Water Treatment FAQ

By Patton Turner

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Water Storage

Quantity

A water ration of as little as a pint per day has allowed life raft survivors to live for weeks, but a more realistic figure is 1 gallon per person per day for survival. 4 gallons per person/day will allow personal hygiene, washing of dishes, counter tops, etc. 5 to 12 gallons per day would be needed for a conventional toilet, or 1/2 to two gallons for a pour flush latrine. For short-term emergencies, it will probably be more practical to store paper plates and utensils, and minimize food preparation, than to attempt to store more water.

In addition to stored water, there is quite a bit of water trapped in the piping of the average home. If the municipal water system was not contaminated before you shut the water off to your house, this water is still fit for consumption without treatment. To collect this water, open the lowest faucet in the system, and allow air into the system from a second faucet. Depending on the diameter of the piping, you may want to open every other faucet, to make sure all of the water is drained. This procedure will usually only drain the cold water side, the hot-water side will have to be drained from the water heater. Again, open all of the faucets to let air into the system, and be prepared to collect any water that comes out when the first faucet is opened. Toilet tanks (not the bowls) represent another source of water if a toilet bowl cleaner is not used in the tank.

Some people have plumbed old water heaters or other tanks in line with their cold water supply to add an always rotated source of water. ***Two cautions are in order: 1) make sure the tanks can handle the pressure (50 psi min.), and 2) if the tanks are in series with the house plumbing, this method is susceptible to contamination of the municipal water system.*** The system can be fed off the water lines with a shutoff valve (and a second drain line), preventing the water from being contaminated as long as the valve was closed at the time of contamination.

Water can only be realistically stored for short-term emergencies, after that some emergency supply of water needs to be developed

Water Collection

Wells

Water can only be moved by suction for an equivalent head of about 20'. After this cavitation occurs, that is the water boils off in tiny bubbles in the vacuum created by the pump rather than being lifted by the pump. At best no water is pumped, at worst the pump is destroyed. Well pumps in wells deeper than this work on one of the following principles:

1) The pump can be submerged in the well, this is usually the case for deep well pumps. Submersible pumps are available for depths up 1000 feet.

2) The pump can be located at the surface of the well, and two pipes go down the well: one carrying water down, and one returning it. A jet fixture called an ejector on the bottom of the two hoses causes well water to be lifted up the well with the returning pumped water. These pumps must have an efficient foot valve as there is no way for them to self-prime. These are commonly used in shallow wells, but can go as deep as 350 feet. Some pumps use the annular space between one pipe and the well casing as the second pipe this requires a packer (seal) at the ejector and at the top of the casing.

3) The pump cylinder can be located in the well, and the power source located above the well. This is the method used by windmills and most hand pumps. A few hand pumps pump the water from very shallow wells using an aboveground pump and suction line. A variety of primitive, but ingenious, pump designs also exist. One uses a chain with buckets to lift the water up. Another design uses a continuous loop rope dropping in the well and returning up a small diameter pipe. Sealing washers are located along the rope, such that water is pulled up the pipe with the rope. An ancient Chinese design used knots, but modern designs designed for village level maintenance in Africa use rubber washers made from tires, and will work to a much greater depth.

Obviously a bucket can be lowered down the well if the well is big enough, but this won't work with a modern drilled well. A better idea for a drilled well is to use a 2' length or so of galvanized pipe with end caps of a diameter that will fit in the well casing. The upper cap is drilled for a screw eye, and a small hole for ventilation. The lower end is drilled with a hole about half the diameter of the pipe, and on the inside a piece of rigid plastic or rubber is used as a flapper valve. This will allow water to enter the pipe, but not exit it. The whole assembly is lowered in the well casing, the weight of the pipe will cause it to fill with water,

and it can then be lifted to the surface. The top pipe cap is there mostly to prevent the pipe from catching as it is lifted.

Springs

Springs or artesian wells are ideal sources of water. ***Like a conventional well, the water should be tested for pathogens, VOCs (Volatile Organic Compounds such as fuel oil or benzene), pesticides and any other contaminants found in your area.*** If the source is a spring it is very important to seal it in a spring box to prevent the water from becoming contaminated as it reaches the surface. It is also important to divert surface runoff around the spring box. As with a well, you will want to periodically treat the spring box with chlorine, particularly if the spring is slow moving. The spring may also be used for keeping food cool if a spring-house is built. If this is the case, it is still recommended to build a spring box inside the house to obtain potable water.

Surface water

Most US residents served by municipal water systems supplied with surface water, and many residents of underdeveloped countries rely on surface water. ***While surface water will almost always need to be treated, a lot of the risk can be reduced by properly collecting the water.*** Ideal sources of water are fast flowing creeks and rivers which don't have large sources of pollution in their watershed. With the small amounts of water needed by a family or small group, the most practical way to collect the water is though an infiltration gallery or well. Either method reduces the turbidity of the collected water making it easy for later treatment.

Water Purification

Heavy Metals

Heavy metals are only a problem is certain areas of the country. The best way to identify their presence is by a lab test of the water or by speaking with your county health department. Unless you are down stream of mining trailings or a factory, the problem will probably affect the whole county or region. Heavy metals are unlikely to be present in sufficient levels to cause problems with short-term use.

Turbidity

Turbidity refers to suspended solids, i.e. muddy water, is very turbid. Turbidity is undesirable for 3 reasons:

1) aesthetic considerations
2) solids may contain heavy metals, pathogens or other contaminants,
3) turbidity decreases the effectiveness of water treatment techniques by shielding pathogens from chemical or thermal damage, or in the case of UV treatment, absorbing the UV light itself.

Organic compounds

Water can be contaminated by a number of organic compound such as chloroform, gasoline, pesticides, and herbicides. These contaminants must be identified in a lab test. It is unlikely ground water will suddenly become contaminated unless a quantity of chemicals is allowed to enter a well or penetrating the aquifer. ***One exception is when the aquifer is located in limestone*.** Not only will water flow faster through limestone, but the rock is prone to forming vertical channels or sinkholes that will rapidly allow contamination from surface water. Surface water may show great swings in chemical levels due to differences in rainfall, seasonal crop cultivation, and industrial effluent levels

Pathogens

Protozoa

Protozoa cysts are the largest pathogens in drinking water, and are responsible for many of the waterborne disease cases in the US. Protozoa cysts range is size from 2 to 15 µm (**a micron is one millionth of a meter**), but can squeeze through smaller openings. In order to insure cyst filtration, filters with a absolute pore size of 1µm or less should be used. The two most common protozoa pathogens are ***Giardia lamblia*** (Giardia) and ***Cryptosporidium*** (Crypto). Both organisms have caused numerous deaths in recent years in the US, the deaths occurring in the young and elderly, and the sick and immune compromised. Many deaths were a result of more than one of these conditions. Neither disease is likely to be fatal to a healthy adult, even if untreated. For example in Milwaukee in April of 1993, of 400,000 who were diagnosed with Crypto, only 54 deaths were linked to the outbreak, 84% of whom were AIDS patients. Outside of the US and other developed countries, protozoa are responsible for many cases of amoebic dysentery, but so far this has not been a problem in the US, due to better wastewater treatment. This could change during a survival situation. Tests have found Giardia and/or Crypto in up to 5% of vertical wells and 26% of springs in the US.

Bacteria

Bacteria are smaller than protozoa and are responsible for many diseases such as typhoid fever, cholera, diarrhea, and dysentery. Pathogenic bacteria range in size

from 0.2 to 0.6 µm, and a 0.2 µm filter is necessary to prevent transmission. Contamination of water supplies by bacteria is blamed for the cholera epidemics which devastate undeveloped countries from time to time. Even in the US, ***E. coli*** is frequently found to contaminate water supplies. Fortunately E. coli is relatively harmless as pathogens go, and the problem isn't so much with E. coli found, but the fear that other bacteria may have contaminated the water as well. Never the less, dehydration from diarrhea caused by E. coli has resulted in fatalities.

Viruses

Viruses are the 2nd most problematic pathogen, behind protozoa. As with protozoa, most waterborne viral diseases don't present a lethal hazard to a healthy adult. Waterborne pathogenic viruses range in size from 0.020-0.030 µm, and are too small to be filtered out by a mechanical filter. All waterborne enteric viruses affecting humans occur solely in humans, thus animal waste doesn't present much of a viral threat. At the present viruses don't present a major hazard to people drinking surface water in the US, but this could change in a survival situation as the level of human sanitation is reduced. Viruses do tend to show up even in remote areas, so case can be made for eliminating them now.

Physical Treatment

Heat Treatment

Boiling is one guaranteed way to purify water of all pathogens. Most experts feel that if the water reaches a rolling boil it is safe. A few still hold out for maintaining the boiling for some length of time, commonly 5 or 10 minutes, plus an extra minute for every 1000 feet of elevation. If one wishes to do this, a pressure cooker would allow the water to be kept at boiling with out loosing the heat to evaporation. One reason for the long period of boiling may be to inactivate bacterial spores (which can survive boiling), but these spore are unlikely to be waterborne pathogens.

African aid agencies figure ***it takes 1 kg of wood to boil 1 liter of water.*** Hardwoods and efficient stoves would improve on this.

Water can also be treated at below boiling temperatures, if contact time is increased. A commercial unit has been developed that treats 500 gals of water per day at an estimated cost of $1/1000 gallons for the energy. The process is similar to milk pasteurization, and holds the water at 161° F for 15 seconds. Heat exchangers recover most of the energy used to warm the water. Solar pasteurizers have also been built that would heat three gallons of water to 65° C and hold the temperature for an hour. A higher temperature could be reached if the device was rotated east to west during the day to follow the sunlight.

Regardless of the method, heat treatment does not leave any form of residual to keep the water free of pathogens in storage.

Reverse Osmosis

Reverse osmosis forces water, under pressure, through a membrane that is impermeable to most contaminants. The most common use is aboard boats to produce fresh water from salt water. ***The membrane is somewhat better at rejecting salts than it is at rejecting non-ionized weak acids and bases and smaller organic molecules (molecular weight below 200).*** In the latter category are undissociated weak organic acids, amines, phenols, chlorinated hydrocarbons, some pesticides and low molecular weight alcohols. ***Larger organic molecules, and all pathogens are rejected.*** Of course it is possible to have a imperfection in the membrane that could allow molecules or whole pathogens to pass through.

Using reverse osmosis to desalinate seawater requires considerable pressure (1000 psi) to operate, and for a long time only electric models were available. Competing for a contract to build a hand powered model for the Navy, Recovery Engineering designed a model that could operate by hand, using the waste water (90 percent of the water is waste water, only 10% passes through the filter) to pressurize the back side of the piston. The design was later acquired by PUR. While there is little question that the devices work well, the considerable effort required to operate one has been questioned by some survival experts such as Michael Greenwald, himself a survivor of a shipwreck. On the other hand the people who have actually used them on a life raft credit the availability of water from their PUR watermaker for their survival.

PUR manual watermakers are available in two models: The Survivor 06 ($500) produces 2 pints per hour, and the Survivor 35 ($1350) produces 1.4 gal/hr. The latter model is also available as the Power Survivor 35 ($1700), which produces the same water volume from 4 Amps of 12 VDC, and can be disconnected and used as a hand held unit. A number of manufactures, including PUR, make DC powered models for shipboard use. PUR recommends replacing the O rings every 600 hours on its handheld units, and a kit is available to do this. Estimates for membrane life vary, but units designed for production use may last a year or more. ***Every precaution should be taken to prevent petroleum products from contacting the membrane as they will damage or destroy the membrane.*** The prefilter must also be regularly changed, and the membrane may need to be treated with a biocide occasionally

Reverse osmosis filter are also available that will use normal municipal or private water pressure to remove contaminates from water, as long as they aren't present in the levels found in sea water.

The water produced by reverse osmosis, like distilled water, will be close to pure H_2O. Therefore mineral intake may need to be increased to compensate for the normal mineral content of water in much of the world.

Distillation

Distillation is the evaporation and condensation of water to purify water. ***Distillation has two disadvantages: 1) A large energy input is required and 2) If simple distillation is used, chemical contaminants with boiling points below water will be condensed along with the water*.** Distillation is most commonly used to remove dissolved minerals and salts from water.

The simplest form of a distillation is a solar still. A solar still uses solar radiation to evaporate water below the boiling point, and the cooler ambient air to condense the vapor. The water can be extracted from the soil, vegetation piled in the still, or contaminated water (such as radiator fluid or salt water) can be added to the still. While per still output is low, they are an important technique if water is in short supply

Other forms of distillation require a concentrated heat source to boil water which is then condensed. Simple stills use a coiling coil to return this heat to the environment. These can be improvised with a boiler and tight fitting lid and some copper tubing (Avoid using lead soldered tubing if possible). FEMA suggests that, in an emergency, a hand towel can be used to collect steam above a container of boiling water. More efficient distillations plants use a vapor compression cycle where the water is boiled off at atmospheric pressure, the steam is compressed, and the condenser condenses the steam above the boiling point of the water in the boiler, returning the heat of fusion to the boiling water. The hot condensed water is run through a second heat exchanger which heats up the water feeding into the boiler. These plants normally use an internal combustion engine to run the compressor. Waste heat from the engine, including the exhaust, is used to start the process and make up any heat loss. This is the method used in most commercial and military desalinization plants

Inflatable solar stills are available from marine supply stores, but avoid the WW2 surplus models, as those who have used them have had a extremely high failure rate. Even new inflatable solar stills may only produce from 30-16 oz under actual conditions, compared to a rating of 48 oz/day under optimum conditions.

Jade Mountain also offers the following portable models in travel cases:

> ***Traveler (WC106)*** 1 gpd, 23 lb., 24x26x10 folded $ 695
>
> ***Base Camp (WC107)*** 2 gpd, 51 lb., 48x48x4 folded $ 895
>
> ***Safari (WC108)*** 48x48x5 $1095 A ruggedized version of the Base Camp above.

Microfilters

Microfilters are small-scale filters designed to remove cysts, suspended solids, protozoa, and in some cases bacteria from water. Most filters use a ceramic or

fiber element that can be cleaned to restore performance as the units are used. Most units and almost all made for camping use a hand pump to force the water through the filter. Others use gravity, either by placing the water to be filtered above the filter (e.g. the Katadyn drip filter), or by placing the filter in the water, and running a siphon hose to a collection vessel located below the filter (e.g. Katadyn siphon filter). Microfilters are the only method, other than boiling, to remove Cryptosporidia. Microfilters do not remove viruses, which many experts do not consider to be a problem in North America. Despite this the Katadyn microfilter has seen considerable use around the world by NATO-member militaries, WHO, UNHCR, and other aid organizations. Microfilters share a problem with charcoal filter in having bacteria grow on the filter medium. Some handle this by impregnating the filter element with silver such as the Katadyn, others advise against storage of a filter element after it has been used. The Sweetwater Guardian suggests using a freezer for short-term storage

Many microfilters may include silt prefilters, activated charcoal stages, or an iodine resin. Most filters come with a stainless steel prefilter, but other purchased or improvised filters can be added to reduce the loading on the main filter element. ***Allowing time for solids to settle, and/or prefiltering with a coffee filter will also extend filter life.*** Iodine matrix filters will kill viruses that will pass through the filter, and if a charcoal stage is used it will remove much of the iodine from the water. Charcoal filters will also remove other dissolved natural or manmade contaminates. Both the iodine and the charcoal stages do not indicate when they reach their useful life, which is much shorter than the filter element. If you are depending on the stage for filtering the water you will have to keep up with how much water passes through it.

New designs seem to be coming out every month. The best selling brands seem to be the PUR, and Sweetwater Guardian. The Katadyn doesn't sell as well to outdoor enthusiasts due to its high cost, but for years it was state of the art for water purification and still has a loyal following, especially among professionals in relief work. Below is the data on a few of the more common units, for a excellent field test of some common units, see the December 96 issue of Backpacker magazine.

Note that the first price is for the filter, the second for the replacement filter. The weight is from manufacturer’s literature if it was not listed in the Backpacker article. Filter life is from manufacturer’s literature and should be taken with a grain of salt.

> [**Alan's note:** These prices are now several years out of date. You'll need to investigate current pricing]
>
> ***Basic Designs Ceramic Filter Pump*** ($29/$15, 8 oz.) Cheap flimsy filter, claimed to filter up to 500 gallons with a 0.9 µm ceramic filter. Not EPA

rated, may not have passed independent lab tests, prone to damage, filter element must be submerged in water.

General Ecology- First Need Deluxe ($70/$30, 20 oz) This filter uses a structured matrix micro strainer, though General Ecology won't reveal what the structure is. It has survived independent lab tests, and filters particles to 4 µm, while actually removing viruses (the only filter capable of doing this) through electrostatic attraction. The filter cartridges can't be cleaned (other than by back flushing), but are good for 100 gallons. Pump design isn't the best. Other models are available from the manufacturer.

Katadyn PF ($295/$145, 22.7 oz). The original microfilter using a 0.2 µm silver impregnated ceramic candle. An extremely thick filter allows it to be cleaned many times for up to 14,000 gallons capacity. While the Katadyn seems well made, one reader of this list reported breaking the candle, and Backpacker Magazine broke the case during a field test. The pump, while probably indestructible, is somewhat slow and hard to use, requiring 20 lbs. of force on a small handle. The PF also lacks a output hose as the Katadyn engineers felt if would be a source of contamination.

Katadyn Combi ($185/$75 (ceramic)/$19 (carbon), 29 oz) A cheaper version of the PF incorporating both ceramic and carbon stages. Much faster filter than the PF.

Katadyn Minifilter ($139/$59, 8.3 oz) A smaller and cheaper version of the PF, easier to pump, but generally not well received. Good for 200 gallons.

Katadyn Expedition ($680/$77, 13 lb.) Similar filter to the PF (exact same cartridge as the Drip Filter Below), but designed for much higher production, stainless steel case with spade type D handle, produces 0.75 gpm. Filter good for 26,000 gallons.

Katadyn Drip Style Filter ($240, $77, 12.5 lb.) Filter elements similar to those in the PF are mounted vertically in top 3 gallon plastic bucket, water drips through filters into second 3 gallon bucket with faucet. 1 qt, per hour with the 2 filters included, a third filter can be added to increase rate 50%. Each filter good for 13,000 gallons. The mounting hardware for the filters is available for $10 to allow you to make your own filter of what ever size is needed. Each mounting kit requires a ½" hole in the bottom of the raw water container.

Katadyn Siphon Filter ($92, 2 lb.) Similar design to PF filter element, but a siphon hose replaces the pump, filters 1-2 quarts per hour (allow 1 hour for the filter to "prime" itself via capillary action), but multiple filters can be used in the same container. Collection vessel must be lower than raw water container. Good for13,000 gallons.

MSR Miniworks ($59/$30, 14 oz) MSR's smaller filter, using a 0.3 µm ceramic element. Pump is well designed, and easy to use. Main drawback is that the clean water discharge is from the bottom of the filter, and no hose is provided. While the bottom is threaded for a Nalgene bottle, it is a pain in the butt to fill a canteen or 2 liter bottle. Claimed to filter 100 gallons, Backpacker Magazine feels this may be one of the few filters without a grossly inflated rating.

MSR Waterworks ($140/$30/$30, 17 oz) MSR's first filter with a 0.2 µ ceramic and membrane stage and a carbon stage. Other wise similar to the Miniworks.

PUR Pioneer ($30/$4, 8 oz), newly introduced low-end microfilter. 0.5 µm, 1 lpm filter rate, 12 gallon capacity

PUR Hiker ($50/$20, 12 oz) PUR's microfilter only design, filters to .5 µm. Well liked, as are the other PUR filters. Very compact. 200 gallon capacity

PUR Scout ($70/$35/$15, 12 oz) Combines a iodine resin stage, a 1.0 µm filter, and a activated charcoal filter. 200 gallon capacity

PUR Explorer ($130/$45, 22 oz) PUR's top of the line model. Bulky, but well made, with a high output (1.4 lpm, faster than any of the hand held models listed and one of the easiest to pump) Has a 1.0 µm filter plus a iodine resin stage, 300 gallon capacity

Sweetwater Walkabout ($35/$13, 8.5 oz.) Sweetwater's low end filter, 0.2 µm, .7 lpm, 100 gal capacity

Sweetwater Guardian ($60/$20, 11 oz) Uses a glass fiber and carbon filter, filters to .2 µm, claimed to last for 200 gallons. An iodine resin stage can be added that will kill viruses, and will last for 90 gallons. Pump is well designed, but it takes a few seconds to pull a captive pin to fold for storage. Available in white or OD.

Timberline Eagle ($20/$13, 8 oz) At 1 µm, this filter only does protozoa, but is much easier to pump, lighter, and cheaper. Filter is attached to pump, and must rest (but doesn't have to be submerged) in water to be purified. Looks flimsy, but seems to hold up. Claimed to last for 100 gallons.

It is also possible to build your own microfilter using ***diatomaceous earth***, sold for swimming pool filters (DE). Usually pressure is required to achieve a reasonable flow rate. A DE filter will remove turbidity as well as pathogens larger than 1 um.

[Alan's note: This type of diatomaceous earth is **NOT** the type you want for food storage. Don't get them confused.

Slow Sand Filter

Slow sand filters pass water slowly through a bed of sand. Pathogens and turbidity are removed by natural die-off, biological action, and filtering. Typically the filter will consist of 24 inches of sand, then a gravel layer in which the drain pipe is embedded. The gravel doesn't touch the walls of the filter so that water can't run quickly down the wall of the filter and into the gravel. Building the walls with a rough surface also helps. A typical loading rate for the filter is 0.2 meters/hour day (the same as .2 m^3/m^2 of surface area). The filter can be cleaned several times before the sand has to be replaced.

Slow sand filter construction information:

Slow sand filters should only be used for continuous water treatment. If a continuous supply of raw water can't be insured (say using a holding tank), then another method should be chosen. It is also important for the water to have as low turbidity (suspended solids) as possible. Turbidity can be reduced by changing the method of collection (for example, building an infiltration gallery, rather than taking water directly from a creek), allowing time for the material to settle out (using a raw water tank), prefiltering or flocculation (adding a chemical such as alum to cause the suspended material to floc together.)

The SSF filter itself is a large box, at least 1.5 meters high. The walls should be as rough as possible to reduce the tendency for water to run down the walls of the filter, bypassing the sand. The bottom layer of the filter is a gravel bed in which a slotted pipe is placed to drain off the filtered water. The slots or the gravel should be no closer than 20 cm to the walls. again to prevent the water from bypassing the sand.

The sand for a SSF needs to be clean and uniform, and of the correct size. The sand can be cleaned in clean running water, even if it is in a creek. The ideal specs on sand are effective size (sieve size through which 10% of the sand passes) between 0.15 and 0.35 mm, uniformity coefficient (ratio of sieve sizes through which 60% pass and through which 10% pass) of less than 3, Maximum size of 3 mm, and minimum size of 0.1 mm.

The sand is added to a SSF to a minimum depth of 0.6 meters. Additional thickness will allow more cleanings before the sand must be replaced. 0.3 to 0.5 meters of extra sand will allow the filter to work for 3-4 years. An improved design uses a ***geotextile*** layer on top of the sand to reduce the frequency of cleaning. The outlet of a SSF must be above the sand level, and below the water level. The water must be maintained at a constant level to insure an even flow rate throughout the filter. The flow rate can be increased by lowering the outlet pipe,

or increasing the water level. One common idea for maintaining the water level is to use a elevated raw water tank or pump, and a ball valve from a toilet.

While the SSF will begin to work at once, optimum treatment for pathogens will take a week or more. During this time the water should be chlorinated if at all possible (iodine can be substituted). After the filter has stabilized, the water should be safe to drink, but chlorinating of the output is still a good idea, particularly to prevent recontamination.

As the flow rate slows down the filter will have to be cleaned by draining and removing the top few inches of sand. If a geotextile filter is used, only the top ½" may have to be removed. As the filter is refilled, it will take a few days for the biological processes to reestablish themselves.

Activated Charcoal Filter

Activated charcoal filters water through adsorption, chemicals and some heavy metals are attracted to the surface of the charcoal, and are attached to it. Charcoal filters will filter some pathogens though they will quickly use up the filter adsorptive ability, and can even contribute to contamination as the charcoal provides an excellent breeding ground for bacteria and algae. Some charcoal filters are available impregnated with silver to prevent this, though current research concludes that the bacteria growing on the filter are harmless, even if the water wasn't disinfected before contacting the filter. The only filter I know of that uses only activated charcoal, and doesn't required pressurized water is the Water Washer ($59). Available from the Survival Center.

Activated charcoal can be used in conjunction with chemical treatment. The chemical (iodine or chlorine) will kill the pathogens, while the carbon filter will remove the treatment chemicals. In this case, as the filter reaches its capacity, a distinctive chlorine or iodine taste will be noted.

Activated charcoal can be made at home, though the product will be of varying quality compared to commercial products. Either purchased or homemade charcoal can be recycled by burning off the molecules adsorbed by the carbon (This won't work with heavy metals of course.)

The more activated charcoal in a filter, the longer it will last. The bed of carbon must be deep enough for adequate contact with the water. Production designs use granulated activated charcoal (effective size or 0.6 to 0.9 mm for maximum flow rate. Home or field models can also use a compressed carbon block or powered activated charcoal (effective size 0.01) to increase contact area. Powered charcoal can also be mixed with water and filtered out later. As far as life of the filter is concerned, carbon block filters will last the longest for a given size, simply due to their greater mass of carbon. A source of pressure is usually needed with carbon block filters to achieve a reasonable flow rate.

Sol-Air Water Treatment

If sufficient dissolved oxygen is available, sunlight will cause the temporary formation of reactive forms of oxygen such as hydrogen peroxide and oxygen free radicals. This form of water treatment is called ***solar photooxidative disinfection*** or sol-air water treatment. Sol-Air water treatment has been shown to dramatically reduce the level of fecal coliform bacteria. There is some evidence that other bacteria and viruses may be affected also. While not as reliable as other methods, it does offer a low-tech solution in emergencies. Sol-Air treatment requires bright sunlight, and has been shown to be effective when ever the sun causes a distinct shadow to be cast. Exposure to 4.5 hours of bright sunlight has been shown to cause a thousand fold reduction in fecal coliforms in lab tests.

In order for Sol-Air to be effective, oxygen must be present. Experiments have shown that shaking a bottle filled 3/4 with air will restore oxygen levels to near saturation. As the treatment continues, some of the oxygen will come out of solution, while other oxygen will be consumed by the killed pathogens, so the shaking should be repeated every few hours. Data shows that maximum activity occurs when the water temperature is above 50° C (122° F), so this method may be unsuitable in colder climates unless special solar collectors are used.

Either glass or plastic bottles may be used. Plastic bottles will allow short wave ultraviolet radiation to pass, increasing the rate of microbial inactivation, but may yellow with age, reducing light transmission, and may leach plasticizers into the water at the elevated temperatures that will occur. The leaching of plasticizers can be reduced by using bottles of PET (polyethlyene terephtalate) rather than PVC. Glass bottles on the other hand are more durable. Research has used bottles with 2 liters of capacity, but if the water is free of turbidity, larger containers can be used. Plastic bags, or some sort of flat glass container represent the ideal container as this maximizes the solar energy received per ounce of water.

Bottles should be filed 3/4 full in the early morning with water as free of turbidity as possible. After capping the bottles should be shaken vigorously for a few minutes then placed upright in the sun, where they will be not be shaded later in the day. The shaking should be repeated at least three times during the day. At the end of the day the water should be reasonably freed of bacteria, though it is most practical to let the water cool for consumption the following day. Each day a new batch should be treated due to the lack of a residual disinfected.

After consumption of the water the bottle should be air dried to prevent algae growth with continual use.

Improvised Mechanical Filter

If the materials aren’t available to build a slow sand filter, or some other means of water treatment is preferred, it may still be advantageous to mechanically filter

the water before treating it with chemicals or passing through a microfilter. Generally the idea is to allow the water to flow as slowly as possible through a bed of sand. In a municipal water treatment plant this is called a rapid sand filter. The particular design below is included, because the designer, a research engineer at Oak Ridge National Laboratories, found it particularly effective at removing fallout from water. The filter will do little or nothing to remove pathogens, though removing suspended solids allow others water treatment methods to work more effectively.

> Expedient water filter, from *Nuclear War Survival Skills*, Cresson Kearny, ORNL
>
> **1)** Perforate the bottom of a 5 gallon bucket, or similar container with a dozen nail holes even spread over a 4" diameter circle in the center of the container.
>
> **2)** Place a 1.5" layer of small stones or pebbles in the bottom of the can. If pebbles aren't available, marbles, clean bottle caps, twisted coat hangers or clean twigs can be used.
>
> **3)** Cover the pebbles with one thickness of terrycloth towel, burlap sackcloth, or other porous cloth. Curl the cloth in a roughly circular shape about three inches larger then the diameter of the can.
>
> **4)** Take soil containing some clay (pure clay isn't porous enough, pure sand is too porous) from at least 4" below the surface of the ground (nearly all fallout particles remain near the surface except after disposition on sand or gravel.)
>
> **5)** Pulverize the soil, then gently press it in layers over the cloth that covers the pebbles, so that the cloth is held snugly against the walls of the can. The soil should be 6-7" thick.
>
> **6)** Completely cover the surface of the soil layer with one thickness of fabric as porous as a bath towel. This is to keep the soil from being eroded as water is being poured into the filter. A dozen small stones placed on the cloth near it's edges will secure it adequately.
>
> **7)** Support the filter on rocks or sticks placed across the top of a container that is larger then the filter can (such as a dishpan)

The contaminated water should be poured into the filter can, preferably after allowing it to settle as described below. The filtered water should be disinfected by some method.

If the 6 or 7 inches of filtering soil is a sandy clay loam, the filter will initially deliver about 6 quarts/hour. If the filter is any faster than this then the fabric layer needs to be removed and the soil compressed more. The filtering rate will drop over time as the filter begins to clog up. When this happens the top 1/2" of soil can be removed to increase the filtering rate. After 50 or so quarts, the filter will need to be rebuilt with fresh soil.

As with any filter, optimum performance will be achieved if sediment in the water will be allowed to settle out before passing the water through the filter

If the water is contaminated with fallout, clay can be added to help the fallout particles to settle out. The procedure is as follows:

> Fill a bucket or other deep container 3/4 full with contaminated water.
>
> Dig pulverized clay or clayey soil from a depth of four or more inches below ground surface and stir it into the water.
>
> Use about 1 inch of dry clay or clayey soil for every 4" depth of water. Stir until practically all of the clay particles are suspended in the water.
>
> Let the clay settle for at least 6 hours. This will carry the fallout particles to the bottom and cover them. Carefully dip out or siphon the clear water and disinfect it.

Chemical Treatment

Chlorine: Chlorine is familiar to most Americans as it is used to treat virtually all municipal water systems in the United States. For a long time chlorine, in the form of Halazone tablets, was used to purify small batches of water for campers and military troops. Later questions emerged about the effectiveness of Halazone, and in 1989, Abbot labs pulled it off the market. If Halazone tablets are encountered outside the US, the nominal shelf life is 6 months, and the dosage is 2 tabs per liter. Until recently, there was no chlorine product designed for wilderness/survival use available in the US.

Chlorine has a number of problems when used for field treatment of water. When chlorine reacts with organic material, it attaches itself to nitrogen containing compounds (ammonium ions and amino acids), leaving less free chlorine to continue disinfection. Carcinogenic trihalomethanes are also produced, though this is only a problem with long-term exposure. Trihalomethanes can also be filtered out with a charcoal filter, though it is more efficient to use the same filter to remove organics before the water is chlorinated. ***Unless free chlorine is measured, disinfection can not be guaranteed with moderate doses of chlorine.***

One solution is superchlorination, the addition of far more chlorine than is needed. This must again be filtered through activated charcoal to remove the large amounts of chlorine, or hydrogen peroxide can be added to drive the chlorine off. Either way there is no residual chlorine left to prevent recontamination. This isn't a problem if the water is to be used at once.

Chlorine is sensitive to both the pH and temperature of the treated water. Temperature slows the reaction for any chemical treatment, but chlorine treatment is particularly susceptible to variations in the pH as at lower pHs, hypochlorous acid is formed, while at higher pHs, it will tend to dissociate into hydrogen and chlorite ions, which are less effective as a disinfectant. As a result, chlorine effectiveness drops off when the pH is greater than 8.

Chlorine, like iodine, will not kill Cryptosporidia.

Methods of chlorine treatment:

Bleach: Ordinary household bleach (such as Clorox) in the US contains 5.25% sodium hypochlorite (NaOCL) and can be used to purify water if it contains no other active ingredients, scents, or colorings. Bleach is far from an ideal source due to its bulkiness (only 5% active ingredient), and the instability over time of the chlorine content in bleach. Chlorine loss is farther increased by agitation or exposure to air. One source claims chlorine loss from a 5% solution at 10% over 6 months if stored at 70° F. Nevertheless, this may be the only chemical means available to purify water, and it is far better than nothing. Normal dosage is 8 drops (0.4 ml) per gallon. Allow the treated water to sit for 30 min., and if there isn't a slight chlorine smell, retreat. ***Note*:** USP standard medicine droppers are designed to dispense 0.045-0.055 ml per drop. Use of other solvents or some chemicals can change this. The dropper can be calibrated against a graduated cylinder for greater accuracy.

Some small treatment plants in Africa produce their own sodium hypochlorite on site from the electrolysis of brine. Power demands range from 1.7 to 4 kWh per lb. of NaOCL. 2 to 3.5 lbs. of salt are needed for each pound of NaOCL. These units are fairly simple and are made in both the US and the UK. Another system, designed for China, where the suitable raw materials were mined or manufactured locally, used a reaction between salt, manganese dioxide, and sulfuric acid to produce chlorine gas. The gas was then allowed to react with slaked lime to produce a bleaching powder that could then be used to treat water. A heat source is required to speed the reaction up.

AquaCure: Designed for the South African military, these tablets contain chlorine and alum. The alum causes the suspended solids to flocculate and the chlorine adds 8 PPM chlorine. This is a great way to treat turbid water,

though it will leave a lot of chlorine in clear water (The one tablet/liter could be halved for clear water.)

The US distributor for Aqua Cure is:

Safesport Manufacturing
Box 11811
Denver, CO 80211
1 800 433 6506

Bleaching Powder (Chlorinated Lime): Can also be purchased and used as a purification means if nothing else is available. Bleaching powder is 33-37% chlorine when produced, but losses its chlorine rapidly, particularly when exposed to air, light or moisture.

Calcium Hypochlorite: Also known as High Test Hypochlorite (HTH). Supplied in crystal form, it is nearly 70% available chlorine. One product, the Sanitizer (formally the Sierra Water Purifier) uses these crystals to superchlorinate the water to insure pathogens were killed off, then hydrogen peroxide is added to drive off the residual chlorine. This is the most effective method of field chlorine treatment. The US military and most aid agencies also use HTH to treat their water, though a test kit, rather than superchlorination, is used to insure enough chlorine is added. This is preferable for large-scale systems as the residual chlorine will prevent recontamination.

Usually bulk water treatment plants first dilute to HTH to make a 1% working solution at the rate of 14g HTH per liter of water. ***While testing to determine exact chlorine needs are preferable, the solution can be used at the dose rate of 8 drops/gallon, or for larger quantities, 1 part of 1% solution to 10,000 parts clear water.*** Either of these doses will result in 1 PPM chlorine and may need to be increased if the water wasn't already filtered by other means.

When test kits are available, the WHO standard is a residual chlorine level of 0.2 to 0.5 mg/l after a 30 min. contact time. The may require as much as 5 mg/l of chlorine to be added to the raw water.

Iodine: Iodine's use as a water purification method emerged after WW2, when the US military was looking for a replacement for Halazone tablets. ***Iodine was found to be in many ways superior to chlorine for use in treating small batches of water.*** Iodine is less sensitive to the pH and organic content of water, and is effective in lower doses. Some individuals are allergic to iodine, and there is some question about long term use of iodine. The safety of long-term exposure to low levels of iodine was proven when inmates of three Florida prisons were given water disinfected with 0.5 to 1.0 PPM iodine for 15 years. No effects on the health

or thyroid function of previously healthy inmates was observed. Of 101 infants born to prisoners drinking the water for 122- 270 days, none showed detectable thyroid enlargement. However 4 individuals with preexisting cases of hyperthyroidism became more symptomatic while consuming the water.

Nevertheless experts are reluctant to recommend iodine for long term use. Average American iodine intake is estimated at 0.24 to 0.74 mg/day, higher than the RDA of 0.4 mg/day. Due to a recent National Academy of Science recommendation that iodine consumption be reduced to the RDA, the EPA discourages the use of iodized salt in areas where iodine is used to treat drinking water.

Iodine is normally used in doses of 8 PPM to treat clear water for a 10 minute contact time. The effectiveness of this dose has been shown in numerous studies. ***Cloudy water needs twice as much iodine or twice as much contact time*.** In cold water (Below 41° F or 5° C) the dose or time must also be doubled. In any case doubling the treatment time will allow the use of half as much iodine

These doses are calculated to remove all pathogens (other than cryptosporida) from the water. Of these, giardia cysts are the hardest to kill, and are what requires the high level of iodine. If the cysts are filtered out with a microfilter (any model will do since the cysts are 6 µm), only 0.5 PPM is needed to treat the resulting water.

Water treated with iodine can have any objectionable taste removed by treating the water with vitamin C (ascorbic acid), ***but it must be added after the water has stood for the correct treatment time.*** Flavored beverages containing vitamin C will accomplish the same thing. Sodium thiosulfate can also be used to combine with free iodine, and either of these chemicals will also help remove the taste of chlorine as well. Usually elemental iodine can't be tasted below 1 PPM, and below 2 PPM the taste isn't objectionable. Iodine ions have an even higher taste threshold of 5 PPM. Note that removing the iodine taste does not reduce the dose of iodine ingested by the body.

Sources of Iodine:

Tincture of Iodine: USP tincture of iodine contains 2% iodine and 2.4% sodium iodide dissolved in 50% ethyl alcohol. For water purification use, the sodium iodide has no purification effect, but contributes to the total iodine dose. Thus it is not a preferred source of iodine, but can be used if other sources are not available. 0.4 cc's (or 8 drops) of USP tincture (2% iodine) added to a liter of water will give the 8 mg/l (same as 8 PPM). If the iodine tincture isn't compounded to USP specs, then you will have to calculate an equal dose based on the iodine concentration.

Lugol's solution: Contains 5% iodine and 10% potassium iodide. 0.15 cc (3 drops) can be added per liter of water, but 3 times more iodine is consumed compared to sources without iodide.

Betadyne (povidone iodine): Some have recommended 8 drops of 10% povidone iodine per liter of water as a water treatment method, claiming that at low concentrations povidone iodine can be regarded as a solution of iodine. One study indicated that at 1:10,000 dilution (2 drops/liter), there was 2 PPM iodine, while another study resulted in conflicting results. However, at 8 drops/liter, there is little doubt that there is an antimicrobial effect. The manufacturer hasn't spent the money on testing this product against EPA standard tests, but in other countries it has been sold for use in field water treatment.

Kahn-Vassher solution: By adding a sufficient amount of iodine crystals to a small bottle, an almost unlimited supply of saturated iodine solution can be produced. As long as crystals remain in the bottle, the solution is saturated. Concentration of the iodine is dependent of temperature, either condition at ambient temperature can be assumed, or commercial models such as Polar Pure incorporate a liquid crystal thermometer to determine dose.

One criticism of this method is the chance of decanting iodine crystals into the water being treated. This isn't that much of a problem as iodine is very weakly toxic, but the Polar Pure incorporates a collar into the neck of the bottle to help prevent this. Another disadvantage to this method is that the saturated iodine solution must be kept in glass bottles, and is subject to freezing, but this is hardly an insurmountable problem. Freezing, of course, doesn't affect the crystals.

This is the method I use, but I do use the commercial Polar Pure bottle, and refill it as necessary with USP crystals. During a crisis, or extended camping trips I would microfilter the water first, so a much lower dose of iodine is needed.

With the Polar Pure bottle, dosage information is provided. Otherwise a 1 oz bottle can be used to carry the solution. The bottle is filled with water after use. At the next use, 1/2 of the supernate (15 cc) is poured off into a liter of water. At 68° F, this will yield a dose of 9 mg/l. To use this method with a microfilter to get a 0.5 PPM concentration, either large batches of water need to be treated (1/2 oz to 4.5 gallons would be 0.5 PPM), or a TB syringe or medicine dropper can be used to measure doses. A USP medicine dropper should give 20 drops per ml.

Iodine can also be dissolved in alcohol to make a solution of known concentration. I am not aware of any commercial products, but a pharmacy

could compound one for you, or you could do it your self. One suggested formula is 8g iodine/100 cc ethyl alcohol which yields enough solution to disinfect 250 gallons of water. At the rate of 0.1 cc (2 drops)/liter to give a concentration of 8 mg/l.

Tetraglycine hydroperiodide (e.g. Potable Aqua): This is the form of iodine used by the US military for field treatment of water in canteen sized batches. Usual dose in one tablet per quart of water to give a concentration of 8 mg/l. Two tablets are used in cloudy or cold water or contact time is doubled. ***The major downside of this product is that the product will loose its iodine rapidly when exposed to the air*.** According to the manufacturer, they have a near indefinite life when sealed in the original bottle, but probably should be discarded within a few months of opening. The tablets will change color from gun metal gray to brown as they lose the iodine, and you should see a brown tint to the water after treating.

Iodine Resin Filter: Some commercial microfilters incorporate an iodine resin stage to kill viruses and bacteria, with out putting as much iodine in the water as if it had been added to the raw water. A few products rely exclusively on an iodine resin stage. Downside of these filters are their fragile nature, dependency of effectiveness on flow rate and the inability to identify when they need to be discarded. If you are going to use one where the water is known to be contaminated with viruses, then one of the better known brands such as the PUR or Sweetwater Viraguard is recommended. More than one pass through the filter may be necessary in cold weather.

Resins do have the advantage of producing less iodine in the water for the same antimicrobial effect as for the most part, they only release iodine when contacted by a microbe. The downside is that physical contact between the microbe and the resin is needed.

Silver: Silver has been suggested by some for water treatment and may still be available outside the US. Its use is currently out of favor due to the EPA's establishment of a 50 ppb MCL (Maximum Contaminate Level) limit on silver in drinking water. This limit is set to avoid ***argyrosis***, a cosmetic blue/gray staining of the skin, eyes, and mucous membranes. As the disease requires a net accumulation of 1 g of silver in the body, one expert calculated that you could drink water treated at 50 ppb for 27 years before accumulating 1 g. Silver has only be proven to be effective against bacteria and protozoan cysts, though it is quite likely also effective against viruses.

Silver can be used in the form of a silver salt, commonly silver nitrate, a colloidal suspension, or a bed of metallic silver. Electrolysis can also be used to add metallic silver to a solution.

Some evidence has suggested that silver deposited on carbon block filters can kill pathogens without adding as much silver to the water.

> Katadyn markets a silver based water treatment product called Micropur. The manufacturer recommends a 2 hr contact time at a dose of 1 tab per liter and states the product is "For the disinfection and storage of clear water. Reliably kills bacterial agents of enteric diseases, but not worm eggs, ameba, or viruses. Neutral to taste... insure protection against reinfection for 1-6 months."; The following forms are available:
>
> Micropur Tablets
>
> - MT1 1 tablets/qt 25 gal
> - MT2 1 tablet/5qts 62.5 gal
>
> Micropur Fluid
>
> - MF 75 10 drops/gal 75 gals
> - MF250 10 drops/gal 250 gals
>
> Micropur Crystal
>
> - MC250 1 packet/gal 250 gal
> - MC 2500 1 spoon/25 gal 2500 gal
> - MC12500 1 spoon/250 gal 12500 gal

Potassium Permanganate: Potassium Permanganate is no longer commonly used in the developed world to kill pathogens. It is much weaker than the alternatives, more expensive, and leaves a objectionable pink or brown color. If it must be used, 1 gram per liter would probably be sufficient against bacteria and viruses (no data is available on it effectiveness against protozoan cysts.

Hydrogen Peroxide: Hydrogen Peroxide can be used to purify water if nothing else is available. Studies have shown of 99 percent inactivation of poliovirus in 6 hr with 0.3 percent hydrogen peroxide and a 99% inactivation of rhinovirus with a 1.5% solution in 24 minutes. Hydrogen Peroxide is more effective against bacteria, though Fe+2 or Cu+2 needs to be present as a catalyst to get a reasonable concentration-time product.

Coagulation/Flocculation agents: While flocculation doesn't kill pathogens, it will reduce their levels along with removing particles that could shield the pathogens from chemical or thermal destruction, and organic matter that could tie up chlorine added for purification. 60-98% of coliform bacteria, 65-99% of

viruses, and 60-90% of giardia will be removed from the water, along with organic matter and heavy metals.

Some of the advantages of coagulation/flocculation can be obtained by allowing the particles to settle out of the water with time (sedimentation), but it will take a while for them to do so. Adding coagulation chemicals such as alum will increase the rate at which the suspended particles settle out by combining many smaller particles into larger floc which will settle out faster. The usual dose for alum is 10-30 mg/liter of water. This dose must be rapidly mixed with the water, then the water must be agitated for 5 minutes to encourage the particles to form flocs. After this at least 30 minutes of settling time is need for the flocs to fall to the bottom, and them the clear water above the flocs may be poured off. Most of the flocculation agent is removed with the floc, nevertheless some question the safety of using alum due to the toxicity of the aluminum in it. There is little to no scientific evidence to back this up. Virtually all municipal plants in the US dose the water with alum.

In bulk water treatment, the alum dose can be varied until the idea dose is found. The needed dose varies with the pH of the water and the size of the particles. Increase turbidity makes the flocs easier to produce not harder, due to the increased number of collisions between particles.

Treatments requiring electricity:

Ozone: Ozone is used extensively in Europe to purify water. Ozone, a molecule composed of 3 atoms of oxygen rather than two, is formed by exposing air or oxygen to a high voltage electric arc. Ozone is much more effective as a disinfectant than chlorine, but no residual levels of disinfectant exist after ozone turns back into O2. (one source quotes a half life of only 120 minutes in distilled water at 20° C). Ozone is expected to see increased use in the US as a way to avoid the production of trihalomethanes. While ozone does break down organic molecules, sometimes this can be a disadvantage as ozone treatment can produce higher levels of smaller molecules that provide an energy source for microorganisms. If no residual disinfectant is present (as would happen if ozone were used as the only treatment method), these microorganisms will cause the water quality to deteriorate in storage.

Ozone also changes the surface charges of dissolved organics and colloidially suspended particles. This causes microflocculation of the dissolved organics and coagulation of the colloidal particles.

UV light: Ultraviolet light has been known to kill pathogens for a long time. A low pressure mercury bulb emits between 30 to 90 % of its energy at a wave length of 253.7 nm, right in the middle of the UV band. If water is exposed to enough light, pathogens will be killed. The problem is that some pathogens are hundreds of times less sensitive to UV light than others. The least sensitive

pathogens to UV are protozoan cysts. Several studies show that Giardia will not be destroyed by many commercial UV treatment units. Fortunately these are the easiest pathogens to filter out with a mechanical filter.

The efficacy of UV treatment is very dependent on the turbidity of the water. The more opaque the water is, the less light that will be transmitted through it. The treatment units must be run at the designed flow rate to insure sufficient exposure, as well as insure turbulent flow rather than plug flow.

Another problem with UV treatment is that the damage done to the pathogens with UV light can be reversed if the water is exposed to visible light (specifically 330-500 nm) through a process known as photoreactivation.

UV treatment, like ozone or mechanical filtering leaves no residual component in the water to insure its continued disinfection. Any purchased UV filter should be checked to insure it at least complies with the 1966 HEW standard of 16 mW.s/cm^2 with a maximum water depth of 7.5 cm. ANSI/NSF require 38 mWs/cm^2 for primary water treatment systems. This level was chosen to give better than 3 log (99.9%) inactivation of Bacillus subtillis. This level is of little use against Giardia, and of no use against Crypto.

The US EPA explored UV light for small scale water treatment plants and found it compared unfavorably with chlorine due to 1) higher costs, 2) lower reliability, and 3) lack of a residual disinfectant.

Questionable or Dangerous methods of water treatment

Aerobic 07: Also sold as Aerobic Oxygen. The company refuses to release the disinfectant. It maybe chlorine dioxide, a well known, if somewhat unstable, disinfectant. The company has shown company sponsored tests showing effectiveness against viruses and bacteria (but not against Giardia). No independent testing has been performed, nor has anybody provided concentration-time data for the product.

Survival Straw: This product claims to destroy and eliminate impurities including bacteria, protozoa. fungi, chemicals and heavy metals using a matrix of metal alloy. The manufacturer claims the product's media meets EPA and FDA specs, which is no indication of the filter's effectiveness. The filter violates a number of laws of physics since it claims that it destroys heavy metals and pathogens without filtering them.