Water Purification

Reprinted 2013
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"Water, Water everywhere…nor any drop to drink" (Coleridge, 1798). Clean drinking water is far more precious than most people think. Over a billion people world-wide, one-fifth of the world's population, lack access to clean water (West, 2009). While humans obviously need water to survive, contaminated water can be poisonous or even lethal. According to the Center for Disease Control, "Waterborne diseases account for approximately 4 billion episodes of illness and 1.8 million deaths every year, predominantly among young children" ("Safe Water System," 2006). Production of safe drinking water is a major concern for much of the world population, many of whom have do not have a government that provides clean water. Many have to rely on contaminated water sources. Fortunately, there are different methods to purify water; some are complex and expensive while others are very primitive but effective. First, however, it is important to understand the water cycle and the chemical and physical aspects of water. Another issue to consider is the different types of contaminants that need to be removed. Only then will it be possible to explore point-of-use methods that can be used by villagers or individual families in an effort to alleviate some of the suffering.

The Water Cycle

In order to understand the production of water, it is important to first study hydrology, the science of water. An important concept in hydrology is the water or hydrologic cycle. The water cycle is nothing more than the movement of water throughout the world, in other words a "continuum of water movement" ("Hydrologic Cycle," 2005). One of the most important and defining characteristics is that the water cycle has no beginning and no end. The nature of the water cycle allows one to start at any point and continue through the entire cycle without pause. A visual representation of the water cycle can be seen in Figure 1 below. The water cycle has no true beginning or end: it is circular.

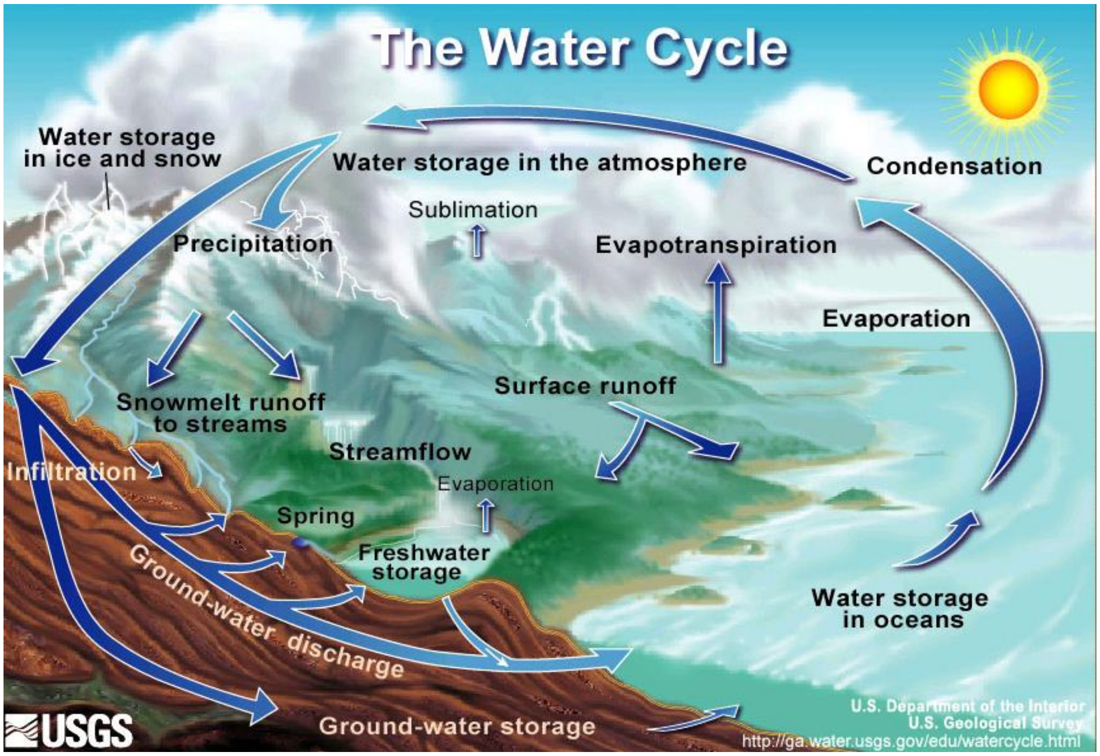

Figure 1: The water cycle and its various stages (http://www.nhn.ou.edu/~jeffery/course/c_energy/energyl/lec004/water_cycle_001.png).

The water cycle is made up of nine physical processes in which water changes in location and/or its state of matter (“Hydrologic Cycle,” 2005). The four states of matter are solid, liquid, gas, and plasma (Russell, “States of Matter,” 2008).

The Four States of Matter

There are four basic states of matter that water moves through as it changes form in the hydrological cycle. Matter with atoms or molecules packed together tightly is as a solid. Solids keep their shape and have a definite volume. Common examples of solids include ice (which is frozen water), wood, and rocks. The process of a solid turning into a liquid is known as melting, and the reverse is called freezing. (Russell, “Solids,” 2008). A liquid is a form of matter whose atoms or molecules are not as tightly bound as those in a solid, so it flows freely and takes the shape of a container in which it is contained. The most common liquid that people are familiar with is water. The process of liquids becoming a gas is known as evaporation (Russell, “Liquids,” 2008). A gas is the form in which atoms or molecules are far apart, flying around at high velocities. The volume of a gas will change, depending on the temperature and pressure that is put upon it. Like a liquid, a gas is a fluid, which means that it can flow freely. The Earth’s atmosphere is made up of multiple gases, ranging from nitrogen gas to oxygen gas. Another common gas is helium (Russell,“Gas,” 2008). The process of a gas turning into a liquid is known as condensation, which is what causes water droplets to be formed around the outside of a cold object, such as a glass of ice. In the hydrological cycle, clouds are formed by water condensing high in the sky (“What is condensation?,” 2007). Figure 2 below shows how condensation produces liquid water, both by expansion of air and by direct cooling of air. (“States of Matter: Preparation,”n.d., p. 2).

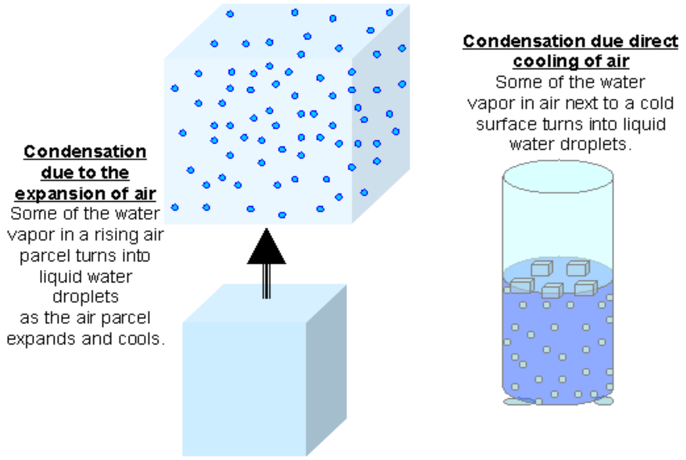

Figure 2: Condensation of water vapor (gas form of water) can occur in two major ways: expansion of air or direct cooling of air (http://www.weatherquestions.com/condensation.gif).

The fourth state of matter is plasma, the most common state of matter in the universe. Stars, whose masses far outweigh those of planets and also far outnumber planets, are made of plasma because the temperature and pressure in them are so high that matter cannot exist as a solid, liquid, or gas. Plasmas are not made out of atoms or molecules, but rather free electrons and ions (which are atoms that have been stripped of their electrons). (“What are Plasmas?,” 2004). While most plasmas are in stars, there are some examples of plasma being on Earth, such as in bolts of lightning, auroras, and in certain man-made objects like fluorescent lights (Grimmitt, 2002). The four states of matter are shown in Figure 3 on the next page.

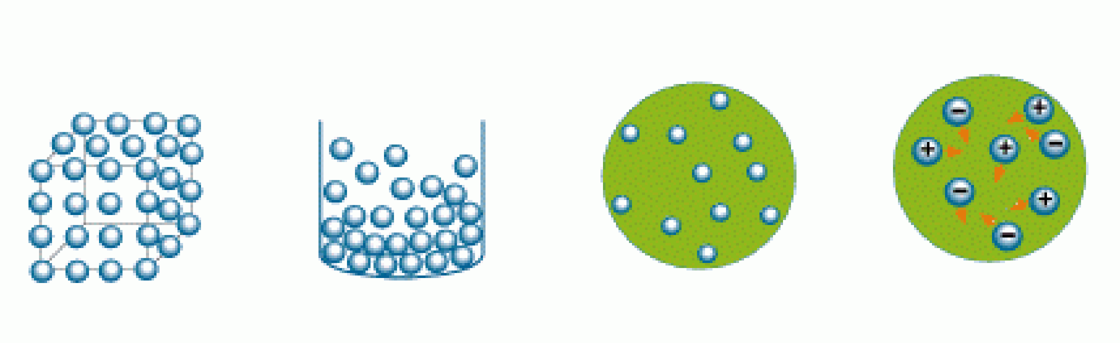

Figure 3: In order from left to right: solid, liquid, gas, plasma. The blue spheres are atoms or molecules Solids are rigid and form a definite shape whereas the liquids, gases, and plasmas can change in shape. (http://www.windows.ucar.edu/sun/Solar_interior/Sun_layers/Core/4_states.gif).

The Physical Processes of the Water Cycle

There are nine basic physical processes in the water cycle: evaporation, condensation, precipitation, interception, infiltration, percolation, transpiration, runoff, and storage. Evaporation is one of the most familiar processes that water undergoes in the water cycle. It occurs when liquid water turns into water vapor. Evaporation occurs when liquid water is heated with energy, around "600 calories of energy for each gram of water, is exchanged during the change of state" ("Hydrologic Cycle," 2005). Normally this energy is provided by the sun with solar radiation, but other sources of heat will cause water to evaporate. For example, a heated building will evaporate water that may have settled on top of the building. Factors that contribute to the evaporative rate of water include air temperature, vapor pressure, atmospheric pressure, and wind ("Hydrologic Cycle," 2005).

Condensation is the opposite of evaporation. It is the change from a gas to a liquid. With water, that means from water vapor back to liquid, normally water droplets, which form fog, dew, and clouds. There are two ways in nature to condense water vapor: the cooling of air and/or reaching the vapor saturation point, which means that no more water vapor can be put into that area ("Saturation point," 2013). The energy needed to turn liquid water into water vapor, 600 calories per gram of water, is released into the surrounding environment when water condenses ("Hydrologic Cycle," 2005).

There are two processes for the condensed water droplets to fall back down to the ground: the coalescence process and the ice-crystal process. In the coalescence process, once enough water has condensed into a cloud, the water droplets will start growing bigger until they reach a critical size. When the droplets are large enough to be affected by gravity, they will fall to the earth as rain. The ice-crystal process occurs when the clouds are cold or high in the atmosphere. Instead of water droplets reaching critical size, the droplets freeze into ice crystals, which will also eventually reach a certain size before falling to the ground in the same way that water droplets do ("Hydrologic Cycle," 2005).

As rain falls to the ground, plants and other objects will collect the raindrops, halting their descent. On a plant's leaf, for example, the water will slide down to the tip of the leaf and stay there until it grows in size enough to break surface tension. The water will then drop to the ground. Whenever an object, be it a plant, a land formation, or a man-made object, stops raindrops, it is called interception because something intercepts the raindrops. This also applies to snow, which is best exemplified "when it snows on conifer forests and hardwood forests that have not yet lost their leaves" ("Hydrologic Cycle," 2005).

When water hits soil, it will usually seep through in a process known as infiltration. Infiltration almost always occurs, but the rate of infiltration will depend heavily on the conditions of the soil. For example, soil that is dry and has cracks in it will allow water to seep through more easily than soil that is moist and is mostly molded together. The water infiltrating the soil will eventually either become part of an underground river/stream or evaporate through the soil in a process called evapotranspiration (“Hydrologic Cycle,” 2005).

The actual movement of water through the ground is called percolation. Water can move through the ground in a variety of ways. The most common ways are through capillary forces and gravity because gravity affects everything on the planet, and the soil can provide tube-like holes for the water to travel through. Once underground, water will stop moving purely downwards and start moving horizontally, depending on the geological conditions of the surface and sub-surface layers. Sometimes there will be spots in the earth where water does not flow much or at all. These underground reservoirs are capable of storing vast amounts of water (“Hydrologic Cycle,” 2005).

Transpiration is the biological process of transferring liquid water to the atmosphere as water vapor from plants. A plant does this to move nutrients to the upper portions of the plant as well as to cool the leaves that are directly exposed to sunlight. Transpiration occurs when the stomata, or water-releasing cells, are open. Most plants only keep a small portion of the water they absorb; most of it is transpired back into the atmosphere (“Hydrologic Cycle,” 2005) .

Wherever there is a stream or river, there is runoff. Runoff usually is when precipitation hits a stream or river. The water starts moving with the flow until it reaches a large storage area, such as a lake or ocean. Water that is underground can move as well and is called sub-surface runoff. Usually the sub-surface runoff will enter a stream or river and become part of a larger surface runoff (“Hydrologic Cycle,” 2005).

Storage in the hydrologic cycle can refer to one of three things: atmospheric water, surface water, or underground water. Water can still move in storage, though not nearly as much as in runoff. Examples of surface storage include lakes, oceans, glaciers, and reservoirs. Atmospheric storage is simply the storage of water vapor in the atmosphere, either as free water vapor or in the form of clouds, fog, and mist. Underground storage is much like surface storage; there are underground lakes and reservoirs, but water can also be stored in rock crevices, the soil, or aquifers (“Hydrologic Cycle,” 2005).

Purification of Water to Make it Potable

The problem is that not all water collected through these geographical means is pure. While some springs provide a natural filtration, and sometimes individuals collect clean rainwater, the vast majority of water on the planet, including rivers and primarily sea water, is too contaminated for safe human consumption. What is needed is a cheap and effective method of purifying water to make it safe for humans to drink. Current methods for purifying water include boiling and chemical treatment. Most cases of water contamination occur because bacteria and viruses like to inhabit natural bodies of water, but there are many cases where water is contaminated by unsafe chemicals. Both boiling and chemical treatment will get rid of biological contamination, bacteria and viruses, easily, but it will not work with chemical pollutants (Curtis, 1998). In that case, special filtration methods may be needed.

Water Contamination

Contamination of water is a serious worldwide issue that must be addressed. Underdeveloped countries, such as those in sub-Saharan Africa, are hit the hardest because of a lack of water treatment facilities, poor sanitation, and poor hygiene. “This amounts to 3.4 million deaths per year, two thirds of which are caused by diarrhea, a disease that claims the lives of more than 2.2 million people every year. Most who die are children in developing countries (“The Role of Ministries of Health,” 2002, p. 2).

In a study of “Data collected in the late 1980s from eight countries in Sub-Saharan Africa (Burundi, Ghana, Togo, and Uganda), Asia/North Africa (Sri Lanka and Morocco), and the Americas (Bolivia and Guatemala),” the statistics “were combined and analyzed to test whether incremental health effects regarding diarrhea and nutritional status result from incremental improvements in water and sanitation conditions” (Esrey, 1996). The findings of this UNICEF study were that when sanitation was improved and when “optimal water” was present, the overall health conditions improved as well, including the measurements of the “heights and weights of children” (Esrey, 1996).

During the International Drinking Water Supply and Sanitation decade (1981-1990), the United Nations tried to ensure safe drinking water for the world’s population. Safe drinking water means water collected from improved sources such as rainwater collection, a protected well or spring, and public or household pipe rather than water from a tanker truck, river, pond, or unprotected well or spring. By 2000, however, there were “1.1 billion people still without access to safe drinking water” (“Safe Drinking Water,” 2001). Countries lacking safe drinking water for over 50% of their population include Guinea, Ethiopia, Chad, Rwanda, Cambodia, Haiti, Angola, Congo, among others. In Figure 4 below, the areas of the world with the least access to clean drinking water are listed in order from least to most. The United States and other fully industrialized countries are considered to have 100% access.

Sub-Saharan Africa	43%
East Asia/Pacific	24%
South Asia	16%
Latin America/Caribbean	14%
Middle East/North Africa	13%
Central Eastern Europe	9%

Figure 4: Percentage of population without access to safe drinking water as of 2000 (“Safe Drinking Water,” 2001).

Lack of clean water is extremely serious. “Today 31 countries, accounting for under 8% of the world population, face chronic freshwater shortages. By the year 2025, however, 48 countries are expected to face shortages, affecting more than 2.8 billion people—35% of the world's projected population” (“Solutions for a Water-short World,” 1998). In many countries, especially in rural areas, people have no choice but to drink contaminated water. Sanitation is a major contributor to the problem; in South-East Asia alone, it was estimated in 2002 that 873 million people practice “open defecation” (“The Role of Ministries of Health,” 2002, p. 3). In fact, “Globally, 19 per cent of deaths due to infectious diseases stem from water, sanitation and hygiene risk factors” (“The Role of Ministries of Health,” 2002, p. 2). This can be seen in Figure 5 below.

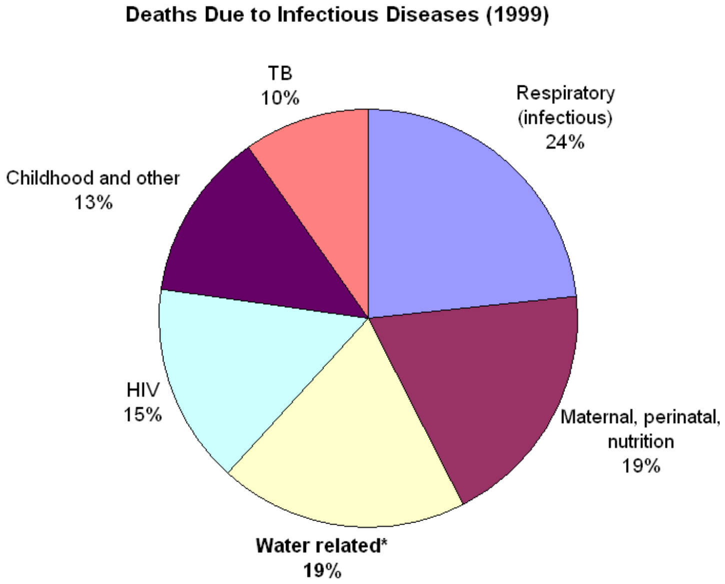

Figure 5: Percentage of deaths due to infectious diseases in 1999 (http://www.worldwaterday.org/wwday/2001/disease/infectl.gif).

Biological diseases such as hepatitis, trachoma, and typhoid can all come from infected water sources. Not only are viruses and bacteria transferred, but infectious parasites can easily be ingested via water. For example, intestinal nematodes, which are a type of roundworm, also infect unsafe water sources ("Role of the Ministries," 2002, p. 2). In fourteen African countries "prone to water shortages," the guinea worm parasite is especially common, causing "crippling pain," which keeps children out of school and leaves adults unable to work ("Progress since the World Summit for Children," 2001).

In addition to biological contaminates, there are also chemical contaminates. For example, arsenicosis and fluorosis can occur from arsenic and fluorine pollution: "…it has been estimated between 35 and 77 million people in Bangladesh are at risk [2002] from drinking arsenic contaminated drinking water…" ("The Role of Ministries of Health," 2002, p. 3). Arsenic pollution can cause neurological damage in humans (Reinhardt). "Fluoride affects an estimated 60 million people in India alone" ("The Role of Ministries of Health," 2002, p. 3). It causes abdominal pain, nausea and vomiting, and long-term exposure can eventually calcify ligaments, causing skeletal abnormalities. Fluorosis is likely to occur in areas that have contaminated runoff at the foot of mountains or deposits from the sea, such as Turkey, Jordan, Egypt, Japan, northern Thailand, China, and Afghanistan ("Fluorosis," 2009).

Water supply contamination is frequently made worse by natural disasters. For instance, after Cyclone Sidr struck Bangladesh in 2007, "At least 300,000 children under the age of 5…[were] forced to drink…polluted water that has [had] been through the storm and picked up diseases from garbage and dead animals" (Williams, 2007). In 1997, flooding in Africa brought cholera due to water supply contamination. In Mexico in 2000, a sewer wall was ruptured because of heavy rain, forcing 6,000 people to live on the rooftops of their houses. Flooding in Ghana polluted over "200 dams, wells, and boreholes," causing people to have to resettle in other areas (Smith, 2001). In Mozambique, another flooding situation put 800,000 people at "increased risk of infectious diseases" (Smith, 2001). Seventy-five percent of the Honduras population (4.5 million) was without access to clean drinking water after Hurricane Mitch in 1998 (Smith, 2001). Natural disasters can seriously affect the water supplies in developing nations.

Although industrialized nations like the United States are not as seriously affected, they too can experience natural disasters. The delta region of the Mississippi River has been contaminated with pollutants for decades. This is caused by agricultural runoffs of chemicals like herbicides, pesticides, and fertilizers, as well as waste treatment center outputs. Even after being filtered and chlorinated, drinking water still had dozens of carcinogens and other harmful chemicals in the delta area. When Hurricane Katrina hit, the pollution was worsened even further by post-storm flood damage (Reinhardt, 2009).

Storm water is not always associated with major storms. Heavy rain or melting snow can also carry pesticides, detergents, car fluids, and even fecal matter (King, 2009). Industrialized nations have the means to purify their water; however, even in the United States, the water purification systems are sometimes flawed. "During 1993 and 1994, there were 30 reported outbreaks of disease associated with drinking water, 23 associated with public water supplies. An outbreak of cryptosporidiosis in Milwaukee during that time resulted in 400,000 victims being treated, with 4000 being hospitalized and over 50 deaths" (Gore, 2008). The problem is that cryptosporidium is one of the pathogens able to pass through the filtration and disinfecting processes. "Safe" water is actually a relative term, and it is possibly less safe for the very young, the very old or those with immunological disabilities (Gore, 2008).

Drinking Water Standards

The Environmental Protection Agency (EPA) sets the minimum standards for safe drinkable water in the United States. There are literally thousands of potential contaminants, both biological and chemical, that can taint water supplies (Gore, 2008). The microorganisms shown in Figure 6 below are not tolerated more than 0.001%. Health risks from microorganisms in water tend to be related to gastrointestinal illnesses, mainly vomiting, diarrhea, and cramps. Microorganisms tend to enter the water supply from human and animal fecal matter ("Drinking Water Contaminants," 2009).

Standards for Microorganism Water Contaminants

Microorganism Contaminant	Percentage Removal
Cryptosporidium	99% removal
Giardia lamblia	99.9% removal
Viruses	99.99% removal

Figure 6: EPA standards for microorganism contaminants ("Drinking Water Contaminants," 2009).

Inorganic contaminants come from a many sources, such as erosion of natural deposits, discharge from factories, and corrosion of plumbing systems. Health effects range from skin problems, kidney and liver problems, to gastrointestinal distress and nerve damage ("Drinking Water Contaminants," 2009). (See Figure 7 below for some of the inorganic contaminants.)

Standards for Inorganic Chemicals

Inorganic Chemical	Maximum Contaminant Level (mg/L)
Arsenic	0.010
Copper	1.3
Cyanide	0.2
Fluoride	4.0
Lead	0.015
Mercury (inorganic)	0.002

Figure 7: EPA standards for inorganic chemical contaminants ("Drinking Water Contaminants," 2009).

Figure 8 below is a sampling of some of the most dangerous organic chemicals. Health effects range from increased risk of cancer, reproductive problems, liver and kidney problems, anemia, immune system deficiencies, to nervous system difficulties. They can come from a variety of areas, from discharge from factories, emissions from combustion, to runoff from insecticides and herbicides ("Drinking Water Contaminants," 2009).

Standards for Organic Chemicals

Organic Chemical	**Maximum Contaminant Level (mg/L)**
Benzene [gasoline]	0.005
Carbon tetrachloride	0.005
Dioxin	0.00000003
Ethylene dibromide	0.00005
Lindane	0.0002
Polychlorinated biphenyls [PCBs]	0.0005

Figure 8: EPA standards for highly dangerous organic chemicals ("Drinking Water Contaminants," 2009).

Radioactive materials in Figure 9 below are some of the most dangerous contaminants. All radioactive substances can potentially cause cancer. They come from erosion of natural deposits and from the decay of natural radioactive minerals ("Drinking Water Contaminants," 2009).

Standards for Radionuclides

Radionuclide	**Maximum Contaminant Level (units depend on radionuclide)**
Alpha particles	15 picocuries per Liter (pCi/L)
Beta particles	4 millirems per year
Radium 226 and Radium 228 (combined)	5 pCI/L
Uranium	30 μg/L

Figure 9: EPA standards for radioactive substances ("Drinking Water Contaminants," 2009).

In addition to the health-threatening contaminants standards, the EPA also sets secondary standards. (See Figure 10 below, continuing to next page.) These standards control "*Aesthetic effects* -- undesirable tastes or odors; *Cosmetic effects* -- effects which do not damage the body but are still undesirable; and *Technical effects* -- damage to water equipment or reduced effectiveness of treatment for other contaminants" ("Secondary Drinking Water Regulations," 2006).

Secondary Standards for Various Contaminants

Contaminant	**Secondary Maximum Contaminant Level (mg/L)**	**Noticeable Effects above the Secondary Maximum Contaminant Level**
Aluminium	0.05 to 0.2	colored water
Chloride	250	salty taste
Color	15 color units	visible tint
Copper	1.0	metallic taste; blue-green staining
Corrosivity	Non-corrosive	metallic taste; corroded pipes/ fixtures staining

Fluoride	2.0	tooth discoloration
Foaming agents	0.5	frothy, cloudy; bitter taste; odor
Iron	0.3	rusty color; sediment; metallic taste; reddish or orange staining
Manganese	0.05	black to brown color; black staining; bitter metallic taste
Odor	3 threshold odor number	"rotten-egg", musty or chemical smell
pH	6.5 – 8.5 pH	*low pH:* bitter metallic taste; corrosion *high pH:* slippery feel; soda taste; deposits
Silver	0.1	skin discoloration; graying of the white part of the eye
Sulfate	250	salty taste
Total Dissolved Solids	500	hardness; deposits; colored water; staining; salty taste
Zinc	5	Metallic taste

Figure 10: The maximum containment level and effects of various contaminants that will not harm the human body (“Secondary Drinking Water Regulations,” 2006).

The EPA handles all of the United States federal regulation of water contaminants. Title 40 Chapter 1 Subchapter D Part 141 defines the national drinking water regulations that the EPA uses. The Safe Drinking Water Act gives the EPA the power to regulate public tap water with the minimum standards. All public water systems are subject to the EPA’s standards unless specifically excluded under Section 1411 of the Safe Drinking Water Act (“National Primary Drinking Water Regulations: Drinking Water Regulations for Aircraft Public Water Systems,” 2008, pp. 3-4).

Water Purification Processes

Water is purified though multiple steps, including sedimentation, filtration, and disinfection, though other purification methods exist. “In a typical municipal water treatment process, water flows through pumps to a rapid mix basin, then to a flocculation basin, to a settling basin, through filters to a clear well, then after disinfection, to storage tanks, and finally to the end users” (Robson, 2006). “These [EPA standards mentioned above] apply to any water distribution system that serves at least twenty-five units [people] daily” (Robson, 2006). Chlorine can be used to disinfect the water, and in some areas, fluorine is also added (Robson, 2006). Chlorination is a cost-effective method of disinfecting water as it can remove pathogens as well as molds and algae. It is effective both in large city water supplies and small rural areas (“Drinking Water Chlorination,” 2008).

Rainwater Filters

There are approximately 155,000 public drinking water systems in the United States. In 2008, 92% of the people in the United States had access to clean drinking water (“FACTOIDS,” 2008, pp. 3, 8). However, in developing countries, one-third of the population has no access to clean drinking water (“Solar Water Disinfection,” 2009). Some of the reasons why third-world countries have far less clean drinking water are lack of expertise and money to run water purification systems, difficulty in making people paying water bills, lack of political commitment, and corruption. Even if a water purification system could get up and running, people illegally gain access to the pipelines and therefore use up all of the clean water before it gets to its destination. According to environmental studies Professor Brent Haddad, a "small is beautiful" philosophy, meaning purification devices on a small scale, could be applied to help provide clean water to third-world countries in the form of "Inexpensive water purification systems that let users pour rainwater through a filter" (McNulty, 2004). Filters work by straining water though a porous material, such as a cloth or coffee filter. They are water-permeable, which means only water can pass through. Large chunks of dirt will not be able to pass through a filter, which can be small enough to keep out most impurities (Sassani, 2009). There are drawbacks to this method, mainly that it requires rain to be present in order to work in the first place. In arid locations, it would not work well at all.

Solar Stills

One of the most unsophisticated methods of collecting potable water is through the use of a solar still. The most basic solar still is a sheet of plastic shaped into a funnel laid in a pit with a collection cup for potable water at the tip. A low point, such as a pebble in the middle of the sheet of plastic, is required for the water to drip into the collection cup. "Solar stills are occasionally used on a longer term basis in developing world settings" ("Solar Still," *MedLibrary.org*, 2009). Doctors Ray D. Jackson and C. H. M. Van Bavel were among the first in the United States to promote solar stills as a survival technique (1377-1379). Their research found that a simple solar still could provide one and a half liters of drinkable water a day. Mamlook and Badran, in a EuroMed 2006 conference on Desalination Strategies, reviewed much of the more recent solar still research. Some of this further research and development has found that asymmetric greenhouse type stills, a cover angle of 15%, and a shallow water basin all increased the efficiency of solar stills. Their own research found that when the "water depth decreases from 3.5 cm to 2cm the productivity increased by 25.7%" (Mamlook & Badran, 2007).

One product based on solar still technology is the Sea Panel Jungle Boss device. It provides one to four liters of distilled water per day. For about $240, it is marketed primarily as a garden irrigator, though it can provide emergency drinkable water ("Sea Panel Jungle Boss System," 2008). Other products include SolAqua's Rainkit 990 and Rainmaker 550. The photograph in Figure 11 below is the Rainmaker 550. These products are described as producing up to six liters of drinkable water. The Rainkit 990 costs $245 while the Rainmaker 550 costs $479 ("Solar Still Basics," 2008).

Figure 11: The Rainmaker 550 when fully assembled (http://us.st12.yimg.com/us.st.yimg.com/I/solaqua_2040_27960).

On the low-tech end, an even simpler form of solar still device is marketed as the Watercone®. National winner of the Energy Globe award in 2008, the Watercone® device is a pre-formed polycarbonate cone fitted on top of a black pan. (See Figure 12 below.) The water evaporates and is collected within the underside lip of the cone. It has a screw at the tip to connect it with a water bottle when the device is flipped over ("Watercone," 2008).

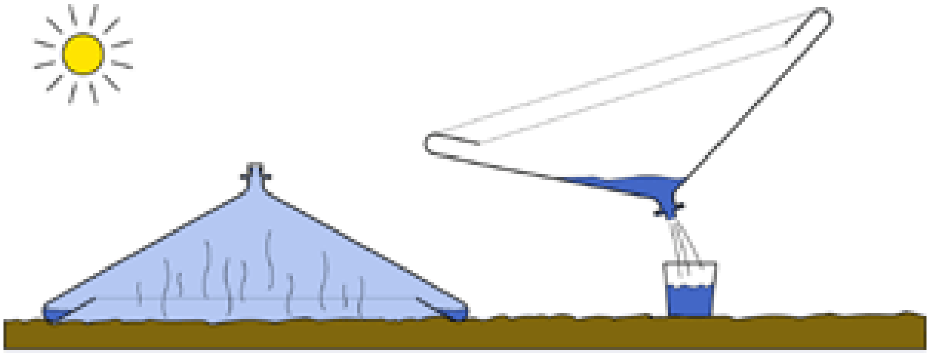

Figure 12: On the left, the Watercone® device collects water; on the right, the device is pouring potable water into a cup (http://watercone.com/pics/funktion300.gif).

The company Mage-Watermanagement GmBH has licensed the Watercone® product and plans world-wide distribution in 2009 ("Watercone," 2008). Another company manufactures a similar conical solar still that is inflatable, which is recommended for sea-faring military and civilians, although it only claims to produce one half to two liters of water a day. It sells for $200, but it is very light-weight, small, and it even floats ("Solar still," *Landfall*, 2009). All of these distilling devices use the energy of sunlight directly to provide the heat for distillation.

To produce one liter of water by distillation, it requires 2260 kilojoules of heat per kilogram, assuming that the system is ideal. Based on a paper for the Schumacher Centre for Technology & Development in the United Kingdom, the typical output of a solar still can be calculated using the equation below (continuing to next page):

> An approximate method of estimating the output of a solar still is given by:
>
> $$Q = \frac{E \times G \times A}{2.3}$$
>
> where:
> Q = daily output of distilled water (litres/day)
> E = overall efficiency
> G = daily global solar irradiation (MJ/m^2)
> A = aperture area of the still ie, the plan areas for a simple basin still (2)
>
> In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre of area is:

$$\text{daily output} = \frac{0.30 \times 18.0 \times 1}{2.3}$$

= 2.3 litres (per square metre)

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 litres/m²/day is typical, the yearly output of a solar still is often therefore referred to as approximately one cubic metre per square metre, 1m³/m²/year ("Solar Distillation," 2009).

Solar Water Disinfection

Another extremely cheap method of purifying water uses solar radiation to remove any bacteria and other biological contaminants from the water. In its most basic form, water is put into a transparent bottle, which is then left in the sunlight for approximately six hours, during which time the sunlight in the 320-to 400-nanometer wavelength, also known as the UV-A spectrum, as well as heat, will destroy pathogenic microorganisms that are the basis of water-borne diseases ("Solar Water Disinfection—The method," 2009). There are disadvantages to using this method, however. For instance, if it is a cloudy day, then the water will need to be left exposed to the sun for two consecutive days to ensure that enough solar radiation has been received. It also only works well with small volumes of water. Using solar radiation to purify water also only affects biological contaminants, so chemical contaminants are left unaffected ("Solar Water Disinfection—How does it work?," 2009).

Heating up liquids to kill microorganisms is known as Pasteurization. The Dome Solar Still Water Purifier/Pasteurizer is a larger device, about four feet long, that claims to clean up to six liters of questionable water in about four hours of midday solar heating. (See Figure 13 below.) In order for solar disinfection to work, the sun must be providing enough heat; therefore, it usually must be "Spring, summer, and fall to use the still" ("Dome Solar Still Water Purifier/Pasteurizer," 2009).

Figure 13: The Dome Solar Still Water Purifier/Pasteurizer, a 2nd generation design (http://home.att.net/~cleardomesolar/DomeStill-asPast-sml.jpg).

Purification Tablets and Boiling

Two of the most common methods of purifying water during camping trips are boiling and purification tablets. Bringing water up to a boil will have the heat kill most, if not all, bacteria and viruses that may be lurking in the water. However, it takes time for the water to reach, and it consumes fuel, which third-world countries would not have much access to. Purification tablets are tablets of iodine or chlorine that are added to water to chemically clean it. Unfortunately, purification tablets have a limited shelf life after being opened, making the tablets good for short-term use, but not so much for long-term use (Sassani, 2009).

Desalination

One particular type of contaminated water is salt water. There are three categories of salt water, based on the concentration of salt in the water: “Brackish water typically contains TDS [total dissolved solids] in concentrations ranging from 1,000 milligrams per liter (mg/l) to 10,000 mg/l. Saline water or salt water has more than 10,000 mg/l TDS. And, brine is very salty water (TDS greater than 35,000 mg/l). Seawater typically is very salty (TDS >35,000 mg/l)” (“Desalination: Frequently Asked Questions,” 2009). Because seawater is so salty, when a person drinks it, he or she takes in so much salt that the body cannot get rid of it fast enough: “Drinking seawater straight is a bad idea because your body must expel the salt by urinating more water than it actually gains” (Schirber, 2007). Seawater has sixty-five times the amount of salt than what is defined as a safe level (Schirber, 2007).

Many countries have long coastlines with many population centers near the sea. Seawater is, of course, not potable. Therefore, these population centers require large desalination plants to be set up in order to provide potable water for the inhabitants. Desalination can also be called “de-mineralization” because modern desalination techniques are able to remove minerals and biological contagions as well as salt (“Desalination – Producing Potable Water,” 2009). Even though desalination is able to make drinkable fresh water from undrinkable seawater, most “Desalination technologies are energy intensive…” (Gezairy, 2007, p. 7).

The energy requirements and costs of desalination technology are the main things holding it back. For example, it takes fourteen kilowatt-hours to produce one thousand gallons of desalinated water, which can cost between three and four dollars. While this may not seem like much, “it is still cheaper in many places to pump water out of the ground or import it from somewhere else” (Schirber, 2007). The table in Figure 14 below (and continuing on next page) breaks down the costs for different methods of desalination, showing the monetary values in Euros (€).

	Multi-Stage Flash Distillation	Multi-Effect Distillation with Thermal Vapour Compression	Mechanical Vapour Compression	Reverse Osmosis
Installation costs (**€/ m**^{3}/day)	1080 – 1690	780 – 1080	1020 – 1500	660 – 1200
Heat consumption (MJ/m^{3})^{b}	194 – 291	145 – 194	0	0
Power consumption (kWh/m^{3})	3.5 – 4.0	1.5 – 2.0	9 – 11	3 – 4.5

Operation & maintenance **(€/m^3)**	0.05 – 0.07	0.04 – 0.07	0.05 – 0.08	0.05 – 0.10
Spare parts & chemicals (**€/m^3**)	0.02 – 0.04	0.02 – 0.03	0.02 – 0.04	0.02 – 0.05
Membranes replacement (**€/m^3**)	0	0	0	0.01 – 0.04

Figure 14: This table shows the capital and operating costs of various desalination technologies. All monetary costs are in Euros (€) (Blanco, 2009).

Research is being done to reduce these costs, such as using alternative energy sources like wind and solar to provide energy; however, massive desalination plants are still in the multi-billion dollar range (Conway, 2008). Therefore, while these plants are feasible in developed nations, they are still out of the reach of developing nations with small budgets. It remains imperative to find ways to desalinate on a point-of-use where families or small groups could process their own drinking or irrigation water.

There are two main types of desalination technologies currently in use: membrane and distillation. Membrane technology, of which reverse osmosis is a type, uses filters to prevent contaminants from moving with water. Distillation, on the other hand, uses the principles of evaporation and condensation. The water is turned into a vapor state with heat, leaving behind or killing contaminants, and is then condensed in another location into fresh and potable water.

The basis of membrane desalination technology is filtration. Water is pumped through a filter, which screens out most contaminants. Figure 60 below shows examples of membrane types, the size of their pores, and what contaminants are removed via that filter. Another form of membrane technology is known as reverse osmosis. Reverse osmosis is based on the osmosis property of water, its ability to penetrate a semi-permeable membrane while leaving behind non-water particles and ions. Osmosis is basically diffusion with water molecules. Under normal circumstances, the process of osmosis continues until equilibrium has been reached: water will keep seeping from the high concentration side into the lower concentration side until both sides of the filter are equal. Reverse osmosis, on the other hand, is the exact reverse of this process. Instead of maintaining equilibrium, pressure is put onto the low concentration side, usually filled with contaminated water, so that water can be moved from that side into the higher concentration side, usually filled with potable water (Helmenstine, 2009).

Comparison of Membrane Performances

Membrane Type	**Pore Size (in μg, approximate)**	**Contaminants Removed**
Microfiltration	0.1 to 1	Particulates, bacteria, protozoa
Ultrafiltration	0.001 to 0.1	Viruses, large organic molecules
Nanofiltration	+/- 0.001	Multivalent metal ions, some organic molecules
Reverse Osmosis	0.0001 to 0.001	Organic molecules >100-300 daltons

Figure 15: Comparison of the pore sizes and contaminants removed between different membrane types in a membrane desalination method (Gezairy, 2007, p. 9).

Distillation can be used to remove both biological and chemical contaminates from water. The process is started by boiling the water in a closed container until it becomes steam. This removes any biological impurities and forces solid chemical impurities to settle. The steam is then directed into a cooler, usually a long tube, where it condenses back into liquid water, free from impurities ("Water Distillation Principles," n.d.). "The effectiveness of distillation for producing safe drinking water is well established and recognized. Most commercial stills and water purification systems require electrical or other fossil-fueled power sources" ("Distillation Purification Capabilities," 2008). Because distillation generally involves boiling water, it may not always be the best choice to purify water for some areas because of the price and availability of fuel.

Conclusion

Purifying water is clearly a vital worldwide need. Too many children and adults are dying from hepatitis, typhoid, intestinal worms and even arsenicosis. The water cycle provides water to the planet, but that water is not necessarily safe to drink. Considering the importance of eliminating both biological and chemical contaminants, it may be beneficial to combine multiple technologies. From filters and membranes to chlorination and even steam or solar distillation, there are many methods of bringing ground or even sea water to proper EPA standards or at least making water safer than is currently available in many emerging countries. While advanced countries may have adequate water-purifying facilities, even they may occasionally have emergency situations from hurricanes, tornados and earthquakes that might require the use of low-cost, point-of-use devices. Boiling water is always a good choice, but it requires fuel, which may not always be readily available. Learning to understand and use simple solar disinfection or solar distillation devices like the Watercone®, The Rainmaker 550, or Dome Solar Still Water Purifier/Pasteurizer may be an even better choice for people throughout the world. In fact, it has been suggested that in the future, the government may only provide water that is usable but not potable, and that POU devices for purification will be a personal responsibility (Land, 2009, p. 47). "Point-of-use (POU) water purification has a solid future….[and] can support a sustainable environment" (Land, 2009, p. 47). It is our responsibility to understand this important survival imperative: clean water is a number-one priority for everyone in every country.

References

Coleridge, S. T. (1798). The rime of the ancient mariner. *The Samuel Taylor Coleridge Archive.* 10 May 1999. Retrieved from http://etext.virginia.edu/stc/Coleridge/poems/Rime_Ancient_Mariner.html

Conway, M. (2008, May 2). Desalination is the solution to water shortages. *redOrbit.* Retrieved from http://www.redorbit.com/news/science/1367352/desalination_is_the_solution_to_water_shortages/

Curtis, R. (1998). OA guide to water purification. *The Backpacker's Field Manual.* New York: Random House. Retrieved from http://www.princeton.edu/~oa/manual/water.shtml

Desalination: Frequently asked questions. (2009, August 25). *Texas Water Development Board.* Retrieved from http://www.twdb.state.tx.us/iwt/desal/faq.html#02

Desalination – Producing potable water. (2009, August 30). *California Resources Agency.* Retrieved from http://resources.ca.gov/ocean/97Agenda/Chap5Desal.html

Distillation purification capabilities. (2008). *Solaqua*. Retrieved from http://www.solaqua.com/solstilbas.html

Dome solar still water purifier/pasteurizer. (2009, July 20). *ClearDome Solar Thermal.* Retrieved from http://home.att.net/~cleardomesolar/solarpurewaterstill.html

Drinking water chlorination. (2008). *American Chemistry.* Retrieved from http://www.americanchemistry.com/100years/Practices.html?gclid=CMf3l96Up5wCFQHAsgodxjzMjg

Drinking water contaminates. (2009, July 14). *U.S. Environmental Protection Agency.* Retrieved from http://epa.gov/safewater/contaminants/index.html#listmcl

Esrey, S. A. (1996). Water, waste, and well-being: A multicountry study." Abstract. *American Journal of Epidemiology*, 143 (6):608+. *The Johns Hopkins University School of Hygiene and Public Health. Oxford Journals.org*. Retrieved from http://aje.oxfordjournals.org/cgi/content/abstract/143/6/608

FACTOIDS: Drinking water and ground water statistics for 2008. (2008, November). *U.S. Environmental Protection Agency.* Retrieved from http://www.epa.gov/safewater/databases/pdfs/data_factoids_2008.pdf

Fluorosis. (2009). *World Health Organization.* Retrieved from http://www.who.int/water_sanitation_health/diseases/fluorosis/en/

Gezairy, H. A. (2007). Desalination for safe water supply. *World Health Organization.* Retrieved from http://www.who.int/water_sanitation_health/gdwqrevision/desalination.pdf

Gore, M. R. (2008, July 15). Drinking water: Clean or contaminated. *suite101.com*. Retrieved from http://public-healthcare-issues.suite101.com/article.cfm/drinking_water_clean_or_contaminated>.

Grimmett, C. (2002). Plasma: The fourth state of matter. *eSSORTMENT.* Retrieved from http://www.essortment.com/all/theplasmastate_rfbb.htm

Helmenstine, A. M. (2009). Reverse osmosis. *About.com.* Retrieved from http://chemistry.about.com/od/waterchemistry/a/reverseosmosis.htm

Hydrologic Cycle. (2005, December 8). *National Weather Service Northwest River Forecast Center.* Retrieved from http://www.nwrfc.noaa.gov/info/water_cycle/hydrology.cgi

King, M. (2009, April 9). Storm water runoff contaminates lakes and rivers. *suite101.com*. Retrieved from http://pollution-control.suite101.com/article.cfm/storm_water_runoff_contaminates_lakes_and_rivers>.

Land, G. (2003, March). A solid future for POU water purification. *Water Quality Products,* 8(3), p. 47. *Roads&Bridges.* Retrieved from http://www.roadsbridges.com/A-Solid-Future-for-POU-Water-Purification-article3841

Mamlook, R., & Badran, O. (2007). Fuzzy set implementation for the evaluation of factors affecting solar still production. *Desalination Directory Online.* Retrieved from http://www.desline.com/articoli/8052.pdf

McNulty, J. (2004, May 3). Thinking small could quench Third World's thirst for reliable, clean water, prof says. *UC Santa Cruz Currents Online.* Retrieved from http://currents.ucsc.edu/03-04/05-03/water.html

National primary drinking water regulations: Drinking water regulations for aircraft public water systems. (2008, April 9). *United States Environmental Protection Agency.* Retrieved from http://www.epa.gov/fedrgstr/EPA-WATER/2008/April/Day-09/w7035.pdf

Progress since the World Summit for Children. (2009, August 10). *UNICEF.* Retrieved http://www.unicef.org/specialsession/about/sgreport-pdf/sgreport_adapted_stats_eng.pdf

Reinhardt, D. (2009, April 21). Poisoned waters and good, safe, healthy waters. *suite101.com*. Retrieved from http://biology.suite101.com/article.cfm/poisoned_waters_and_good_safe_healthy_waters

Robson, M. G. (2006). Water treatment. Lester Breslow, ed. *Encyclopedia of Public Health*. Gale Cengage. *eNotes.com*. Retrieved from http://www.enotes.com/public-health-encyclopedia/water-treatment

The role of ministries of health in reducing disease burden due to water, sanitation and hygiene related illnesses. (2002, April 14). *World Health Organization: Regional Office for South-East Asia.* Retrieved from http://www.searo.who.int/LinkFiles/Health_Topics_reducing-disease.pdf

Russell, R. (2008, February 8). Gas. *Windows to the Universe.* Retrieved from http://www.windows.ucar.edu/tour/link=/physical_science/gas_state.html

Russell, R. Liquids. *Windows to the Universe.* 8 Feb 2008. Retrieved from http://www.windows.ucar.edu/tour/link=/physical_science/liquid_state.html

Russell, R. (2008, February 13). Solids. *Windows to the Universe.* Retrieved from http://www.windows.ucar.edu/tour/link=/physical_science/solid_state.html

Russell, R. (2008, February 13). States of Matter. *Windows to the Universe.* Retrieved from http://www.windows.ucar.edu/tour/link=/sun/Solar_interior/Sun_layers/Core/four_states.html

Safe drinking water. (2001). *UNICEF.* Retrieved from http://www.unicef.org/specialsession/about/sgreport-pdf/03_SafeDrinkingWater_D7341Insert_English.pdf

Safe water system: A low-cost technology for safe drinking water. (2006, March). *Center for Disease Control and Prevention.* Retrieved from http://www.cdc.gov/safewater/publications_pages/fact_sheets/WW4.pdf

Sassani, B. (2009, August 8). Different water purification techniques. *suite101.com.* Retrieved from http://backpacking-gear.suite101.com/article.cfm/different_water_purification_techniques

Saturation point. (2009). *Dictionary.com Unabridged (v 1.1)*. Random House, Inc. Retrieved from http://dictionary.reference.com/browse/saturationpoint

Schirber, M. (2007, August 30). Why desalination doesn't work (yet). *LiveScience.* Retrieved from http://www.livescience.com/environment/070625_desalination_membranes.html

Sea panel jungle boss system. (2008). *SEA.* Retrieved from http://www.seapanel.com/p_prod_jungleboss.html#

Secondary drinking water regulations: Guidance for nuisance chemicals. (2006, November 28). *U.S. Environmental Protection Agency.* Retrieved from http://www.epa.gov/safewater/consumer/2ndstandards.html

Smith, R. S. (2001, January). World Water Day 2001: Floods and droughts. *World Water Day.* Retrieved from http://www.worldwaterday.org/wwday/2001/thematic/floods.html

Solar distillation. (2009, October 21). *Practical Answers.* Retrieved from http://practicalaction.org/practicalanswers/product_info.php?products_id=165

Solar still. (2009). *Landfall.* Retrieved from http://www.landfallnavigation.com/memss.html

Solar still. (2009, September 3). *MedLibrary.org.* Retrieved from http://medlibrary.org/medwiki/Solar_still

Solar still basics. (2008). *SolAqua.* Retrieved from http://www.solaqua.com/solstilbas.html

Solar water disinfection. (n.d.). *SODIS.* Retrieved from http://www.sodis.ch/

Solar water disinfection—How does it work? (n.d.) *SODIS.* Retrieved from http://www.sodis.ch/Text2002/T-Howdoesitwork.htm

Solar water disinfection – The method. (2009). *SODIS.* Retrieved from http://www.sodis.ch/Text2002/T-TheMethod.htm

Solutions for a water-short world.(1998, September). *John Hopkins Bloomberg School of Public Health: The INFO Project.* Retrieved from http://www.infoforhealth.org/pr/m14edsum.shtml

States of matter: Preparation. (n.d.) *Micron Technology, Inc.* Retrieved from http://download.micron.com/pdf/education/lessonplans/StatesOfMatter.pdf

Watercone. (2008). *MAGE Water Management.* Retrieved from http://watercone.com/mage.html

Water distillation principles. (n.d.) *The Farm.* Retrieved from http://www.thefarm.org/charities/i4at/surv/distill.htm

West, L. (2009). "World Water Day: A billion people worldwide lack safe drinking water. *About.com*. Retrieved from http://environment.about.com/od/environmentalevents/a/waterdayqa.htm

What are plasmas? (2004). *Perspectives on Plasmas.* Retrieved from http://www.plasmas.org/what-are-plasmas.htm

What is condensation? (2007). *WeatherQuestions.com.* Retrieved from http://www.weatherquestions.com/What_is_condensation.htm

Williams, S. (2007, December 4). Cyclone Sidr pollutes water. *suite101.com*. Retrieved from http://environmentalism.suite101.com/article.cfm/cyclone_sidr_pollutes_water

Photos and Graphics

http://home.att.net/~cleardomesolar/DomeStill-asPast-sml.jpg

http://www.nhn.ou.edu/~jeffery/course/c_energy/energyl/lec004/water_cycle_001.png

http://us.st12.yimg.com/us.st.yimg.com/I/solaqua_2040_27960

http://watercone.com/pics/funktion300.gif

http://www.weatherquestions.com/condensation.gif

http://www.windows.ucar.edu/sun/Solar_interior/Sun_layers/Core/4_states.gif

http://www.worldwaterday.org/wwday/2001/disease/infectl.gif