COLLECT
CONVERT
CONSUME

ZAW THAN TOE
LANDSCAPE ARCHITECTURE SENIOR THESIS 2014
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C^3 : Collect - Convert - Consume

Senior Thesis

ZAW THAN TOE

Presented to the faculty of the Landscape Architecture program at the University of California, Davis, in partial fulfillment of the requirements for the degree of Bachelors of Science in Landscape Architecture.

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ABSTRACT

In a world where millions of people do not have the access to clean drinking water, this research thesis is carried out to understand the basics of sources of water, how it is converted to drinkable water, and how drinkable water is used.

COLLECT identifies major sources of groundwater and surface water, and methods of where and how drinkable water is collected.

CONVERT explores the methods and systems that convert collected water into actual drinkable water. This chapter also explores the parameters of water quality, and what kind of minerals and bacteria exist in water.

CONSUME applies lessons learned from above and hopes to integrate an appropriate water filtering technology to the water crisis stricken South Sudan.

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I would like to thank Elizabeth Boults, Gerry Robinson and Gayle Totton for their memorable classes and instructions.

Their expertise, and guidance have helped and pushed me beyond my comfort zone to complete this senior thesis.

Sincerest thanks are also due to my fellow friends and classmates for their invaluable company, endless critiques and laughter that make my college experience full of fun and unforgettable moments.

Zaw Toe

DEDICATION

To all the unfortunate souls struggling to survive in harsh environmental conditions without help and aid.

To the souls that commit to working hard everyday in order to provide essential care for their family and loved ones.

Within these pages, I have poured my sweat and blood to understand the importance and challenges of the vast field of making water drinkable.

I would also like to dedicate this thesis to my parents, who has given me an opportunity to completely change my life and continue my studies in the United States. Without their help, guidance and love, I would not be where I am today.

Zaw Toe

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INTRODUCTION

Global Water Crisis

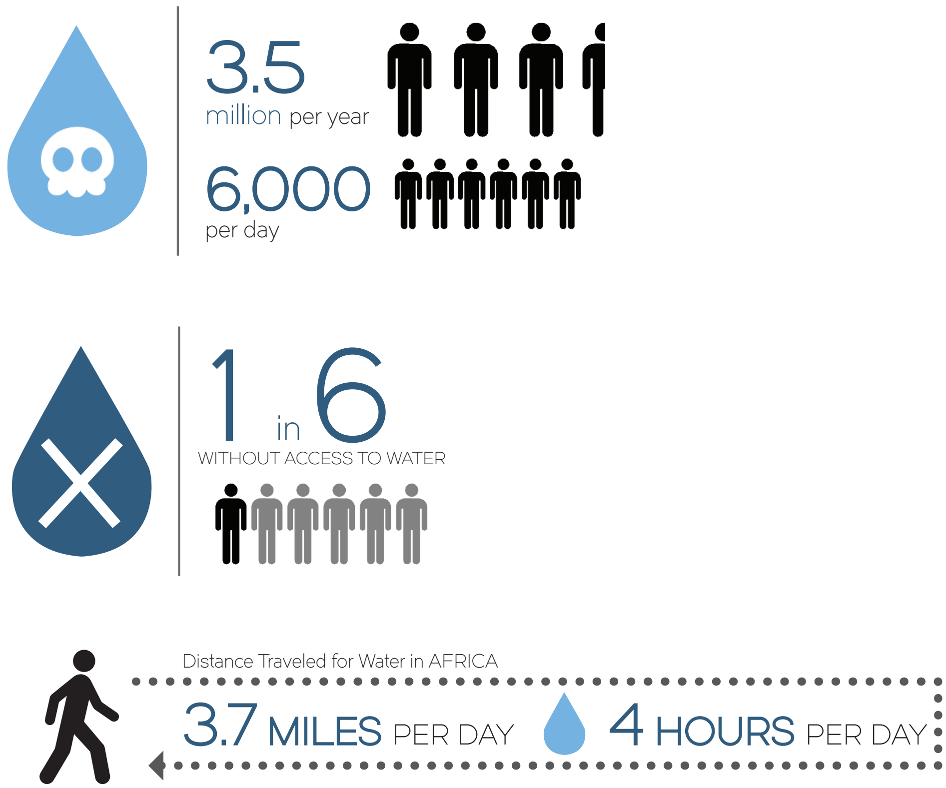
Global Water Crisis

Water crises still exist in many parts of the world today. Only one in six people has access to clean water, while there are 3.5 million deaths and casualties related to lack of access to clean water. (Smolan 97) The United Nations and World Health Organization has set out to reduce these numbers and improve water access. While there have been many improvements in the past decade, it is still estimated that one billion of the human population still suffers from lack of clean water. (Smolan 32) Having access to clean water should be a right of every human being that lives on the planet. This research thesis explores three major components of clean, drinkable water.

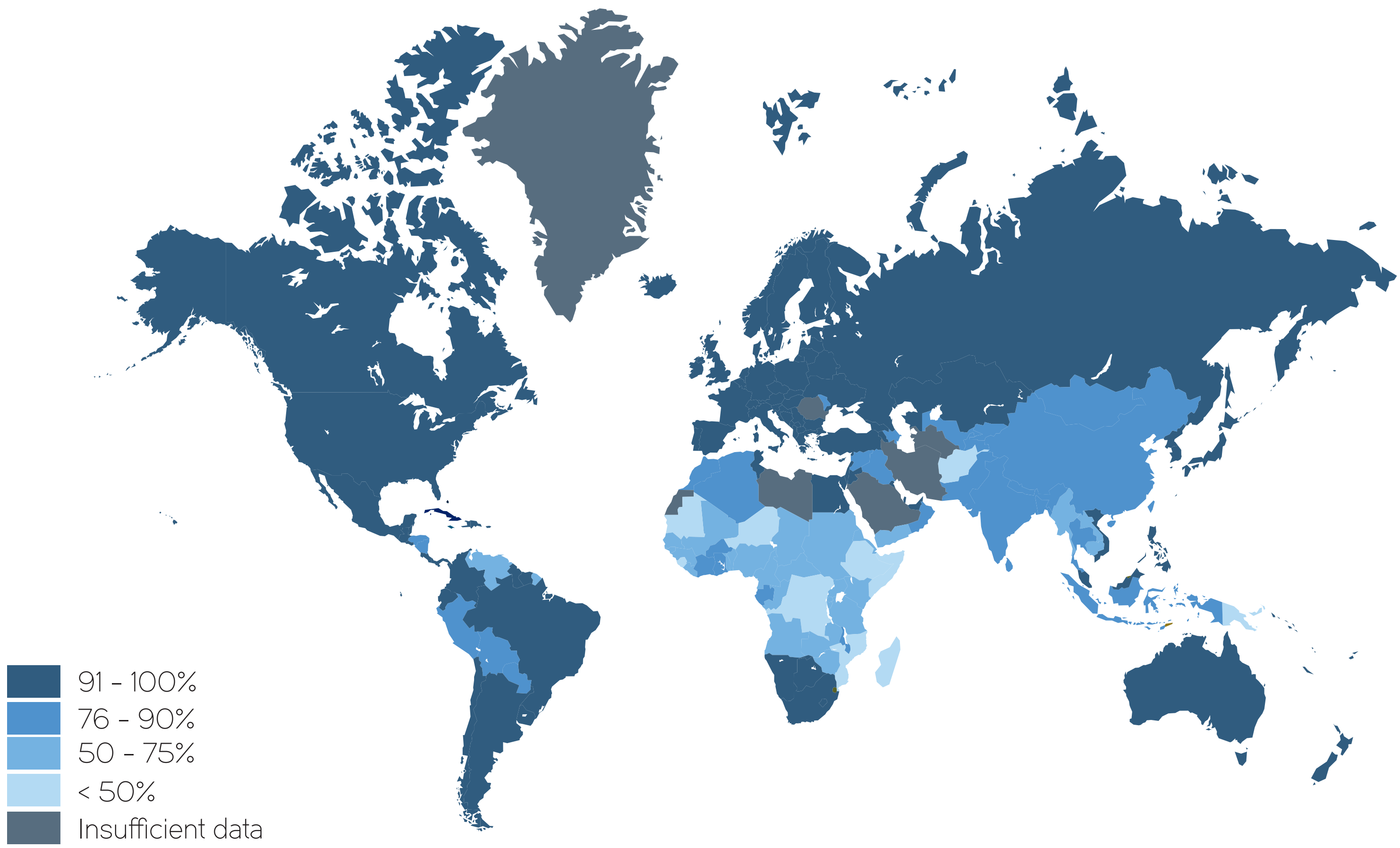
COLLECT identifies major sources of groundwater and surface water, and methods of where and how drinkable water is collected.

CONVERT explores the methods and systems that convert collected water into actual drinkable water. This chapter also explores the parameters of water, and what kind of minerals and bacteria exist in water.

CONSUME applies lessons learned from above and hopes to integrate an appropriate water filtering technology to the water crisis stricken South Sudan.



World Water Access Crisis Figure (1.1)
Source: Blue Planet Run



Improved Water Access Figure (1.2)
Source: World Health Organization

02

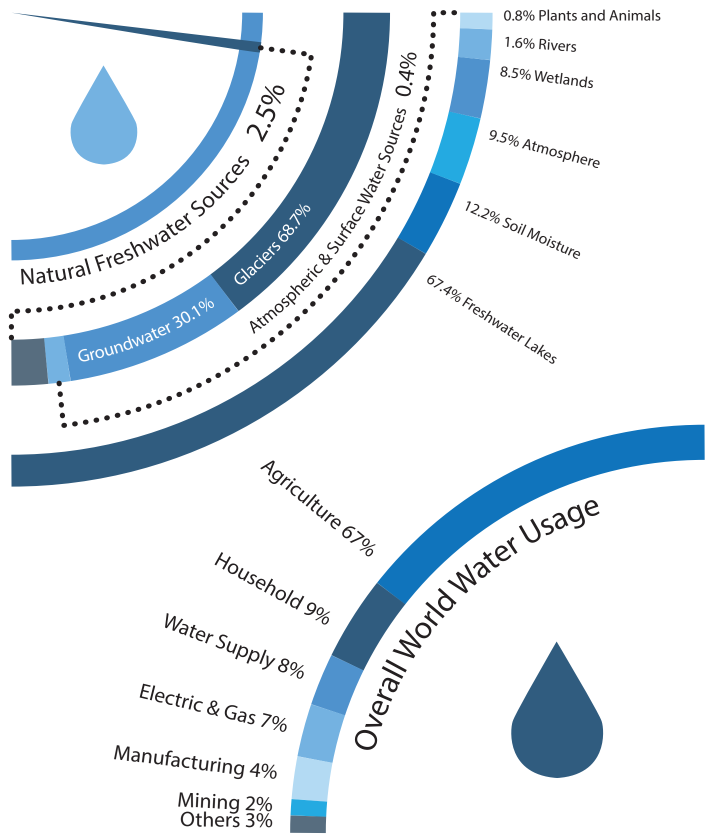
COLLECT

Water Sources and Uses
Ground water
Surface water

Water Sources And Uses

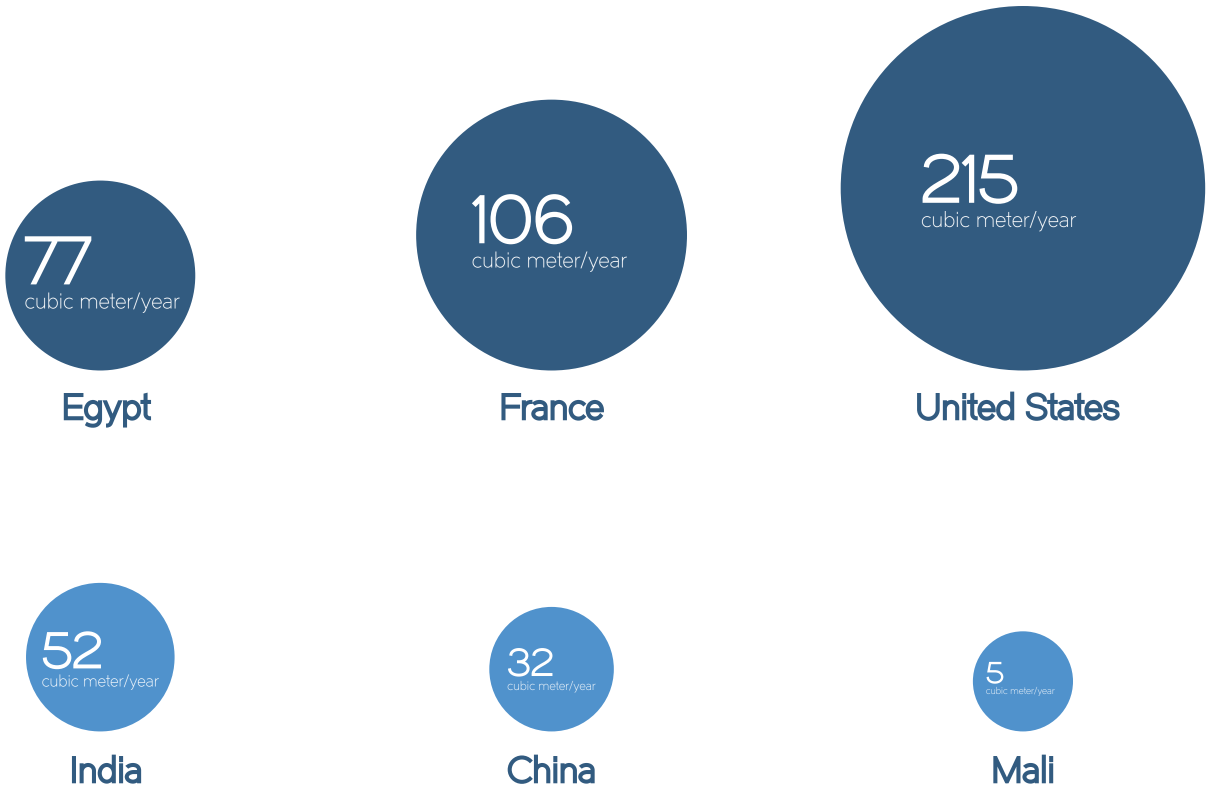
Water makes up 80% of the entire planet, it may seem that water is very abundant. But, only 2.5% of Earth's water makes up natural freshwater sources, which can be consumed. 30.1% of freshwater sources are groundwater, where the majority cannot be tapped. In addition, 68.7% is available in glaciers. Freshwater sources that are easily available only make up 0.4%, which represent atmospheric and surface water sources (Smolan 97).

Water consumption rate is climbing higher in both urban and rural environments. Examining overall world water uses reveals that 67% of water consumption goes to agriculture, with 9% for household uses, and 8% for water supply applications (Smolan 98).



FreshWater Sources Figure (2.1)
Source: Blue Planet Run

Figure (2.1) World Freshwater Sources and World Water Uses
Figure (2.2) Water Use per Capita



Water Use per capita Figure (2.2)
Source: Blue Planet Run

Ground Water

Ground water is one of the most important sources of water to every community, especially those in rural environments. Among various sources, ground water is the most practical and safe in nature as it is likely to be free of pathogenic bacteria (Wagner 65). Ground water comes from mostly rainfall that has percolated into the earth to form underground deposits that are called aquifers. These aquifers are essentially reservoirs. But these aquifers are where supply can exceed demand. Ground water can be extracted in various methods such as wells, springs and infiltration galleries.

Wells

Wells are the most commonly used method to extract ground water. There are three principal methods of construction. The first are hand-dug wells that are used with modern materials, tools and equipment as shown in Figure (2.4). While being an economical method, the construction process can be slow. In addition, these wells enable water to percolate into them at night (Wagner 68). The second types of wells are called drilled wells, which are most practical in situations with higher water demand. The advantage of this type of construction is the deeper depth that the drills are able to reach. The third types of wells are called jetted wells where water is driven into shallow aquifers. This type of well is suitable where water can be extracted from water-bearing sands that may naturally filter the water through its sandy beds (Wagner 90). In rural areas, contamination of ground water from bacteria and chemical pollutants can occur. Thus, wells should be located at a distance from septic tanks, barnyard manure, so that pollution cannot reach the wells.

Infiltration Galleries

Infiltration galleries are horizontal wells, built along rivers or lakes that collect water over their entire lengths. This method is best when streambeds and lakeshores are sandy. The galleries are built to gather naturally filtered water, from digging a trench in the water-

Figure (2.3) Natural Spring
Figure (2.4) Hand-dug Well

The water is then collected in perforated pipes. This type of water harvesting is essential to smaller communities that are located relatively close to streams, and lakes (Wagner 105).

Springs

Springs are usually the result of water flowing over impervious stratum onto the surface. They appear as water holes or wet spots at foothills and along riverbanks as shown in Figure (2.4). In addition, water from a fissure can rise under pressure from between two impermeable beds that results in constant spring water (Wagner 112). Springs generally are exposed to contamination when it nears the surface and thus require collection methods that will avoid contamination before the water reaches the surface. With strict regulations, springs provide safe and economical source of water (Wagner 113).

Groundwater

Surface Water

Surface water originates mainly from rainwater that is mixed with run-off water and ground water. Surface water can accumulate to form rivers, lakes, ponds and streams from springs and run-off (Wagner 161). Water quality can vary f water bodies. Rainfall can collect dust, oxygen and carbon dioxide from the air, silts, and organic matter from the ground. In addition, water from habituated areas can collect microorganisms, and human and industrial wastes (Wagner 162). Therefore, water bodies from such sources have to be thoroughly filtrated for human consumption. Surface water can be collected in several methods, such as ponds and reservoirs, streams, rivers and rainwater cisterns and basins.

Figure (2.5) Reservoir

Ponds and Reservoirs

Ponds and reservoirs provide an abundant supply of water that can be used in both urban and rural environments. Water quality from these water bodies can vary. But generally, they require little treatment with provided sanitation practices such as protecting water flow from human pollution areas, from erosion, and preventing suitable breeding places for mosquitos, etc (Wagner 166). Strict measures have to be taken during construction phases of small dams since they have to be engineered to maintain a required capacity.

Soil Catchment Basins

Soil catchment systems are those where collected rainwater is led into storage tanks by means of trenches and drainage pipes (Wagner 165). These types of basins are used where rainfall is scarce. Water collected from these are mainly used for irrigation purposes, but with thorough treatment, can provide a source for human consumption.

Surface Water

Surface Water

Rivers

Using river water for consumption should be avoided due to the high contaminants that rivers can collect from human and animal wastes, disease carriers. Thus, river water has to be thoroughly treated in rural conditions (Wagner 167). In addition, submerged pipes and point source pollution from industrial conditions can be dumped into rivers, thus making them unsuitable for human consumption.

Cisterns and Tanks

Rainwater collection using cisterns and tanks is mostly used in individual houses or farms that do not have access to ground water. The quality of water can be maintained for human consumption as potable water, but strict restrictions and maintenance are required (Wagner 162). Rainwater is collected mainly through clean roof surfaces, overhangs, and gutters into storage tanks. Specific materials for these elements can alter water quality. In addition, mesh, sand filters are used to obtain water clean enough to use in sinks, baths and for irrigation purposes (Wagner 163). The storage has to be sanitized with regular maintenance to ensure the best quality.

Figure (2.7)

Figure (2.6) River and Waterfall
Figure (2.7) Plastic Storage Water Tanks

03

CONVERT

Water Properties

To understand how drinkable water is produced, it is important to analyze the different parameters that make up water. This chapter explores the physical properties of water, which includes taste, odor, pH and turbidity, etc. Biological parameters are also explored, which reveals the numerous disease causing microorganisms. Finally, the chapter explores the water filtration methods that can be applied in rural and small communities.

Physical Properties

Taste and Odor

Aesthetic qualities of water, such as taste, odor and appearance are not regulated by the USEPA. But water contamination and water treatment systems can result in unfavorable taste and odor. These qualities can determine whether water is contaminated, they are important indicators and should not be ignored. Substances such as minerals, metals, salts and end products from biological reactions can cause changes in taste and odor (Spellman 143). They are present mainly in natural raw water source from which drinking water is produced. Water treatment facilities often use oxidation to remove taste and odor, such as potassium permanganate and chlorine (Spellman 143). In addition, activated carbon filters are utilized for their adsorptive properties.

Color

Water quality can also be determined by its color. Color is an æsthetic property of water and is not regulated. But, it is used as an indicator to determine whether a water source is contaminated (Spellman 145). Pure water is colorless, with organic matter from soils, vegetation, minerals and aquatic organisms. Furthermore, it is contributed by industrial and municipal wastes.

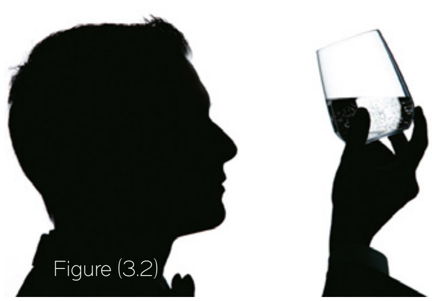


Figure (3.2)

Figure (3.2) Water Tasting
Figure (3.3) Water Turbidity

Temperature

Water temperature is usually not used to evaluate water quality. Temperature variation provides important parameters in natural water systems. It also affects the efficiency and effectiveness of water treatment systems (Spellman 146). For example, temperature affects on the rate of which chemicals dissolve and react. Chlorine demand may be required if water temperature is high.

Figure (3.3)

Turbidity

Turbidity measures the quantity in which light travels through a water column that is scattered by suspended organic and inorganic particles (Spellman 147). Basically, turbidity measures how clear the water is. Suspended particles can be present in both calm, gentle currents (lakes) and in faster currents (flowing rivers). The amount of suspended material depends on how fast water is moving. Turbidity is often composed of organic and inorganic constituents in addition to microorganisms. Thus, turbidity increases the possible growth of pathogenic microorganisms (Spellman 147). Turbidity is important in water quality because it is used as an indicator for pathogens and bacteria. Total Coliform Rule requires water treatment facilities to test turbidity in combination with fecal coliform (Spellman 147).

pH

Raw water for drinking purposes usually has pH levels between 4 and 9. pH is defined as the negative log-base 10 of hydrogen ion concentration (Spellman 149). As the number gœs higher, hydrogen ion is found in water. pH is caused by the equilibrium of dissolved substances and compounds in the water body. In natural forms, pH determines a carbonate system, which includes carbon dioxide, carbonic acid, bicarbonate and carbonate. Acid can alter the properties of pH where lower pH can cause corrosion in pipes, as it releases metal ions such as copper, lead, zinc and cadmium (Spellman 149).

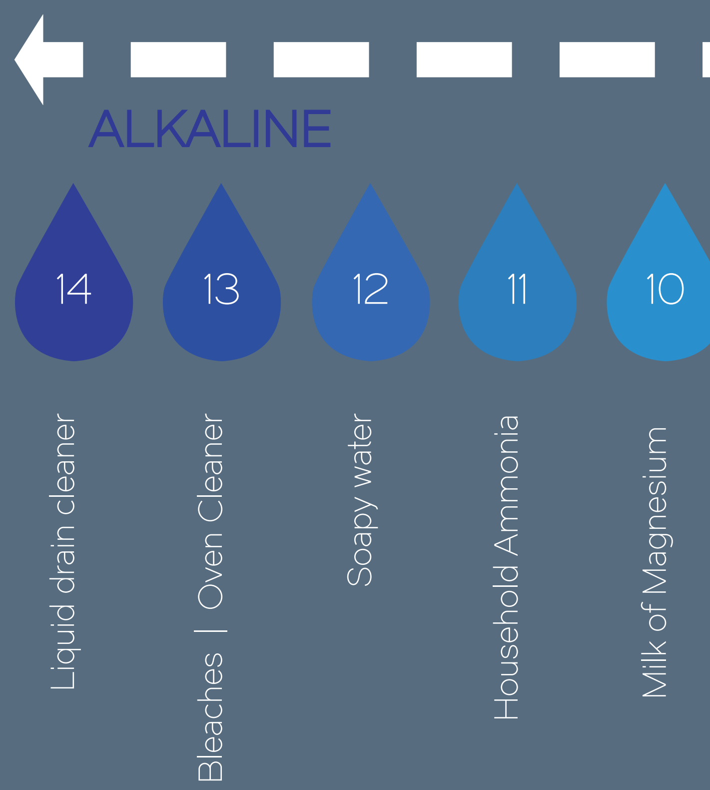
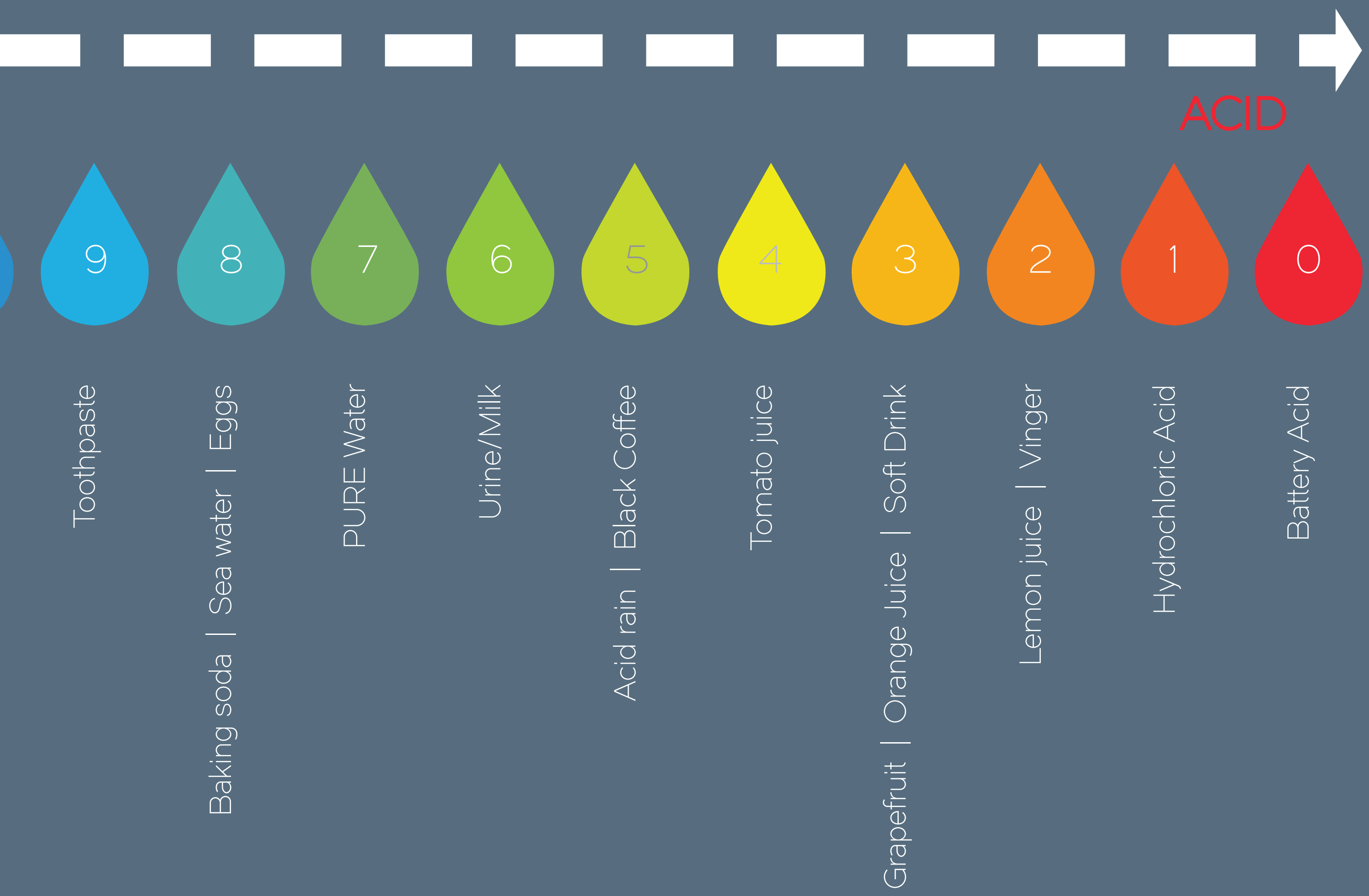


Figure (3.4) pH Chart

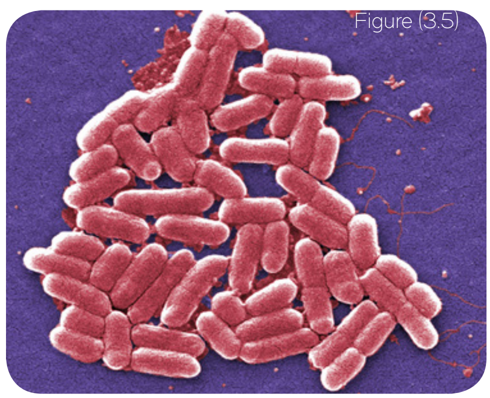
pH SCALE


ACID
9
8
7
6
5
4
3
2
1
0
Toothpaste
Baking soda | Sea water | Eggs
PURE Water
Urine/Milk
Acid rain | Black Coffee
Tomato juice
Grapefruit | Orange Juice | Soft Drink
Lemon juice | Vinger
Hydrochloric Acid
Battery Acid

Biological Properties

Bacteria

Fecal coliform are bacteria that live in the digestive tract of humans and animals. They are usually found in excretions of humans and animals, where they can be present in improperly treated wastewater, septic systems, and water runoff from pastures and farms (Spellman 94). *Escherichia coli* or *E. coli* is a fecal coliform bacterium dœs not pose danger to people or animals. But, the bacteria are used as indicators for other pathogenic bacteria and microorganisms (Spellman 97). Disease causing bacteria are not able to live outside the body of animals, and thus, are difficult to monitor and locate. Bacteria associated with fecal coliform cause diseases in humans, such as diarrhea, dysentery, cholera and typhoid fever. Fecal materials in water bodies add excess organic matter, which can deplete the oxygen supply during decay. Fecal coliform can be reduced with chlorine disinfection. It is important to monitor how much chemicals are used, as they can kill aquatic animals and plants. Total Coliform Rule, part of the Safe Drinking Water Act requires water treatment systems to remove all fecal coliform (Spellman 98).



Protozoa

Protozoa are a group of eukaryotic organisms that have formed to serve as single-celled organisms. Some can exist independently while others can colonize. Some types are pathogenic for example, *Giardia lamblia, Cryptosporidium* and *Cyclospora* (Spellman 109). Because sewage water can carry eggs and cysts of these microorganisms, water treatment be carried out prevent contamination. USPEA implemented the Surface Water Treatment Rule in 1989 to control contamination of these protozoa in water supplies (Spellman 110).

Figure (3.5) E. coli under a Microscope

Biological Properties

Giardia

Giardia lamblia is a microscopic parasite, which infects warm-blooded animals and humans (Spellman 110). They can survive for longer periods as cyst that has a protective outer shell. *Giardia*, as the most identified source of water-borne biological matter, can occur in two ways: by animal activity in watershed environments and by water sewage contamination in watersheds. Since Giardia is not host specific, it can be excreted by animals and infect humans. Giardiasis has been identified as the most common waterborne disease in the United States for the past 15 years (Spellman 111). The disease's symptoms include and not limited to diarrhea, abdominal cramps, bloating, flatulence, fatigue and weight loss. These symptoms can persist around two to three months. People in urban environments whose drinking water supplies are sourced from streams or rivers without proper water treatment facilities are most at risk for Giardia contamination. Giardia lamblia cannot survive in high temperatures, and thus boiling water can remove the protozoa. In addition, chlorine disinfection can also remove the protozoa, but disinfection dœs not work all the time. Chlorine disinfection works best when water is exposed to chlorine for long periods of time (Spellman 113). Filters can be effective against *Giardia*. Sand filters are effective when water bodies are given time to settle for filtration. Sometimes, chlorine or iodine disinfection is added after sand filtration to ensure removal of protozoa, bacteria and other disease-causing microorganisms. Furthermore, filters with pore size of 6 to 8 micrometers are able to remove *Giardia* (Spellman 115).

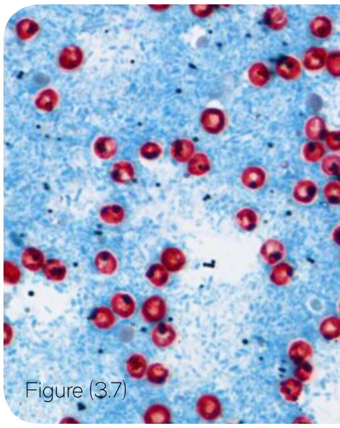


Figure (3.7)

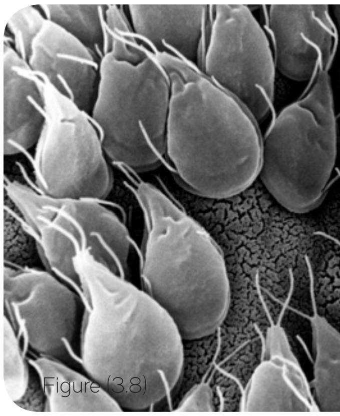
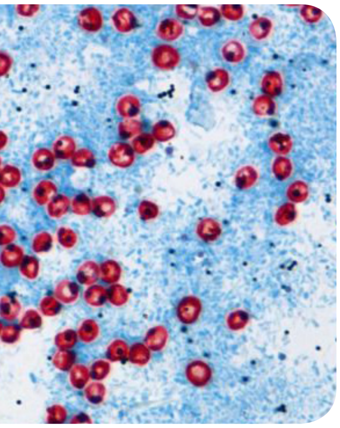
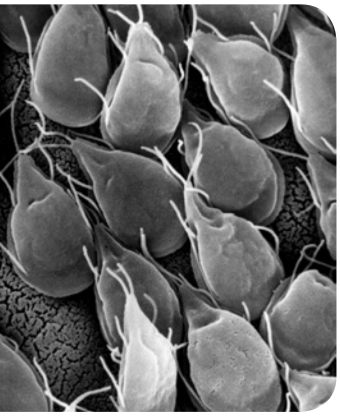


Figure (3.8)

Figure (3.7) Giardia lamblia under a Microscope
Figure (3.8) Cryptosporidium under a Microscope





Cryptosporidium

Cryptosporidium is a single-celled protozoa that develops in the gastrointestinal tract of vertebrates through out their lifecycle. Oocysts, the dormant form of Cryptosporidium is usually excreted in the feces of infected human and animals, where they can survive in a variety of environmental conditions (Spellman 124). Oocysts are present in most surface water bodies, where human and animal wastes from surrounding areas can gather during rainwater runoffs. As drinking water supplies mostly come from surface water bodies, it is essential for the water to go under treatments to remove the disease-causing protozoa. Consuming something that has come into contact with an infected person or animal can spread *Cryptosporidium* (Spellman 125). Thus, drinking contaminated water, or eating raw, undercooked meat that are already infected can infect a person. Symptoms of *Cryptosporidium* include diarrhea, headache, abdominal cramps, nausea, vomiting and fever. The symptoms usually last from one to two weeks, and the immune system will act to remove the protozoa. Filtration systems that can remove oocysts must be utilized in the water treatment process. Sand filtration combined with coagulation and æration is an effective method in reducing oocysts. Ozone disinfection is also an alternative method since *Cryptosporidium* oocysts can withstand chlorine and iodine disinfection (Spellman 126).

Chemical Properties

Nitrogen

Nitrogen, a primary component of the earth's atmosphere, is present in many forms and occurs in many biological reactions. Nitrogen sources include runoff from animal feedlots, fertilizer runoff, municipal wastewater discharges and even bacteria and algæ. Nitrogen, commonly found in the form of nitrates, act as indicators of water with sewage. Nitrates are able to enter groundwater sources from chemical fertilizers and excessive amounts can cause harm when these sources are consumed in high concentration.

Chemical Properties

Hazardous Trace Minerals

Lead
Lead is one of the greatest threats to human health. Lead poisoning in recent decades has become very apparent to the world. Lead can be found near industrial wastes, solid waste landfills, and home plumbing systems. Medical scientists and doctors have associated excessive amount of lead concentration with mental retardation, high blood pressure, etc. Even low levels of lead can slowly poison the immune system's ability to defend against infections.

Cadmium
Cadmium, found in small amounts in nature, can be amplified due to waste disposal from electroplating, photography, insecticides and mining industries. Cadmium is a highly toxic mineral, which can lead to deadly effects such as high blood pressure, kidney disease and emphysema after accumulating twenty years of cadmium in the body.

Mercury
Mercury is a mineral that is rarely found in water naturally. However, because of increased use of mercury compounds, the contamination can become very drastic. Mercury mainly affects the nervous system and kidneys. The most notable threat is when mercury enters a food chain. In recent years, some fish has been found carrying large concentrations of mercury.

Arsenic
Arsenic, a very hazardous mineral, can be distributed through solid waste landfills and agricultural use of insecticides. It has already caused many deaths in Bangladesh. Arsenic is known to affect tissues of the digestive tract, kidneys, liver, lungs and skin. It also causes serious damage to capillaries that can later lead to gastrointestinal hemorrhage and heart failures.

Source: Keough, Water Fit to Drink
Figure (3.9) Hazardous and Essential Minerals in Water

Essential Trace Minerals

24 Cr

Chromium
Chromium is an insoluble mineral that is essential in the body's metabolism of sugar and carbohydrates. It is also a key component in the prevention of coronary artery disease.

29 Cu

Copper
Copper is a minor constituent of natural waters, which is often supplemented by corroded plumbing and industrial wastes. Copper is introduced into reservoirs to control algæ growth. In small amounts, copper is important in the formation of water from oxygen and hydrogen at body temperatures.

27 Co

Cobalt
Cobalt, in tiny amounts of water is an essential component of vitamin B12 and is important to nerve functions and red blood cell formation.

26 Fe

Iron
Iron, a very abundant mineral is part of every component of earth. It is an integral component of red blood cells and is involved in the transport of oxygen. Iron-deficiency anemia can lead to fatigue, heartburn, dizziness, headaches and sore tongue. However, cadmium and lead can reduce absorption of iron.

3 L

Lithium
Lithium is used as a mood stabilizer that leads to lower cardiovascular mortality rates, and lower frequency of violent behavior. Areas with higher concentration of lithium are also found with low rate of coronary heart disease and stomach ulcers.

25 Mn

Manganese
Manganese is another mineral that is essential to all living things that take part of reactions of enzymes. Even in large concentrations, it is still not harmful.

42 Mo

Molybdenum
Molybdenum, used in metallurgy and fertilizers can be found in surface and groundwater at small concentrations.

30 Zn

Zinc
Zinc can be abundant due to urban and industrial runoff, although trace amounts can be found in natural water bodies. If consumed in small amounts, zinc has the properties to improve health. Night blindness is caused by zinc deficiency, but can improved with zinc supplements. It is also true for healing stomach ulcers, improving the flexibility of rheumatoid arthritis and also reducing swollen prostate glands.

Rural Water Filtration Methods


Figure (3.10)


Figure (3.11)

Sedimentation

Sedimentation in reservoirs and ponds usually removes turbidity and reduces pathogenic bacteria. Turbidity removal depends on the suspended material and allowed settling time. Less dense and smaller suspended materials usually take longer to settle. In addition, turbidity removal can vary according to different conditions of stream flow. Sedimentation reduces bacteria because they die off faster than they reproduce. Low pH water fastens the reduction process. In such reservoirs, it is important to identify sources of contamination, especially when it is caused by human development. Sedimentation reservoirs not only clean the water, but they also provide water storage. Water storage in open reservoirs for longer periods of time provides opportunity for growth of algæ. Algæ can grow where nutrients such as soluble nitrogen, phosphorus. Thus, reservoirs are highly economical in providing both water treatment and storage.

Aeration

Aeration for filtration purposes is best used (1) to control tastes and odors, (2) to precipitate iron and manganese, and (3) to remove carbon dioxide from a water. Taste and odors in water occurs due to dissolved gases such as hydrogen sulfide, in addition to decomposing organic matter, chemical wastes from micro-organisms. Aeration is a process that introduces and improves oxygen content of water and removes foul tastes and odors. The process also collects iron and manganese content that is present in water, which can be filtered out. With contact with free oxygen, iron compounds become insoluble and settle out. In addition, introducing oxygen can remove excessive amounts of carbon dioxide that can inhibit growth of aquatic life.

Corrosion Control

In order to control corrosion, it is important to understand the many causes of corrosion to utilize the correct treatment. Corrosion can be caused by both high acidity or alkalinity. A pH adjustment unit is normally used to add potassium carbonate or potassium

Figure (3.10) Sedimentation Pond
Figure (3.11) Aeration Tanks
Figure (3.12) Ceremic Filters for rural communities
Figure (3.13) Boiling Water in rural communities

Source: Wagner, Water Supply for Rural Areas and Small Communities


Figure (3.12)


Figure (3.13)

hydroxide to neutralize the acidity. It also removes bacteria and other microorganisms. If the water is high in alkalinity, it should be passed through a water softener or ion-exchange medium. The mediums will remove carbonates and ions.

Boiling

Boiling is a method that is very practical in destroying disease organisms in water. It is effective whether the water is clear, cloudy, pure or contaminated with organic matter. Water is usually brought to a "rolling" boil. This is usually enough to destroy organisms in the water. In addition, boiling alters the taste of water since dissolved gases are mostly removed.

Chlorine disinfection

Chlorination is one of the most widely used forms of disinfection for drinking water. It is very effective against water-borne diseases. When using chlorine, it is important to use an effective dose, as insufficient chlorine can go under chemical combination with organic matter in water. Thus, water high in turbidity and organic matter has to go through filtration before chlorine disinfection can be effective. Chlorine is mainly applied in the form of a solution. Laundry bleaches, bleaching powder, chlorinated lime, and hypochlorite also contain different amounts of chlorine that is effective for their purposes.

Iodine disinfection

Iodine is also used as a disinfectant for water. Iodine can be ineffective if the water is high in turbidity, cloudy and with noticeable color. If the water is extremely cloudy, iodine doses should be doubled. Higher doses of iodine dœs not affect water quality, but it produces a medicinal taste.

Ceramic Filters

Several types of ceramic filters, such as pressure filters, filter pumps and non-pressure filters, exist in the market today. These filters come with varying media with varying pore dimensions. The most important part of all these filters is the ceramic candle where suspended matter is filtered. For example, coarse-grained filter candles are favorable in removing suspended particles, but are ineffective against bacterial and other disease organisms. In such cases, water has to be further purified to be safe for consumption. Another effective ceramic filter is the diatomaceous earth filter. These filters can be made with different pore sizes. The finer-grained types can filter out water safe for consumption. The smaller the pore sizes, the greater amount of bacteria it will remove. In addition, some diatomaceous earth filters are coated with silver catalyst, which kills bacteria in contact with the surface.

Activated Carbon

Activated carbon materials are very effective in removing foul taste and odor, and organic pollutants. Furthermore, activated carbon is essential in removing arsenic from contaminated water sources. These materials purify water by adsorption, where substance surfaces attract and attach themselves to each other. Activated carbon is derived from carbonaceous materials such as wood and plant materials, carbon and petroleum residues. These materials are burned at high temperatures in absence of oxygen to produce char, which is then activated by oxidizing at higher temperatures that produces porous structures. This large surface area aids in adsorption. Two forms of activated carbon are used in water treatment processe, powdered activated carbon and granular activated carbon. Granular activated carbon is mainly used in filter beds, where powdered activated carbon is mainly used to eliminate foul odor and taste.

Figure (3.14) Activated Carbon
Figure (3.15) BioSand Filter application

Source: Wagner, Water Supply for Rural Areas and Small Communities

Sand Filtration

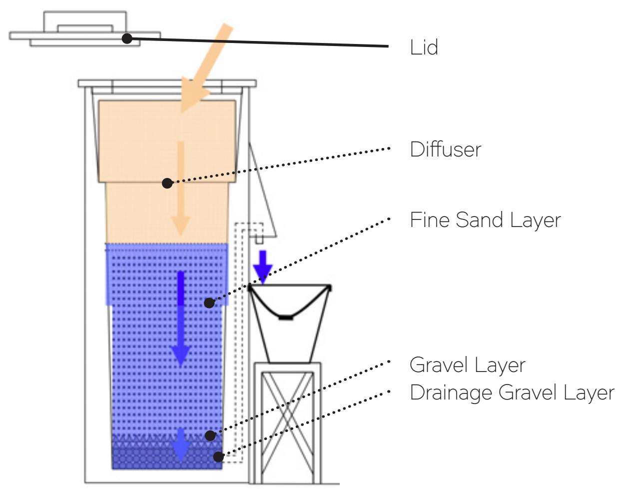
Sand filtration system is an exceptional method for water treatment for rural communities. Sand filters can reduce bacterial counts by 85% to 99%, and also reduce turbidity. These systems use different sizes of sand and gravel to capture particulate matter that contaminates water sources. Purification and filtration of water takes place via adsorption, and an organic layer called schmutzdecke. This layer consists of microorganisms that would later break down biological matter from water sources. In addition, some of the biological impurities die out in between sand particles due to lack of nutrients.

There are two types of sand filters, rapid sand filters and slow sand filters. Rapid Sand filters mainly consist of closed vessels or tanks, with beds of varying sand and gravel where water is forced under pressure. These filters are mainly used in plants where automation can be installed, which raise the initial cost. Because water is fed through rapidly, impurities are deposited more quickly, which requires frequent maintenance and scraping of the sand beds.

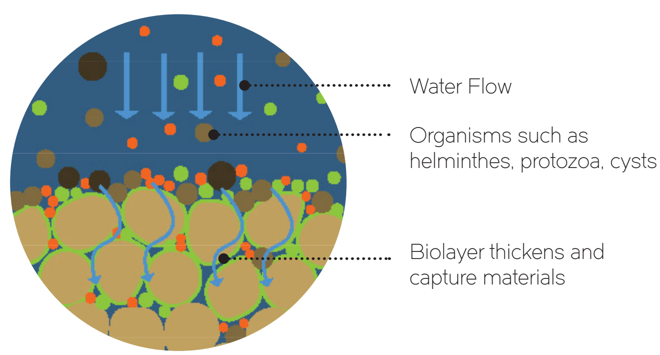
Slow sand filters mainly consist of open-topped tanks, which is partly filled with filtering sand layers, where water is fed from the top and sinks to the bottom via gravity. This slow movement is where water purification takes place. In addition, under drainage systems are located at the bottom, where gravel beds are used. The purification process in this type of filters can take much longer than rapid sand filters.

Case Study: BioSand Filter

Manz Biosand filter is an adaptation of a slow sand filter that is made by David Manz to be used in developing nations and rural environments. Traditional slow sand filters have been used for community drinking water for the past 200 years. The system is very compact , and is suitable for a single family's home. The filter utilizes specially prepared sand and gravel and a biolayer, which comprises of a community of bacteria to remove pathogens and suspended solids (Manz). Biosand works solely on gravitational forces, thus requiring no electricity. In addition, it filters up to 1 hour for 12-18 liters of water. The filter is tested to remove 100% *Helminthes*, up to 100% protozoa, up to 98.5% bacteria and 70% to 90% viruses. (Manz) The disadvantage of the Biosand Filter is that there might still be some bacteria left after filtration, thus requiring further disinfection by boiling or solar disinfection.



David Manz BioSand Filter Figure (3.16)



BioSand Filtration Mechanism Figure (3.17)

Figure (3.16) David Manz BioSand Filter
Figure (3.17) BioSand Filtration Mechanism
Figure (3.18) BioSand Filter Application

Case Study: BioSand Filter

Traditional Slow Sand Filter v. BioSand Filter

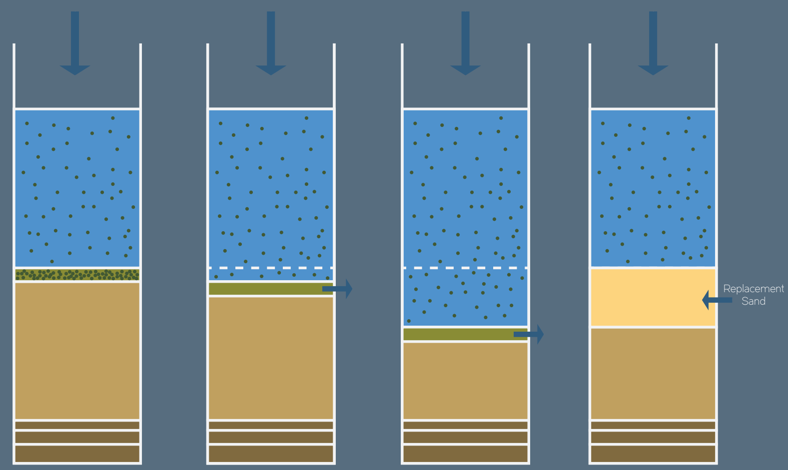
Filter	Sizing	Operation	Treatment	Cleaning
Traditional Slow Sand Filter	3.5 to 4 m	Continuous Flow	Large treatment Plants	• Scraping (harrowing) • Biolayer is removed • Requires days for cleaning process • Labor intensive
BioSand Filter	0.8 to 2 m	Demand basis	Small treatment Plants (Household)	• Agitating • Biolayer is intact • Requires less than 10 minutes for cleaning process • Easy Labor

Comparison of TSSF and BSF Figure (3.19)

Biosand Filters (BSF) and Traditional Slow Sand Filters (TSSF) both utilize the same concepts of adsorption to filter bacteria, protozoa and other microorganisms from water. Both filters make use of the development of schmutzdeke or biolayer to remove bacteria and organisms. Organisms that will not be removed 100% by both type of filters can be easily killed with additional disinfection procedures (Manz).

Following the recommendations from American Water Works Association Guidelines, BSF filters are designed to have minimum depth of filter media that is tested to be necessary for removing viruses and bacteria. While normal Slow Sand Filters require about 3.5 to 4 m in height, BSF filters may use 0.8 to 2 m. Operation of TSSF requires continuous flow in order maintain an optimum ability to remove bacteria (Manz). The technology is designed for large treatment plants that require large land area, where operation can be continuous. On the other hand, BSF filters can be operated on need basis mainly for smaller treatment operations.

Figure (3.19) Comparison of TSSF and BSF
Source: David Manz

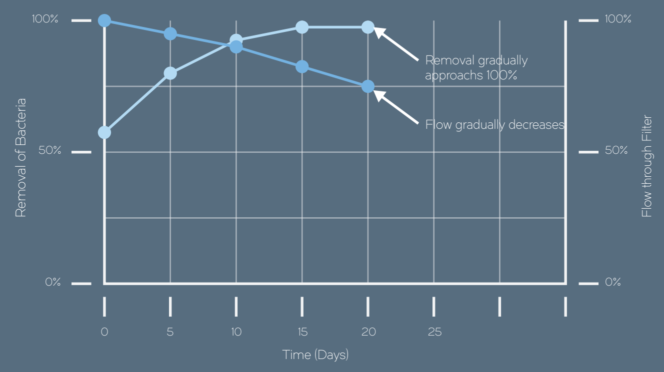


Flow is stopped and water is drained from filter.

Filter bed biolayer is removed (scraped) and discarded

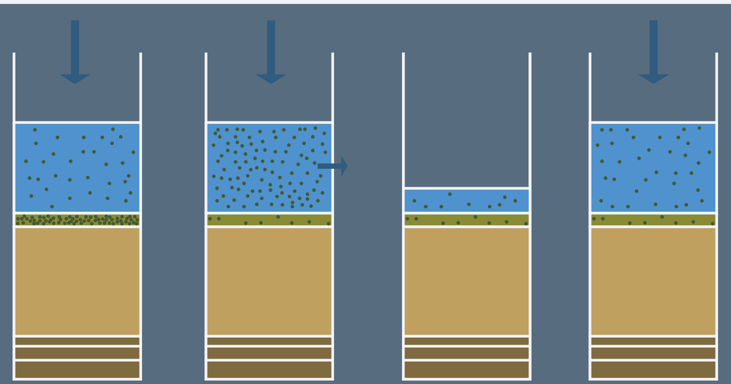
Biolayer reformed after each scraping of filter media

After several scraping, sand is replaced, and new biolayer forms



Cleaning Process

Performance

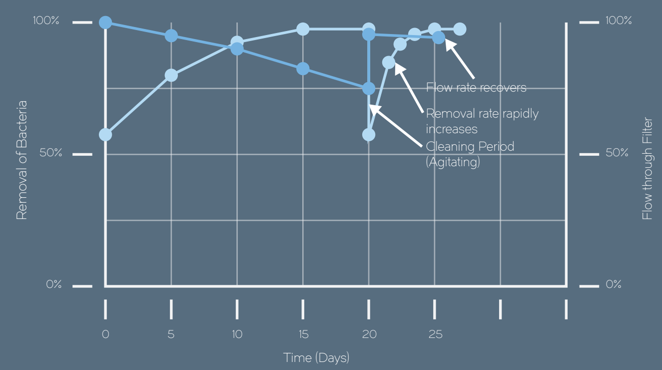


Flow is paused when particles are captured in biolayer

Upper layer of filter media is agitated and frees particles

Decanted water is disgarded and biolayer is still intact.

Filter can now be resumed after backwashing



The operation of both TSSF and BSF are similar in that a biolayer is needed to filter bacteria and viruses. Formation of biolayer depends on the ecology of water that is treated, where greater concentration of organisms and quantity of water, the faster the biolayer will form. With numerous uses, filter media particles become covered by a biofilm made up of bacteria and organic matter, which later thickens the organic layer in the filter (Manz). As the layer builds up with numerous uses, the flow rate for both filters gradually decreases. Thus, cleaning the top layer is required to increase the flow rate. BSF has an advantage over TSSF in maintenance in that agitating the top sand layer with a small depth of water level is enough to clean the filter media and increase the flow rate, where in TSSF, the filter media has to be scraped (harrowing), which requires the entire process to form schmutzdecke, which renders the filter ineffective for a few days (Manz).

04

CONSUME

Freshwater Withdrawals
Drinking Water Consumption
Water Quality Standards

Different industries and sectors use up freshwater all year round. The sectors that use up most are agriculture, industry and domestic use. Figure (4.1) shows that in most countries, especially in Asia, where agriculture is their main consumer, withdraws the most freshwater. Developed countries in America and Europe show even percentage among agricultural and industrial uses.

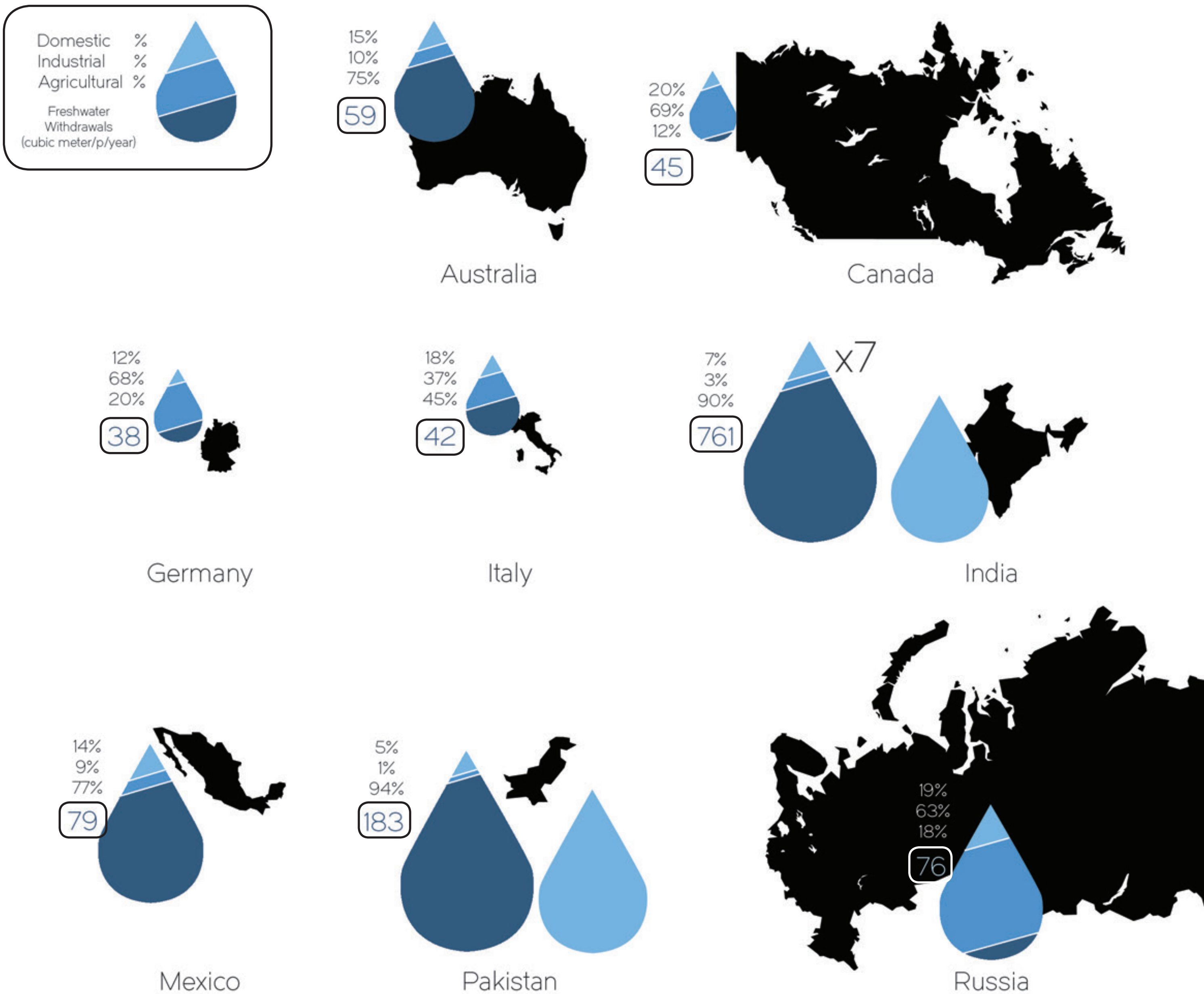
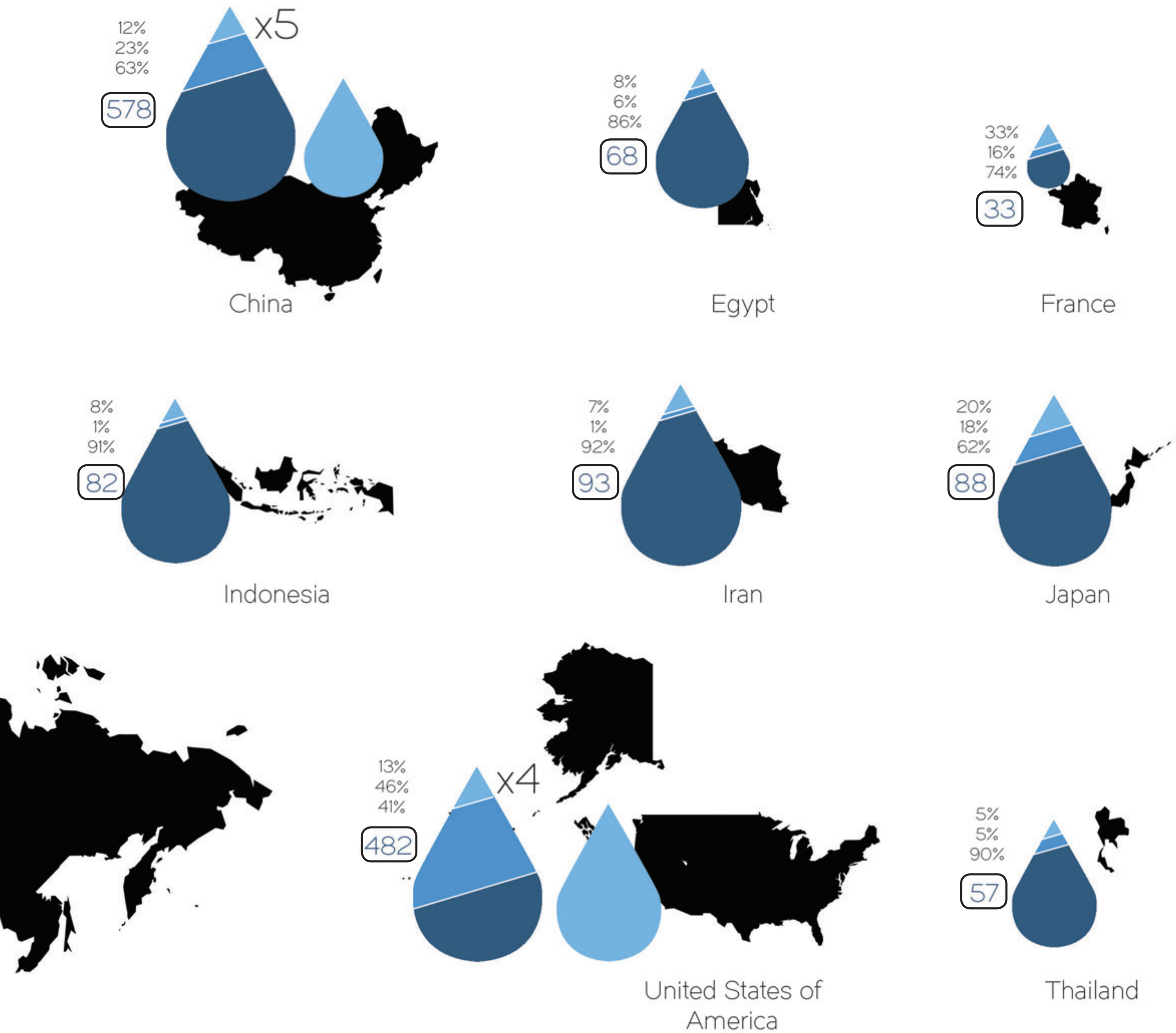


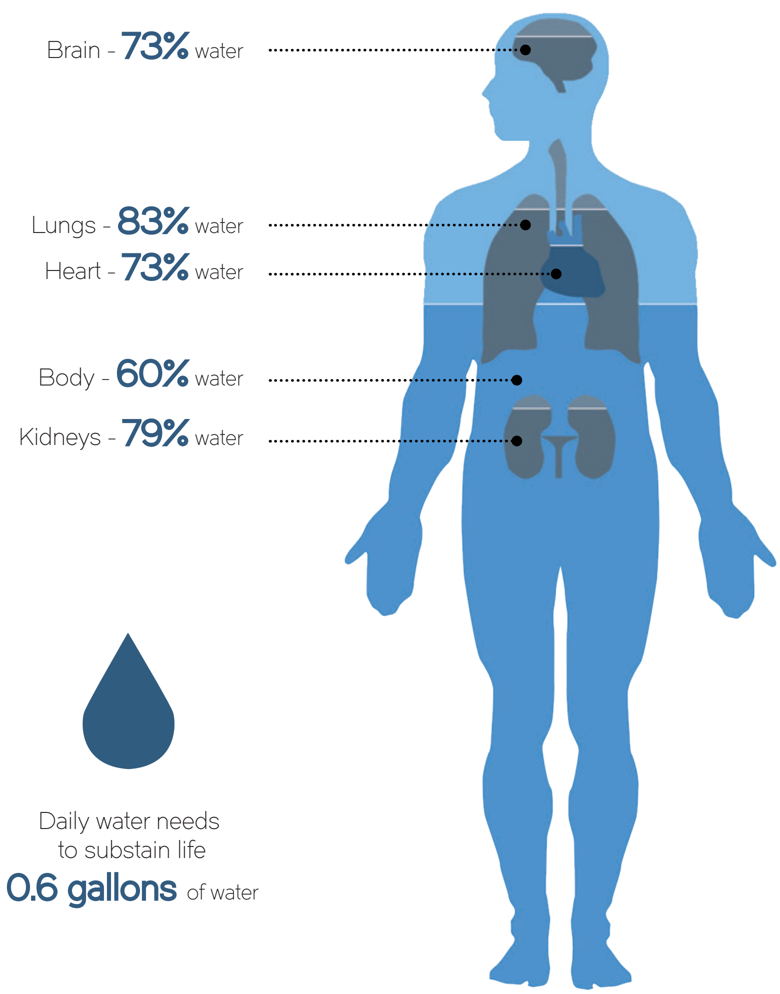
Figure (4.1) Freshwater Uses and Withdrawals by Country
Source: www.fao.org

Freshwater Withdrawals



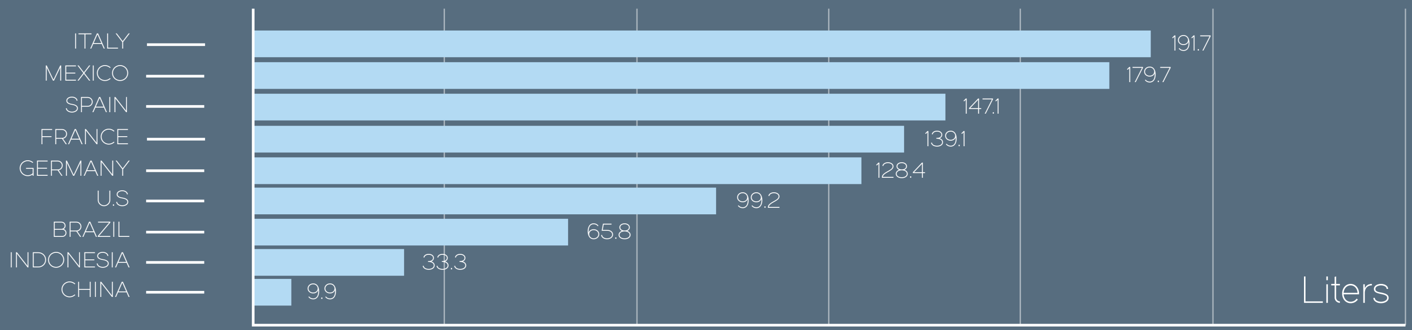
Drinking Water Consumption

The human body is made up of 60% water, while the brain and the heart is 73% water. Human beings require at least 0.6 gallons of water to sustain life, consumed from either food or water (Smolan 98). The amount of water consumed for drinking purposes is very low compared to industrial uses. Figure (4.3) shows the amount of bottled water consumed by countries. The graph shows that those in Europe rely on bottled water more than tap water, which can be controversial as plastic bottles waste much more energy to produce.

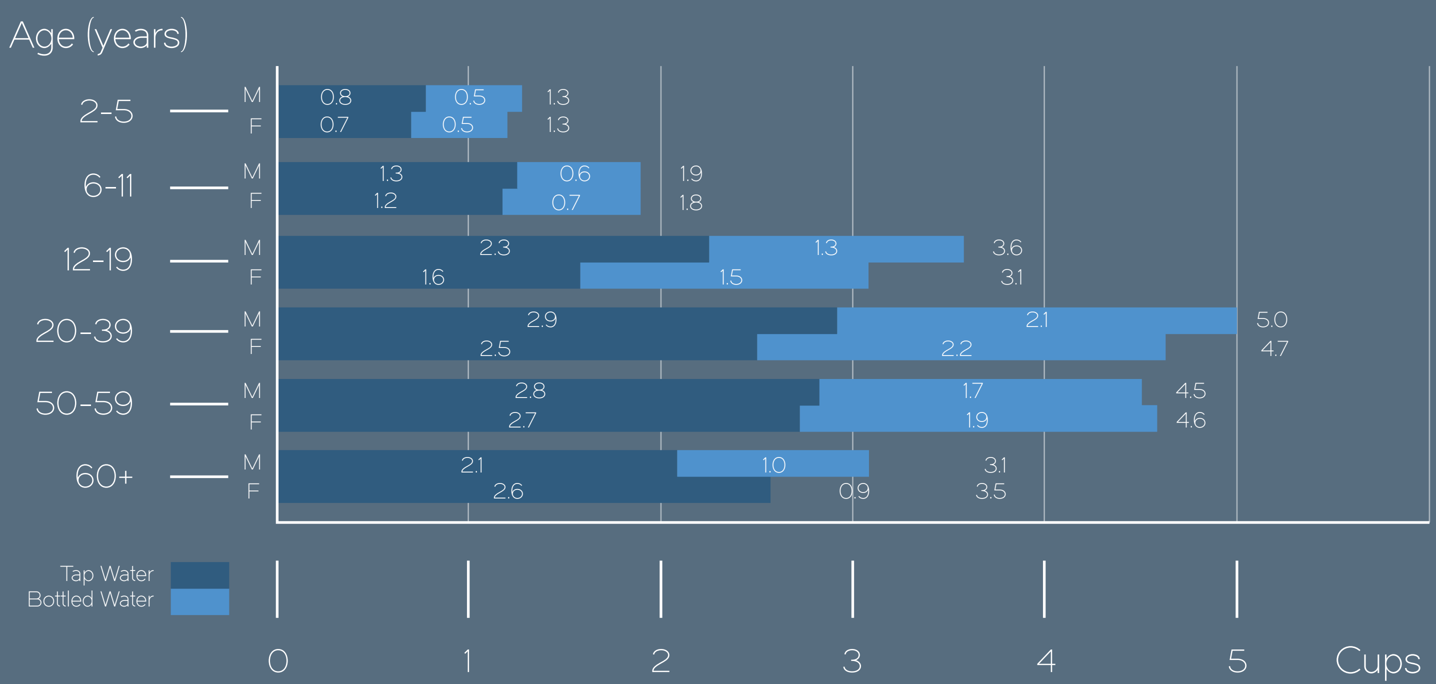


Human Body Water Needs Figure (4.2)
Source: Blue Planet Run

Figure (4.2) Human Body Water Needs
Figure (4.3) Bottled Water Consumption by Country
Figure (4.4) U.S Drinking Water Consumption



Bottled Water Consumption by Country Figure (4.3)
Source: Blue Planet Run



Drinking water intake in U.S for a day by gender and age Figure (4.4)
Source: www.ars.usda.gov

Water Quality Standards

Microorganisms	Guideline Values
All water intended for drinking	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100ml sample
Total coliform bacteria	Must not be detectable in any 100ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100ml sample
Total coliform bacteria	Must not be detectable in any 100ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100ml sample
Total coliform bacteria	Must not be of samples detectable in any 100ml sample. In the case of large supplies, where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period.

WHO Water Quality Standards

Figure (4.5) WHO Drinking Water Quality Standards
Figure (4.6) EPA Drinking Water Quality Standards

EPA Water Quality Standards

Contaminents	MCLG (mg/L)	MCL or TT (mg/L)	Potential Health Effects	Sources of Contaminents
Cryptosporidium	Zero	99% removal	Gastrointestinal illness (diarrhea, vomitting, cramps)	Human and animal fecal waste
Giardia lamblia	Zero	99.9% removal	Gastrointestinal illness (diarrhea, vomitting, cramps)	Human and animal fecal waste
Heterotrophic plate count	n/a	500 bacteria colonies per ml	No health effects, Used to indicate treatment effectiveness	HPC measures bacteria naturally present in environment
Legionella	Zero	TT	Pneumonia	Found naturally in water
Total Coliforms	Zero	5.0%	Used as indicator for harmful bacteria	Found naturally in water, fecal coliforms and E. coli from human and animal fecal waste
Turbidity	n/a	1 NTU (nephelo-metric turbidity units)	Used as indicator for harmful bacteria	Soil runoff
Ecentric Viruses	Zero	TT	Gastrointestinal illness (diarrhea, vomitting, cramps)	Human and animal fecal waste

Maximum Contaminant Level (MCL): The highest level of contaminant that is allowed in drinking water
Maximum Contaminant Level Goal (MCLG): The level of a contaminant in drinking water below which there is no known or expected risk to health.
Treatment Technique (TT): Guidelines varying different water treatment techniques

05

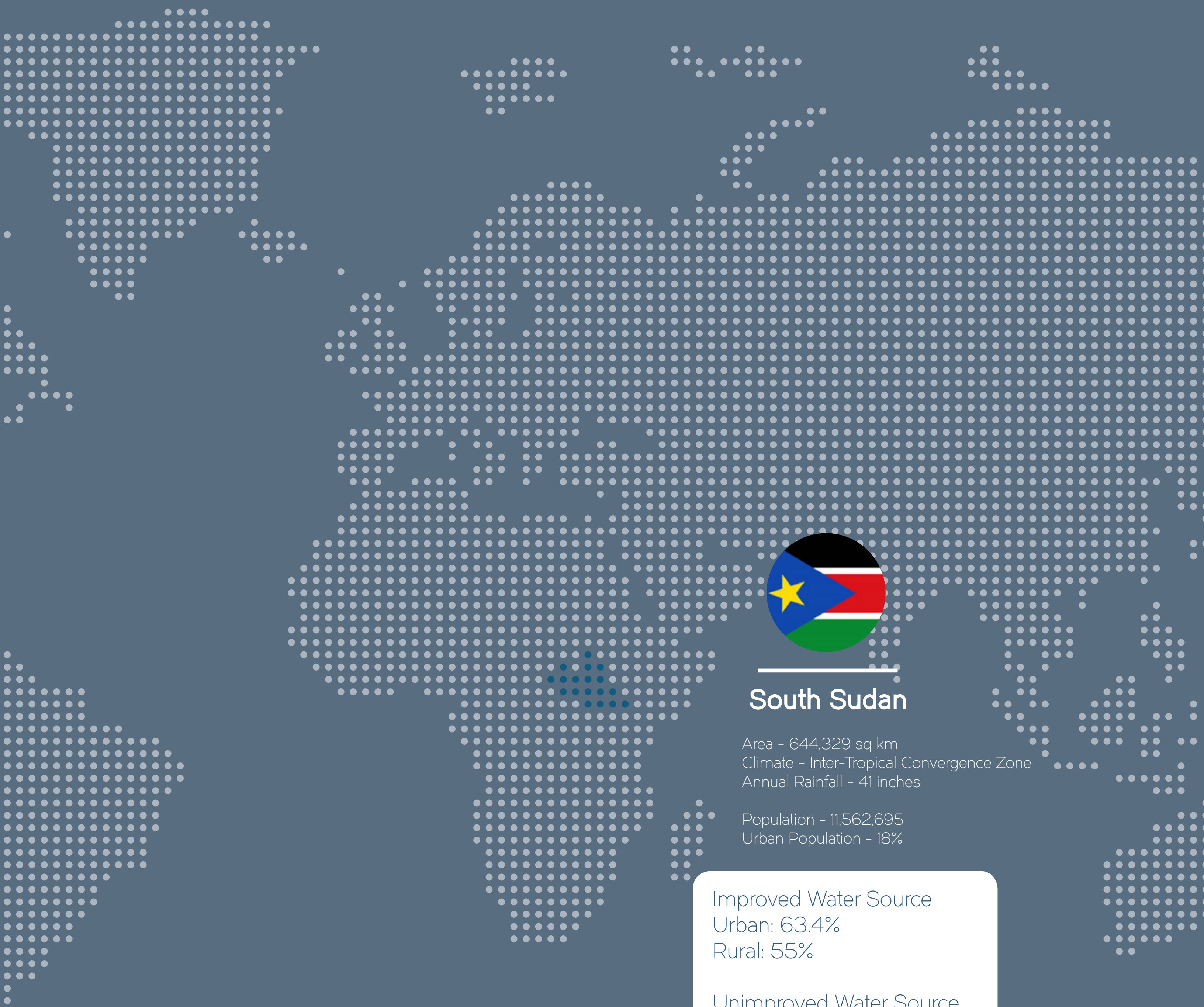
SOUTH SUDAN

South Sudan
Living Conditions
What has been done?

South Sudan

South Sudan, located in northeastern region of Africa, is listed as one of the poorest countries in the world. South Sudan, a young independent state is bordered by Sudan to the north, Ethiopia to the east, Uganda and Kenya to the southeast, Democratic Republic of Congo to the southwest and Central African Republic to the west. The river, White Nile cuts through the country, which people of South Sudan are dependent on. The country is in a sub-tropical region with high humidity and plenty of rainfall. The rainy season varies each year and ranges from April to November. Average annual rainfall for South Sudan lies around 41 inches.

Figure (5.1) South Sudan Map and Facts
Source: www.cia.gov



South Sudan

Area - 644,329 sq km
Climate - Inter-Tropical Convergence Zone
Annual Rainfall - 41 inches

Population - 11,562,695
Urban Population - 18%

Improved Water Source
Urban: 63.4%
Rural: 55%

Unimproved Water Source
Urban: **36.6%**
Rural: **45%**

Living Conditions

67 percent of South Sudan's population has access to improved drinking water sources, where many organizations have helped recently. On the other hand, the Ministry of Water Resources and Irrigation stated that 30-50 percent of water facilities are currently not functional due to the lack of spare parts supplies, weak maintenance and poor management (USAID). Thus, the level of access to clean water sources in rural conditions drops down to 34 percent. This percentage represents 90 percent of the population that are living in poverty. Furthermore, intense dry seasons force those in the rural areas to travel in search of clean water. While 34 percent travel less than 30 minutes, the rest have to travel more than 30 minutes to reach an improved water source. These intensive daily tasks are usually carried out by adult women (85.6%) and children (8.8%) (US AID). Because of these daily tasks, many children are unable to attend schools. Lack of clean water is the main cause of water-related diseases such as diarrhea, cholera, and infection from guinea worm.

Figure (5.2) Tukul Exterior
Figure (5.3) Tukul Interior

Figure (5.3)

Tukul

populations live in simple thatched roof structures, called Tukuls, where the walls are made out of mud bricks that are made by mixing water with mud and letting the mixture dry in the sun. This creates rock-hard bricks offering a solid barrier for the tukuls. The single thatched roof structure is simply made of locally sourced materials made from poles, grass and bamboo (Obakki Foundation). Thus, Tukuls cannot support traditional rainwater harvesting systems such as roofs, gutters and downpipes.

Tukul

What has been done?

Water for South Sudan, Inc., has contributed to drill wells and install hand pumps that help thousands of lives in South Sudan. These pumps provide clean, fresh water. Since 2005, the organization helped build tens of wells and pumps. Other organizations such as International Rescue Committee, Kids Ark Foundation, and Water Project have also build wells to provide clean water sources for the people. Tearfund, a non-profit organization, has carried out rainwater harvesting projects to reduce reliance on groundwater and surface water resources (Burt and Kieru). Because most of the housing structures (Tukuls) do not use traditional roof materials, installation of a typical rainwater harvesting systems with components such as gutters, downspouts, and flush dividers is not appropriate. Therefore, the organization implemented a simple system using stands and plastic sheets. Thus, families can now install these systems easily in their own homes.

Non-profit Organizations

Figure (5.6)

Figure (5.4) Hand-pump in Africa
Figure (5.5) Hand-pump in Africa
Figure (5.6) Non-profit Organizations in South Sudan

06

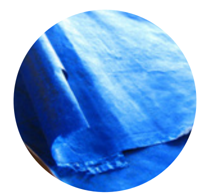
C^3 System

Rainwater Harvest
Modular Storage
BioSand Filter
Exchange Network

Rainwater Harvest

Currently, their major source of water comes from groundwater sources such as hand-dug wells and surface water sources such as streams and rivers. In order to reduce these numbers, the people have to start investing in rainwater harvesting systems, that can be cheaply built using local materials such as bamboo poles, rope and typical disaster relief plastic sheets. Since tukul housings cannot support traditional roof systems, the proposed structure would utilize locally available and cheap materials. The largest commercially available plastic sheet provides 301 square footage with 13' x 23'. With 41 inches of rainfall annually, the plastic sheets can provide 256 gallons per month and 7,688 gallons per year and of harvested rainwater.

Bamboo



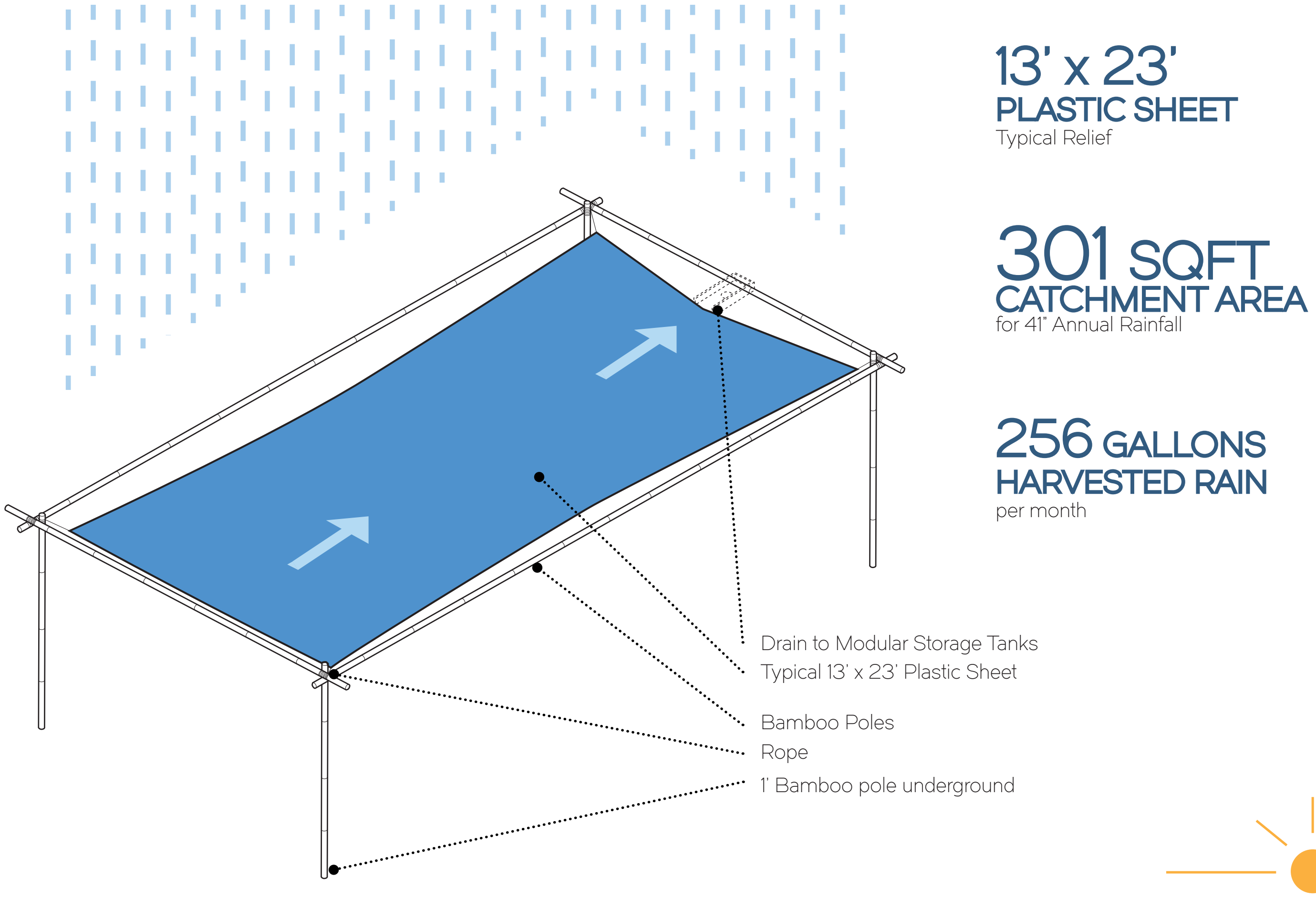
Plastic Sheet

Rope

Local Materials

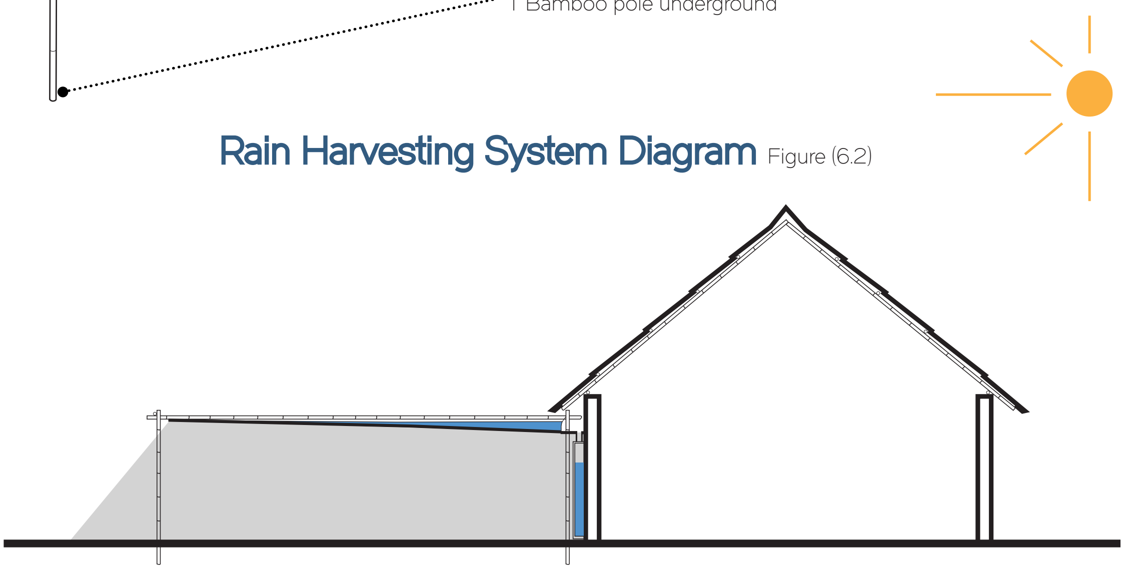
Figure (6.1)

Figure (6.1) Local available materials
Figure (6.2) Rain Harvesting system Diagram
Figure (6.3) Shadow Study



Rain Harvesting System Diagram Figure (6.2)

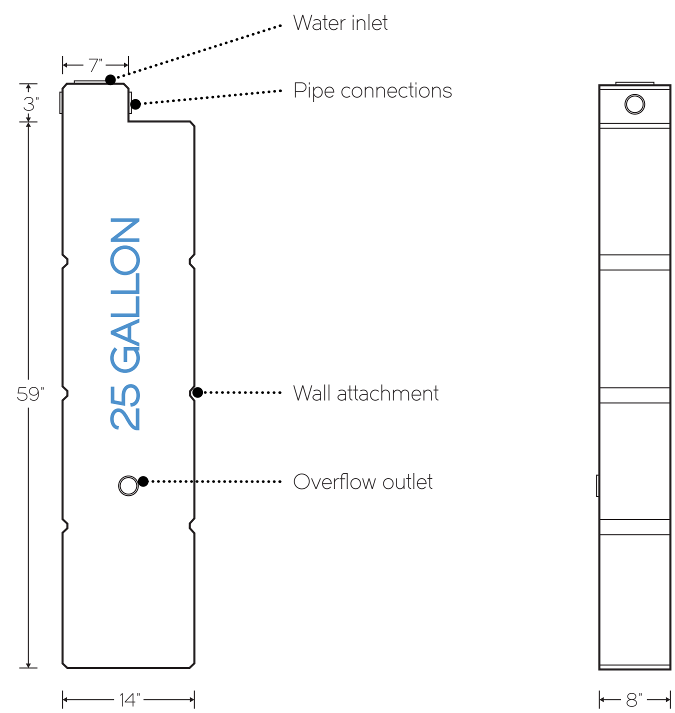
256 GALLONS
HARVESTED RAIN
per month



Shadow Study Figure (6.3)

Modular Tanks

United Nations recommends that a person needs 5 to 13 gallons per day in order to maintain a healthy lifestyle (WHO). In South Sudan, their particular lifestyles would lower require at least 5 gallons per day. With an average of 5 family members per tukul house, daily needs for each household would add up to 25 gallons per day. In dry months, women and children of South Sudan tend to go out in search for water, and they would make multiple trips in a day to meet daily needs due to the limited size of water buckets. Thus, a traditional large storage tank for rainwater will not be ideal for this particular situation. But, modular storage tanks would be appropriate as they will be able to transport these modular units to collect water. A 25-gallon storage tank would



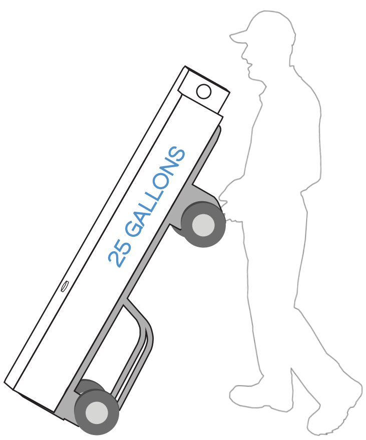
30 GALLONS
Daily water need

210 lbs
25 GALLONS
Water Load

Modular Storage Tank diagram Figure (6.4)

Figure (6.4) Modular Storage Tank diagram
Figure (6.5) Storage Tank on hand truck
Figure (6.6) Storage Tank Isometric pipe connections

2 PERSON TRIP



REDUCED
TRAVEL TRIPS
w/ larger capacity

41" ANNUAL RAINFALL

X

301 SQ FT
CATCHMENT AREA
13' x 23' Plastic Sheet

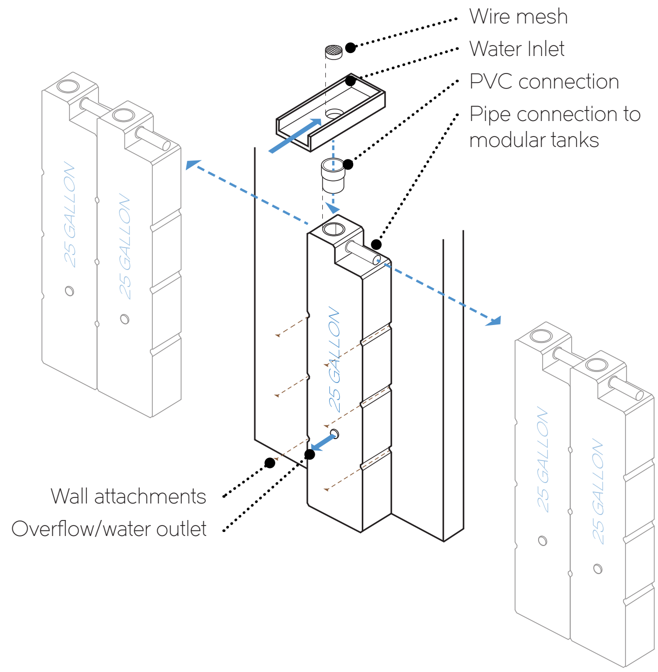
X

0.623

=

~ 256 GALLONS
HARVESTED RAIN
per month

Modular Storage on hand truck Figure (6.5)



6 X 25 GALLON = 150 GALLONS
Modular Tanks
Capacity

Modular Storage Isometric Figure (6.6)

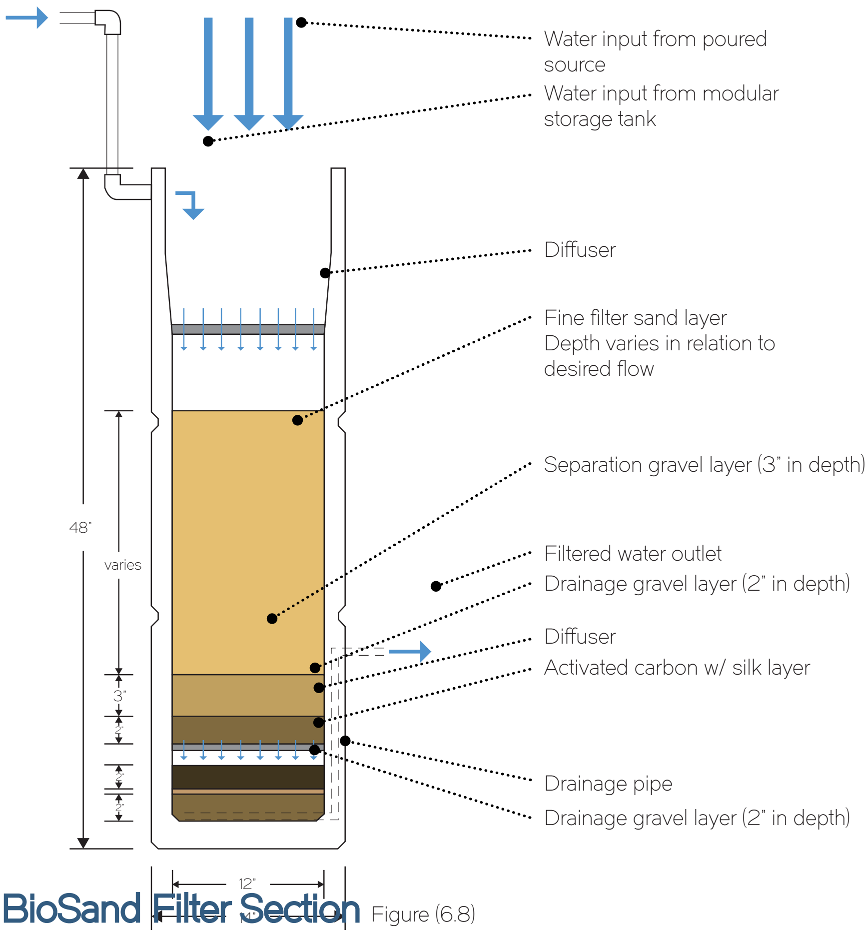
Storage Tanks

Modular Tanks

be appropriate, as this will require only one trip to meet daily water needs. The modular tanks would weigh about 200 pounds when filled with water. This would require at least two persons and a hand dolly to transport. Although the weight can be substantial, water trips can be reduced to just one, which would allow children the opportunity and time to get education, and women to help around the house. With South Sudan getting 41 inches of annual rainfall, the proposed 301 square feet plastic sheets would help harvest 256 gallons per month. Therefore, 6 of these 25-gallon tanks would store 150 gallons in full capacity. During monsoon season, this capacity would be more than enough to help maintain healthy lifestyles for a single household.

Figure (6.7) Modular Storage Tank rendering

BioSand Filter



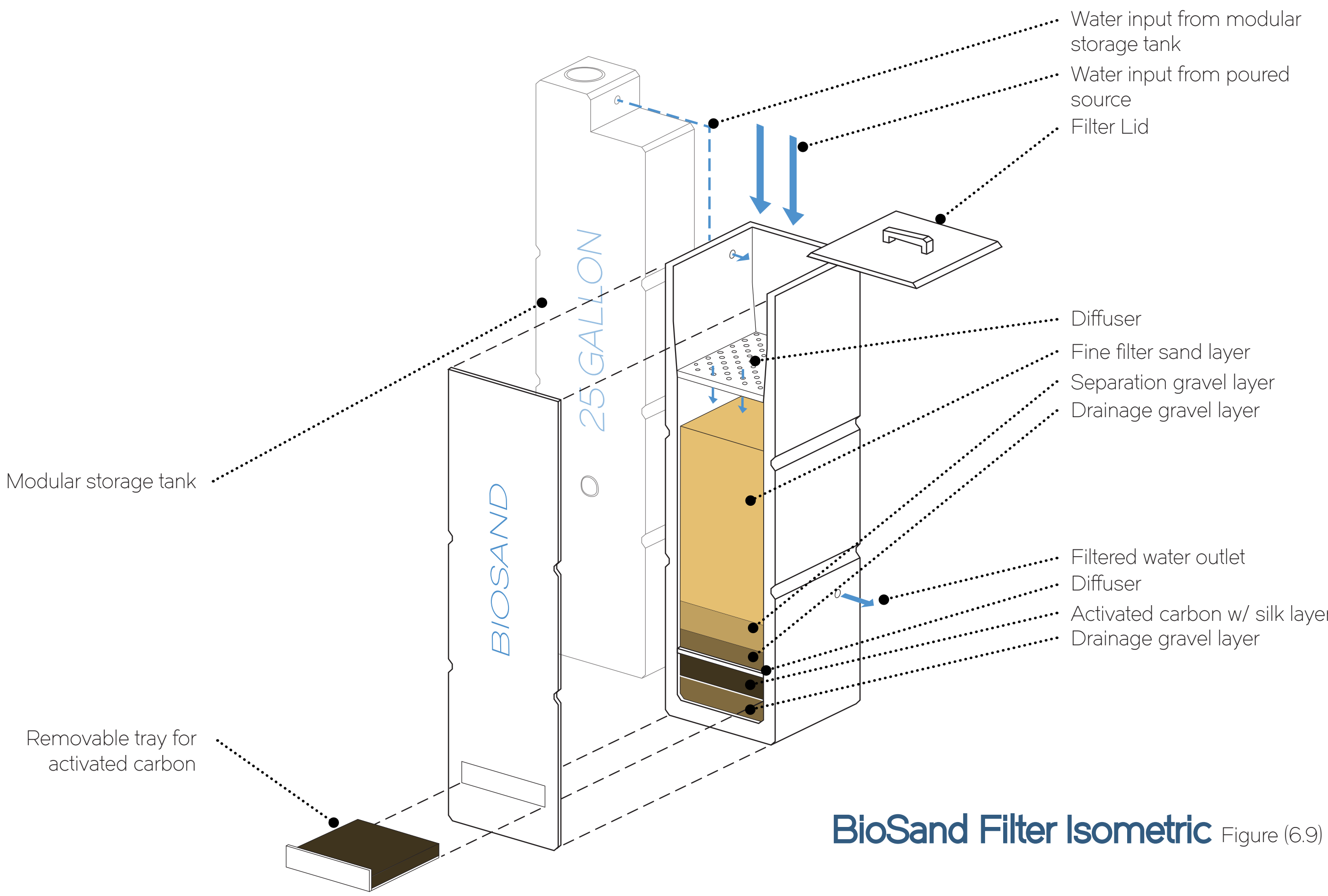
BioSand Filter Section Figure (6.8)

The proposed BioSand filter is similar to that of David Manz's original design, with the addition of an activated carbon layer. The filter will utilize several layers of media from fine sand to larger drainage gravel. Two diffusers are also added to the filter not to disturb the biological layer that will develop with use. The biological layer will develop with time and use, and it will be the main layer that will filter protozoa, bacteria and suspended particles from water. The additional activated carbon is to filter chemicals such as arsenic, which can be present in groundwater sources and is hazardous for consumption. This layer is placed on a tray at the bottom of the biosand filter, and is designed to be removable in order to change out the carbon that can become ineffective after many uses. In addition, the filter will be able to filter 12 – 18 liters of water per hour.

Filters up to
12 – 18 litres in ONE hour

Removes up to
100% Protozoa
100% Helminthes
98% Bacteria
90% Virus

Figure (6.8) BioSand Filter Section
Figure (6.9) BioSand Filter Isometric
Figure (6.10) Different Filter Media



BioSand Filter Isometric Figure (6.9)

Filtration Sand
< 0.7 mm (0.03")

Seperating Gravel
0.7 mm (0.03") - 6mm (1/4")

Drainage Gravel
6mm (1/4") - 12 mm (1/2")

Activated Carbon

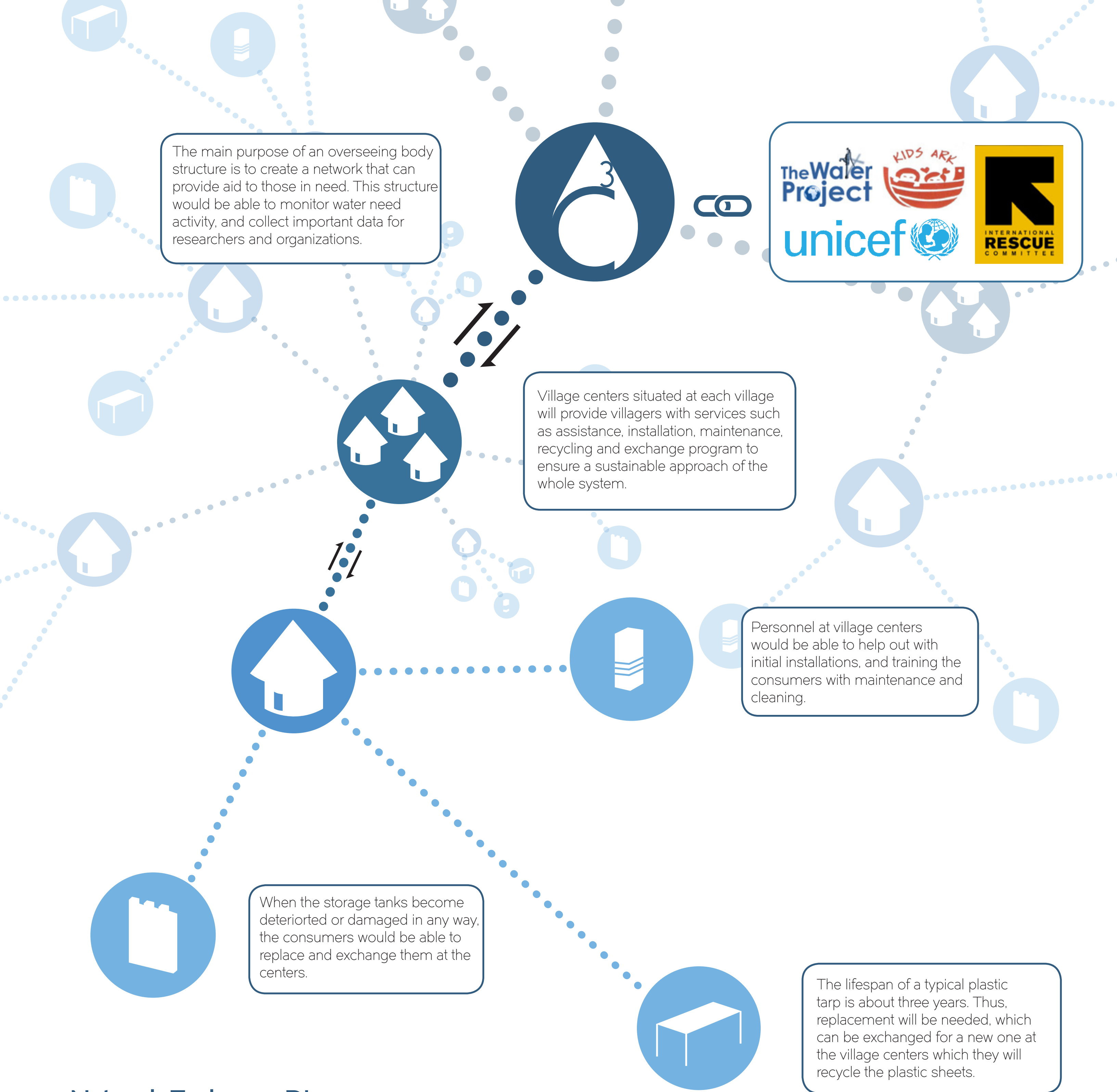
Different Filter Media Figure (6.10)

BioSand Filter

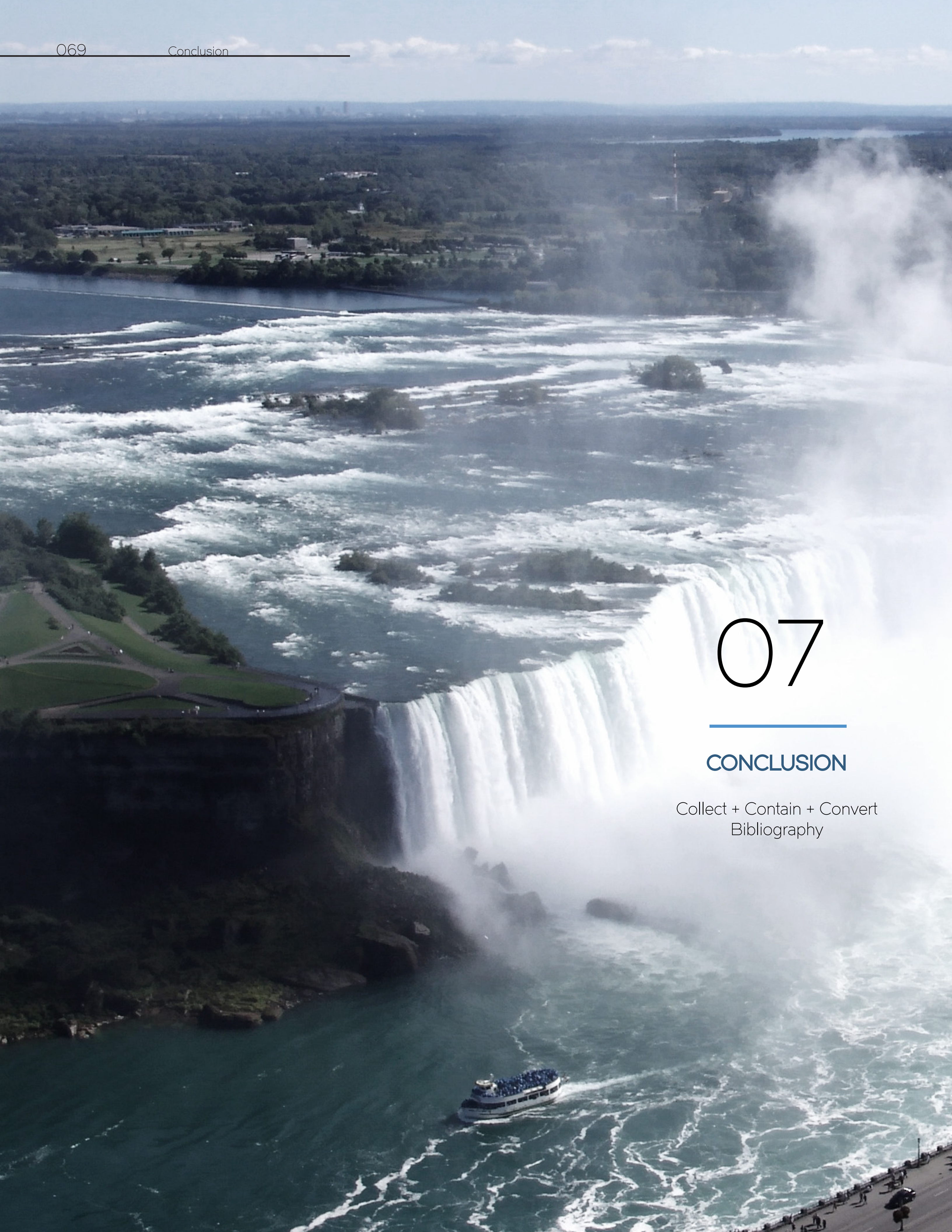
Exchange Network

Implementing the C^3 system in a village would require aide and assistance. An overseeing body structure can provide a network that can aid to those in need. The overseeing body can be linked to government and non-profit organizations such as UNICEF or the Water Project, where donations can be made. Organizations, with direct network to the people can inquire statistical data and information for research and other purposes. Under this body, village centers are placed in each status, where villagers and consumers of the C^3 system can follow a program to ensure longevity of the system. These centers will be able to provide services such as installation, maintenance, recycling and exchange program to ensure a sustainable approach of the whole system. For example, if the plastic tar for the catchment becomes damaged, consumers would be able to exchange them for a new one, where the old tarps can be recycled for other uses. The modular storage tanks could also be exchanged for a new one if become damaged. By utilizing the exchange principle, the village centers would be able to repair and repurpose the tanks, and eliminating reliance on inexperienced consumers. The village centers would be able to rent out hand trucks for those in search of a water source. Initial installation and preparation of the biosand filter would be another benefit of the centers. In addition, training for maintenance and cleaning of the filters can be provided.

Figure (6.11) Network Exchange Diagram

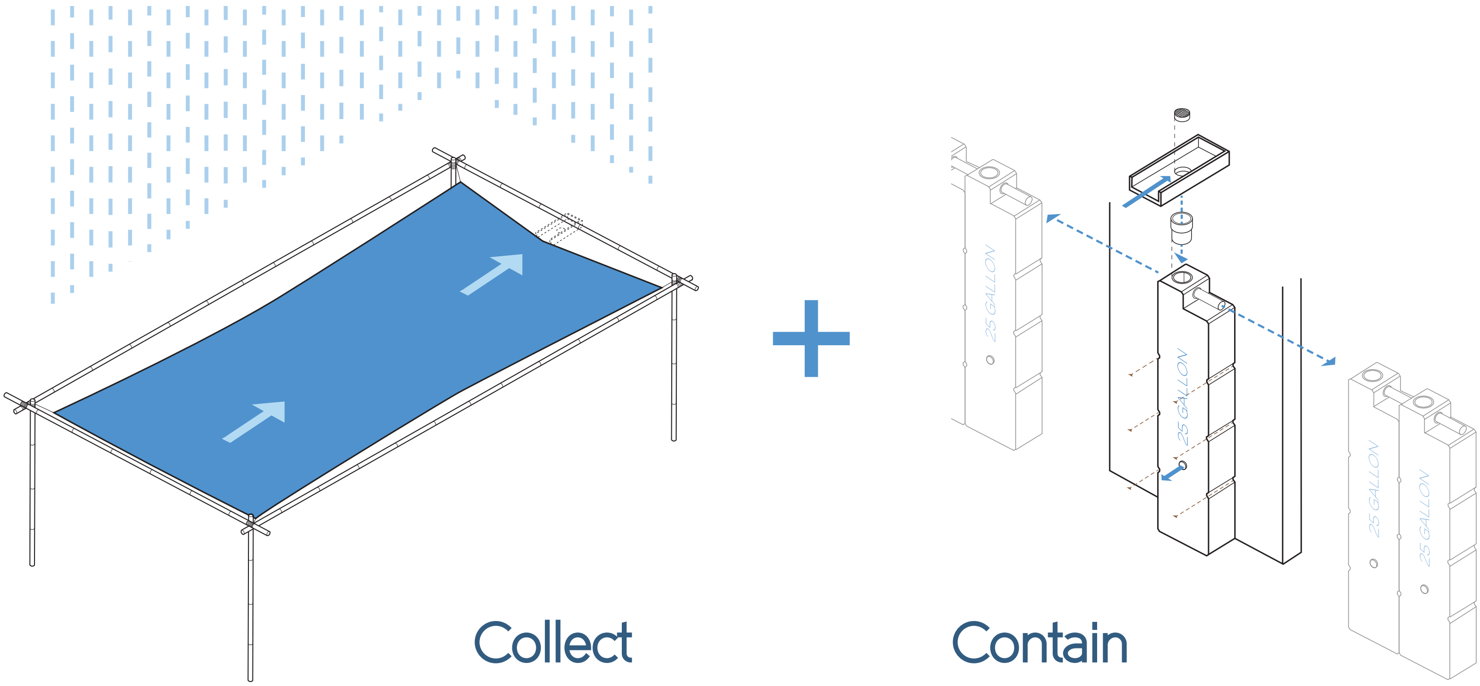


Network Exchange Diagram
Figure (6.11)



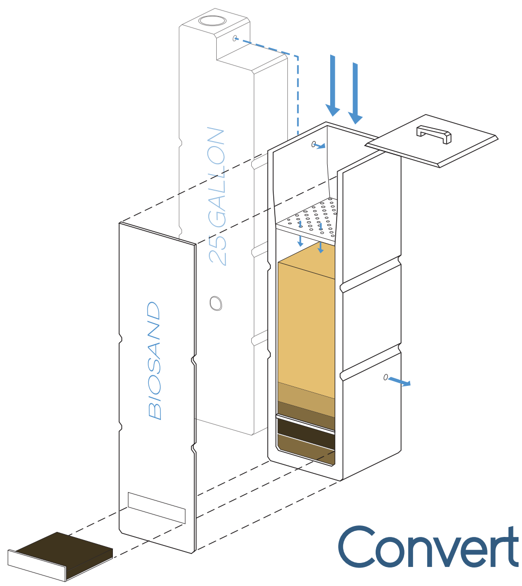
07

CONCLUSION



Collect + Contain + Convert

Collect + Contain + Convert



In order to help the people of South Sudan, and improve upon the current water crisis, it is essential to utilize their natural source of rainwater. This reflects on how the above three design elements in cohesion can improve the lives of many in South Sudan. Imagine a village of tukuls with the installed rain harvesting and filtering systems improves the lives of many. The same systems can be applied to any village that is stricken with water crises.

Figure (7.1) Collect + Contain + Convert
Figure (7.2) Village with C^3 systems

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25 GALLON
BioSand
25 GALLON

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