PRACTICAL ACTION
Technology challenging poverty

# WATER TREATMENT SYSTEMS

**Water supply can be contaminated by a number of external sources before it is consumed and used by households for cooking, cleaning and drinking. Industries that don't consider the effects of pollution they create can seriously endanger the health of local communities. This technical brief outlines some water treatment solutions which can help communities have access to cleaner and safer water.**

## Looking after Water Sources

The following are best practices to follow:

- Selecting the best possible water source is more effective to start with, since water treatment systems are not perfect
- Disinfection is necessary but not always sufficient
- For an unprotected source coagulation and sand filtration should be carried out in addition to disinfection
- Water quality should be tested for faecal contamination.

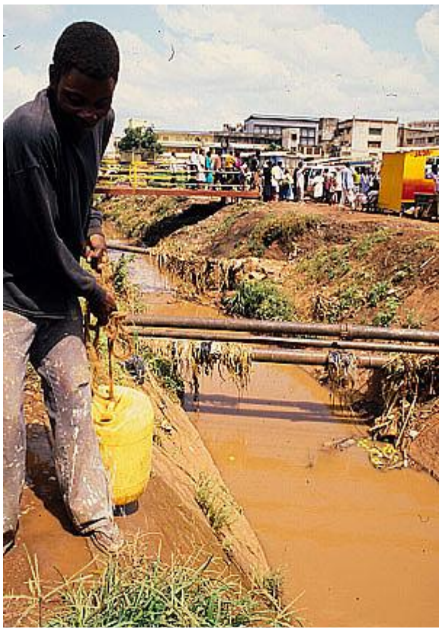

Figure 1: A man collecting water from a polluted stream in Uganda. Photo: Simon Ekless.

The best water source is one that doesn't need treatment. Rainwater that can be collected is relatively clean, whereas surface water tends to have been polluted before reaching the consumer

If the source water has been tested and found to be safe then things are obviously going to be easier. There are ways of improving the source if it is not safe; covering wells with a concrete slab, keeping animals away form the source, ensuring rubbish is not thrown down the well, the type of bucket used to extract water etc. Tubewells with hand pumps are usually quite well protected from contamination. Others sources such as surface water sources are not safe.

## Water Quality and Contaminants

### Chemical contaminants

Heavy concentrations of iron and manganese in ground water result in an unpleasant taste and give the water a brownish colour which can be passed on to clothes and food. They are often removed by aeration which makes that iron and manganese insoluble resulting in a fine, dark sediment. Aeration can be achieved by allowing the water to fall from a height into a storage tank. See the section in this document on aeration.

Other chemicals such as salts, fluoride and nitrates are more difficult to remove from water at the village level.

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technical brief

Nitrites and nitrates have been associated with methaemoglobinaemia; this is when a larger proportion of haemoglobin is caused to turn into methaemoglobin which means less oxygen is able to be carried in the blood. This leads to cyanosis, especially in bottle-fed infants of 3-6 months old, and is also known as 'blue baby syndrome'. Nitrates can leach into groundwater due to the use of fertilisers or from wastewater. It is better to prevent the intrusion of nitrite and nitrates into the water source since it is difficult to treat. The removal of nitrates is covered in Nitrate Removal Storage: A Review of Possible Mechanisms and a Summary of Observed Changes by the Water Research Association.

Fluoride is present in all natural water but high levels can lead to mottling of teeth and skeletal fluorosis. Coagulation and activated alumina can remove excess fluoride. Activated alumina is an adsorbent; a highly porous material made from aluminium hydroxide. Activated alumina may be available and affordable for communities in developing countries (WHO, 2004). To find out more about fluoride removal, IGRAC have published Fluoride in Groundwater: Overview and evaluation of removal methods.

Arsenic also occurs naturally depending on the type of rock the water filters through. High levels of arsenic can lead to skin lesions and higher risk of cancer. Arsenic contamination and its removal are covered in a separate document; see A Small-scale Arsenic and Iron Removal Plant.

### Biological Contaminants

Faecal-borne pathogens can be transmitted by water but it must be remembered that these diseases can also be passed through any faecal-oral route.

Parasitic worms, like roundworms, flatworms and guinea worms can transmit their eggs to humans through drinking water and cause infection. They must be completely absent from any water supply.

Legionella bacteria are common in hot and warm water pipes. Infection happens through inhalation of mist or spray. It causes Legionnaires' disease which can lead to pneumonia associated with respiratory function.

Cyanobacteria, also known as blue-green algae, produce dangerous toxins called cyanotoxins. Cyanotoxins can affect humans in various ways depending on the type of toxin and on whether it has been ingested or has contact with skin.

For more detail on the various types of infection that can be transmitted by water, refer to the WHO (World Health Organisation) website and the book *Environmental Health Engineering in the Tropics*.

### Physical Contaminants

These include particles and suspended solids. This is mostly a problem when sourcing surface water and varies seasonally due to heavy rains and velocity of the water flows. Drinking turbid water is dangerous; solids in water can provide the perfect environment for bacteria to breed. Suspended solids must always be removed before disinfection.

Turbidity is measured in NTU (nephlometric turbidity units) using a turbidity tube. If water is more than 5 NTU then turbidity must be reduced before disinfection. A sedimentation test must be carried out to obtain settling times for the suspended solids and decide on whether a coagulant is needed in order to remove colloidal matter. Colloidal matter appears as a fine suspension and will take longest to settle because particles are statically charged, making them more attracted to water molecules. For more on sedimentation and coagulation see Sedimentation.

**Roofwater Harvesting**
Although there are fewer of contamination for roofwater, care must be taken to take into account contamination from the roof, gutters, piping system and storage facility. Water from rooftops should be filtered and boiled before consumption.

There is no risk from iron sheeting itself (usually a layer of oxidisation forms on the galvanized sheet), but there is a risk of bacteriological contamination if there are animal faeces on the roof - from birds, lizards, etc. A roof should be kept as clean as possible and a first flush system used to wash away the first couple of millimetres of rain during the first storm of the season.

There is evidence that using asbestos sheeting can be used without risk, as it is only through inhalation (and not through ingestion) that asbestos is harmful (WHO, 2003). The World Health Organisation concluded there is no evidence that asbestos in drinking water is carcinogenic and therefore would not publish a guideline for asbestos levels in drinking water.

Most grasses are not suitable; only certain types of hardy grasses are suitable for rain collection on thatch.

The use of lead pipes and fittings (especially if water is acidic) can result in high levels of lead in the water and can cause neurological damage.

See the technical brief Rainwater Harvesting.

## Water Treatment Methods

The World Health Organisation (WHO) ranks the treatment processes available according to their technical complexity in Table 1, the higher ranking being more complex. It is usually the case that the more complex the system, the higher the capital and operating costs.

**Table 1: Ranking of technical complexity and cost of water (WHO, 2008)**

| Ranking | Examples of Treatment Processes |
|---|---|
| 1 | Simple Chlorination<br>Plain filtration (rapid sand, slow sand) |
| 2 | Pre-chlorination plus filtration<br>Aeration |
| 3 | Chemical coagulation<br>Process optimisation for control of DBPs |
| 4 | Granular activated carbon (GAC) treatment<br>Iron exchange |
| 5 | Ozonation |
| 6 | Advanced oxidation process<br>Membrane treatment |

In order to ensure water is acceptably free from both sediments and pathogens, a multi-stage treatment is best to consider. This document will outline several processes which should be considered as different stages of the cleaning process. Choosing which processes to adopt will depend on the quality of the water being treated, what contaminants need to be removed, the scale of operations and capital and operating costs. Costs to bear in mind would include, but are not limited to, local labour, mechanical and construction works, chemicals, electricity and life expectancy.

The following processes for treating water will be described, with directions to links for further reading:

Aeration
Sedimentation
Coagulation
Roughing filters
Rapid sand filters
Slow sand filter
Chlorination
UV Treatment
Distillation
Reverse Osmosis
Activated carbon
Multi-Stage Filtration

## Aeration

Aeration is used in order to remove dissolved iron and manganese – these can give water an unpleasant taste and stain food and food and clothes with a brownish colour. The iron and manganese can be turned into sediment using this process which is easier to remove.

A simple aeration system can be set up on a rural basis using a system comprising of four cylinders. The top three cylinders have a mesh or sieve at the bottom that holds small stones or sand, and have ventilations slots in the side walls. The two cylinders at the top contain stones of about 25mm in diameter to a depth of 150mm and the third cylinder contains coarse sand to a depth of 300mm. Water is piped to the top of the system where it is sprayed onto the layer of stones. The water drips down though the layers of stones becoming more aerated and the sand layer removes the sediment. Water is collected in the forth cylinder at the bottom of the column where it can then be collected. The sand needs to be replaced once a month.

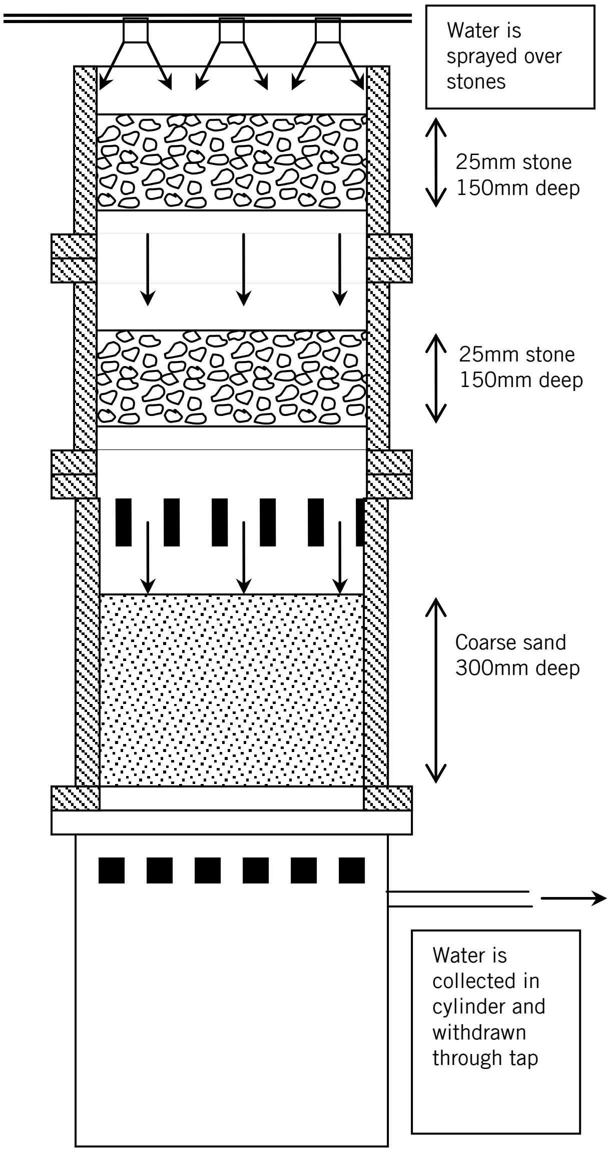


Figure 2: A cylinder aeration system. (Illustration by A. Elias based on Pickford (1977))

Other configurations of aeration tanks are described in the [Slow Sand Filtration Manual.](#)

## Sedimentation

Sedimentation is often required due to the large silt content found in water extracted from rivers. Water is passed through a large tank slow enough for solid particles to settle. It is easier to pass water through a filter once the larger solids have been removed, and this is usually done through a sedimentation process. Coagulation chemicals may be used to speed up the process but it is often the case that these are not available to rural communities.

Two types of sedimentation tank are shown in Figures 3 and 4: Horizontal flow settling tank and an upward flow clarifier.

In a horizontal tank water travels from one end of the tank to the other with a rentention time of 4-6 hours. An upward flow tank makes use of a “sludge blanket”, where a layer of floc (coagulated sediment) is formed and filters the water passing upwards. This is more efficient than the horizontal flow tanks since it has a retention time of 1-3 hours. It does however cost more and is less easy to operate than the horizontal flow tank. Water that has a silt content of more than 1000mg/l should be treated using a horizontal flow tank, since this can cause an upward flow tank to be less efficient and difficult to operate.

## Coagulation

Coagulation can be achieved by using an additive to the water which helps to bring solid matter together. This makes the clusters of particles heavier and achieves a faster settlement time. Adding iron or aluminium sulphate 10-70mg per litre results in a positive charged that will combine with the negative charged bacteria, viruses and fine clay which then fall out of the water as sediment. Water must be turbulent to mix the coagulant with the water and this can usually be done by passing water over a weir or through constrictions.

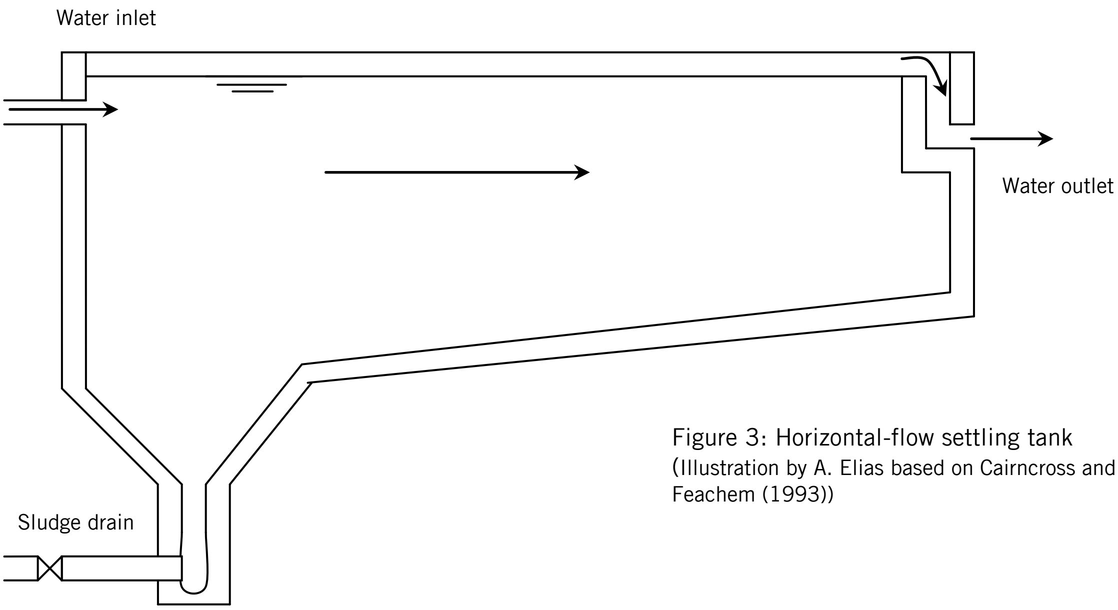


Figure 3: Horizontal-flow settling tank
(Illustration by A. Elias based on Cairncross and Feachem (1993))

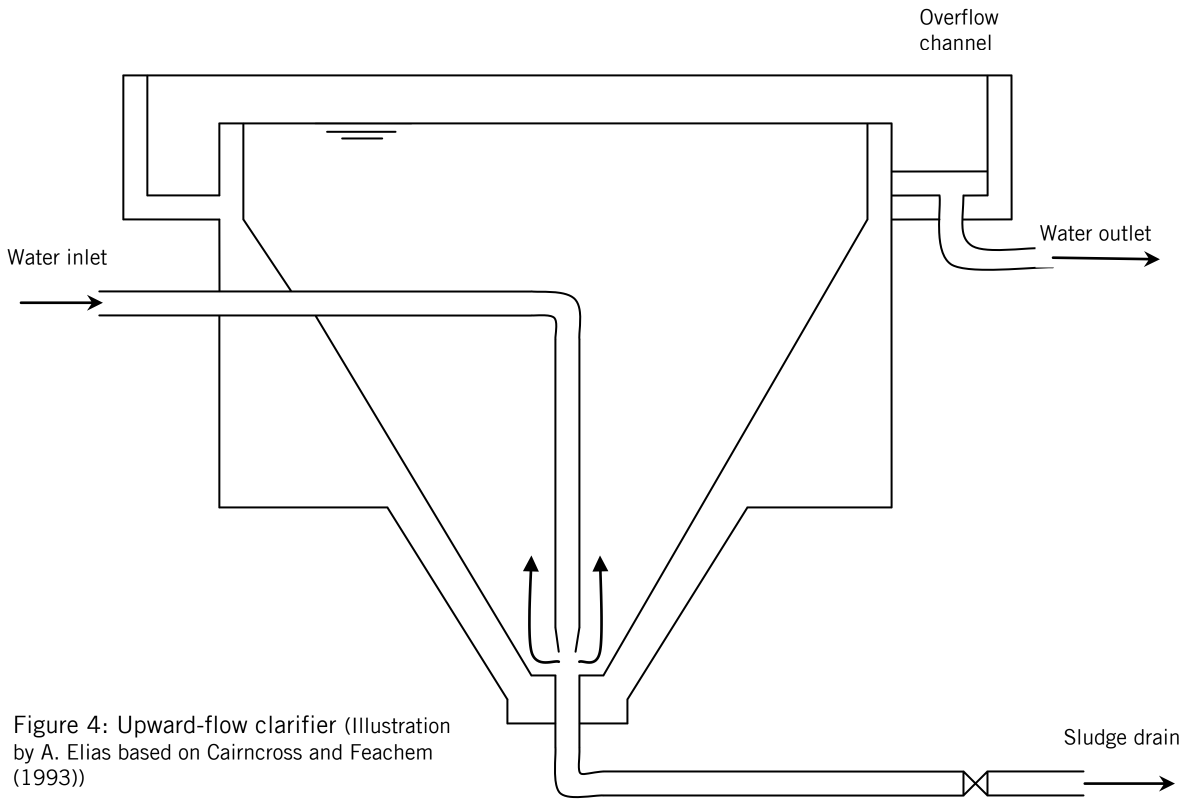


Figure 4: Upward-flow clarifier (Illustration by A. Elias based on Cairncross and Feachem (1993))

## Roughing filters

Roughing filters include a bed of coarse gravel and crushed stones to treat water with high turbidity (50 NTU). Water is passed horizontally through a tank of about 10m so it can take advantage of filtration through the medium and by gravity settling. A typical filtration rate for roughing filters is 0.3-1.0m/h (metres per hour).

Water treated this way can then be passed through a Slow Sand Filter. See Multi Stage Filtration.

## Rapid sand filters

Rapid sand filters use a coarse sand to remove suspended solids and water moves at the flow rate of 4-8 m/hr. The filter uses sand of around 0.5-1.0mm particle size and is 0.6-2.0m deep. The sand bed needs to be regularly cleaned (daily) and this is done by backwashing where reversing the flow removes the trapped matter.

Water that has been pre-treated by sedimentation and coagulation is often treated using this process. Alternatively a coagulant can be added to the water and filtered directly, but this will require more maintenance of the filter and storage for the collected solids. This method is effective at reducing turbidity and for removing iron oxides and manganese. It does not remove pathogens from water and would need to be disinfected or passed through a slow sand filter.

The operational and construction cost, along with the need for regular maintenance are often inappropriate for developing countries.

## Slow sand filter

Slow sand filtration is a very effective method of removing particulate and suspended matter. It can be used for groundwater containing suspended solids but is more often used to remove organic material and pathogens from surface water.

Water stands in a tank 1m above a sand filter bed and moves down at about 0.1- 0.2 m/hr. Different grades of sand can filter out physical impurities and they can also eliminate pathogens as they develop a layer of algae that feeds on the bacteria. This occurs at the top of the sand bed and is called a schmutzdecke. The schmutzdecke is effective at killing and retaining various bacteria, pathogens and viruses, which makes it more effective than a rapid sand filter. The sand filter will block up over time with inorganic matter but this can be removed by backwashing. Inorganic matter can be removed through rough filtering or by using sedimentation tanks.

These systems are simple in design and easy to construct using local materials. The use of special piping and equipment, mechanical maintenance and imported materials can and should be kept to a minimum, especially in hot countries where these filters work best. Operational costs include mostly cleaning out the filter bed, which can be done manually. Chemicals do not need to be added to the process but chlorination is sometimes used. Compared to other forms of treatment the amount of chlorine needed for disinfection is far less.

Sand filter systems are described at length in the document Slow Sand-Filtration Water Treatment Plants produced by Soluciones Prácticas.

Some construction guidelines are available at the following website.
http://www.biosandfilter.org/biosandfilter/index.php/item/330

## Chlorination

Chlorination is a simple disinfection treatment which needs to be carried out even after slow sand filtration. It is effective at reducing the risk of disease but limited against protozoal pathogens and some viruses (WHO, 2008). Chlorination alone will not be enough to disinfect water particularly if it is very turbid (cloudy), since sediments and flocs of particles can protect pathogens from disinfection.

Chlorine is an oxidising agent. The amount of chlorine required varies with the impurity of the water and the dose needs to be greater than the chlorine demand of the water. There will be chlorine residual which is needed to help protect against future contamination. Chlorine is cheap, reliable, readily available and easy to add to the water supply but it can produce a nasty taste and can produce unwanted by-products.

Alternative treatments include chlorine dioxide $Cl_2$ or ozone $O_3$.

## UV Treatment

UV light can be used to kill pathogens in water if the water does not have a large quantity of physical contamination which would block the light (i.e. have a high turbidity). UV light between the wavelengths of 180-320 nm can inactivate protozoa, bacteria, yeasts, viruses, algae and fungi. It can be done on a large or small scale. It does not remove chemical pollutants but it can be used as a catalyst when using an ozone treatment.

At its most basic level Solar Disinfection (or SODIS) can be carried out by placing water in transparent plastic bottles which are then left out in direct sunlight thus exposing the pathogens' to UV light which destroys them. See http://www.sodis.ch/.

MEDRIX have developed a small scale UV water treatment system.

USA Mailing Address:
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PO Box 178
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USA
Phone: (425) 485-5423
Fax: (425) 485-4972
E-mail: office@medrix.org
Website: http://www.medrix.org/water.html

Vietnam Office:
**MEDRIX**
10th Floor
Prime Business Center
Pacific Place Building
Ly Thuong Kiet Street
Hoan Kiem Dist.,
Hanoi, Vietnam

## Distillation

Distillation can remove virtually all salt, nitrates, and heavy metal such as arsenic from water as well as pathogens and other biological contaminants from water.

Distillation will remove chemicals but it may not be easy to sustain as it uses a lot of energy. However, heat could be obtained from the sun. Solar distillation is a low cost but low volume approach to treating water. Essentially water is evaporated by the sun and condenses on a cooler surface from where it is collected. A common design of a solar still is shown below. A glass or plastic plate is fixed on top of the still to increase the temperature in the still, and the bottom of the still is lined with a black material such as bituminous paint, butyl rubber, epoxy enamel, fibreglass painted black or aluminium painted black, to act as a heat absorber. It is also important that the whole still is well-insulated to improve efficiency. The sides and base of the still are typically brick or concrete. Moulding of stills from fibreglass was tried in Botswana. This was more expensive than a brick still and more difficult to insulate sufficiently, but has the advantage of the stills being transportable.

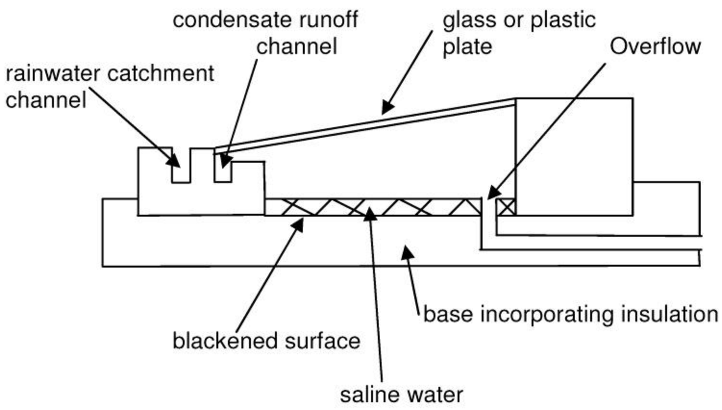


Figure 5: Schematic of a single-basin still. Illustration: Otto Ruskulis for Practical Action.

The collected water will not have any taste, so may need some salt added to make it pleasant to drink.

Also see Solar Distillation.

## Reverse Osmosis

Reverse osmosis filters everything under high pressure. Reverse osmosis is a relatively high technology approach that would need to have a sophisticated support system to maintain it. It is also inherently energy hungry. It involves forcing solvents from low concentration solution to a high concentration solution, which is the opposite of the process of osmosis. The process is used widely for seawater and brackish water.

Small-scale stand alone reverse osmosis technology using solar power was developed by RADG. They have also worked on low-cost bacteriological water testing.

**RADG - Remote Areas Development Group**
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Perth
Australia
etc@murdoch.edu.au
http://www.etc.murdoch.edu.au/etcV03/pages/radg/radgpages/radghome.html

CSMCRI developed a small-scale bullock-driven reverse osmosis unit in India.

**Central Salt & Marine Chemicals Research Institute**
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Email: salt@csir.res.in, salt@csmcri.org
Website: http://www.csmcri.org/

## Activated carbon

A study by WEDC has been carried out to show that Granule Activated Carbon can be used to filter iron and manganese. It has been used in Europe and North America since it is particularly good at removing soluble organic matter. There have also been studies that show it removes several cyanotoxins.

Activated carbon is able to adsorb compounds due to its porous nature and large surface area. It can be added as a powder or as granules. Activated carbon is made by heating up carbonaceous materials like wood, coal, peat or coconut shells. Organic compounds are adsorbed by the carbon and then removed by separate treatment process. In the case of Powder Activated Carbon, the powder is added as slurry and then removed by flocculation or mechanically. Powder Activated Carbon (PAC) is therefore suitable for surface water treatment. Granule Activated Carbon (GAC) is used in fixed beds, either in replacement of sand or as separate adsorption filters. Some GACs can be reactivated by burning off the organic compounds, but some GACs and PAC can only be used once. The treatment can effectively remove pesticides and improves the taste of water but requires maintenance and regular replacement of the carbon, making it less suitable for situations in developing countries.

It is possible to produce activated charcoal on a small scale using by-products from crops, like seed husks or coconut shells. Often pit charcoaling is done in an uncontrolled environment, i.e. oxygen entering the system cannot be 100% controlled and there is not systematic control of temperature reached in order to activate the charcoal afterwards. Once made, the charcoal needs to be ground into a particle size of 0.2 to 2mm and heated again to above 150°C; this will increase the pore size needed for effective adsorption.

## Multi-Stage Filtration

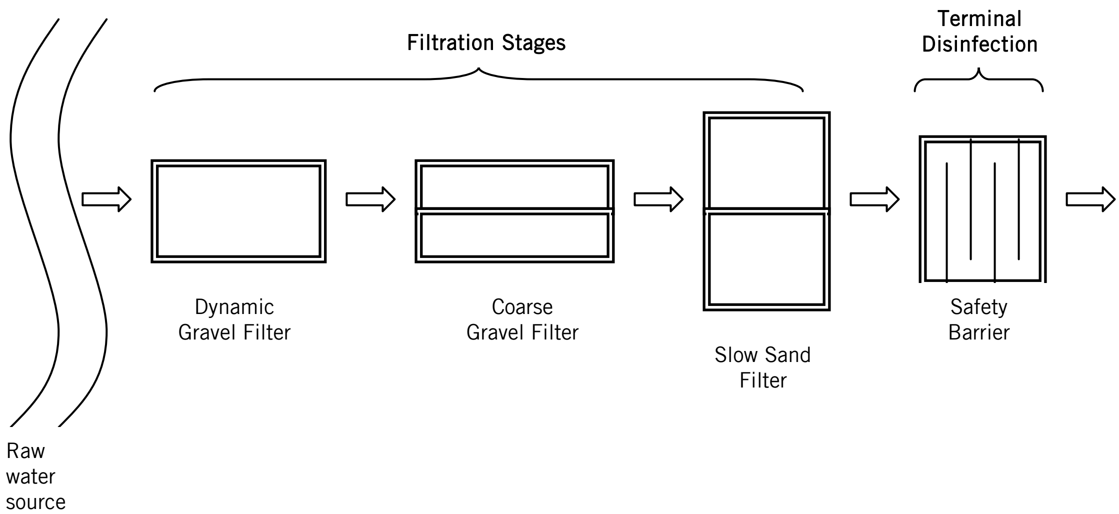


Figure 6: Layout for a multi-stage filtration system (Illustration by A. Elias based on Galvis, G. IRC 2006)

This system combines some of the less complex processes of water treatment: coarse gravel filtration and slow sand filtration. Removing large particulates through sedimentation or sand traps should still be carried out before running water through a multi-filtration system. It is most suited to rural communities and small to medium sized towns where the use of chemical treatment or more complex technologies would not be feasible.

The International Water and Sanitation Centre has published some guidelines on how to build such a system, including the design process, which can be downloaded at: http://www.irc.nl/page/31601

## References and further information

Caincross, S., Feachem, R. (1993) *Environmental Health Engineering in the Tropics: An Introductory Text*, 2nd Edition. West Sussex, John Wiley.

McConnachie, G.L., Warhurst, A.M., Pollard, S.J.T. and Chipofya, V.H. (1996) *Activated carbon from Moringa husks*, 22nd WEDC conf., "Reaching the unreached - challenges for the 21st Century", New Delhi, India, WEDC

Pickford, J. (1977) *Water Treatment in Developing Countries, in Water, Wastes and Health in Hot* Climates. London, John Wiley, London.

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WHO (2004) *Fluoride in Drinking-water*. Geneva, World Health Organisation. [online] Available at:

WHO (2008) *Guidelines for Drinking-water Quality* - *3rd Ed*. Geneva, World Health Organisation. [online] Available at:

Oxfam
Water Treatment in Emergencies PDF

UNICEF
Resources on water sanitation and hygiene URL
Arsenic Primer PDF
Ceramic Water Pots in Cambodia PDF

WEDC
Wastewater Treatment Options PDF

World Health Organisation
Guidelines for Drinking-water Quality URL
Fluoride in Drinking-water PDF

**IRC International Water and Sanitation Centre**
Browse the IRC digital library to find more resources at: http://www.irc.nl/page/100

Arsenic in Drinking Water URL
Waste Stabilisation Ponds URL
Smart Water Solutions URL

Lifewater International
http://www.lifewater.org/resources/tech_library.html

Water Treatment Overview
Methods of Water Treatment (RWS.3.M) PDF
Determining the Need for Water Treatment (RWS.3.P.1) PDF
Taking a Water Sample (RWS.3.P.2) PDF
Analyzing a Water Sample (RWS.3.P.3) PDF
Planning a Water Treatment System (RWS.3.P.4) PDF
Water Treatment in Emergencies (RWS.3.D.5) PDF

Household Water Treatment
Designing Basic Household Water Treatment Systems (RWS.3.D.1) PDF
Constructing a Household Sand Filter (RWS.3.C.1) PDF
Operating and Maintaining Household Treatment Systems (RWS.3.O.1) PDF

Sedimentation Basins
Designing a Small Community Sedimentation Basin (RWS.3.D.2) PDF
Constructing a Sedimentation Basin (RWS.3.C.2) PDF
Operating and Maintaining a Sedimentation Basin (RWS.3.O.2) PDF

Slow Sand Filters
Designing a Slow Sand Filter (RWS.3.D.3) PDF
Constructing a Slow Sand Filter (RWS.3.C.3) PDF
Operating and Maintaining a Slow Sand Filter (RWS.3.O.3) PDF

Disinfection Units
Designing a Small Community Disinfection Unit (RWS.3.D.4) PDF
Constructing a Disinfection Unit (RWS.3.C.4) PDF
Operating and Maintaining a Chemical Disinfection Unit (RWS.3.O.4) PDF

## Further Reading


- *Solar Disinfection of Water – a Case Study from Kenya* Stephen Burgess and Collins Onyonge Waterlines Vol. 22 No 4 April 2004
- *Promoting SODIS in Guatemalan Villages* Sharon Price, Liasa Rudge, Este Capilla Prades Waterlines Vol. 22 No 4 April 2004
- *Water quality and treatment* a selection of Practical Action Technical Briefs


This document was written by Aimi Elias for Practical Action November 2010.


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