion exchange process. In their experiment, a solution of ammonium sulphate was passed through soil. The filtrate collected was composed of calcium sulphate instead of ammonium sulphate. The importance of this discovery (in ion exchange terms) was not fully understood until later in that decade, when it was found that this reaction was reversible. Ion exchange was then primary used to soften water. The presence of calcium and/or magnesium in water results in water being considered "hard". Calcium and magnesium ions in water react with heat, metallic plumbing and chemical agents such as detergents to decrease the effectiveness of nearly any cleaning task. Hard water can be softened using an ion exchange softening process. Ion exchange processes can also remove various charged atoms or molecules (ions) such as nitrates, fluoride, sulphates, perchlorate, iron and manganese ions as well as toxic metals (radium, uranium, chromium, etc.) from water. The most typical application of ion exchange is the preparation of high purity water for industrial applications, water softening, recovery or removal of metals in the chemical industry.

Ion Exchange Resins
Synthetic and industrially produced ion exchange resins consist of small, microporous beads that are insoluble in water and organic solvents. The most widely used base-materials are polystyrene and polyacrylate. The diameter of the beads is in the range of 0.3 to 1.3 mm. The beads are composed of around 50% water, which is dispersed in the gel-structured compartments of the material. Since water is dispersed homogenously throughout the bead, water-soluble materials can move freely in and out. To each of the monomer units of the polymer, so called "functional groups" are attached. These functional groups can interact with water-soluble species, especially with ions. Ions are either positively charged (cations) or negatively charged (anions). Since the functional groups are also charged, the interaction between ions and functional groups is exhibited via electrostatic forces. Positively charged functional groups interact with anions and negatively charged functional groups interact with cations. The binding force between the functional group and the attached ion is relatively weak. The exchange can be reversed by another ion passing across the functional group. This process can be repeated continually, with one exchange reaction following another.

WATER Purification Methods Ion Exchange

Ion Exchange Process
The main component of ion exchange equipment is a microporous exchange resin, which is supersaturated with a loosely held solution. For water softening, this is usually done with sulfonated polystyrene beds that are supersaturated with sodium to cover the bed surface. As water passes through this resin bed, ions attach to the resin beads releasing the loosely held solution into the water. After a time, the beds become saturated and the exchange resin must be regenerated or recharged. To regenerate, the ion exchange resin is flushed with a salt brine solution. The sodium ions in the salt brine solution are exchanged with the ions, which are flushed out with wastewater.

Operation
Maintenance of water softening equipment is somewhat dependent on the type of softener. Some degree of monitoring or managing the regeneration process is generally required. Adequate backwashing of the resin bed is important to ensure the regeneration of the unit. However, regeneration creates wastewater.

Costs
The costs for ion exchange systems are very variable depending on scale and region. Moreover, costs depend on pre-treatment requirements, discharge requirements and utilisation.

Health Aspects
People on restricted sodium diets due to health reasons should account for increased intake through softened water. Drinking and cooking with softened water is often avoided by having a cold water line to the kitchen tap that bypasses the water softener. This provides hard water for drinking cooking and other uses. It is not recommended to repeatedly use softened water for plants, lawns or gardens due to the sodium content.

Applicability
The most common applications of ion exchangers are water softening (remove calcium and magnesium ions), water demineralisation (removal of all ions), and de-alkalisation (removal of bicarbonates). Cation exchange resins can also remove most positively charged ions in water such as iron, lead, radium, barium, aluminium and copper among others. Anionic exchange units can remove nitrate, sulphate, and other negatively charged atoms (called anions). Researchers are developing resins to selectively remove nitrate more efficiently than can currently be done. Ion exchangers are also used to remove or recover metal ions from wastewater in the chemical industry. Some contaminants (such as arsenic, fluoride, lithium ions) are difficult to remove with ion exchange due to a poor selectivity of the resins. Ion exchangers are also used to remove or recover metal ions from wastewater in the chemical industry. Some contaminants (such as arsenic, fluoride, lithium ions) are difficult to remove with ion exchange due to a poor selectivity of the resins.

30 Geothermal Desalination

31 Freezing Desalination

32 Advanced Oxidation Processes

WATER Purification Methods Advanced Oxidation Processes

Hazardous organic waste, widely spread in water by industrial, military and domestic sources, is an emerging issue. Advanced Oxidation Processes (AOPs) are efficient methods to remove organic contamination not degradable by means of biological processes. AOPs are a set of processes involving the production of very reactive oxygen species able to destroy a wide range of organic compounds. AOPs are driven by external energy sources such as electric power, ultraviolet radiation (UV) or solar light, so these processes are often more expensive than conventional biological wastewater treatment. Moreover, AOPs can be applied for the disinfection of water, air and for remediation of contaminated soils.

Overview	**Working Principle** Production of reactive oxygen species able to destroy toxic compounds and biologic contamination in water.	**Capacity/Adequacy** High-tech equipment required.	**Performance** High efficiency except for few chemicals	**Costs** High operation costs	**Self-Help Compatibility** Engineers are required for the design
	O&M Generally continuous supply of chemicals (ozone, H2O2…) required	**Reliability** Reliable if operating conditions are scaled taking into account wastewater content	**Main Strength** Destroys almost all organics without pollution transfer to another phase	**Main Weakness** Operation costs	

Advantages	• Destroys toxic organic compounds without pollution transfer to another phase	• Very efficient to treat almost all organic pollutants and remove some toxic metals	• Works also for water disinfection	• Cheap to install	• Adaptable to small scales in developing countries
Disadvantages	• Relatively high operation costs due to chemicals and/or energy input	• Formation of oxidation intermediates potentially toxic	• Engineers are required for the design and often also for operation	• Emerging technologies (still a lot of research is required)	

Introduction
Advanced Oxidation Processes (AOPs) refer to a set of oxidative water treatments that can be used to treat toxic effluents at industrial level, hospitals and wastewater treatment plants. AOPs are successful to transform toxic organic compounds (e.g. drugs, pesticides, endocrine disruptors etc.) into biodegradable substances. AOPs in general are cheap to install but involve high operating costs due to the input of chemicals and energy required. To limit the costs, AOPs are often used as pre-treatment combined with biologic treatment. Advanced oxidation was recently also used as quaternary treatment or a polishing step to remove micro-pollutants from the effluents of municipal wastewater treatment plants and for the disinfection of water. The combination of several AOPs is an efficient way to increase pollutant removal and reduce costs.

Examples of AOPs	Dark AOP	Light Driven AOP
Many methods are classified under the broad definition of AOPs. The table shows some of the most studied processes. Advanced oxidation generally uses strong oxidising agents like hydrogen peroxide (H_2O_2) or ozone (O_3), catalysts (iron ions, electrodes, metal oxides) and irradiation (UV light, solar light, ultrasounds) separately or in combination under mild conditions (low temperature and pressure). Among different available AOPs, those driven by light seem to be the most popular technologies for wastewater treatment as shown by the large amount of data available in the literature (STASINAKIS 2008). Solar AOPs are particularly attractive due to the abundance of solar light in regions where water scarcity is high and due to their relatively low costs and high efficiencies.	• Ozone (O_3) • Fenton (Fe^{2+} + H_2O_2) • Electrolysis (electrodes + current) • Sonolysis (Ultrasounds)	• Photolysis (UV + H_2O_2) • Photocatalysis (light + catalyst) • Photo-Fenton (solar light + Fenton)

AOP Mechanism

Advanced oxidation involves several steps schematised in the figure below and explained as follows:

1	Formation of strong oxidants (e.g. hydroxyl radicals).
2	Reaction of these oxidants with organic compounds in the water (KOMMINENI et al. 2008) producing biodegradable intermediates.
3	Reaction of biodegradable intermediates with oxidants referred to as mineralisation (i.e. production of water, carbon dioxide and inorganic salts).

Strategies to Implement AOPs

The costs of AOPs are relatively high and directly related to the efficiency and operational time of the processes. It is therefore worth optimising implementation of AOPs at the right place to limit costs. Several strategies were found to achieve this:

- Simultaneous application of different AOPs promotes the rates of organics oxidation. Typical examples include UV/H_2O_2, UV/H_2O_2/TiO_2, UV/Fenton and Ultrasound/UV/TiO_2, among others. These types of combinations may lead to synergetic effects when treatment efficiencies are greater than the sum of efficiencies that could be achieved by the individual treatments alone.
- Sequential application of various AOPs can treat effluents containing a mixture of organics. This approach is useful when the compounds in the mixture present different levels of reactivity towards different AOPs.
- Application of separation treatment prior to AOP treatment to transfer pollutants to another phase so that they can be treated more easily. Such separation treatment includes stripping, coagulation-flocculation, sedimentation, filtration, adsorption etc.

- AOPs can be applied in pre-treatment stage to enhance biodegradability and to reduce toxicity followed by biological post-treatment. This approach is based on the fact that biological treatment is perhaps less costly and more environmentally friendly than other destructive treatments and that complete mineralisation by AOPs incurs excessive treatment costs.
- AOPs can be installed at different stages of waste (and also drinking) water treatment plants depending on influent composition and desired effluent quality. AOPs can be installed either as tertiary treatment after the biological (secondary) treatment of wastewater, or as pre-treatment stage in order to enhance the biodegradability of trace organic contaminants.

Applicability

AOPs have a wide range of applications such as air (odour elimination, purification), soil (remediation) and water decontamination. In water, these processes have the ability to destroy organic pollutants but they can also be adapted to the removal of inorganic metals. Furthermore AOPs are successful to inactivate bacteria, viruses etc. Different kinds of water are therefore suitable for an AOP treatment: for example industrial wastewater containing toxic compounds can be treated by solar photo-Fenton; surface or ground water can be disinfected by means of improved solar water disinfection by adding H_2O_2 (see also H_2O_2 and SODIS); both bacteria in drinking water plants or micro-pollutants in sewage systems can be degraded using ozonation; Dissolved arsenic can be removed from water by co-precipitation by means of simple methods in presence of iron.

5 Water Storage

Already treated or purified water has to be stored properly to prevent recontamination. Safe storage means keeping your treated water away from sources of contamination, and using a clean and covered container. It also means that drinking from the container should be done in a way that cross-contamination can be avoided. The container should prevent hands, cups and dippers from touching the water, so that the water does not get recontaminated. There are several possibilities to store water. They range from very small covered buckets to large tanks or cisterns. Another possibility is to store water in bottles. Furthermore, the hygienic conditions in a household are crucial. Good hygienic measures include the following.

- Careful storage of household water and regular cleaning of all household water-storage facilities.
- Construction, proper use, and maintenance of latrines.
- Regular hand washing, especially after defecation and before eating, preparing food or handling drinking water.
- Careful storage and preparation of water and food.

Treated water should be stored in plastic, ceramic, or metal containers especially when using treatment options that do not leave residual protection. The following characteristics of containers serve as physical barriers to recontamination.

- A small opening with a lid or cover that discourages users from placing potentially contaminated items such as hands, cups, or ladles into the stored water.
- A spigot or small opening to allow easy and safe access to the water without requiring the insertion of hands or objects into the container.
- A size appropriate for the household water treatment method, with permanently attached instructions for using the treatment method and for cleaning the container.

The following aspects should be considered when planning for safe storage and prevention of recontamination. The water storage container must be covered and only used for treated water.

- Location of storage vessel
- Design of storage vessel
- Removal of water

Containers

Container Types

These are the different plastic types ordered by resin identification code. This code is the number printed onto any plastic items which is surrounded by a recycle icon. They are generally pretty easy to spot and can help identifying what that plastic can be used for.

Plastic Type	Use	Notes & Safety	Water Storage	Food Storage
Plastic #1 - PET Polyethylene Terephthalate (PET)	Water, juice and soft drink bottles	Considered safe but PET can leach metal antimony. The longer it sits on a shelf - the greater the dose present based on factors like sunlight, temperature and pH level.	Shouldn't use for water storage	Safe for food storage

Plastic #2 - HDPE High Density Polyethylene (HDPE)	Milk, water, juice bottles, shampoo containers, cereal liners and grocery bags	Has been found to release estrogenic chemicals which can disrupt hormones and alter cell structure. Can contain the common plastic toxin BPA.	Safe for water storage	Safe for food storage
Plastic #3 - PVC Polyvinyl Chloride (PVC)	Bags for bedding, shrink wrap, deli and meat wrap, plastic toys, plastic flooring, table cloths and medication blister packs	Contains toxins like DEHP which is a plastic softener. Linked to allergies, asthma and autism.	Avoid for water storage	Avoid for food storage
Plastic #4 - LDPE Low Density Polyethylene (LDPE)	Bread bags, newspapers, fresh produce, household garbage, frozen food, paper milk cartons, hot + cold beverage cups	Does not contain BPA but may leach other estrogenic chemicals.	Safe for water storage	Shouldn't use for food storage
Plastic #5 - PP Polypropylene (PP)	Yoghurt containers, plastic ware, deli foods, medications and take-out meals	High heat tolerance making it unlikely to leach chemicals.	Safe for water storage	Safe for food storage
Plastic #6 - PS Polystyrene (PS)	Cups, bowls, take-out containers and meat trays	Known to leach styrene which can damage nervous system and is linked to cancer. Heating PS releases more chemicals faster.	Avoid for water storage	Shouldn't use for food storage
Plastic #7 - Other Other	Sauce bottles, condiment bottles, babies' feeding bottles, infants' drinking cups, reusable water bottles	Usually often contains BPA or BPS which are endocrine disruptors.	Avoid for water storage	Avoid for food storage
Tritan - Nalgene Nalgene Bottles	Water Bottles	Categorized as Plastic #7 Contains no BPS, BPA or estrogen.	Safe for water storage	?

Portable Containers (1-5 Litres)

These are bottles or other containers that are used to transport small quantities of water and can easily fit in a backpack.

Water Bottle	Water bottles can hold any amount of water, but typically from 200ml to 2L. Consider the weight of the bottle when purchasing it as it could add quite a lot of additional weight you don't need. Be sure that the bottle is strong enough to last weeks or months depending on your situation and choose a size based on your location. (Larger for desert areas)
Flexible Water Bottle	Flexible bottles range from 1L to 10L. Flexible water bottles are light bottles that can be folded to a compact size when empty to save pack space.
Water Bladder	Water bladders typically hold between 1-10L of water. Bladders are used in backpacks and often have a sipper function that lets you drink from them while hiking without hands.

Semi-Portable Containers (5-100 Litres)

These containers are larger than bottles and are often bought from camping shops letting you fill them from home. These containers are better for longer trips without access to clean water and can be used for showering as well. Typically they come in either blue or white plastics to make it easier to identify the contents.

Fixed Containers (100+ Litres)

Fixed containers are not easily portable containers (once filled) that contain huge amounts of water

Water Tanks	**Rigid Water Container** o	**PVC Water Holder** o			

Water Towers

Water towers can be made of concrete or steel and can take various forms. The most suitable form for concrete towers is a cylinder with a curved shaped bottom or with a flat bottom. Steel tanks may have a spherical or dome shaped bottom. The shape chosen is usually a compromise between function, construction and maintenance costs, as well as aesthetics. The lowest water level in the tank is determined according to the pressure requirements in the pipeline. The pressure in the pipelines may vary depending on the type of community and pressure needs of different areas in a city. To keep pumping costs low, water depth in the tank is generally kept small. Due to structural considerations, the depth is kept equal to the diameter.

Storing

Tips on how to store water in containers and how to store the containers.

Water Storage Tips	Containers must not contain BPA and only have been used to store water. Airtight containers prevent bacteria growing. Treat water with chlorine or colloidal silver before storing and again after storage. Check for contamination before drinking stored water. Water becomes flat over time, shake it to reoxygenate it. Ensure a tight seal and that barrels aren't stored on cement which can leak chemicals. Hard containers should resist 5 drop tests full of water from 2m high, flexible containers should resist 2 drops from 2m high. Don't use recycled plastics for long term water storage.
Storage Life	

6 Water Purity

WATER Water Purity

In many parts of the world, water is not safe enough to drink. There are basic qualitative observations that quickly determine if water is not safe to consume. However, there are also many "invisible" substances that must be tested for professionally to identify the contaminants and to figure out how the specific polluted water can be purified. Testing can be done in the field with portable test kits or mobile laboratories. Water samples can also be collected and sent to a professional laboratory.

Drinking water can come from different sources depending on where we live in the world. Three sources that are used to collect drinking water are:

- Groundwater
- Surface water
- Rainwater

Water is in continuous movement on, above, and below the surface of the earth. As water is recycled through the earth, it picks up many things along its path. Water quality will vary from place to place, with the seasons, and with the various kinds of rock and soil it moves through. For the most part, it is largely natural processes that affect water quality. For instance, water moving through underground rocks and soils may pick up natural contaminants, even with no human activity or pollution in the area. In addition to nature's influence, water is also polluted by human activities, such as open defecation, dumping garbage, poor agricultural practices, and chemical spills at industrial sites. When considering drinking water quality, microbiological contamination is the main concern in most cases since it is responsible for the majority of illnesses and deaths related to drinking unsafe water.

Even though water may be clear, it does not necessarily mean that it is safe for us to drink. It is important for us to judge the safety of water by taking the following three qualities into consideration (see also pathogens and contaminants):

1. **Microbiological** – bacteria, viruses, protozoa, and worms
2. **Chemical** – minerals, metals and chemicals
3. **Physical** – temperature, colour, smell, taste and turbidity

Safe drinking water should have the following microbiological, chemical and physical qualities:

- Free of pathogens
- Low in concentrations of toxic chemicals
- Clear
- Tasteless and colourless (for aesthetic purposes)

Qualitative Observations

The first step to check water quality can be done by very simple observations:

Water Observation	Possible Contaminants
Foamy	Detergents
Black in colour	Manganese, bacterial growth
Brown, yellow or reddish in colour	Iron
Dark brown or yellow in colour	Tannins and pigment from leaves and bark
White deposits or scale	Hardness, dissolved metals
Earthy, fishy, muddy, peaty odour	Organic matter, algae, bacteria
Rotten egg odour	Hydrogen sulphide
Chlorine odour	Chlorine residual from water treatment process
Bitter or metallic taste	pH, zinc, copper

Portable Testing Kits
Analyses for many physical, chemical and microbiological contaminants can be carried out in the field or in a temporary laboratory using specifically designed products that are portable and relatively easy to use. A significant advantage of field analysis is that tests are carried out on fresh samples whose characteristics have not been contaminated or otherwise changed as a result of being stored and transported over long distances. Portable water quality test kits should have the following characteristics:

- Easy to use with simple instructions
- Small and easy to transport
- No restrictions on air transport
- Fast results
- Limited requirement for distilled or deionised water
- Dilution not necessary
- Does not require calibration
- Robust (limited effects from UV light, shock, humidity or temperature)
- Can test several parameters
- Easy to repair or replace
- Limited consumables or consumables are easy to obtain

Water Testing

How to test water for pH, turbidity, chlorine, bacteria, viruses, dissolved compounds etc.

Faecal Coliform Count

Measures the concentration of total coliform bacteria associated with the possible presence of disease causing organisms.

Turbidity Test

Measures the amount of suspended matter in a water supply.

Chlorine and pH Test

Measures the amount of chlorine and pH levels in the water.

Conductivity

By touching the negative and positive leads of a voltmeter that is on in the resistance setting allows you to measure the conductivity of water, a test of its purity. When water conducts electricity, it is made possible by water impurities such as metal and salt.

Materials
- Voltmeter / Multimeter
- Battery
- Wire
- Water Sample

Method
Pour the water into a container. Turn on the voltmeter and connect the battery to the corresponding electrical lead based on which end you've connected. Take note of the voltage. Then place the wire on the positive end of the battery with the voltmeter's negative end on the negative side of the battery. Dip the batteries wire and the positive voltmeter end into the water read the measurement.

Example Measurements **Battery** - 1.57v - 100% **Sea Water** - 0.6v - 38% **Tap Water** - 0.146v - 9.29% **Distilled Water** - 0.0059v - 0.37% **Bottled Water** - 0.0046v - 0.29% - Very Pure Water	The higher the voltage the less pure the water is. Temperature should also be accounted for in the measurement, as this drastically changes the conductivity. In standard water (such as tap water) the conductivity result will change by around 2% per °c change. In deionised water the effect of temperature is amplified, and can reach as high as 10% per °c change.

Chemical Tests

pH Ranges

Potential Hydrogen pH or Potential of Hydrogen measures the acidity or basicity of an aqueous solution in moles/L of Hydrogen atoms. Solutions with a pH less then 7 are acidic and solutions with a pH greater then 7 are basic.	**Range 0-3** ● Battery Acid (-0.2) ● Gastric Fluid (1.2) ● Lemon Juice (2.2) ● Carbonated Drinks (2.5) ● Vinegar (3.0)	**Range 3-6** ● Orange Juice (3.6) ● Beer (4.3) ● Black Coffee (4.9) ● Pure Rain (5.6) ● Egg Yolk (5.6)	**Range 6-9** ● Milk (6.6) ● Distilled Water (7) ● Blood (7.4) ● Seawater (8) ● Baking Soda (8.2)	**Range 9-12** ● Milk of Magnesia (10.6) ● Ammonia (11.4) **Range 12-15** ● Bleach (12.7) ● Lye/Caustic Soda (13.6)

Inorganic Materials

A list of the inorganic materials commonly found in water in (MCL/(mg*L-1)).	**Antimony** - 0.0006 **Arsenic** - 0.01 **Barium** - 2 **Beryllium** - 0.004 **Cadmium** - 0.005	**Chromium (total)** - 0.1 **Copper** - 1.3 **Cyanide** - 0.2 **Fluoride** - 4 **Lead** - 0.015	**Mercury** - 0.002 **Nitrate** - 10 **Nitrile** - 10 **Selenium** - 0.05 **Thallium** - 0.002	

Turbidity

NTU stands for Nephelometric Turbidity Unit. Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.

Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids), very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal. These small solid particles cause the liquid to appear turbid.

NTU	Level	Description
0-5	**No identifiable matter in the bottle**	Crystal clear water, recommended turbidity level prior to consumption. The only NTU level safe for UV sterilization.
6-24	**Between 10-20% reduced visibility through a standard Nalgene bottle**	Slight Turbidity, drinkable but filtering below 10 NTU is preferred. Boiling highly recommended.
25-50	**Between 20-50% reduced visibility through a standard Nalgene bottle**	Minor Turbidity, drinkable but filtering is preferred. Boiling essential.
50-100	**Between 50-90% reduced visibility through a standard Nalgene bottle**	Some Turbidity, drinkable but filtering is highly preferred. Distillation Preferred.
100-150	**90-100% Opaque liquid in a standard Nalgene bottle**	Fair Turbidity, not drinkable without filtration. Distillation Essential.
150-300	**100% Opaque liquid in a standard Nalgene bottle**	Moderate Turbidity, filtering through a good filter will correct it easily. Boiling not recommended - find alternative water. Distillation Essential.
300-500	**Fingers disappear if hand put in up to wrist**	Moderate Turbidity, filtering through a shirt will reduce it easily. Distillation Essential.
500-1000	**Fingernail disappear if a whole finger is put in**	High Turbidity, recommended filtering through a high quality filter. Distillation Essential.
1000-2000	**Fingernail disappears if immersed up to the first finger joint**	Extreme Turbidity, recommended filtering through a high quality filter. Distillation Essential.
2000+	**Anything disappears almost instantly**	Insane Turbidity, recommended filtering through a high quality filter. Distillation Essential.

Treating Turbid Water

Flocculation / Coagulation
Use Aluminium Sulphate, Ferric Chloride, Gypsum or Poly-Aluminium Chloride as a coagulation agent to drop suspended particles to the bottom. Coagulation will remove about 95.6% of turbidity from the water based on variables. Filtering through a fine medium such as an item of clothing will reduce the turbidity a little.

7 Water Resistance

Information on water resistance and types of waterproofing.

Water Resistance

Water resistance is an important fact to consider when you're going to be immersed in water or walking in rain. It measures the resilience of gear to liquids and how long they can survive immersion. Generally it applies to mobile phones and watches. Watches are often classified by watch manufacturers by their degree of water resistance which, due to the absence of official classification standards, roughly translates to the following (1 metre ≈ 3.29 feet). These vagueries have since been superseded by ISO 22810:2010, in which "any watch on the market sold as water-resistant must satisfy ISO 22810 – regardless of the brand.

Resistance Types

Depth Rating
Terms such as "water resistant to 50 meters" or "water resistant to 200 meters" indicate that the watch can be worn underwater to various depths but it can be misleading. Generally a watch used for water sports and swimming should have at least 100m (10bar) water resistance.

Bar Rating
The bar is a metric unit of pressure, but is not approved as part of the International System of Units (SI). It is defined as exactly equal to 100,000 Pa, which is slightly less than the current average atmospheric pressure on Earth at sea level.

1 Bar Approximately Equals
- 0.987 ATM
- 14.5038 PSI Absolute
- 29.53 inHg
- 750.06 mmHg
- 750.06 Torr
- 1,019.72 centimetres of water (cmH2O).

Atmospheres (ATM)
The ATM of a watch is short for Atmospheres and is a measure of the level of water pressure a watch is designed to withhold. A higher ATM means that a watch can withhold more water pressure, whilst a lower ATM mean that it was designed to withstand less pressure.

Japanese Industrial Standard (JIS)
The Japan Industrial Standards (JIS) for water resistance uses a "0" to "8" scale to define the level of water ingress protection built into each product.

JIS Grade 0	Non-protected
JIS Grade 1	Vertically dripping water shall have no harmful effect (Drip resistant 1)
JIS Grade 2	Dripping water at an angle up to 15 degrees from vertical shall have no harmful effect (Drip resistant 2)
JIS Grade 3	Falling rain at an angle up to 60 degrees from vertical shall have no harmful effect (Rain resistant)
JIS Grade 4	Splashing water from any direction shall have no harmful effect (Splash resistant) ● Protected against solid foreign objects 1.0 mm diameter and greater.
JIS Grade 5	Direct jetting water from any direction shall have no harmful effect (Jet resistant) ● Dust protected. Ingress of dust is not totally prevented, but dust shall not penetrate in a quantity to interfere with satisfactory operation of the apparatus or to impair safety.
JIS Grade 6	Direct jetting water from any direction shall not enter the enclosure (Water tight) ● Dust tight. No ingress of dust.
JIS Grade 7	Water shall not enter the enclosure when it is immersed in water under defined conditions (Immersion resistant)
JIS Grade 8	The equipment is usable for continuous submersion in water under specified pressure (Submersible)

IP Code (Ingress Protection Marking)

Classifies and rates the degree of protection provided against intrusion (body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures.

First Digit
Solid particle protection
- The first digit indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects.

Protects Against
X - No Data
0 - No Protection
1 - Objects >50 mm
2 - Objects >12.5 mm
3 - Objects >2.5 mm
4 - Objects >1 mm
5 - Dust Protected
6 - Dust Tight

Second Digit
Liquid ingress protection
- The second digit indicates the level of protection that the enclosure provides against harmful ingress of water. The ratings for water ingress are not cumulative beyond IPX6. A device which is compliant with IPX7, covering immersion in water, need not be compliant with IPX5 or IPX6, covering exposure to water jets.

Protects Against
X - No Data
0 - No Protection
1 - Dripping water
2 - Dripping water when tilted at 15°
3 - Spraying water
4 - Splashing of water
5 - Water jets
6 - Powerful water jets
6K - Powerful water jets with increased pressure
7 - Immersion, up to 1 m depth
8 - Immersion, 1 m or more depth
9K - Powerful high temperature water jets

Additional Letters
D - Wire
f - Oil resistant
H - High voltage device
M - Device moving during water test
S - Device standing still during water test
W - Weather conditions

North America (NEMA Rating)

In the USA, the National Electrical Manufacturers Association defines NEMA enclosure types in NEMA standard number 250. The following table outlines which IEC 60529 IP code each respective NEMA rating meets. Ratings between the two standards are not directly equivalent: NEMA ratings also require additional product features and tests (such as functionality under icing conditions, enclosures for hazardous areas, knock-outs for cable connections and others) not addressed by IP ratings.

NEMA / IP Code Equivalency
- 1 = IP20
- 2 = IP22
- 3, 3X, 3S, 3SX = IP55
- 3R, 3RX = IP24
- 4, 4X = IP66
- 5 = IP53
- 6 = IP67
- 6P = IP68
- 12, 12K, 13 = IP54

Resistance Equivalency

Water Resistance Rating

Depth Rating	Bar Rating	Atmospheres (ATM)	PSI	Japanese Industrial Standard (JIS)	Suitability	Remarks
Non-Water Resistant	0 Bar	0 Atmospheres	0 PSI	JIS Grade 0	Avoid direct contact with all water.	
Water Resistant (W.R) 10m-30m (32-98ft)	1-3 Bar	~1-3 Atmospheres	14.7-44.1 PSI	JIS Grade 1 JIS Grade 2 JIS Grade 3	Can withstand perspiration, face washing water drops, rain, etc., in daily life, but cannot be used for water-using works, water sports, skin diving, and other types of diving. Do not use it under conditions in which the water pressure changes sharply.	Standing at sea level, your watch is already experiencing 1 atmosphere.
30m (98ft)	3 Bar	~3 Atmospheres	44.1 PSI	JIS Grade 4 JIS Grade 5 JIS Grade 6	Suitable for everyday use. Splash/rain resistant.	Not suitable for showering, bathing, swimming, snorkelling, water related work, fishing, and diving.
50m (164ft)	5 Bar	~5 Atmospheres	73.5 PSI	JIS Grade 7	Suitable for everyday use, showering, bathing, snorkelling, water related work, fishing. Splash/rain resistant.	Not suitable for diving or swimming.
100m (328ft)	10 Bar	~10 Atmospheres	147.0 PSI	JIS Grade 8	Suitable for recreational surfing, snorkelling, sailing and water sports.	Not suitable for diving, it can be taken swimming but it's not recommended.
200m (980ft)	20 Bar	~20 Atmospheres	294 PSI	JIS Grade 8	Suitable for professional marine activity, serious surface water sports and skin diving.	Suitable for skin diving.
300m (984ft)	30 Bar	~30 Atmospheres	441 PSI	JIS Grade 8	Suitable for professional marine activity, serious surface water sports and skin diving.	Suitable for skin diving.
1,000m (3280ft)	100 Bar	~100 Atmospheres	1470 PSI	JIS Grade 8	Suitable for all the above including deep sea diving.	
2,000m (6561ft)	200 Bar	~200 Atmospheres	2940 PSI	JIS Grade 8	Suitable for all the above including deep sea diving.	
Diver's 100 m				JIS Grade 8	Minimum ISO standard (ISO 6425) for scuba diving at depths not suitable for saturation diving.	Diver's 100 m and 150 m watches are generally old(er) watches.
Diver's 200 m or 300 m				JIS Grade 8	Suitable for scuba diving at depths not suitable for saturation diving.	Typical ratings for contemporary diver's watches.
Diver's 300+ m for mixed-gas diving				JIS Grade 8	Suitable for saturation diving (helium enriched environment).	Watches designed for mixed-gas diving will have the DIVER'S WATCH xxx M FOR MIXED-GAS DIVING additional marking to point this out.

ISO 2281

The International Organization for Standardization issued a standard for water-resistant watches which also prohibits the term waterproof to be used with watches, which many countries have adopted. This standard was introduced in 1990 as the ISO 2281:1990 and only designed for watches intended for ordinary daily use and are resistant to water during exercises such as swimming for a short period. They may be used under conditions where water pressure and temperature vary; German Industrial Norm DIN 8310 is an equivalent standard.

However, whether they bear an additional indication of overpressure or not, they are not intended for submarine diving. The ISO 2281 standard specifies a detailed testing procedure for each mark that defines not only pressures but also test duration, water temperature, and other parameters. Besides this ISO 2859-2 Sampling plans indexed by limiting quality (LQ) for isolated lot inspection and ISO 2859-3 Sampling procedures for inspection by attributes – Part 3: Skip-lot sampling procedures concerning procedures regarding lot sampling testing come into play, since not every single watch has to be tested for ISO 2281 approval.

- Resistance when immersed in water at a depth of 10 cm. Immersion of the watch in 10 cm of water for 1 hour.
- Resistance to different temperatures. Immersion of the watch in 10 cm of water at the following temperatures for 5 minutes each, 40 °C, 20 °C and 40 °C again, with the transition between temperatures not to exceed 1 minute. No evidence of water intrusion or condensation is allowed.
- Resistance to water overpressure. Immersion of the watch in a suitable pressure vessel and subjecting it within 1 minute to the rated pressure for 10 minutes, or to 2 bar in case where no additional indication is given. Then the overpressure is reduced to the ambient pressure within 1 minute. No evidence of water intrusion or condensation is allowed.

- Condensation test. The watch shall be placed on a heated plate at a temperature between 40 °C and 45 °C until the watch has reached the temperature of the heated plate (in practice, a heating time of 10 minutes to 20 minutes, depending on the type of watch, will be sufficient). A drop of water, at a temperature between 18 °C and 25 °C shall be placed on the glass of the watch. After about 1 minute, the glass shall be wiped with a dry rag. Any watch which has condensation on the interior surface of the glass shall be eliminated.
- Resistance of operative parts. Immersion of the watch in 10 cm of water with a force of 5 N perpendicular to the crown and pusher buttons (if any) for 10 minutes.
- Resistance to air overpressure. Exposing the watch to an overpressure of 2 bar. The watch shall show no air-flow exceeding 50 μg/min.

- No magnetic or shock resistance properties are required.
- No negative pressure test is required.
- No corrosion test is required.

ISO 6425

The standards and features for diving watches are regulated by the ISO 6425 – Divers' watches international standard. This standard was introduced in 1996. ISO 6425 defines such watches as: A watch designed to withstand diving in water at depths of at least 100 m and possessing a system to control the time. Diving watches are tested in static or still water under 125% of the rated (water) pressure, thus a watch with a 200-metre rating will be water resistant if it is stationary and under 250 metres of static water. ISO 6425 testing of the water resistance or water-tightness and resistance at a water overpressure as it is officially defined is fundamentally different from non-dive watches, because every single watch has to be tested. Testing diving watches for ISO 6425 compliance is voluntary and involves costs, so not every manufacturer present their watches for certification according to this standard.

● Reliability under water. The watches under test shall be immersed in water to a depth of 30±2 cm for 50 hours at 18 to 25 °C and all the mechanisms shall still function correctly. The condensation test shall be carried out before and after this test to ensure that the result is related to the above test.
● Resistance to thermal shock. Immersion of the watch in 30±2 cm of water at the following temperatures for 10 minutes each, 40 °C, 5 °C and 40 °C again. The time of transition from one immersion to the other shall not exceed 1 minute. No evidence of water intrusion or condensation is allowed.
● Water-tightness and resistance at a water overpressure. The watches under test shall be immersed in water contained in a suitable vessel. Then an overpressure of 125% of the rated pressure shall be applied within 1 minute and maintained for 2 hours. Subsequently, the overpressure shall be reduced to 0.3 bar within 1 minute and maintained at this pressure for 1 hour. The watches shall then be removed from the water and dried with a rag. No evidence of water intrusion or condensation is allowed.

● Resistance of crowns and other setting devices to an external force. The watches under test shall be subjected to an overpressure in water of 125% of the rated pressure for 10 minutes and to an external force of 5 N perpendicular to the crown and pusher buttons (if any). The condensation test shall be carried out before and after this test to ensure that the result is related to the above test.
● An optional test originating from the ISO 2281 tests (but not required for obtaining ISO 6425 approval) is exposing the watch to an overpressure of 200 kPa. The watch shall show no air-flow exceeding 50 μg/min.
● Condensation test. The watch shall be placed on a heated plate at a temperature between 40 and 45 °C until the watch has reached the temperature of the heated plate (in practice, a heating time of 10 minutes to 20 minutes, depending on the type of watch, will be sufficient). A drop of water, at a temperature of 18 to 25 °C shall be placed on the glass of the watch. After about 1 minute, the glass shall be wiped with a dry rag. Any watch which has condensation on the interior surface of the glass shall be eliminated.

Diver's Watches

Diving at a great depth and for a long period is done in a diving chamber, with the (saturation) diver spending time alternately in the water and in a pressurized environment, breathing a gas mixture. In this case, the watch is subjected to the pressure of the gas mixture and its functioning can be disturbed. Consequently, it is recommended to subject the watch to a special extra test. ISO 6425 defines a diver's watch for mixed-gas diving as: A watch required to be resistant during diving in water to a depth of at least 100 m and to be unaffected by the overpressure of the mixed gas used for breathing.

● Test of operation at a gas overpressure. The watch is subject to the overpressure of gas which will actually be used, i.e. 125% of the rated pressure, for 15 days. Then a rapid reduction in pressure to the atmospheric pressure shall be carried out in a time not exceeding 3 minutes. After this test, the watch shall function correctly. An electronic watch shall function normally during and after the test. A mechanical watch shall function normally after the test (the power reserve normally being less than 15 days).
● Test by internal pressure (simulation of decompression). Remove the crown together with the winding and/or setting stem. In its place, fit a crown of the same type with a hole. Through this hole, introduce the gas mixture which will actually be used and create an overpressure of the rated pressure/20 bar in the watch for a period of 10 hours. Then carry out the test at the rated water overpressure. In this case, the original crown with the stem shall be refitted beforehand. After this test, the watch shall function correctly.
● Marking. Watches used for mix-gas diving which satisfy the test requirements are marked with the words "DIVER'S WATCH xxx M FOR MIXED-GAS DIVING". The letters xxx are replaced by the diving depth, in metres, guaranteed by the manufacturer. The composition of the gas mixture used for the test shall be given in the operating instructions accompanying the watch.

Waterproofing

Information on how to waterproof anything from electronics to tents.

8 Water Flow

Water Flow

Waves

Tides

Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun, and the rotation of the Earth. Tide tables can be used for any given locale to find the predicted times and amplitude (or "tidal range"). The predictions are influenced by many factors including the alignment of the Sun and Moon, the phase and amplitude of the tide (pattern of tides in the deep ocean), the amphidromic systems of the oceans, and the shape of the coastline and near-shore bathymetry.

They are however only predictions, the actual time and height of the tide is affected by wind and atmospheric pressure. Many shorelines experience semi-diurnal tides – two nearly equal high and low tides each day. Other locations have a diurnal tide – one high and low tide each day. A "mixed tide" – two uneven magnitude tides a day – is a third regular category.

Tides vary on timescales ranging from hours to years due to a number of factors, which determine the lunitidal interval. To make accurate records, tide gauges at fixed stations measure water level over time. Gauges ignore variations caused by waves with periods shorter than minutes. These data are compared to the reference (or datum) level usually called mean sea level.

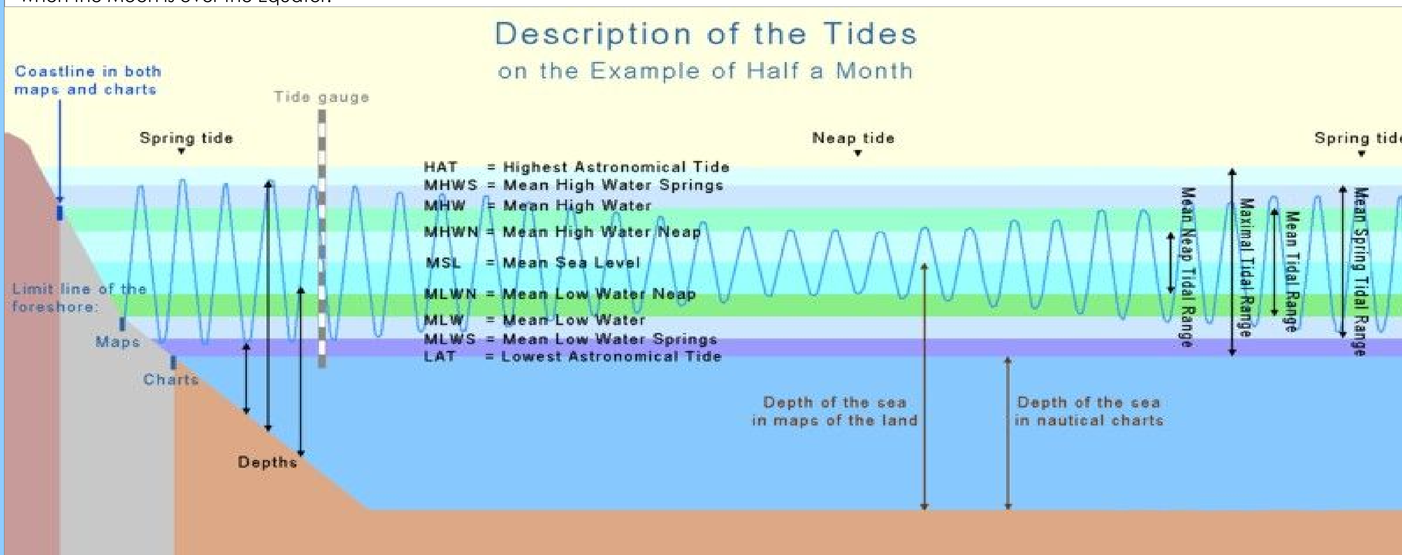
While tides are usually the largest source of short-term sea-level fluctuations, sea levels are also subject to forces such as wind and barometric pressure changes, resulting in storm surges, especially in shallow seas and near coasts. Tidal phenomena are not limited to the oceans, but can occur in other systems whenever a gravitational field that varies in time and space is present. For example, the shape of the solid part of the Earth is affected slightly by Earth tide, though this is not as easily seen as the water tidal movements.

Characteristics

Tide changes proceed via the following stages:
- Sea level rises over several hours, covering the intertidal zone; flood tide.
- The water rises to its highest level, reaching high tide.
- Sea level falls over several hours, revealing the intertidal zone; ebb tide.

The water stops falling, reaching low tide.

Oscillating currents produced by tides are known as tidal streams. The moment that the tidal current ceases is called slack water or slack tide. The tide then reverses direction and is said to be turning. Slack water usually occurs near high water and low water. But there are locations where the moments of slack tide differ significantly from those of high and low water. Tides are commonly semi-diurnal (two high waters and two low waters each day), or diurnal (one tidal cycle per day). The two high waters on a given day are typically not the same height (the daily inequality); these are the higher high water and the lower high water in tide tables. Similarly, the two low waters each day are the higher low water and the lower low water. The daily inequality is not consistent and is generally small when the Moon is over the Equator.



- Highest astronomical tide (HAT) – The highest tide which can be predicted to occur. Note that meteorological conditions may add extra height to the HAT.
- Mean high water springs (MHWS) – The average of the two high tides on the days of spring tides.
- Mean high water neaps (MHWN) – The average of the two high tides on the days of neap tides.
- Mean high water neaps (MHWN) – The average of the two high tides on the days of neap tides.
- Mean sea level (MSL) – This is the average sea level. The MSL is constant for any location over a long period.
- Mean low water neaps (MLWN) – The average of the two low tides on the days of neap tides.
- Mean low water springs (MLWS) – The average of the two low tides on the days of spring tides.
- Lowest astronomical tide (LAT) and Chart Datum (CD) – The lowest tide which can be predicted to occur.

Head of Tide

Head of tide or tidal limit is the farthest point upstream where a river is affected by tidal fluctuations, or where the fluctuations are less than a certain amount. This applies to rivers which flow into tidal bodies such as oceans, bays and deltas. Though this point may vary due to storms, spring tides, and seasonal or annual differences in water flows, there is generally an average point which is accepted as the head of tide. A river's tidal data are recorded at various locations downstream of this point.

A river's head of tide may be considered the upper boundary of its estuary. The head of tide is important in surveying, navigation, and fisheries management, and thus many jurisdictions establish a legal head of tide. As the head of tide is useful for navigation, separate maps can be made of the tidal zones up to the head of tide, such as was done in New Jersey. The head of tide may be many miles upstream from the river's mouth. For example, on the Hudson River, it is located 140 miles (225 km) upstream, near Albany, New York. On the Saint Lawrence River, tides affect shipping upstream past Quebec City, which is located several hundred miles inland from the Gulf of Saint Lawrence and the Atlantic Ocean.

Storm Surge

A storm surge, storm flood, tidal surge or storm tide is a coastal flood or tsunami-like phenomenon of rising water commonly associated with low pressure weather systems (such as tropical cyclones and strong extratropical cyclones), the severity of which is affected by the shallowness and orientation of the water body relative to storm path, as well as the timing of tides. Most casualties during tropical cyclones occur as the result of storm surges. It is a measure of the rise of water beyond what would be expected by the normal movement related to tides. The two main meteorological factors contributing to a storm surge are a long fetch of winds spiralling inward toward the storm, and a low-pressure-induced dome of water drawn up under and trailing the storm's centre.

Mechanics

At least five processes can be involved in altering tide levels during storms:	• The atmospheric pressure effect • The direct wind effect • The rainfall effect. • The effect of the Earth's rotation • The effect of waves near the shore

The pressure effects of a tropical cyclone will cause the water level in the open ocean to rise in regions of low atmospheric pressure and fall in regions of high atmospheric pressure. The rising water level will counteract the low atmospheric pressure such that the total pressure at some plane beneath the water surface remains constant. This effect is estimated at a 10 mm (0.39 in) increase in sea level for every millibar (hPa) drop in atmospheric pressure. Strong surface winds cause surface currents at a 45° angle to the wind direction, by an effect known as the Ekman Spiral.

Wind stresses cause a phenomenon referred to as "wind set-up", which is the tendency for water levels to increase at the downwind shore and to decrease at the upwind shore. Intuitively, this is caused by the storm blowing the water toward one side of the basin in the direction of its winds. Because the Ekman Spiral effects spread vertically through the water, the effect is proportional to depth. The pressure effect and the wind set-up on an open coast will be driven into bays in the same way as the astronomical tide. The Earth's rotation causes the Coriolis effect, which bends currents to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. When this bend brings the currents into more perpendicular contact with the shore, it can amplify the surge, and when it bends the current away from the shore it has the effect of lessening the surge.

The effect of waves, while directly powered by the wind, is distinct from a storm's wind-powered currents. Powerful wind whips up large, strong waves in the direction of its movement. Although these surface waves are responsible for very little water transport in open water, they may be responsible for significant transport near the shore. When waves are breaking on a line more or less parallel to the beach, they carry considerable water shoreward. As they break, the water particles moving toward the shore have considerable momentum and may run up a sloping beach to an elevation above the mean water line, which may exceed twice the wave height before breaking.

The rainfall effect is experienced predominantly in estuaries. Hurricanes may dump as much as 12 in (300 mm) of rainfall in 24 hours over large areas and higher rainfall densities in localized areas. As a result, surface runoff can quickly flood Streams and rivers. This can increase the water level near the head of tidal estuaries as storm-driven waters surging in from the ocean meet rainfall flowing downstream into the estuary.

Extratropical Storms
Similar to tropical cyclones, extratropical cyclones cause an offshore rise of water. However, unlike most tropical cyclone storm surges, extratropical cyclones can cause higher water levels across a large area for longer periods of time, depending on the system. In North America, extratropical storm surges may occur on the Pacific and Alaska coasts, and north of 31°N on the Atlantic Coast. Coasts with sea ice may experience an "ice tsunami" causing significant damage inland. Extratropical storm surges may be possible further south for the Gulf coast mostly during the wintertime, when extratropical cyclones affect the coast, such as in the 1993 Storm of the Century.

Reverse Storm Surge
Water can also be sucked away from shore prior to a storm surge. This was the case on the western Florida coast in 2017, just before Hurricane Irma made landfall, uncovering land usually underwater. This phenomenon is known as a reverse storm surge, or a negative storm surge.

Rips

A rip current, often simply called a rip, or by the misnomer rip tide, is a specific kind of water current which can occur near beaches with breaking waves. A rip is a strong, localized, and narrow current of water which moves directly away from the shore, cutting through the lines of breaking waves like a river running out to sea, and is strongest near the surface of the water. Rip currents can be hazardous to people in the water. Swimmers who are caught in a rip current and who do not understand what is going on, and who may not have the necessary water skills, may panic, or exhaust themselves by trying to swim directly against the flow of water.

Because of these factors, rips are the leading cause of rescues by lifeguards at beaches, and rips are the cause of an average of 46 deaths by drowning per year in the United States. A rip current is not the same thing as undertow, although some people use the term incorrectly when they often mean a rip current. Contrary to popular belief, neither rip nor undertow can pull a person down and hold them under the water. A rip simply carries floating objects, including people, out beyond the zone of the breaking waves.

Cause

A rip current forms because wind and breaking waves push surface water towards the land, and this causes a slight rise in the water level along the shore. This excess water will tend to flow back to the open water via the route of least resistance. When there is a local area which is slightly deeper, or a break in an offshore sand bar or reef, this can allow water to flow offshore more easily, and this will initiate a rip current through that gap.

Water that has been pushed up near the beach flows along the shore towards the outgoing rip as "feeder currents", and then the excess water flows out at a right angle to the beach, in a tight current called the "neck" of the rip. The "neck" is where the flow is most rapid. When the water in the rip current reaches outside of the lines of breaking waves, the flow disperses sideways, loses power, and dissipates in what is known as the "head" of the rip.

Rip currents can often occur on a gradually shelving shore where breaking waves approach the shore parallel to it, or where underwater topography encourages outflow at a specific area. Rip currents can form at the coasts of oceans, seas, and large lakes, whenever there are waves of sufficient energy. The location of rip currents can be difficult to predict; whereas some tend to recur always in the same places, others can appear and disappear suddenly at various locations along the beach.

The appearance and disappearance of rip currents is dependent on the bottom topography and the exact direction that the surf and swells are coming in from. Rip currents can potentially occur wherever there is strong longshore variability in wave breaking. This variability may be caused by such features as sandbars, by piers and jetties, and even by crossing wave trains, and are often located in places such as where there is a gap in a reef or low area on a sandbar. Rip currents may deepen the channel through a sandbar once they have formed.

Rip currents are usually quite narrow, but tend to be more common, wider, and faster, when and where breaking waves are large and powerful. Local underwater topography makes some beaches more likely to have rip currents; a few beaches are notorious in this respect. Although rip tide is a misnomer, in areas of significant tidal range, rip currents may only occur at certain stages of the tide, when the water is shallow enough to cause the waves to break over a sand bar, but deep enough for the broken wave to flow over the bar. (In parts of the world with a big difference between high tide and low tide, and where the shoreline shelves gently, the distance between a bar and the shoreline may vary from a few meters to a kilometre or more, depending whether it is high tide or low tide.)

A fairly common misconception is that rip currents can pull a swimmer down, under the surface of the water. This is not true, and in reality a rip current is strongest close to the surface, as the flow near the bottom is slowed by friction. The surface of a rip current may appear to be a relatively smooth area of water, without any breaking waves, and this deceptive appearance may cause some beach goers to believe it is a suitable place to enter the water.

Visible Signs

Rip currents have a characteristic appearance, and, with some experience, they can be visually identified from the shore before entering the water. This is useful to lifeguards, swimmers, surfers, boaters, divers and other water users, who may need to avoid a rip, or in some cases make use of the current flow. Rip currents often look a bit like a road or a river running straight out to sea, and are easiest to notice and identify when the zone of breaking waves is viewed from a high vantage point. The following are some characteristics that can be used to visually identify a rip:

- A noticeable break in the pattern of the waves — the water often looks flat at the rip, in contrast to the lines of breaking waves on either side of the rip.
- A "river" of foam — the surface of the rip sometimes looks foamy, because the current is carrying foam from the surf out to open water.
- Different colour — the rip may differ in colour from the surrounding water; it is often more opaque, cloudier, or muddier, and so, depending on the angle of the sun, the rip may show as darker or lighter than the surrounding water.
- It is sometimes possible to see that foam or floating debris on the surface of the rip is moving out, away from the shore. In contrast, in the surrounding areas of breaking waves, floating objects are being pushed towards the shore.

These characteristics are helpful in learning to recognize and understand the nature of rip currents so that a person can recognize the presence of rips before entering the water. In the United States, some beaches have signs created by the National Oceanic and Atmospheric Administration (NOAA) and United States Lifesaving Association, explaining what a rip current is and how to escape one. These signs are titled, "Rip Currents; Break the Grip of the Rip". Beachgoers can get information from lifeguards, who are always watching for rip currents, and who will move their safety flags so that swimmers can avoid rips.

Dangers

WATER Water Flow Rips Dangers

Rip currents are a potential source of danger for people in shallow water with breaking waves in seas, oceans and lakes. Rip currents are the proximate cause of 80% of rescues carried out by beach lifeguards. Rip currents typically flow at about 0.5 m/s (1.6 ft/s), but they can be as fast as 2.5 m/s (8.2 ft/s), which is faster than any human can swim. However, most rip currents are fairly narrow, and even the widest rip currents are not very wide; usually swimmers can exit the rip easily by swimming at a right angle to the flow, parallel to the beach. Swimmers who are unaware of this fact may exhaust themselves trying unsuccessfully to swim against the flow. The flow of the current also fades out completely at the head of the rip, outside the zone of the breaking waves, so there is a definite limit to how far the swimmer will be taken out to sea by the flow of a rip current.

In a rip current, death by drowning occurs when a person has limited water skills and panics, or when a swimmer persists in trying to swim to shore against a strong rip current, thus eventually becoming exhausted and unable to stay afloat. According to NOAA, over a 10-year average, rip currents cause 46 deaths annually in the United States, and 64 people died in rip currents in 2013. However, the United States Lifesaving Association "estimates that the annual number of deaths due to rip currents on our nation's beaches exceeds 100." A study published in 2013 in Australia revealed that rips killed more people on Australian territory than bushfires, floods, cyclones and shark attacks combined.

WATER Water Flow Rips Dangers

People caught in a rip current may notice that they are moving away from the shore quite rapidly. It is often not possible to swim directly back to shore against a rip current, so this is not recommended. Contrary to popular misunderstanding, a rip does not pull a swimmer under the water, it simply carries the swimmer away from the shore in a narrow band of moving water. The rip is like a moving treadmill, which the swimmer can get out of by swimming across the current, parallel to the shore, in either direction, until out of the rip current, which is usually not very wide. Once out of the rip, swimming back to shore is relatively easy in areas where waves are breaking and where floating objects and swimmers are being pushed towards the shore.

As an alternative, swimmers who are caught in a strong rip can relax and go with the flow (either floating or treading water) until the current dissipates beyond the surf line, and then they can signal for help, or swim back through the surf diagonally away from the rip and towards the shore. It is necessary for coastal swimmers to understand the danger of rip currents, to learn how to recognize them and how to deal with them, and if possible to swim in only those areas where lifeguards are on duty. Experienced and knowledgeable water users, including surfers, body boarders, divers, surf lifesavers and kayakers, will sometimes use rip currents as a rapid and effortless means of transportation when they wish to get out beyond the breaking waves.

Currents

WATER Water Flow