# An Overview of Sustainable Drinking Water Disinfection for Small Communities in the Developing World

Written April 2003 for the requirements of
CE 5993 *Field Engineering in the Developing World*

by

Dan Nover
M.S. Candidate
Department of Civil and Environmental Engineering
Master's International Program
Michigan Technological University
www.cee.mtu.edu/peacecorps

## Introduction

The World Health Organisation estimates that 1.2 billion people are affected by polluted water worldwide. Furthermore, 15 million children under the age of 5 die each year due to water borne diseases (WHO, 2002). Depending on the region, this problem may be complicated by overpopulation (Earthwatch Radio, 2003), contaminated water sources, poor sanitation infrastructure, lack of hygiene education, or some combination of these causes (WHO, 1996). "At any given time perhaps one-half of all peoples in the developing world are suffering from one or more of the six main diseases associated with water supply and sanitation (diarrhoea, ascaris, dracunculiasis, hookworm, schistosomiasis and trachoma)" (WHO, 1996). In addition to affecting people directly through disease, poor health acts as a mechanism to further marginalize people by limiting their ability to work, produce food, and interact socially (Bunge, 2000).

Finding a way to provide clean and safe drinking water in affected areas is therefore one necessary step in any effort to improve the quality of life of people in underserved areas and to mitigate the devastating effects of disease on the people of the developing world. For a variety of reasons, methods for clarification and disinfection of drinking water typically used in the developed world are not feasible in the developing world. A number of complicating factors make the gap in resources between the developed and developing world impossible to bridge with the same technologies.

Drinking water treatment facilities in the developed world are typically very expensive to construct and operate. A quick search for personal water filtration systems indicated an initial cost of at least $150-$200, plus periodic replacement of filters (Yourwaterneeds.com, 2003). In addition, costs implicitly associated with living in the developed world (taxes associated with municipal water treatment, etc.) are further expenses which must be paid constantly in order to guarantee proper maintenance and performance of water treatment facilities. Money is often at a premium in the developing world, and what may seem like a cost effective way to reach a treatment goal in one situation is often completely impossible in another. The low annual income earned by most citizens of developing countries makes it seem unlikely that an individual in such a country would be willing or able to part with a large portion of her/his income to improve drinking water quality.

Perhaps more important than the ongoing need for capital inputs, materials and expertise which are not locally available may also be necessary for sustained operation of such a facility. The lack of money needed to develop the elaborate drinking water infrastructure favored in the developed world in addition to the difficulty or impossibility associated with importing materials and expertise necessary for sustainable operation of such facilities demand another solution. Different approaches must therefore be developed and undertaken in the developing world if safe drinking water is to be supplied indefinitely into the future.

In light of the existing and ever increasing crisis associated with both insufficient quantities and quality of safe, potable water, efforts are underway to develop and disseminate viable and sustainable technologies capable of delivering clean, safe drinking water to the people of the developing world. The solution to this problem will not be easy and it will not be achieved by traditional methods. The complex nature of inter-cultural interactions, international development efforts, and technology development will require a rigorous and thoughtful approach requiring researchers to abandon old attitudes in favor of community outreach and participation in concert with appropriate technological solutions (Padmasiri et. al, 1997).

In "A Handbook of Gravity-Flow Water Systems" (2000), Jordan claims that "at the current time, there is no practical water treatment system which can be broadly used in Nepal. Thus emphasis must lie in locating the cleanest possible source of drinking water, then properly securing it against future contamination." This is likely the best approach in many developing countries, Nepal included. However, Amendment 9/78 of the Sanitary Engineering and Public Health Handbook says, "raw waters obtained from natural sources are assumed to not be completely satisfactory for potable use. The quality of water, as discussed in chapter 20, is in a state of continuous change." In light of these disparate attitudes, situations inevitably arise in which a clean source of water is simply not available. Furthermore, some level of treatment/disinfection should be applied to secure the health of those drinking the tainted water. There are appropriate technologies available that can be applied to eliminate particulate matter, taste, and odor. In the interest of brevity, however, this review will discuss only technologies intended to treat biological pathogens in drinking water using little if any external input (capital, material, expertise, etc.). The following review will provide an overview of techniques capable of eliminating or neutralizing water-borne pathogens and a comprehensive list of relevant references, literature, and links supplying the information necessary to invoke these techniques.

## Boiling

In terms of limiting the need for external inputs, it would be difficult to imagine a technique simpler and more sustainable than boiling water. Water is simply placed in a clean container and brought to a full boil for at least three minutes. This will eliminate all pathogenic activity, including giardia (Extension Bulletin, 2003) "If you are more than 5,000 feet above sea level, you must increase the boiling time to at least 5 minutes (plus about a minute for every additional 1,000 feet). Boiled water should be kept covered while cooling (Drinking Water Resources, 2003). Unfortunately, external inputs are not the only obstacle to boiling drinking water.

Many developing countries experience a rainy season. During these times, finding enough or any dry wood for boiling water may be difficult or impossible. However, the major obstacle in this case is the basic availability of fuel wood. Boiling drinking water requires the consumption of these valuable supplies (in addition to draining the energy of the people of the developing world, fuel wood burning and harvesting both contribute to deforestation and air pollution). Even if adequate fuel wood is available, the time and energy required for its collection make boiling drinking water less than appealing (Bourgoing, 1989). Indeed, wood gathering becomes a further drain on the overworked people of the developing world. Furthermore, if fuel wood were not available in adequate supply, it would have to be purchased in order to provide safely boiled water (Troy, 2003). Because of typically low incomes in the developing world, and the traditional unwillingness of individuals to spend a large fraction of their income on something viewed as a luxury, purchasing fuel wood for water disinfection is unsustainable. Because of the complications associated with boiling, it is really only ideal in emergency situations and other, more sustainable methods of small-scale drinking water treatment should be sought.

## UV Treatment

It has long been known that UV light of an approximate wavelength of 254 nm can disrupt the ability of yeast, viruses, bacteria, and protozoa to reproduce. By effectively neutering these organisms in water, it can be made potable at little cost in a short amount of time. In addition to the reduction in biological activity, UV light is also effective at degradation of a number of chemical compounds known to have adverse health effects (Watersolve International, 2003). Sterilization can be achieved with complex and expensive UV systems. However, the very simple UV treatment schemes described in this section are intended to make water potable quickly and cheaply, although some biological activity may still be present (Rolla, 1998). On a large scale, UV treatment becomes very money, resource and expertise intensive, as seen across the developed world. However, for the individual or family, a small amount of water (as much as can be contained in existing plastic containers) can be made potable in a short amount of time. (Although complex and expensive UV treatment technologies are beyond the scope of this paper, links and references for information and products in this category will be listed at the end of this section.)

Using ultra violet light from the sun is amongst the easiest and most sustainable method for drinking water treatment. The simplest UV treatment scheme requires only clear plastic or glass bottles and bright sun, two commodities that are well supplied in most areas of the developing world. Water is simply placed in the plastic bottle. Because oxygen content of water has been shown to correlate well with inactivation in fecal bacteria (Reed, 1996), the bottle should be shaken vigorously in order to oxygenate the water. The bottles should then be left in full sunlight for at least 3-6 hours with occasional shaking to maintain oxygen content of the water. The bottles can then be stored overnight for use the following day (Reed, 1997). This simple method of disinfection has been shown to be very effective in reducing water borne disease. Reed (1997) presents data indicating a 99.9 % inactivation of coliform bacteria and viral infection using the very simple UV disinfection method. An important consideration in this method is the turbidity of the water, since greater turbidity can results in a longer time to 99.9 % inactivation (See Figure 1 below). However, Rolla (1998) reports that this does not completely eliminate biological activity.

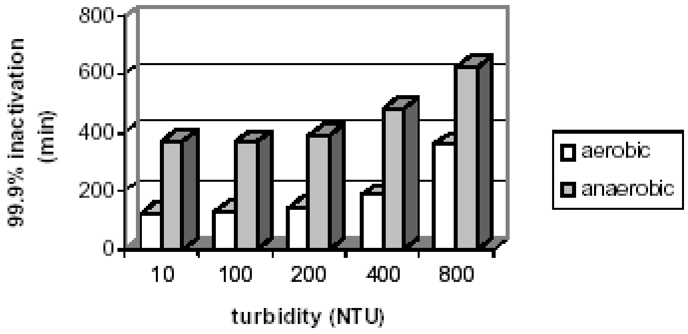

Figure 1. Effect of turbidity on inactivation of faecal coliform bacteria

In order to eliminate biological activity, pasteurization temperature (150 F or 65 C) must be achieved. This is difficult to do with plastic bottles alone. The simplest solutions to this problem are the solar box and the solar pond. A solar box consists of an insulated box constructed from wood or cardboard with a glass or plastic lid. The inside surfaces should be painted black. A covered vessel with water (ideally, also black) is placed inside. The pot needs to remain in the box until pasteurization temperature is achieved for a few minutes. On average, a solar box can pasteurize about 1 gallon of water in 3 hours on a very sunny day (Rolla, 1998).

Figure 2
A solar box made from cardboard and foil. (Andreatta, 1994)

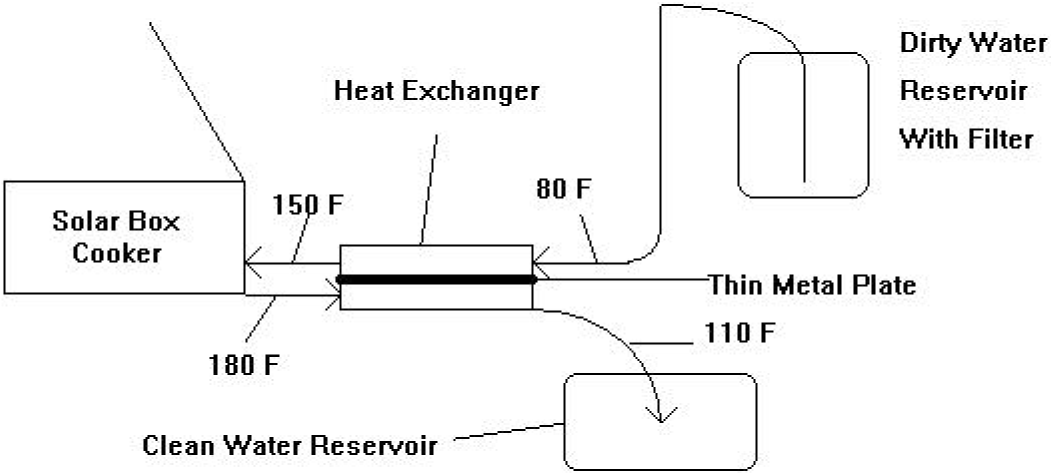

Figure 3: A schematic of a more advanced version of the solar box with a flow in and out, providing appropriate retention time to continually pasteurize drinking water. (Andreatta, 1994)

If the materials for a box are unavailable, a pond is also a feasible solution. A shallow pit must be dug (about 4 inches deep and 3 feet square) and insulated with grass, leaves, etc. Layers of clear and then black plastic can be used to line the pit. Water is added and then covered with another layer of plastic, rocks or wadded paper for spacing, followed by another layer of plastic. Rocks and dirt can be used to hold down the plastic. At a cost of $4, such a procedure yielded 17 gallons of water on a sunny day in Berkeley, California (Rolla, 1998).

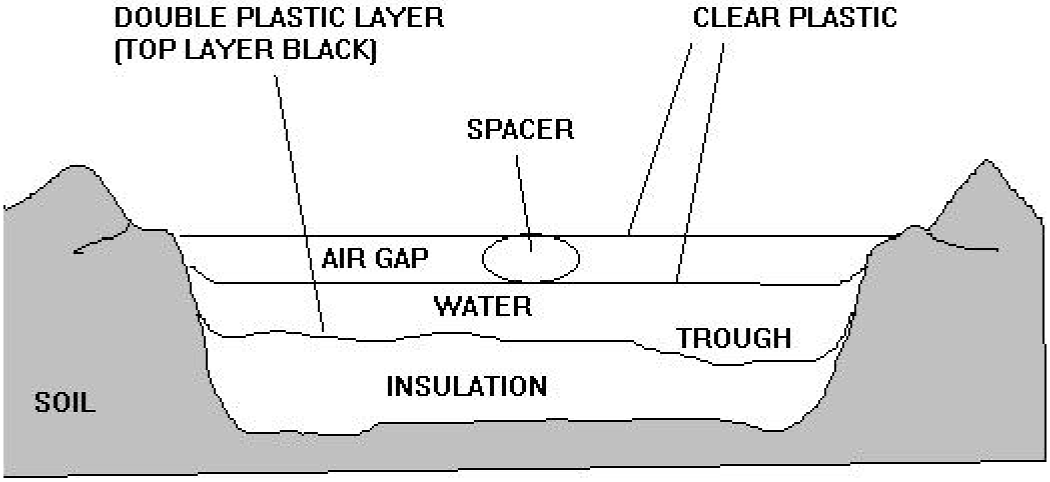

Figure 4: A basic schematic of a solar pond (Andreatta, 1994)

However, there are still problems with UV treatment techniques. Although most biological activity is neutralized by these techniques, giardia cysts will survive UV treatment regardless of the system used for disinfection (Extension Bulletin 795, 2003). In the developing world, it may be difficult to know that pasteurization temperature has been reached. If thermometers are available, they can be used to this end. If not, another method must be found to guarantee the achievement of the appropriate temperature. "An ingenious method developed by Dr. Fred Barrett (U.S. Department of Agriculture, retired) in 1988 is the Water Pasteurization Indicator (WAPI)." This device is a polycarbonate tube, sealed at both ends, and partly filled with a blue soybean fat, which melts at 156 F. It is placed fat end up in the water container, so the user can easily identify when the fat has melted and the water is at the appropriate temperature (Rolla, 1998).

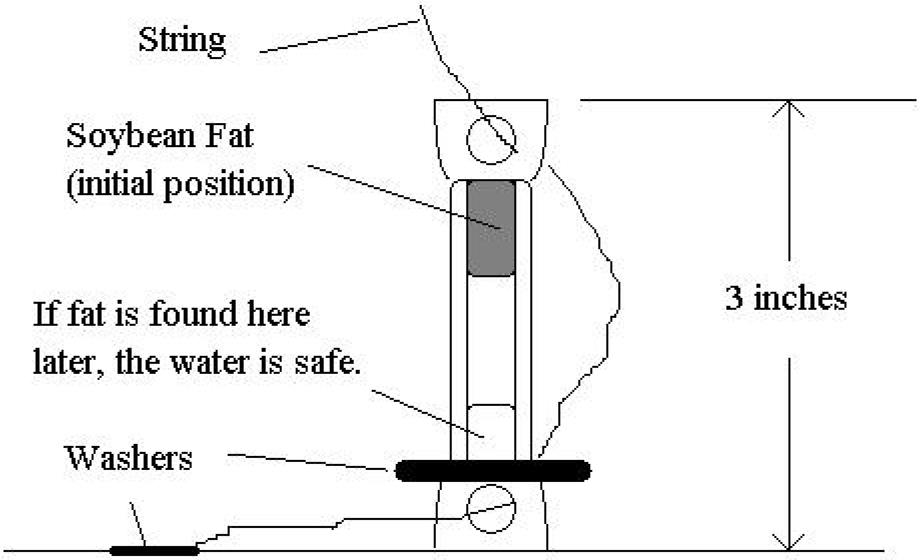

Figure 5: A schematic of the WAPI. (Andreatta, 1994)

In addition to the inability to inactivate giardia spores, simple UV treatment will not work on cloudy or rainy days. For this reason, it is necessary to have a back up plan for drinking water disinfection. The real advantage to these techniques is that they require little in the way of inputs, either material or monetary. The expertise required is likewise very small. These benefits make UV treatment a viable plan for very small-scale drinking water treatment in the developing world. As mentioned above, a large-scale UV treatment procedure would be more expensive and more difficult to manage. However, the following links provide references and information for those interested in investigating larger scale UV treatment operations.

See "Additional References" for links and references available for design and implementation of the above technologies.

Table 1: Costs and capacities of different boiling and solar treatment schemes. (Andreatta, 1994)

| System Name | Initial Cost (US dollars) | Liters of Water/ Dollar (long term) |
|---|---|---|
| a) Flame-heated water pot (Heated to boiling with no pasteurization indicator) | Small | 50 |
| b) Flame-heated water pot with pasteurization indicator | 3 | 96 |
| c) Solar Box Cooker with pasteurization indicator | 23 | 580 |
| d) Solar Puddle ("family size") | 6 | 1800 |
| e) Solar Puddle (community size, 10 ft. by 25 ft) | 25 | 3500 |

## Iodine

Chemical disinfection can be a very effective method of drinking water purification. However, implicit in the use of chemicals is some level of input from external sources. Such a method requires money, a source, and the ability to import the chemicals. If the resources are available, iodine disinfection can effectively purify water of biological agents. However, inactivation of giardia is unreliable, as in the case of UV systems (Extension Bulletin 795, 2003). This procedure, however, can be made more reliable if the water is allowed to have a contact time of 15 hours or more (CDC, 2003). For individual home use, .25 ml of 2% tincture of iodine (readily available over the counter internationally) is simply added to one quart/liter of clear water (or .5 ml added to one quart/liter cloudy water). The solution is then shaken and allowed to sit for thirty minutes for immediate disinfection. As mentioned above, this technique will only eliminated giardia spores if allowed to sit for 15 hours or more (CDC, 2003).

There are many issues surrounding the use of iodine in drinking water disinfection. The diets of many living in underserved areas of the developing world suffer from iodine deficiencies, leading to giant goiters (Wilson, 1941), birth defects, miscarriages, and a host of developmental disabilities (NCCDP, 2003). As one remedy, the National Cambodia Community Development Project recommends iodine addition to village water supply. So, in areas identified as deficient in dietary iodine, this method of drinking water disinfection may be advisable and doubly beneficial.

At present, there are no proven adverse health effects associated with iodine (Extension Bulletin 795, 2003). However, it is an active chemical in the human body and it has been widely speculated that it may have some negative and as yet undetermined health effects. For this reason, Health Canada cautions: “iodine disinfection of drinking water should be reserved for emergency and occasional use. Iodine should not be used for long-term continuous disinfection because it is physiologically active, and ingestion in excessive amounts may be harmful (Health Canada, 2003, Extension Bulletin 795, 2003). Iodine can be injected in greater quantities into a larger scale water supply system. “Iodine solutions are injected into a water system using bypass saturator systems or injection pumps. A holding tank or coil of pipe is used after iodine injection to provide the necessary holding time” (Extension Bulletin 795, 2003). Such a system is somewhat complicated, although it may be feasible if the community has enough money and the relevant expertise to install and maintain iodinater(s). However, given the contentious nature of iodine use in drinking water disinfection, it seems safe to say that it is not exactly the most sustainable solution.

## Chlorine

Chlorination is similar in many ways to iodination of drinking water. Like iodine, chlorine treatment can be used to inactivate bacteria, viruses, and some protozoa. However, at the low levels of chlorine typically used for drinking water treatment, giardia spores will not be inactivated. Chlorine concentrations of 10 mg/L must be maintained for 30 minutes in order to inactivate giardia (Extension Bulletin 795, 2003). A number of variables influence the amount of chlorine necessary for disinfection. These include PH, water temperature, and turbidity (Extension Bulletin 795, 2003). Longland gives a thorough explanation of tests that can be conducted in order to determine the chlorine demand in a given water supply (Longland, 1983).

Six drops of ordinary household bleach (5.25 % free chlorine) is sufficient to disinfect each gallon of drinking water. The water must be shaken and kept in contact with bleach for thirty minutes. Industrial bleach (15 % free chlorine) and dry bleach (4% free chlorine) contain different concentrations of chlorine and calculations need to be made in order to determine the appropriate amount to be added per gallon of water (National Center for Environmental Health, 2003).

Table 2: Information adapted from Wagenet (1988)

| Liquid Chlorine (Sodium hypochlorite) | | Dry Chlorine (Calcium hypochlorite) | |
|---|---|---|---|
| 5.25% Chlorine in domestic bleach | 6 drops/gallon | 4% Chlorine in dry chlorine powder | Follow Mixing recommendations in Wagenet (1988) or Life Water.org. |
| 18% Chlorine in commercial bleach | 2 drops/gallon | | |

On a larger scale, either more chlorine can be added manually, or a box chlorinator can be installed in order to constantly deliver an appropriate concentration of chlorine to the water supply. Like the iodinater, this will require materials and relevant expertise to install.

Also like iodine, the negative health effects associated with chorine are ill defined. “The adverse effects of chlorination result both from chlorine and from compounds formed by the reactions of chlorine with other chemicals present in water”(Garfield, 1985). Although adverse health effects associated with chlorine disinfection are proven, it is still amongst the best technologies available in the developed world. The promise of chlorination in the developing world is therefore also great, considering the low cost of bleach. Nonetheless, alternatives should be constantly considered to reduce the potential for adverse health effects related to chlorine disinfection.

## Filtration

Most filtration systems produced commercially are expensive and labor/maintenance intensive. However, there are a couple of simple filtration processes that require a minimum of external inputs and expertise for continued operation and maintenance. For example, passing drinking water through a double layer of thin fabric will remove the guinea worm, an important parasite in many parts of Africa (Peace Corps, 2003). This is a very specific and simple technology appropriate only in places known to have a single problem, the guinea worm. In places with more common drinking water problems, such as protozoa, bacteria, viruses, and chemical contaminants, the slow sand filtration system may be a good treatment technology for a small community or village.

Jordan (1980) provides a quick explanation and further references on how to construct a slow sand filter in a rural community. The slow sand filter is a good solution, provided the materials are available for construction and the water flow through the filter is small enough. Although the quality of filtered water is typically good, Jordon (1980) reports that the slow sand filter can only filter 7-11 liter/hour, per square meter of filter surface area. This is an important consideration when installing such a filter in a rural community.

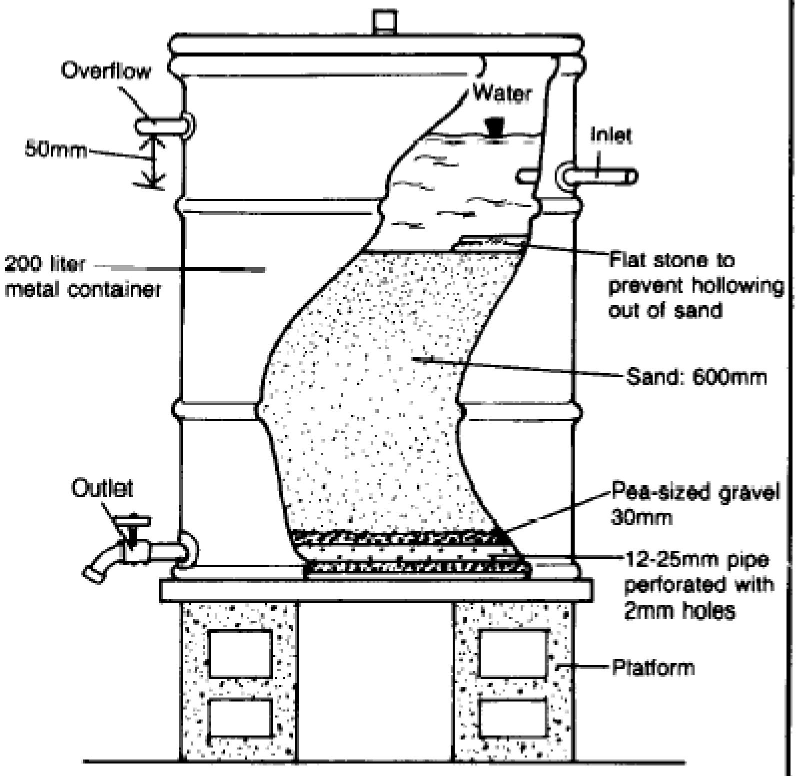

**Figure 1. Household Sand Filter**

Figure 6: From Lifewater.org

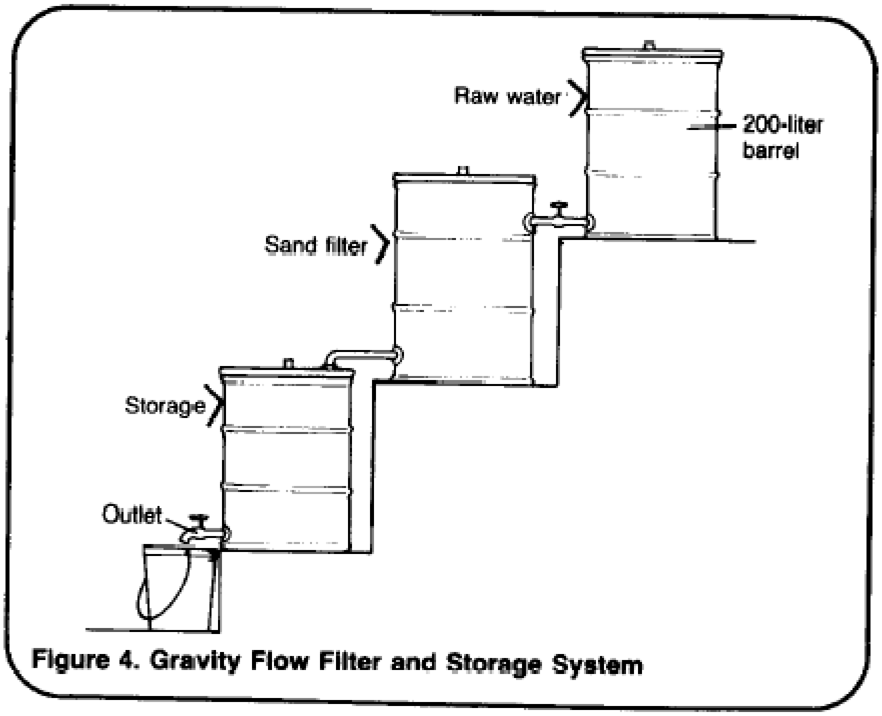

Figure 7: From Lifewater.org.

## Community Participation, Money, External Inputs

The technologies presented here are primarily those requiring the smallest amount of money and resources to initiate and operate and the smallest amount expertise to sustain. Nonetheless, all of these technologies require some of these things. Boiling requires wood or other fuel. UV treatment requires plastic bottles or other materials. Sand filtration requires materials and the skill to assemble such a device. Regardless of the technology chosen for a given household or community, the main contributing factors to the success or failure of the technology will be education, community outreach and participation. Experience from the relevant literature indicates that the successful drinking water projects in the developing world have focused attention beyond technical aspects of the project (FAO, 2003). Reasons for such a phenomenon are obvious. Involving people in the process and the understanding of the causes of their problems and exposing them to appropriate technologies aimed at the eradication of these problems well necessarily be more successful and sustainable than traditional methods focusing on implementation of strategies almost in spite of the needs and wants of the people (Keketso, 2003). These sometimes elaborate methods, which have excluded native people from the process of addressing and fixing their problems has proven to fail in the past and may well account for the relatively poor record of sustainability for development projects in the past (Keketso, 2003).

## Table 3: Treatment Summary

| Issues | Boiling | Plastic Bottes | Solar Box/Pond | Iodine | Chlorine | Slow-Sand Filtration |
|---|---|---|---|---|---|---|
| Cost | Low to High | Low | Low to Moderate | Moderate to High | Moderate to High | Low to Moderate |
| Required Expertise | Low | Low | Low to Moderate | Low to Moderate | Low to Moderate | Moderate to High |
| Required External Inputs | Low to High | Low | Low to Moderate | Moderate to High | Moderate to High | Low to Moderate |
| Adverse Health Effects | None | None | None | Yes | Yes | None |

**References**

Andreatta, Derek T. Yegian, Lloyd Connelly, and Robert H. Metcalf. 1994. "Recent Advances In Devices For The Heat Pasteurization Of Drinking Water In The Developing World." From the proceedings of the 29th Intersociety Energy Conversion Engineering Conference, American Institute of Aeronautics and Astronautics, Inc. Site Visited April 11, 2003. Available: http://solarcooking.org/solarwat.htm.

Bourgoing, Robert. 1989. "Cleaning water with sunshine." IDRC reports

Bunge, Mario. 2000. "Social science under debate: a philosophical perspective." Toronto: University of Toronto Press.

CDC Traveler's Health. 2003. "Risks From Food and Drink" Site Visited March 24, 2003. Available: http://www.cdc.gov/travel/food-drink-risks.htm

Drinking Water Resources. 2003. "Treatment Methods: Boiling." Site Visited March 28, 2003. Available: http://www.cyber-nook.com/water/Solutions.html#boiling

Earthwatch Radio. 1996. "World Water Woes." Site Visited: March 29, 2003. Available: http://ewradio.org/program.aspx?ProgramID=1262

Extension Bulletin 795 795. 2003. "Ultraviolet." The Ohio State University. Site Visited March 26, 2003. Available: http://ohioline.osu.edu/b795/b795_9.html

Garfield, Eugene. 1985. "Essays of an Information Scientist", Vol:8, p.339-347, 1985 Current Contents, #36, p.3-11, September 9.

Health Canada. 2003. "Water Treatment Devices for Disinfection of Drinking Water." Site Visited March 30, 2003. Available: http://www.hc-sc.gc.ca/ehp/ehd/catalogue/general/iyh/disinfection_devices.htm

Jordan, Thomas D. Jr. 1980. "A Handbook of Gravity-Flow Water Systems." Intermediate Technology Publications, London.

Keketso, Lawrence. 2003. "The mixed blessings of the Lesotho Highlands Water Project: An assessment based on local perspectives." Mountain Research and Development. Vol. 23 #1. Feb: 7-10.

Longland, F. 1983. "Field Engineering: An introduction to development work and construction in rural areas." Intermediate Technology Publications, London.

National Center for Environmental Health. 2003. CDC. Site Visited March 25, 2003. Available: http://www.cdc.gov/nceh/emergency/flood/default.htm

Northeast Cambodia Community Development Program (NCCDP). 2003. "Lesson on iodine deficiency disorders (IDD's) for community members." Site visited March 24, 2003. Available: http://rc.racha.org.kh/resources/documents/101-200/121-140/133/NU-024.pdf

Padmasiri, J.P. and Wickremasinghe, N.I. 1997. "Participatory role in rural water treatment." 23rd WEDC Conference. Durban, South Africa.

Reed, R.H. 1996. 'Sol-air' water treatment: 22nd WEDC. Conference Proceedings.

Reed, R.H. 1997. "Water and sanitation for all: partnerships and innovations." 23rd WEDC Conference Durban, South Africa. Conference Proceedings

Rolla, Trudy C. 1998. "Sun and water: an overview of solar water treatment devices." Journal of Environmental Health. 06/98, v60:n10. p30(3).

SD Dimensions. 2003. FAO. Site Visited March 31, 2003. Available: http://www.fao.org/waicent/faoinfo/sustdev/PE2_en.htm

Troy, Steve. 2003. "Safe Water Systems." Sustainable Village. Site Visited March 25, 2003. Available: http://www.thesustainablevillage.com/projects/solsaver.html

Wagenet, Linda and Lemley, Ann. 1988. "Chlorination of Drinking Water: Fact Sheet 5." Cornell Cooperative Extension, New York State College of Human Ecology.

Water in Africa. 2003. Peace Corps. Site Visited March 30, 2003. Available: http://www.peacecorps.gov/wws/water/africa/countries/burkinafaso/healthnutrition.html

Watersolve International, LLC. 2003. "Ultraviolet Systemes." Site Visited March 23, 2003. Available: http://www.watersolve.com/..%5C..%5C..%5C..%5C..%5C..%5C..%5C..%5C..%5C..%5Cws_uv.htm

WHO. 1996. "Fact Sheet #112: Water and Sanitation." Site Visited: March 29, 2003. Available: http://www.who.int/inf-fs/en/fact112.html

Wilson, Dagmar C. 1941. "Fluoride in the Aetiology of Endemic Goitre." The Lancet Feb 15, 1941 (p. 212-213), India.

Yourwaterneeds.com. 2003. "Drinking Water Systems." Site Visited: March 29, 2003. Available: http://www.yourwaterneeds.com/DW_US_Reverse_Osmosis.asp.

9/78 WO Amendment 9. 2003. Sanitary Engineering and Public Health Handbook. Site Visited March 31, 2003. Available: http://www.fs.fed.us/im/directives/fsh/7409.11/42-42.29.txt

## Additional References

See http://solarcooking.org/sunandwater.htm for a good overview of low technology solar treatment technologies. For more advanced technologies and larger systems for community or village level drinking water disinfection, see http://www.thesustainablevillage.com/projects/solsaver.html, which gives links, references and resources for establishing small-community based UV disinfection systems

See http://www.lifewater.org/wfw/rws3/rws3c1.pdf for an in depth description on construction of sand filters, as well as a host of other treatment technologies appropriate for the developing world.

In order to find information describing how to "shock" chlorinate a well see http://www.cdc.gov/nceh/emergency/flood/wells.htm This provides an easy to follow and thorough procedures and a set of calculations which can be made in order to determine the appropriate quantity of bleach or chlorine granules necessary to disinfect a well.

See http://www.metrokc.gov/health/env_hlth/dwp/springs.htm for an explanation about chlorinating a water supply originating at a spring box.