The Water Chariot

In the 21st Century, all people—no matter how poor—deserve adequate and safe water.

Environmental Resource Council
2829 Verndale Avenue
Anoka, Minnesota 55303
763-753-2817
www.envrc.org

The Environmental Resource Council (ERC) is a non profit organization that for 40 years has received support from government agencies and private foundations to find solutions to problems in health and environment. Our web site can be reached by Googling "envrc."

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Serving our social and physical environments since 1973

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PROJECT SUMMARY

The Burden of Water in the 21st Century

In 2012, two leading economists with the World Bank, Karina Trommlerova and Gabriel Demombynes, reported a well-documented drop in childhood mortality among low-income families in Africa. The World Bank goal of reducing childhood mortality by 50% within a decade was, in fact, becoming a reality. Michael Clemons, representing the Center for Global Development, described the report as, "the biggest, best story in the history of development."

While heroic medical surgeries and food lifts have been part of outreach to stressed populations for generations, this miracle had much to do with water—greater quantities of water for hygiene and safer water for drinking. The "Water Chariot" we have developed is intended to build upon this inspiring progress.

What is the Water Chariot?

The Water Chariot is a tank also serving as an axle; it can hold 18 gallons of water and can be pulled over both smooth and rough terrain with minimal human effort. Its wheel hubs hold 14 used PET plastic beverage containers filled with water, which is vigorously agitated/oxygenized as the Chariot is moved. Once arriving at its destination, the Chariot can be suspended upright and the wheels easily removed. The PET bottles resting in the multi-spectrum, reflective wheel bays are then exposed to direct sunlight and enhanced levels of ultraviolet radiation and solar heat for 6 to 8 hours. Although small doses of chemical additives may sometimes be required, the water in the PET containers becomes completely safe for ingestion.

Limited access to water for hygiene and ingestion of contaminated water will cause diarrhea and consequent dehydration—the leading causes of illness and death among the world's children. Use of a system like the Water Chariot can have a profound impact on both the quality of life and especially the health of water stressed families.

Our Hope

The relationship between low-income people and water access is not apparent to most who live in developed nations. Reaching out to water stressed families is the most physically humane act we can do in the 21st Century. Quite simply, as we responsibly help families obtain access to water for hygiene and to potable water for drinking, we proportionally enrich and safeguard their lives. The Water Chariot can become a principal tool in this historic endeavor.

Bruce Bomier, MPH
Board Chair
Environmental Resource Council

The Water Chariot

Introduction

The Water Chariot permits people to move water far more easily than carrying or rolling it like a drum, and provides a means to purify a portion of the water for drinking.

The Chariot utilizes what is considered trash—discarded PET plastic beverage bottles—to hold water that is agitated as it is moved, thereby becoming oxygenated. When the Chariot arrives at its destination, it is suspended off the ground via use of a lever, and the wheels containing the 14 PET bottles in "bays" are removed and laid on the ground, exposing them to direct sunlight.

The oxygenation and ultraviolet radiation, enhanced by the multi-spectrum bays, and the selective introduction of chemical additives when needed, will purify the water.

The wheels are removed and directly exposed to sunlight for 6 to 8 hours.

Human Water Needs

Access to water is a basic human need. More than any other factor, the availability and quality of water determine the likelihood that low-income families will thrive.

The World Health Organization estimates that, to remain healthy, the average adult male must ingest .8 gallons (3.028 liters) of fresh water per day, and an adult woman, .6 gallons (2.271 liters). Although variable by age, weight, and climate, a reasonable estimate is that a child should ingest .5 gallons (1.89 liters). If additional water is available for hygiene purposes, even if its purity is not assured, health is further improved, especially among children. Limited and compromised water are the leading causes of illness and death among the world's children.

The amount of water needed for general hygiene and basic sanitation, which does not necessarily need to be potable, is variable. The amount of water needed for washing clothing and personal hygiene is around three times the amount for ingestion. The quantity and quality of water a typical water-challenged family can acquire directly correlates to income. Wealth equates to having more ready access to water and to better health, and is usually simply a factor of distance to a water source. The United Nations has estimated that "low income" populations are typically 1.5+ miles from a water source. The UN defines "low income" populations as families earning $995 or less per year, with an average of four children, while "lower middle income" families earn $996-$3,945 per year and have an average of three children. As incomes rise, family size, statistically, is smaller.

A reasonable extrapolation is that low-income families would require around 10.2 gallons (38.61 liters) of water per day, or essentially 85 pounds (38.6 kilograms) of water. In lower middle-income families, the amount would be 8.6 gallons (32.6 liters), or 73 pounds (33.11 kilograms) of water, 24 pounds (10.9 kilograms) of which should be potable (fewer children).

Each day, 9 or 10 gallons (30-35 liters) of water should be available to a low or lower middle income family, 3.5 or 4.0 gallons (10-12 liters) of which, optimally, could be converted to safely ingested water. Public health data clearly demonstrate that this is not occurring.

Although improved sanitation and other health care advances have substantially improved over the last 50 years in many developing countries, with subsequent reductions in infant mortality, we still have unacceptably tragic levels of childhood disease and death attributed to compromised water quality. Childhood mortality within low-income populations is 120 per 1,000 live births; among lower middle-income groups, it is 60 per 1,000 live births. This compares to childhood mortality rates of 7 per 1,000 among high-income populations.

The leading cause of serious illness and death among water-challenged children involves bacteria-induced gastrointestinal infections, resulting in diarrhea and consequent death through dehydration and related complications.[1] The exception would be HIV/AIDS, particularly within certain African communities, where diarrhea-related disease ranks second as a

In a rural Eastern European community, there is a single, shared point of water availability. Community members fill containers and carry the water to the place of final use.

cause of childhood mortality.[2] Among low-income, water-challenged populations, childhood mortality involves 3.3 million deaths, worldwide, annually.[3] Where adequate water and soap for hygiene have been provided, and hand-washing promoted, diarrheal disease has been reduced by 45% among low-income populations.[4]

Low-income populations are located throughout Africa, in portions of Central America and in Haiti, and lower-income populations in sections of Eastern Europe, portions of the Caribbean, the Middle East, India, and Indochina, and in more remote areas of China.

Problems also exist in the more populated "emerging" nations, often referred to as the BRICS nations (Brazil, Russia, India, China and South Africa). The "BRICS" term has also come to include other rapidly developing nations, e.g. the Philippines, Ecuador, Vietnam, etc. These are regions or nations where responsible public health and civil engineering/infrastructure have not caught up to rates of more obvious commercial development.

In India, government census data sought to quantify water availability and identified that 45% of its citizens do not have "routine access" to safe drinking water. Those people are termed, "away" people, since they must carry water from a water distribution site at least several kilometers "away." This means that 540 million Indians—more than the entire populations of the United States, Mexico, and Canada—must physically move heavy burdens of water to survive. Understandably, this population has an array of health problems relating to poor hygiene, especially gastrointestinal disease.[5]

Because of water access challenges in India, 40 children under five years of age die per hour, principally from contaminated water and consequent diarrhea.[6] Put another way, 365,000 contaminated-water deaths of children under five occur each year in India, more than 10% of the population of the United States.[7] While India has the most targeted data, allowing projections based on the link between water availability and childhood mortality, it is reasonable to assume that other developing countries have similar public health situations. These emerging populations have some disposable income but also have serious water challenges.

Beyond health issues, the significant time and effort required for obtaining and transporting water

This well in southern India provides drinking water for several communities. Those who use the well typically travel 1.5 miles (2.4 kilometers).

degrade quality of life, especially that of women and children. Typically, it is the women and children, especially young girls, who are responsible for making the trek to a water site, filling the containers, and then transporting the water supply back to the family. They usually have to make this journey twice a day, since an adult can carry only about 40 or so pounds (18 kilograms) of water, or 5 gallons (19 liters), and a child, less. The better part of a day must be committed to physical transport of water. In developing nations, this "water burden sacrifice" has been identified as a leading factor in limiting a girl's educational opportunity. The physical and psychological quality of life debilitation among women and young children is hard for 21st Century water-privileged communities to comprehend.

Almost by definition, poor civics is inherent within water-deprived communities. Access to limited water resources is often denied to the most vulnerable and least empowered families in these poorly governed communities. Similarly, the rapid but poorly managed development in emerging nations is problematic. Sewage drainage systems are often unprofessionally constructed, using low-grade and poorly joined PVC plastic piping laid in shallow ditches. These are typically placed in close proximity to piping used for fresh water delivery. In other words, ditches bringing in PVC-piped potable water also carry out PVC-piped sewage. Responsible soil testing, which is an institutionalized part of civil engineering projects in developed nations, is not typically part of water and sewage projects in developing nations. If there is an abrasion or insult to the physical subsurface area shared by both systems, especially if the pipes were laid in incompatible soils with low-grade piping, the drinking water likely will become directly contaminated with sewage. When the system fails, potable water must again be either physically transported from a great distance or treated. Finding or creating wholesome, potable water, and moving that heavy burden of water via human labor over a distance, is a constant struggle for an eighth of humanity.

One recent study estimates that "women in developing countries (low income) presently walk an average of 3.7 miles daily to get water."[8] This is likely a worst-case situation, but the distance is comparable to other estimates. Potable and non-potable water supplies are moved through muscle, either animal or human. In low-income communities, less than 6% of the population has access to any sort of motorized transportation; among lower middle-income populations, it is around 20%.[9] In both cases, "motorized transportation" usually refers to motorcycles or scooters that are unable to safely transport quantities of water. For a substantial portion of the one billion low-income family members, and the four billion who are lower middle-income, a less debilitating way to move and purify water would profoundly improve health and enhance quality of life.

Development of the Water Chariot

The goal of the Environmental Resource Council (ERC) was to develop an economically feasible device that could be purchased through non-government organizations (NGOs), government programs, community groups, or even by the low-income families, themselves, to enable a lifetime of far less debilitating movement and purification of water. Making creative use of the new but ubiquitous "trash" of disposable 20- and 24-ounce plastic PET beverage bottles, we have designed a way to move large quantities of water while simultaneously facilitating water purification. Specifically, the mechanism can transport up to 175 pounds (79 kilograms) of water while vigorously agitating and potentially blending purification chemicals added to the water contained in fourteen 20- or 24-ounce (8.3-10 liters) PET beverage bottles. The goal was that a single, somewhat non-stressful trip to the water site would provide two days' water supply for a family.

With support from professionals in public health, civil engineering, and toxicology, ERC developed and field tested a rickshaw-like device, allowing easy movement of a large amount of water while simultaneously creating a supply of potable drinking water.

After much consideration, we made a determination to promote use of iodine-based water purification chemicals in situations where the combination of agitation/oxidation and multi-spectrum ultraviolet radiation and solar heat may not be enough to neutralize pathogenic microbes. Obviously, the need for purification support in this process depends upon the nature and quality of the water introduced into the PET bottles. While the enhanced SODIS (Solar Disinfection; see Att. 1) process involving multi-spectrum refraction from UV radiation to oxygenated water may be adequate, the high burden of microbial colonization in some of the water may require the addition of chemicals to complement the passive procedures.

We selected iodine-based support because the active ingredient, Tetraglycine Hydroperiodide, has been safely and cost effectively used for decades in dose-controlled water purification procedures. The typically 30-minute contact time would likely be shortened through the agitation process and, considering that the UV radiation would also require the PET containers to remain sealed and exposed to sunlight for at least six hours, chemical reaction time would not be an issue. It is also important to note that a number of reliable corporations have mass-produced and distributed this compound with appropriate hydrophilic treatment safely for decades.

There is both taste and color impact on the water using this process, which can be mostly neutralized through introducing an inexpensive ascorbic acid compound. We are testing this process in India. One consideration is that an emerging health-conscious, water-challenged population may actually identify the taste and color differentiation as a sort of "safety verification" of the water. It may make sense to retain the taste and color identifier among some groups.

We are also considering introduction of both nutrient additives and a blue tint to the water, which would help indicate to the final user that the water has been appropriately treated for ingestion. Unfortunately, inappropriate marketing of non-potable water as potable has become somewhat common among many water-challenged communities.

The fundamental enabling component of the Water Chariot approach is the relatively new introduction of PET plastic beverage bottles into the environment of low-income, water-challenged communities. Globally, Coca-Cola and Pepsi-Cola PET bottles have become ubiquitous and identified with containing both a safe and pleasurable soft drink. As incomes have increased and availability of some consumer goods has opened up, these bottles are looked upon as a quality of life asset and have even inspired a number of cottage industries:

- In parts of the world where electricity is unavailable or prohibitively expensive, used PET plastic bottles are inserted into roofing systems. The bottles are filled with water and then essentially cemented into roofs, allowing darkened interiors of buildings to be brightened through light refraction. Use of these bottles in roofing systems is a thriving industry throughout Africa, Asia, and Central America.

- Another use for PET bottles is in footwear, where the bottles are filled with sand, then crushed, then molded to an individual's feet and converted into sandals. While less than optimal for walking, there is no question that village craftsmen have learned how to make the bottles functional as footwear, to the advantage of locals with limited income.

- In some emerging communities, two-stage septic systems use shredded PET bottles in the second stage to increase non-degradable surface areas for enhancing bacterial degradation of waste products.

- Another, more obvious use for PET bottles is as a functional way to carry and store small quantities of water. The photograph below shows a missionary school with limited access to potable water. The children collect bottles, fill them with the cleanest water they can obtain by straining the water, usually through tightly woven cloth, and then shake the bottles for an extended period of time to promote oxidation. They then place the bottles on a quasi-reflective surface to expose them to variable wavelength ultraviolet radiation. Attachment 1 describes the well-established SODIS process.

PHOTO CREDIT: SVEN TORFINN/PANOS

PET bottles have been placed on a reflective, corrugated metal sheet to hopefully redirect UV radiation generated by sunlight in an attempt to reduce pathogenic microbial colonies.

Moving and treating water through use of the Water Chariot complements the current approach of water-challenged populations. Instead of struggling to manually carry 40 pounds (18.4 kilograms) of water, a

These water bearers in southern India will soon have use of the Water Chariot.

person or persons, using the Water Chariot, can "roll" 175 pounds (79 kilograms) with much less effort and no lifting, as well as having a standardized and reliable process for assuring water purity. Obviously, the strength of the water bearer(s), the distance to be traveled, and nature of the terrain will determine the degree of transportation challenge. In addition,

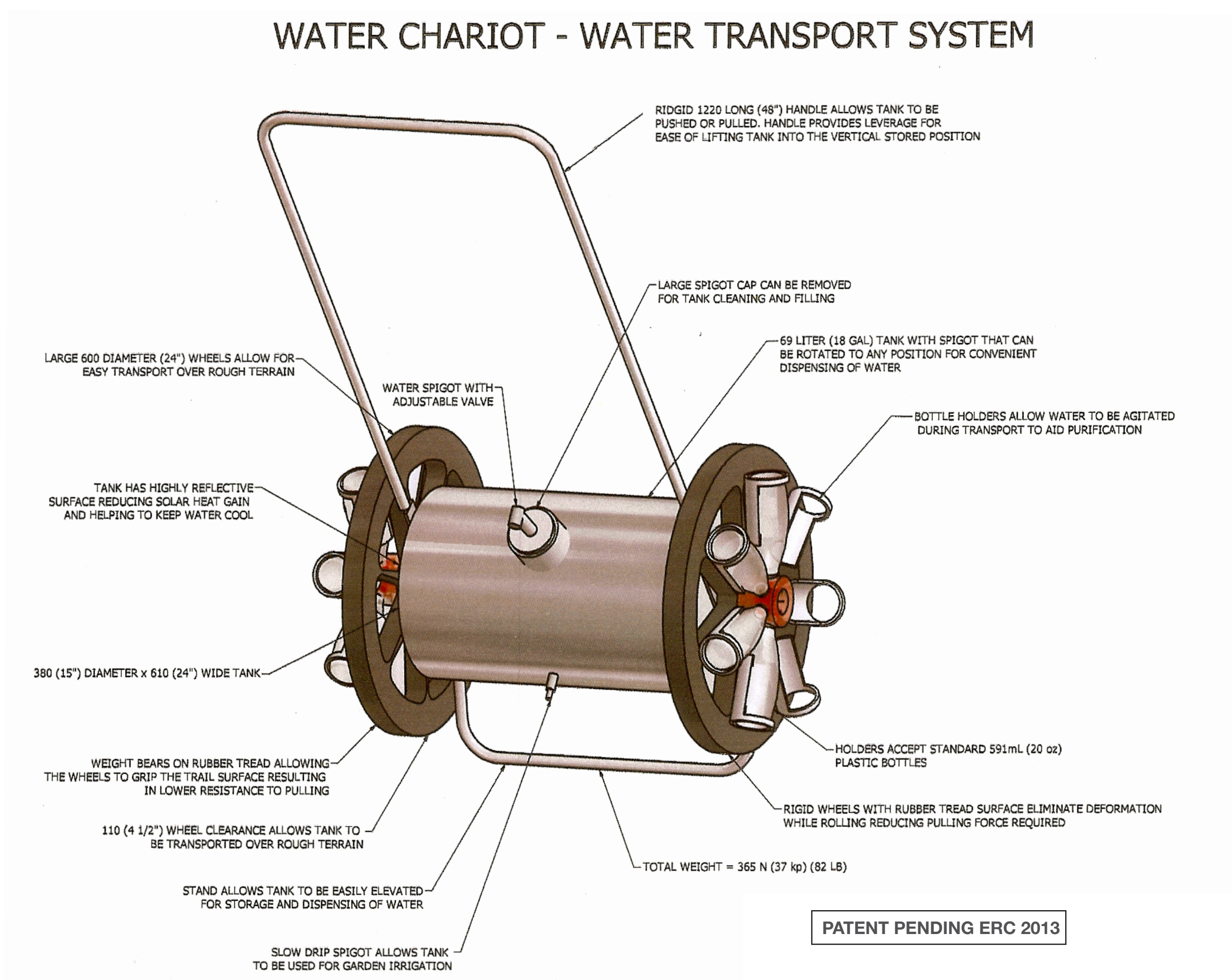
Presently, a few families in India are already using the Water Chariot.

the Chariot system is designed to operate at a family or neighborhood level, without involvement of local government; this avoids the often compromised civics of many under-developed communities, where local authorities have turned improved access to water into personal privilege.

Once the Water Chariot has reached its destination, it is easily pulled upright by using the handle as a lever. The Chariot then becomes an elevated water tank from which water can be efficiently extracted. This also allows the wheels to be easily spun by hand, allowing purification of additional water. A family would simply fill more beverage bottles from the tank, apply the pre-established dose of chemicals, if necessary, and agitate the bottles by spinning the balanced wheels before detaching and exposing the bottles in the wheel bays to sunlight.

Specifics of Operation

The Water Chariot mechanism is essentially a cylinder with a diameter of 15 inches (.38 centimeters), and length of 24 inches (61 centimeters). The cylinder itself serves as an axle attached to two wheels with a unique set of grit resistant discs that allow the wheels to be easily rotated. Vulcanized rubber wheel covers significantly minimize friction (see Att. 2). Each of the wheels contains "bays" that can secure 7 bottles containing 20- or 24-ounces (8.3 or 10.0 liters) of water. Depending upon the strength of and/or number of people pulling the mechanism, the tank can be filled with up to 18.35 gallons (69.45 liters) of water, weighing 153.25 pounds (69.5 kilograms). If all 14 PET bottles are filled with water, an additional 6.2 gallons (23.5 liters) of water can be transported. The potable water would weigh 21.86 pounds (18.4 kilograms). At a maximum, 175 pounds (79.4 kilograms) of water, or 21 gallons (79.5 liters), would be transported from the source to the family home. In addition to purifying the water, one trip would accomplish what previously required about four trips.



Once the Water Chariot arrives at its destination, the tank can be easily lifted off the ground using leverage from the handle. There are two orifices in the tank—one is a plastic faucet, the other a smaller nozzle that can be opened to permit ambient air to displace the water as it is gravimetrically removed, allowing a smooth, controlled flow of water from the tank. This smaller nozzle can also be adapted for drip irrigation purposes; a small hose can be run from the nozzle to different plantings to slowly add moisture.

The water in the tank can also fill a second set of PET plastic bottles. The wheels (which are off the ground) can be easily spun by hand, with minimal friction, and the SODIS process repeated for the additional set of bottles.

Current prototypes of the Water Chariot are designed of corrugated metal and over-built. Optimally, the device would be stamped out with different blends of molded plastic material. The only non-plastic portions of the mechanism would be the rubber wrapping around wheel edges, the snaps and straps to secure PET bottles, the coatings for the wheel discs, and other reflective coatings.

The multi-color, reflective coatings on the tank and bays have several purposes. First, the reflective material in the bays makes it easy to determine when the tint of the water is exactly right for assuring potability. Second, the surface reflects sunlight and heat, keeping the water in the tank cooler, consequently restricting growth of microbial colonies. The reflective nature of the Chariot also makes it safer to use. Typically, children carry the water, often along poorly regulated, poorly lit roads.

In terms of imagery, the multi-color design resembles a rainbow, the universal symbol equating with reception of life-giving moisture into the ecosystem, and the end of the storm.

The most important characteristic of the Chariot is the multi-spectrum reflection/refraction of UV radiation from the bays into the PET bottles, which stress the pathogenic microbial colonies, along with oxygenation and heat, rendering the water more potable.

Conclusion

Our least affluent populations have, by and large, been out of the line of vision and interest of those capable of developing new products. As our human values refocus toward a better world for all people in the 21st Century, reaching out with new, real-world innovations to address the needs of the least fortunate among us takes on a new and proper significance. There is simply no more valuable gift to a challenged family than providing continued, reasonable access to wholesome water.

I hope you will judge yourselves not on your professional accomplishments alone, but also on how well you have addressed the world's deepest inequities... And how well you treated people a world away who have nothing in common with you but their humanity.

*—**Bill Gates** (addressing the 2007 graduating class at Harvard)*

References

[1]Jorgenson, Andrew K.; Global Inequity, Water Pollution and Infant Mortality: Department of Sociology, University of California, Riverside. CA 92521-0419… The Social Science Journal; Vol. 41, Issue 2: 2004

[2]The high prevalence of HIV/AIDS in undeveloped areas, especially among women, has been subject to substantial research. Both sexual practices and poor hygiene have been identified as intensifiers of both incidence and prevalence of HIV/AIDS. Presumably, better access to water and soap, and pro-hygiene messages, would reduce both incidence and prevalence as a consequence of reduced topical infection.

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[4]Interdisciplinary Perspectives on Infectious Diseases; Volume 2012 (2012), Article ID 579681-doi: 155/2312/579681.

[5]The Energy Resource Institute, New Delhi, November 2009, p.5.

[6]UNICEF/The World Health Organization: Diarrhea: Why Children Are Still Dying and What Can Be Done (available as an article in freestanding publication).

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Attachment 1

Solar Disinfection (SODIS) through Ultraviolet Radiation Exposure, Enhanced Oxidation, and Temperature Enhancement

Over the last decade, there has been substantial publication, both for the lay community and the professional public health community, on use of a combination of passive approaches to render compromised water safe for drinking. These have focused on contained water being exposed to enhanced levels of ultraviolet radiation. The Water Chariot described in this document is designed to make the best possible use of this passive process, termed "SODIS," outlined in 1984 by Professor Aftim Acara in a UNICEF publication released internationally through the United Nations. Most research efforts and real-world use of this product have occurred since 2000.

We are attaching a November 2012 description of the process, focusing on research conducted and interpreted by the Swiss Federal Institute of Aquatic Science and Technology.

It is important to understand several characteristics of the SODIS process. While it is unquestionably effective for bacteria, including pathogenic microbes, in a laboratory setting and verified in field testing, its impact on both viruses and protozoa is somewhat less effective in controlled laboratory conditions, and at this point, field data relating to actual impact is limited. The SODIS process is effective against all three categories of potentially pathogenic agents; however, the variables regarding the amount of agitation/oxidation, UV radiation, heat exposure and, above all, the characteristics of the initial matrix of microbes and protozoa in the original water used, make consistent reliance upon the SODIS process, alone, problematic.

It is our view that, in spite of some successful research and especially highly positive anecdotal information regarding SODIS, a chemical support option to help assure the potability of water may still be important in some situations. The process and supportive systems inherent in use of the Water Chariot would allow measured introduction of a low-cost chemical to help assure potability, if there are concerns regarding the impact of the SODIS process.

We believe the best approach would be to test the water using a SODIS process, alone, in enough variations to determine whether or not the initial source would permit achievement of safe, potable water through passive mechanisms. Given limited testing ability, variables in characteristics of water sources, and variations within a single water source, an iodine-based potability-enhancing agent probably makes sense. If the agent is not affordable, or the chemical simply cannot be obtained, the Water Chariot still serves to move water more easily and should enhance the safety margin of the water in the PET plastic bottles.

The attached document is a somewhat optimistic review of the passive SODIS process, but it is a fundamentally fair representation, modified in November 2012, describing the value of the SODIS process.

It should be noted there is growing concern regarding water contaminated by arsenic within developing communities. This contamination, largely industry (mining) based, requires a completely different approach. We refer the concerned reader to an excellent resource and protocol developed by the Massachusetts Institute of Technology: wwwmit.edu/watsan/tech_hwts_chemical_kanchanarsenicfilter.html

UV treatment / Solar disinfection (SODIS)

From Akvopedia

Solar disinfection is a simple water treatment method using solar radiation (UV-A light and temperature) to destroy pathogenic bacteria and viruses present in the water. It can be used to disinfect small quantities of water with low turbidity. Most commonly, contaminated water is filled into transparent plastic bottles and exposed to full sunlight. The pathogens are destroyed during the exposure to the sun. Users determine the length of exposure based on the weather conditions.

Other forms of batch treating and continuous treatment of water with sunlight are under development by various organizations.

How it works

Plastic bottles filled with contaminated water are placed in the sunlight. Photo: SODIS. (http://www.sodis.ch/index_EN)

Exposure to sunlight has been shown to deactivate diarrhea-causing organisms in polluted drinking water. EAWAG/SANDEC (2002) describes the three effects of solar radiation which are believed to contribute to the inactivation of pathogenic organisms:

- Ultraviolet-A (UV-A) radiation causes damage to DNA and kills living cells.
- UV-A (wavelength 320-400nm) reacts with oxygen dissolved in the water and produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides), that are believed to also damage pathogens.
- Infrared radiation heats the water and causes pasteurization when the temperature is raised to 70-75 degrees Celsius. If the water temperatures raises above 50°C, the disinfection process is three times faster.

Many pathogens are not able to resist increased temperatures, nor do they have any protection mechanisms against UV radiation (EAWAG/SANDEC, 2002).

More pathogens are destroyed when they are exposed to both high temperature and UV-A light at the same time. A synergy of these two effects occurs for water temperatures above 50 degrees Celsius (Wegelin et al, 1994).

SODIS is more efficient in water with high levels of oxygen. Sunlight produces highly reactive forms of oxygen in the water. These reactive molecules also react with cell structures and kill pathogens (Kehoe et al, 2001).

The SODIS method (and other methods of household water treatment) can very effectively remove pathogenic contamination from drinking water. However, infectious diseases are also transmitted through other pathways such as direct person-to-person contact, food, or unhygienic living conditions. Lack of sanitation and hygiene practices exacerbate the problem. Studies (http://www.sodis.ch/Text2002/T-Research.htm) on the reduction of diarrhea among SODIS users show reduction values of 30-80%.

History

The fact that sunlight can kill micro-organisms has been known for centuries and has been scientifically established.

The idea of solar water disinfection (SODIS) was presented by Professor Aftim Acra for the first time in a booklet published by UNICEF in 1984. SODIS has been promoted worldwide since 1991 when an interdisciplinary research team at EAWAG/SANDEC began laboratory and field tests to assess the potential of SODIS and to develop an effective, sustainable and low cost water treatment method. Solar disinfection is recommended by the World Health Oganization (WHO) as one viable option for drinking water treatment at household level.

Suitable conditions

Basically the SODIS is suitable for batches of 1-2 litres per bottle. The system is not useful for treating large volumes of water, several are bottles needed for a large family.

Bottles will melt and deform if the temperature reaches 65°C.

The following issues should be considered for SODIS operation:

- **Bottle material:** Some glass or PVC materials may prevent ultraviolet light from reaching the water. Commercially available bottles made of PET (Polyethylene terephthalate), such as the plastic bottles in which soft drink beverages are sold, are recommended. The handling is much more convenient in the case of PET bottles. Polycarbonate blocks all UVA and UVB rays, and therefore should not be used. Glass also blocks UV rays and therefore would be ineffective.

- **Aging of plastic bottles:** SODIS efficiency depends on the physical condition of the plastic bottles, with scratches and other signs of wear reducing the efficiency of SODIS. Heavily scratched or old, blind bottles should be replaced.

- **Shape of Containers:** the intensity of the UV radiation decreases rapidly with increasing water depth. Bottles used for SODIS should not exceed 10 cm in water depth. 1-2 litre volume PET bottles do not exceed this depth when they are horizontally placed in the sunlight (EAWAG/SANDEC, 2002). PET soft drink bottles are often easily available and thus most practical for the SODIS application.

- **Oxygen:** Sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These reactive molecules contribute in the destruction process of the microorganisms. Under normal conditions (rivers, creeks, wells, ponds, tap) water contains sufficient oxygen (more than 3 mg oxygen per litre) and does not have to be aerated before the application of SODIS.

- For turbidity levels greater than 30 NTU, the water should first be filtered through a cloth or sedimented (Sommer et al, 1997).

Advantages	Disadvantages
- Very cheap, no capital costs except plastic bottle, no consumables required.	- Cannot be used on days with continuous rainfall.
- Independent from energy sources other than sunlight. - Treated water is protected from re-contamination in the bottles. - The taste of treated water is fresh, not stale or otherwise altered. - Convenient for storage and transportation. - SODIS has shown to significantly reduce diarrhoea	- Cannot be used to treat very turbid water (>30 NTU). - Bottles need to be replaced every 4-6 months. - Has a waiting period of 6-12 hours. - Needs to be cooled before consumption - Does not remove suspended partices of dissolved compounds

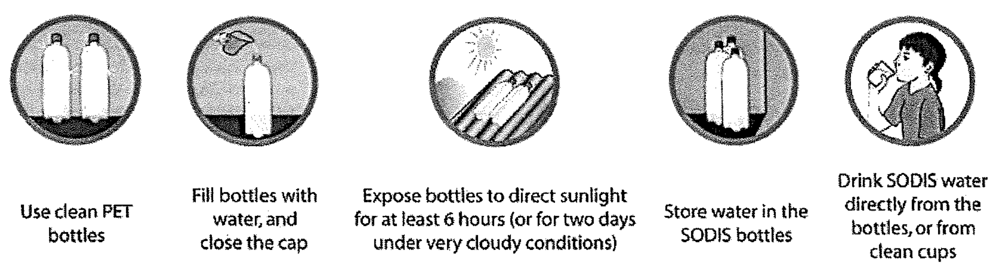
Highly effective for:	Somewhat effective for:	Not effective for:
- Bacteria - Viruses - Protozoa - Helminths		- Turbidity - Chemicals - Taste, odour, colour

Treatment process:
Disinfection Safe Storage
Inlet water criteria:
Turbidity < 30 NTU

The bottle can be used as a safe storage container. Requires suitable climate and weather conditions: the most favourable location is between latitudes 15° and 35° north/south; next most favourable location is between latitudes 15° north/south and the equator. PET bottles are abundant in urban areas, but may not be available in rural areas.

Construction, operations and maintenance

Operation



Transparent water bottles are filled with water from contaminated sources. To increase the oxygen dissolved in the water, bottles can be filled three quarters, then shaken for 20 seconds (with the cap on), then filled completely. Highly turbid water (turbidity higher than 30 NTU) must be filtered prior to exposure to the sunlight.

Filled bottles are then exposed to the sun. The treatment efficiency can be improved if the plastic bottles are placed on sunlight reflecting surfaces, such as corrugated aluminum or zinc roofs. This can increase the water temperature by about 5°C.

Place the bottles horizontally on a roof or rack in the sun for the following times:

- 6 hours in sunny weather
- 6 hours for up to 50% cloudy weather
- 2 consecutive days for 50-100% cloudy weather
- Do not use SODIS during days of continuous rainfall, use rainwater harvesting instead.

The efficiency of SODIS is dependent on the amount of sunlight available. The bottles must NOT be placed so that they are in shade for part of the day. The most favourable geographical regions for SODIS are located between latitudes 15oN and 35oN (as well as 15oS and 35oS). The majority of developing countries are located between latitudes 35oN and 35oS (EAWAG/SANDEC, 2002). If the water bottles are not exposed to sunlight for the proper length of time, the water may not be safe to drink and could cause illness. If the day is more than 50% cloudy, then it is necessary to expose the bottles for 2 days. If the temperature of the water is more than 50 degrees C, only 1 hour of exposure is required.

After treatment, the water can be consumed. The risk of re-contamination can be minimized if water is stored in the bottles. The water should be consumed directly from the bottle or poured into clean drinking cups. Re-filling and storage in other containers increases the risk of recontamination. Non-pathogenic organisms, such as algae, may grow in the conditions created in a SODIS bottle (EAWAG/SANDEC, 2002).

Users are unable to determine when sufficient disinfection has taken place. Users need to organize a rotation system to ensure they always have treated water and know which bottles have been treated.

Manufacturing

Materials and facilities needed are:

- 1 or 2 litre clear plastic bottles (2 sets of 2 bottles per person, one set of bottles must be filled and placed on the roof each day, while the water in the other set is consumed)

- An alternative design using specially fabricated bags with a one-way valve integrating a temperature indicator has been proposed see YouTube video [1] (http://www.youtube.com/watch?v=_k-SeaRj_QY)
- Accessible surface that receives full sunlight (e.g. roof, rack).

Safety

There has been some concern over the question whether plastic drinking containers can release chemicals or toxic components into water, a process possibly accelerated by heat. The Swiss Federal Laboratories for Materials Testing and Research have examined the diffusion of adipates and phthalates (DEHA and DEHP) from new and reused PET-bottles in the water during solar exposure. The levels of concentrations found in the water after a solar exposure of 17 hours in 60°C water were far below World Health Organization (WHO) guidelines for drinking water and in the same magnitude as the concentrations of phthalate and adipate generally found in high quality tap water.

Concerns about the general use of PET-bottles were also expressed after a report published by researchers from the University of Heidelberg on antimony being released from PET-bottles for soft drinks and mineral water stored over several months in supermarkets. However, the antimony concentrations found in the bottles are orders of magnitude below WHO [2] (http://www.who.int/water_sanitation_health/dwq/chemicals/antimonysum.pdf) and national guidelines for antimony concentrations in drinking water. Furthermore, SODIS water is not stored over such extended periods in the bottles.

Treatment Efficiency

	Bacteria	Viruses	Protozoa	Helminths	Turbidity	Iron	-
Laboratory	99.9 – 99.99%	90 - 99.9%	90 - 99.9% [1]	[1]	0	{{{lab:iron}}}	
Field	91.3-99.4%	not available	not available	not available	0	{{{field:iron}}}	-

Maintenance

Bottles and caps should be cleaned on a regular basis.

Estimated Lifespan

Bottles become scratched or aged by sunlight and must be replaced periodically.

Costs

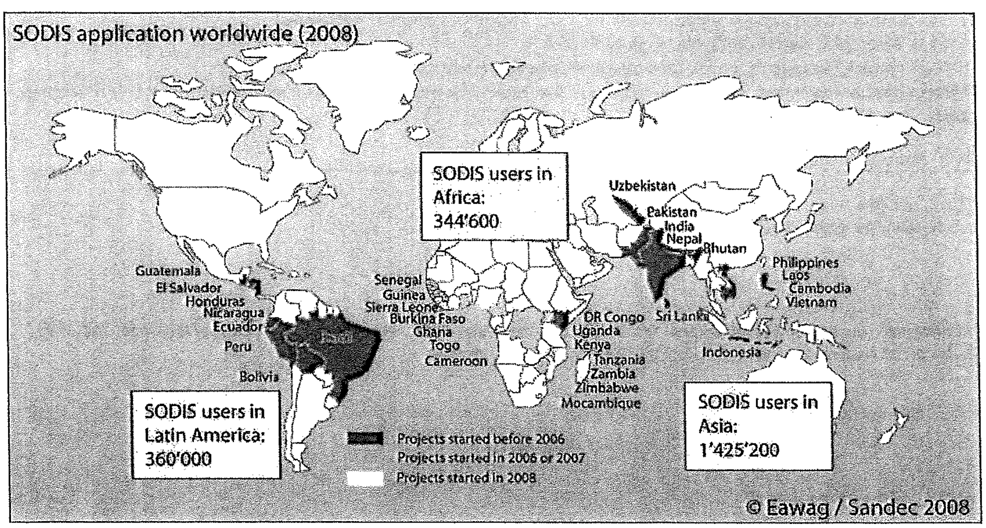
Capital cost	Operating cost	Replacement cost	Estimated 5 year cost	Cost / litre treated
US$ 0-5 (*)	US$ 0	US$ 2-5/year	US$ 10-25	US$ 0.003-0.008

Note: Program, transportation and education costs are not included. (*) PET bottles may be free or cost less than US$0.50

The cost of SODIS are very low, re-use of plastic bottles is common. According to a comparative study (http://www.iwaponline.com/jwh/005/jwh0050599.htm) on the cost-effectiveness of different household water treatment systems, SODIS is the least expensive method with an annual mean cost of US$0.63 per person.

Field experiences

Used by more than 1,000,000 in Asia, Africa and Latin America.



The Swiss Federal Institute of Aquatic Science and Technology (Eawag), through the Department of Water and Sanitation in Developing Countries (Sandec), coordinates SODIS promotion projects in 33 countries including Bhutan, Bolivia, Burkina Faso, Cambodia, Cameroon, DR Congo, Ecuador, El Salvador, Ethiopia, Ghana, Guatemala, Guinea, Honduras, India, Indonesia, Kenya, Laos, Malawi, Mozambique, Nepal, Nicaragua, Pakistan, Perú, Philippines, Senegal, Sierra Leone, Sri Lanka, Togo, Uganda, Uzbekistan, Vietnam, Zambia, and Zimbabwe. Contact addresses and case studies of the projects coordinated by the Swiss Federal Institute of Aquatic Science and Technology (Eawag) are available at sodis.ch

Attachment 2

Comparison of the Water Chariot to Existing Water-carrying Implements and Mechanisms

The use of jugs or pottery to move water has always been endemic to human populations. Some means to assure constant availability of water is necessary for human society to thrive.

In the last 30 years, those who must carry water manually have switched, where possible, to plastic containers that are comparatively indestructible and lightweight. Also where possible, people will select lighter colored containers that do not absorb heat as readily; consequently, microbial colonies are less likely to foul the standing water as rapidly.

Within the last decade, several versions of a plastic water tank or a barrel that can be rolled have been produced, either provided through NGOs or sold to populations that must move water manually. One of the most commonly used water barrels involves a sort of donut-shaped wheel that can be pulled with a rope. A more recent version is pushed, using a lightweight metal handle. Where available, these are understandably popular, especially in South Africa where government programs subsidize their purchase. There have also been aggressive requests for donations to provide the rolling barrels, which allow water bearers to transport water more easily.

The Water Chariot differs, to the user's advantage, in several ways:

- Most significantly, the Water Chariot enables purification of a portion of the water. The water contained in the barrel is not agitated during transportation because it slides along the smooth internal surface of the barrel as it is rolled. Without agitation, the water becomes stagnant, even while being transported. Also, unfortunately, most barrels are a dark color, which absorbs heat more readily and contributes to the growth of microbial colonies. The rolling barrel does serve to make transport of greater quantities of water less difficult, but does not contribute in any way toward healthier water for ingestion. If use of the barrels causes greater quantities of water to be left standing for longer periods, it may actually increase the incidence of disease.

- Switching from a barrel to the Chariot substantially reduces the amount of human energy required to transport the water. It simply takes less human effort to roll a suspended burden on wheels than to roll a drum. The attached engineering report quantifies the comparative ease of rolling the Chariot, as opposed to pushing or pulling a barrel.

- Other helpful characteristics involve the ability to raise the barrel through leveraging the pulling handles and to carefully adjust withdrawal of the water through a faucet and complementary air intake. Once it gets to the destination, it is simply easier and more efficient to use. Also, the coloration of the mechanism serves to reflect sunlight and heat, as well as providing an extra margin of safety when being pulled in areas of motorized traffic. In response to information that water was often transported during moisture-challenged times to support gardens, we developed the Chariot's mechanism to enable drip irrigation. Finally, since the water-containing drum is suspended six inches off the ground it will not be subject to insults or abrasion while being pulled, a much lighter-grade plastic can be used, reducing production costs.

While not specifically to the user's advantage, the Chariot mechanism can convert PET plastic beverage containers—usually considered trash—into tools that enrich the lives of families, especially children, in water challenged communities. Regarding use of what would otherwise be waste products, the Water Chariot is a model of responsible ecology.

Environmental Resource Council

Water Chariot – Water Transport System Analysis

February 4, 2013

IEA Project #201310086

CERTIFICATION

I hereby certify that this report was prepared by me or under my direct supervision, and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Name: STEVEN J. ZECHMEISTER

Signature: ____________________

Date: 2/4/13 License #47570

Mr. Bruce Bomier
Environmental Resource Council
2829 Verndale Avenue
Anoka, MN 55303
Phone: 763-753-9713
Email: bbomier@envrc.org

Dear Bruce,

IEA examined the Water Chariot transport system you have designed as compared to rolling barrel water transport systems currently in use, and found that your design has distinct advantages. Your Water Chariot system should require less effort to transport water under most situations.

INTRODUCTION

IEA compared the Water Chariot (see Figure 1) with commonly used rolling barrel type systems (see Figure 2) to determine which would require less effort to transport water.

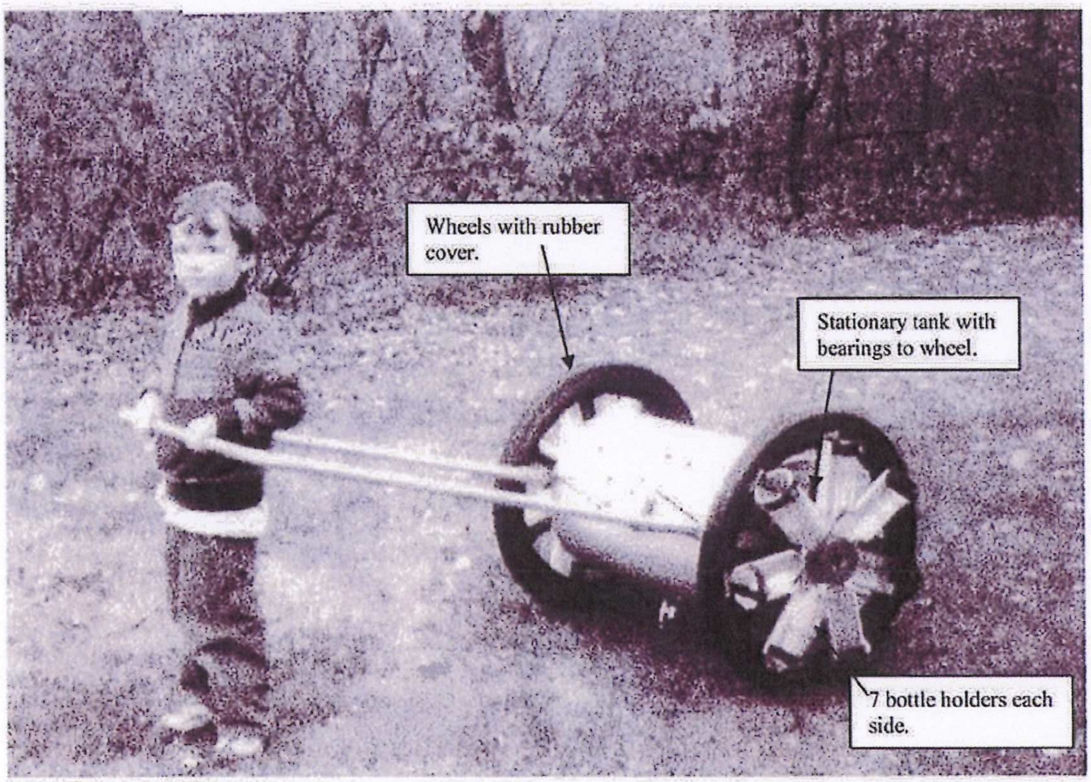


Figure 1: Water Chariot

Figure 2: Example Current Mode of Water Transport

The comparison was made using a typical surface of a compacted dirt road or path. The Water Chariot operates like a rickshaw with wheels on bearings and a stationary tank. The Water Chariot was compared to the type of tank shown in Figure 2, which consists of a donut-shaped barrel with a rope looped through the hole for pulling. In addition, there are tanks similar to this in use that have a ridged handle for pulling and pushing instead of a rope.

ANALYSIS

There are several types of forces at work that provide resistance to transporting water in this manner:

1. Weight of the tank against gravity.
2. Rolling friction between the tank and the road.
3. Bearing friction between the wheels and the tank or between the pulling mechanism and the tank.
4. Deformation of the wheel or tank.
5. Deformation of the road or path.

Items 2 & 4 listed above are relatively equal for both systems. However, the Water Chariot is a better system to avoid the energy losses incurred by items 1, 3, and 5 above. The Water Chariot design allows the tank to be elevated, and the portion in contact with the road is narrow compared to a tank that rolls on the ground. This allows the tank to better handle rough terrain. A significant energy loss incurred in this type of water transport is due to the up-and-down motions associated with rolling on rocks and rough roadways. The Water Chariot design reduces the amount of mass that shifts vertically as it rolls, which conserves energy.

Bearing friction between the wheels and the tank or between the pulling mechanism and the tank is another difference between these two designs. The Water Chariot handles this friction more efficiently with bearings. When pulling a tank with a rope, there is significant friction loss between the rope and the tank.

In addition, the Water Chariot can save energy that is lost in many situations due to deformation of the road surface. Since the rolling barrel design has much more surface area in contact with the road, the vertical force on the road (normal force) is lower than that of the Water Chariot. In many situations, the rolling barrel is more susceptible to sliding or pushing the road surface which results in significant wasted energy. The Water Chariot is better able to grip the road surface with less slippage, in many situations, due to the higher normal force and rubber tread wheels.

CONCLUSION

In most situations, it appears that the Water Chariot design will allow water to be transported with less effort than the typical rolling barrels that are currently in use.

If you have any questions, please contact our office at 763-315-7900.

Sincerely,

Steve Zechmeister, P.E.
Indoor Environments Division

SZ:sda 020413