

Guidelines to Planning Sustainable Water Projects and Selecting Appropriate Technologies

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Water & Sanitation Rotarian Action Group

Final



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INTRODUCTION

A Guide to Selecting a Sustainable WASH Project System

A safe and reliable drinking water and access to adequate sanitation is not available to nearly one billion people. Rotary International has recognized this problem and has made it one of the six areas of focus for its new grant model.

Bringing safe and reliable drinking water to the developing world has been a challenge to Rotary clubs and other non-governmental organizations (NGOs), with the result that an estimated fifty percent of all water projects built by these organizations have failed within five years of being built. This high level of failures can be attributed to many factors, including:

- Selection of inappropriate technologies
- The Myth: “Just built it and it will work forever.”
- Poor water point siting
- Lack of on-going operations and maintenance training
- Lack of spare parts
- Poor or changing water quality
- Vandalism, theft, or conflict
- Lack of finance for operations and maintenance
- Ineffective community water committees
- Weak follow-up and project supervision by project sponsors
- No long-term project monitoring and evaluation

Rotary International, The Rotary Foundation and Wasrag have initiated a pilot program that is designed to change this failure rate. The one-year pilot program, Project Enhancement Process (PEP), was initiated in nine districts in July 2012.

Planning For Sustainability

With over one billion people without safe drinking water and over two billion without adequate sanitation facilities, the challenge of providing everyone with safe drinking water and proper sanitation is daunting. With 34,000 Rotary clubs in the world, the number of projects that would be required to make a difference will require all of the Rotarians to work together with partner organizations, host country governments, and village leaders with a new approach to WASH projects.

This simple analysis demonstrates the importance of doing each project right and ensuring that they continue to provide the services intended for the design life of the facility is obvious and the importance of efficiently and effectively working together to build projects that are sustainable.

The goal is that Rotarians plan, design and complete water and sanitation projects that remain functional and that are maintained by the village water committees throughout their intended lives. Just as Rotary continues to seek to totally eradicate Polio in the world, we must seek to build sustainable projects that will continue to be fully functional for ten or more years of operation that must be incorporated into the system plan for serving the village.

To Wasrag, sustainable means “Meeting the needs of the present without compromising the ability of future generations to meet their needs.” Critical to creating sustainable projects is that Rotary clubs integrate their local project into a regional planning effort lead by the village leaders, host country Rotarians, and active in-country NGO, with the support from the international Rotary club sponsors.

The following steps are designed to help Rotary clubs achieve sustainable projects:

1. Identifying potential alliances in the host country to support the leadership and assist in monitoring and evaluating successful operation of the installed system
2. Ensuring community ownership and to demonstrate self-sufficiency in operation

3. Focusing on needs, the current state of the community, the desired future (such as access to clean water year-round and reduction in water-borne diseases) and an assessment of technical, socio/cultural and financial risks affecting the likely long-term viability of the project,
4. Involving women in the initial design of the system and in ensuring that the system is maintained and associated hygiene and behavioral changes take place.,
5. Choosing appropriate technologies are installed and operational support is available, and
6. Focusing on the overall community goals of a healthy and economically stable future is planned for.

The three part approach that the PEP Pilot is testing includes:

1. Formation of a Country Regional Team or Water Committee that provides the in country priorities and overall guidance of a phased program;
2. Develop a Program Planning and Performance Team (PPP, also known as Rotary Service Corps) that assists the Regional Team and village leaders in completing a needs assessment and conduct an Alternative Analysis of the best technical and operational solution
3. Use of the Wasrag Technical Guidelines and in-country support system to achieve the Sustainable System that meets the jointly defined village needs for WASH.

This PEP Pilot is seeking to support a program that will over time provide WASH services for 100 percent coverage of all of the villages in each country/RI District. This approach helps create a shared support system designed to enable a health and hygiene program and an operator/water committee training program for the project service area that will be sustained.

The regional approach may also provide for increased efficiency and use of shared facilities and operational support systems to serve a larger number of villagers at a lower unit cost. When the provision of one project at a time is done in rural areas and in isolation from the larger district, the higher cost of overhead management, training, monitoring and support for the maintenance of the facilities reduces the time and resources available to do the next project. This also contributes to the probability of a higher project failure rate within the first five years.

Doing More With The Same Resources

With over two billion people needing help with developing safe drinking water and proper sanitation, service organizations cannot afford to approach this challenge in an ineffective way. Even though Rotary has a finite number of volunteers and financial resources, it has a history and reputation of applying good management principles and business practices to its humanitarian endeavors. The PEP Pilot is undertaking steps to obtain a greater efficiency and effectiveness through a coordinated approach of the host and international Rotary clubs working in the same country along with the in-country NGO and governments in partnerships as a normal course of action and a centralized Rotary (Wasrag) management and support structure.

The strategic partnerships with organizations with a shared vision of sustainable projects, will allow for an approach to completing needs assessments on a country-by-country or region-by-region basis. This needs assessment will focus on a shared action plan to design, fund, and implement water and sanitation systems with 100 percent coverage of the priority areas, which will leverage the limited resources of organizations that have a shared goal of providing safe water and proper sanitation systems on a sustainable basis. This approach is built into the PEP Pilot that began in July 2012.

Using This E-Learning Document for Planning & Building Sustainable Projects

The Wasrag Technical Guideline—*Guidelines for Planning Sustainable Water Projects and Selecting Appropriate Technologies* (and its companion guidelines, *Guidelines for Planning Sustainable Sanitation*

Projects and Selecting Appropriate Technologies, and Guidelines for Selection Sustainable Health and Hygiene Programs) is the first step in this new e-learning program. This document reviews how to—

- evaluate sources of water supply
- evaluate water quality
- evaluate and select appropriate treatment technologies
- plan and construct a project
- monitor performance of the constructed project

The document is designed for Rotarians with basic levels of understanding of water issues, yet it will lead the reader to advanced levels of system design and operation.

After participating in this e-learning program, participants will have access to the Water and Sanitation Rotarian Action Group (Wasrag) technical experts through their “Ask an Expert” program. The participants have personal access to someone with long professional experience with the issue in question.

SURFACE WATER SUPPLIES

Introduction

Surface water is humanity's first direct contact with water. It comes in the form of rainfall, rivers, lakes, and oceans. It is not surprising that the vast majority of humans live near a surface water body. The following discussion provides an overview about surface water and how it can be developed as a drinking water source, particularly in the developing world where Rotarians spend much of their humanitarian time and energy. This discussion is taken largely from Wikipedia (http://en.wikipedia.org/wiki/Water_resources#Surface_water).

Are We Running Out Of Water?

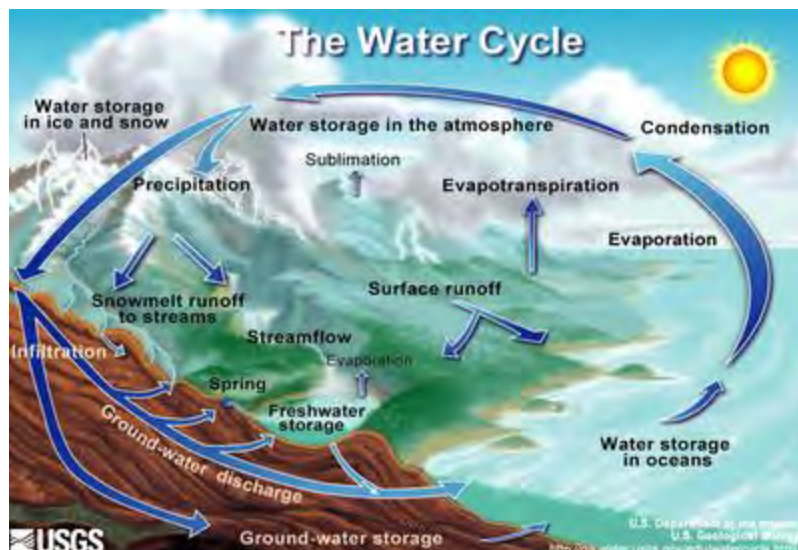
This is a question that is often asked. The answer is no, there is the same amount of water on the Earth as there was at the end of the last ice age, 10 to 12 thousand years ago. Water covers 70.9% of the Earth's surface and is vital for all known forms of life.

On Earth, 96.5% of the planet's water is found in oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation.

Only 2.5% of the Earth's water is fresh water, and 98.8% of that water is in ice and groundwater. Less than 0.3% of all freshwater is in rivers, lakes (surface water), and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products.

Safe drinking water is essential to humans and other life forms. Access to safe drinking water has improved over the last decades in almost every part of the world, but approximately one billion people still lack access to safe water and over 2.5 billion lack access to adequate sanitation. There is a clear correlation between access to safe water and gross domestic product (GDP) per capita. However, some analysts have estimated that by 2025 more than half of the world population will be facing water-based vulnerability. A recent report suggests that by 2030, in some developing regions of the world, water demand will exceed supply by 50 times. Approximately 70% of the fresh water used by humans goes to agriculture.

WATER CYCLE



The water cycle (known scientifically as the hydrologic cycle) refers to the continuous exchange of water within the hydrosphere, between the atmosphere, soil water, surface water (including the oceans, ice, rivers and lakes), groundwater, and plants.

Water moves perpetually through each of these regions in the water cycle consisting of the following transfer processes:

1. Evaporation from oceans and other water bodies into the air and transpiration from land plants and animals into air;
2. Precipitation, from water vapor condensing from the air and falling to earth or ocean;
3. Runoff from the land usually reaching the sea.

Most water vapor over the oceans returns to the oceans, but winds carry water vapor over land at the same rate as runoff into the sea, about 47 trillion tons per year. Over land, evaporation and transpiration contribute another 72 trillion tons per year. Precipitation, at a rate of 119 trillion ton per year over land, has several forms: most commonly rain, snow, and hail, with some contribution from fog and dew. Condensed water in the air (clouds) may refract sunlight to produce rainbows, as well as trap the sun's energy from escaping back into space, thus contributing to global warming.

Water runoff often collects over watersheds flowing into rivers. Some of the water is diverted to irrigation for agriculture. Rivers and seas offer opportunity for travel and commerce. Through erosion, runoff shapes the environment creating river valleys and deltas which provide rich soil and level ground for the establishment of population centers. A flood occurs when overflows its banks and flows into an adjacent area of land, usually low-lying. A drought is an extended period of months or years when a region notes a deficiency in its precipitation, resulting in a decrease availability in water supply.

What Is Surface Water?

Surface water is water in a river, lake or fresh-water wetland and glacial ice. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation, evapotranspiration and sub-surface seepage.

Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors. These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates. All of these factors also affect the proportions of water lost.

Human activities have a large and sometimes devastating impact on these factors. Humans often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Humans increase runoff quantities and velocities by paving areas and channelizing stream flow.

The total quantity of water available at any given time is an important consideration. Some human water users have an intermittent need for water. For example, many agricultural farms require large quantities of water in the dry seasons, and no water at all in the rainy seasons. To supply such a farm with water, a surface water system may require a large storage capacity to collect water throughout the year and release it in a short period of time.

Nevertheless, over the long term, the average rate of precipitation within a watershed is the upper bound for average consumption of natural surface water from that watershed.

Natural surface water can be augmented by importing surface water from another watershed through a canal or pipeline. It can also be artificially augmented from any of other sources, however in practice, the quantities are negligible. Humans also cause surface water to be "lost" (i.e. become unusable) through pollution.

What Is The Seasonal Yield Of Water In A Region?

Surface water availability fluctuates with season. The seasonality is influenced by the precipitation, temperatures and other climatic phenomena. Therefore, the surface water yield according to the season has to be taken into consideration while planning for its collection and preservation.

Proper planning should reflect routine and emergency response to surface water seasonality fluctuations.

Droughts, for example, are periodically reoccurring disasters that require an emergency response and therefore are important to be understood and planned for. Typically, emergency responses focus on the delivery of food aid and life-saving humanitarian support including rehabilitating boreholes, emergency vaccination campaigns and so on. Following a drought, there is a need to move into rehabilitation programs, and then back to 'normal' development activities in various sectors, such as health and education (Oxfam, "Disaster Risk Reduction in Drought Cycle Management: A Learning Companion," <http://community.eldis.org/?233@@.59cdc973/10!enclosure=.59cf3bc9&ad=1>).

How Can the Impacts of Droughts be Reduced?

A Draft Cycle Management (DCM) model conceptualizes drought as a cycle of four warning phases: normal, alert, emergency and recovery. There are clear advantages in viewing drought as a cyclical process rather than an isolated event preceded and followed by 'normal' development activity (Oxfam, "Disaster Risk Reduction in Drought Cycle Management: A Learning Companion," <http://community.eldis.org/?233@@.59cdc973/10!enclosure=.59cf3bc9&ad=1>). Some of the benefits of integrating the model into programming are as follows:

- The model improves the timeliness and the appropriateness and effectiveness of work, by ensuring that activities are matched to the current stage of the drought cycle.
- It provides a common framework against which humanitarian, development and advocacy work can be aligned to reinforce each other.
- It reduces the prominence of traditional relief activities and emphasizes the need for disaster mitigation and preparedness activities.

Drought Risk Reduction (DRR) is a valuable way of analyzing humanitarian development and advocacy programs, to improve their quality and effectiveness in targeting the most vulnerable people.

Risk is most effectively reduced when DRR principles are internalized into wider programming. DRR should be considered at each stage of the program cycle.

The essential outputs of this process should include an understanding of:

- The range and relative importance of hazards affecting the target population;
- The priority risks expressed by the community;
- The groups most likely to be severely affected;
- Why some groups are more affected than others (including a capacity analysis of all stakeholders, especially the community itself);
- Why some groups are less able to cope than others;
- The additional activities required to reduce risks and vulnerability and build communities' capacity to cope and respond;
- An action plan (for example, a community-based disaster management plan – CBDM).

A key aspect of integrating DCM into programs in arid and semi-arid land areas is learning the 'drought-proof' program work. This means that all program teams need to consider how all interventions will continue or be modified in the (very likely) event of a drought (Oxfam, "Disaster Risk Reduction in Drought Cycle Management: A Learning Companion,"

<http://community.eldis.org/?233@@.59cdc973/10!enclosure=.59cf3bc9&ad=1>). As a minimum this will entail ensuring that:

- Project proposals include options for a range of activities at different stages of the drought cycle;
- Budgets include contingency amounts for additional or expanded activities that may be required during the drought;
- Project staff have the skills and training required to implement both development and humanitarian activities as circumstances dictate; and
- Information from specialized external or internal early warning systems is incorporated into program decision-making, even where the program's focus is not working directly on response to hazards. For example, an education project will still need early warning information about drought or floods, in order to implement contingency plans accordingly.

Good information is central to DCM programming, both to identify the drought cycle stage and to review and assess the appropriateness of interventions (Oxfam, "Disaster Risk Reduction in Drought Cycle Management: A Learning Companion,"

<http://community.eldis.org/?233@@.59cdc973/10!enclosure=.59cf3bc9&ad=1>). The following recommendations will ensure the quality of information management systems:

- *Improve external context monitoring.* Moving from a project-based monitoring and evaluation system to a comprehensive information management system helps program staff to understand how the external context affects their programming activities. For example, this might include collecting data to show changes in community wealth status (wealth ranking), access to and usage of productive assets, infrastructure and resources (resource mapping), and changes in policies or laws.
- *Collect the right information.* Most programs already collect too much information. Programs must examine what decisions they need to influence and what information is required to do this, and then collect only the needed information.

The list below highlights potential components and intervals for gathering data.

- *Ensure information systems are driven by a few smart indicators.* A single strategy with shared goals and objectives is a key element of the 'One-Program Approach'. Progress in achieving these goals and objectives should be measured using a minimum number of agreed targets and indicators. The indicators should clearly relate to the program logic and should include reference to vulnerability and coping capacity. Having similar indicators which require different data or setting too many indicators makes it less likely that data will be gathered and that monitoring and evaluation will give the information needed to make decisions.
- *Increase the capacity to use, analyze and respond to information.* Often, it is not the quantity of information that is a problem, but the critical gap in the quality and use of this information.
- *Create a learning organization.* Recording and sharing information between staff within programs and between different areas or country programs is essential.

What is Conjunctive Use and Who Can this Practice Reduce Drought Impacts

In many parts of the world, droughts and wet periods come in nearly predictable cycles. "Nearly" means that we can guess to within a year or two when one or another part of the wet-dry cycle will reoccur. What is harder to guess is the magnitude and duration of the wet or dry period. For example, in California, significant droughts lasting two to four years can be expected every ten years or so. With this understanding, water engineers can plan appropriate technologies that allow water use during droughts and capture water for some sort of storage during the wet periods.

When the amount of water available during wet and dry cycles limits water supplies to a region, one can implement a **conjunctive use** program. This means that during droughts, when surface water availability is limited (water in lakes and reservoirs are depleted and rivers dry up), water is taken from ground water using wells. As rainy periods cycle back, water users switch to surface water for their supplies, as well as for replenishing depleted ground water storage. Normally, surface water in storage is available for one or two years before it is depleted without significant precipitation. Ground water in storage, on the other hand, can last several years before ground water levels drop to critical levels (below the pumping points in water wells).

Where precipitation events follow extreme wet-dry cycles, conjunctive use of water supplies should be considered. Even though this creates a more complex solution to solving a water supply problem, it has the advantage of being more sustainable and better for long-term economic growth and prosperity.

What Is Meant By The Total Sustainable Yield?

Before a region can grow and prosper, the amount of water available to it in the form of surface water and ground water must be determined. Only then can the limits of growth be determined. This ultimate amount of water that is available is called the **“Total Sustainable Yield.”** Generally, sustainable yield should be determined by a hydrologist; very often, the country in which the project is planned employs hydrologist who have the knowledge to assist in the water resources planning. The following is the definition of Surface Water Sustainable Yield:

- Total water resource less environmental water requirements
- Rivers with estimated environmental flow rules in place: current yield
- Humid zone: twenty per cent of divertible yield (median annual flow)
- Arid zone: five per cent of divertible yield, defined as the amount that takes into account the environmental flow requirement
- Difference between annual median flow and the estimated environmental flow
- Levels of average annual quantities of water (also equivalent to developed yield)
- Allocation of volume pending the outcome of detailed investigations of environmental water requirements
- Reported yields by considering likely development scenarios and the application of management objective factors (including environmental water provisions) for the users.

To ascertain surface water availability for human consumption and food production, proper water management should be implemented. Water management should include:

- Water resource planning
- Expansion of yield from existing surface water
- Safe yield analyses
- Protection of surface water supplies
- Surface water evaluation and extraction
- Water rights and resource acquisition
- Water quality management

Practiced methods of determining sustainable yields are:

- Simple estimate
- Simple analytical calculation
- Detailed numerical modeling

There is a strong, significant relationship between climatic variations and water yield in surface water bodies. Rainfall makes the highest contribution, and the positive contribution was found to be highly statistically significant. As discussed in the section above concerning conjunctive use, the implication of this finding for water yield is that good rainfall years will improve water yield while poor rainfall or drought years will diminish water yields. Since recent climatic trends tend to suggest a pattern

towards dryness, it is important that a number of strategies be developed towards solving the real and potential water shortage problems. Some of such strategies are listed below:

- At the household level, individuals can begin to adapt to limited water supply by increasing their efficiency of water use.
- At the farm level, water conserving irrigation methods, such as point-drop (drip), pitcher or water-can irrigations, should be adopted in preference to sprinkler irrigation, which consumes more water.
- Mulching should also be widely practiced as a way of reducing evapotranspiration from the soil.
- At the policy level, serious effort should be made by governments to transfer water from abundant basins (where there is surplus water budget) to poor basins region through inter-basin transfer using pipelines. The use of pipelines in the transfer is recommended because it reduces the risk of evaporation during transit, as opposed to canalization.
- Massive afforestation programs should be embarked upon so as to moderate the regional weather and climate, stabilize the ecosystem, improve the hydrological regime, improve water yields in reservoirs, halt the migration of sand dunes (wherever applicable), reduce the frequency of droughts and reverse the drying trend.
- Conjunctive use of surface water and ground water supplies.

On Monitoring and Evaluation (M&E) it is recommended to review the systems proposed by the Independent Evaluation Group (IEG) of the World Bank - "How to Build M&E Systems " by Keith Mackey.

What Are The Water Quality Considerations For Surface Water Supplies?

This section provides a brief overview on how water quality can impact surface water. The material presented in this section is from Wikipedia article on water quality (http://en.wikipedia.org/wiki/Water_quality). More details on water quality standards and impacts of various contaminants are provided in the section of this document titled "Water Quality."

Water quality is the physical, chemical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species, as well as human need or purpose. It is most frequently used by reference to a set of standards, compliance to which can be assessed. The most common standards used to assess water quality relate to health of ecosystems, safety of human contact and drinking water.

For human consumption, contaminants that may be in untreated water include microorganisms such as:

- Viruses and bacteria
- Inorganic contaminants such as salts and metals
- Organic chemical contaminants from industrial processes and petroleum use
- Pesticides and herbicides
- Radioactive contaminants.

Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution and overuse (which may lower the level of the water).

Primary standards regulate substances that potentially affect human health, and secondary standards prescribe aesthetic qualities (those that affect taste, odor, or appearance).

Regulations that establish limits for contaminants in water must provide protection for public health. Drinking water may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk.

Untreated water, drawn directly from a stream, lake, or aquifer, will be of uncertain quality. Surface waters are generally lower in mineral content. On the other hand, they possess far more contamination and can be unsafe for human consumption unless properly treated.

Pollution of water comes from many sources. Municipalities and industries sometimes discharge waste materials and sewage into bodies of water that are used as public sources of supply. This is a most serious source of contamination. Surface run-off also brings mud, leaves, and decayed vegetation, together with human and animal wastes, into streams and lakes. In turn, these organic wastes cause algae and bacteria to flourish.

In many countries and communities, mostly in developing regions, there is often no proper separation between the water sources and the sewage systems.

There is a belief that rivers and streams purify themselves in the course of their flowing 20 miles. This action should not be taken for granted; however, organic pollution of water is reduced by nature in many ways, such as:

- Bacteria and algae consume large quantities of organic waste. Larger microorganisms devour the bacteria and algae. In turn, those microorganisms provide food for fish and other higher forms of animal life.
- Unless the rate of flow is too fast, mud and suspended matter will naturally settle to the bottom and oxidation will reduce the impacts caused by organic matter. Rough bed streams, riffles and spill-ways speed up this process.
- Due to its ultraviolet rays, sunlight also has some germicidal effect on the water. Sunlight is not constant due to cloudy weather and its unavailability at night.

In general, lakes and reservoirs (especially large ones) show fairly constant dissolved solids content. Because they are relatively quieter than moving bodies of water, lakes and reservoirs are very efficient settling basins. As a result, they possess less turbidity than flowing water.

Large bodies of water are frequently subject to seasonal changes that cause the water to become quite turbid for a period of time. Heavy storms will also churn up a river, lake or reservoir and make its water turbid.

To provide the right water for any demand, whether that of the public health authority, or household, two all-important factors must be considered:

- What does analysis of the raw water supply indicate?
- To what end use will the water be put?

A potential water source for human use should be monitored for a certain period of time:

- *Primary Contaminants*
 - Fecal and Total Coliform - Weekly for 1 year
 - Turbidity, Color, Odor, Temperature, Suspended and Total Dissolved Solids – Monthly
- *Secondary Contaminants*
 - Total Organic Carbon – Seasonally
 - Nitrogen Series (nitrate, nitrite, ammonia) – Monthly
 - Algae - Monthly throughout the year at intake, major tributaries and at one or more locations in the water body.

Analysis of a water source may show that it contains:

- Dissolved minerals
- Dissolved gases
- Turbidity and sediment,
- Color and organic matter,
- Taste and odor, and/or
- Micro-organisms.

Whether or not any of these impurities are harmful in a given situation in turn depends on:

- The nature and the amount of the impurities
- The tolerance permissible for each of these impurities
- The end use of the water.

Surface water quality should be routinely monitored and reports should be prepared including

- Monthly monitoring reports
- Quarterly monitoring reports
- Annual Water Quality Reports
- Baseline Surface Water Quality Assessment
- Surface Water Management Plan

A local technician, or other suitable person, should be trained to carry out the routine tests and provide the relevant results/information to the decision makers. Appropriate procedures should be prepared and implemented.

How Does The Distance To The Supply Source Impact The Use Of Surface Water Supplies?

In developed countries, water is provided by the authorities at the points of demand by transmission and distribution systems. In many developing countries, mostly in rural areas, water may not be available close to the communities and has to be hauled over long distances using various types of containers, carried by the local people. Lack of proper conveying piping, pumping facilities, electricity supply, storage facilities and traditional habits – are all dominant factors in the deficiency of water supply chain.

The consequences of distant sources of water from points of consumption are:

- Inadequacies in water supply
- Much expenditure of time and energy in manual water hauling (especially by women and children)
- Low levels of water consumption resulting in water-washed diseases

In Africa alone, people spend 40 billion hours every year just walking for water. Women and children usually bear the burden of water collection, walking miles to the nearest source, which is unprotected and likely to make them sick (Charity:Water, <http://www.charitywater.org/whywater/>). Some impacts caused by this practice include:

- Time spent walking and resulting diseases keep children from school, and women from work and taking care of their families.
- Along their long walk, they are subjected to a greater risk of harassment and sexual assault.
- Hauling cans of water for long distances takes a toll on the spine and many women experience back pain early in life.
- Children hauling heavy loads over long distances are subject to direct injury.
- With safe water nearby, women are free to pursue new opportunities and improve their families' lives. Children can get education and build the future of their communities.

Assessment of the time spent in hauling water can be done in several ways and using different methods, but the simplest one is calculation of the daily amount needed by a household and the community, multiplied by the volume of water hauled in one trip, the time needed for a round trip and the resulting time invested in the process.

It is difficult to estimate the impact of hauling water on the carriers' health and this will have to be assigned a qualitative value. On the other hand, the freed-from-water hauling time, can be assigned an economic value by diverting such time to productive activities.

There are few ways to reduce manual, humanly done, hauling water over long distances:

- Basic boreholes close to the demanding community and assuming there is a sufficient aquifer nearby. Such borehole to rely on manual pumping or similar device and not on electricity which is usually not available and on more than basic devices which may need maintenance (see next section, “Ground Water”).
- Development of means of transportation – piping or open, concrete-lined canals – to bring the water to the point of demand. Such systems maximize use of gravity flow, taking advantage of the topographical conditions, and minimize use of external source of energy
- Development of storage capacity based on surface water, which, after proper treatment, can replace the water hauled from far away.

Such locally devised simple plans should be developed in cooperation with the local community leaders, people in charge to be appointed and trained and functionality over time being monitored, assessed and improved.

How Is Storage Capacity Determined For Surface Supplies?

Reliable access to water is the difference between food security and famine for millions of smallholder farmers. For millions of people dependent on rain-fed potable water and agriculture, reliable access to water can make all the difference between chronic diseases and hunger and steady progress toward a healthier life and food security (International Water Management Institute, *Flexible Water Storage Options*, http://www.iwmi.cgiar.org/Publications/Water_Policy_Briefs/PDF/WPB31.pdf).

The classic response thus far has been to store water in dams, tanks or ponds during times of abundance, so that it can be conserved for times of shortage.

Water storage spurs economic growth and helps alleviate poverty by making water available when and where it is needed. Today, many developing countries, even those with abundant water, have insufficient water storage capacity.

Inadequate storage leaves farmers vulnerable to the effects of climate change. This mainly affects those farmers heavily reliant on rain-fed subsistence agriculture. The lack of storage infrastructure means that farmers have limited ability to cope with droughts and floods.

Therefore, there is an urgent need for appropriate investments in water storage, to increase safe water availability and agricultural productivity and to ensure people have options for adjusting to the harsh effects of climate change.

During the rainy season, precipitation over limited catchment basins runs off and concentrates in natural ponds where the soils are sufficiently impervious to prevent leaking. Most of these ponds dry out a few weeks after the end of the rainy season, due to the combined effect of evaporation and seepage (Food and Agriculture Organization of the United Nations, Corporate Document Repository, <http://www.fao.org/docrep/R7488E/r7488e06.htm>).

However, sedimentation and location often make the rational use of surface water difficult and the improvement of the natural storage conditions desirable. Sanding up of ponds decreases their storage capacity until it becomes negligible, so that the actual number of usable ponds is smaller every year. This phenomenon is aggravated by overgrazing and resulting desertification, which makes the upper soil layers more sensitive to the wind and water erosion.

The main purposes of surface water development will be to increase the storage capacity of natural ponds to extend their period of utilization, and to create new surface water reservoirs in order to better the rangeland resources.

However, permanent water supplies will rarely be desirable because of the following factors:

- In arid and semi-arid regions, runoff coefficients vary in the opposite direction with the size of the basin; the bigger the catchment basin, the lower the runoff coefficient. Therefore, the quantities of water which can be collected by intercepting the runoff are usually small.

- Evaporation is high and may exceed 2 m/year, which corresponds to the maximum depth of most of the ponds even after deepening.
- Seepage also contributes to loss of water in the surface reservoirs, and the techniques of lining (with plastic or rubber sheets) are too costly and difficult to maintain in developing countries.
- Permanent surface reservoirs in a hot climate are often subject to health hazards, while parasitic diseases are much less common around non-perennial ponds.

An excavated reservoir is one of the simplest to construct and the only type of earth reservoir that can be constructed economically in relatively flat terrain. The fact that the capacity of these reservoirs is obtained by excavation limits their practical size, and they are best suited to locations where a comparatively small reservoir is sufficient, a small amount of runoff is expected, and impervious soils prevail.

Since they expose a minimum amount of surface area in proportion to their volume, they are advantageous in areas where evaporation losses are high and water is scarce. The ease with which they can be constructed, their compactness, their safety from flood-flow damage, their flexibility of location and their low maintenance requirements make their use popular in most of the semi-arid areas.

Improved natural ponds are also included in the same category of surface water storage system.

Excavated reservoirs are preferably located in the topographically low area of small closed drainage basins or in upland watersheds where the drainage divide is low and the topography is gentle. In some areas ancient sand dunes, now fixed by vegetation, form ideal closed areas.

In some regions excavated reservoirs reach the groundwater table and may become more or less permanent.

Large excavated and impounded reservoirs are, broadly speaking, "water harvesting" devices, but the term is generally used for smaller storages where the tributary runoff area is treated to increase runoff. The basic methods to choose a drainage area and a storage volume are the same.

A pond or reservoir, no matter how well planned and built, must be maintained in order to preserve its storage capacity, as well as proper functioning of the watering facilities, if any, throughout its expected life. When fenced, a pond needs a permanent maintenance in order to ensure the integrity of the fence during the whole period of presence of water in the reservoir.

In the case of non-fenced ponds, the main objective of maintenance is to remove the wind- or water-transported material, which accumulates and decreases the storage capacity of the pond. This operation is necessary every 4 to 5 years.

At the household level, it is recommended to store water in plastic, ceramic, or metal containers with the following characteristics, which serve as physical barriers to contamination (Centers for Disease Control and Prevention, *Safe Water Storage*, <http://www.cdc.gov/safewater/storage.html>):

- A small opening with a lid or cover that discourages users from placing potentially contaminated items such as hands, cups, or ladles into the stored water;
- A spigot or small opening to allow easy and safe access to the water without requiring the insertion of hands or objects into the container; and,
- A size appropriate for the household water treatment method, with permanently attached instructions for using the selected treatment method and for cleaning the container.

Evidence also suggests that safe storage containers (in the absence of household water treatment) are effective at preventing contamination of potable water during transport and storage.

Safe storage options fall into three general categories:

- Existing water storage containers in the home;
- Water storage containers used in the community and modified by an intervention program;
- Commercial safe storage containers purchased and distributed to users.

To determine the appropriate safe storage container, there is need first to identify containers currently used for water collection, transport, and storage in the community, as these existing containers might already be safe, or could easily be modified to be safe storage containers.

Care should be taken to avoid using any container previously used for transport of toxic materials (such as pesticides or petroleum products) as a drinking water storage container.

Lastly, locally-appropriate cleaning mechanisms – such as use of soap and brushes, or chlorine solution, or an abrasive – should be developed and recommended to clean the container on a regular basis.

Many water systems require some form of storage. Storage is necessary--

- When rainwater is collected for drinking water;
- For most distribution systems where the source's continuous supply is barely sufficient or is insufficient to meet the daily demand ;
- Where a single well serves a community through a distribution system. Storage ensures that an adequate quantity of water is always available to users and that water quality is protected.

Several factors should be considered in determining water storage needs:

- The source of water,
- The amount of water available for consumption
- The demand for water and the materials available and economic resources of the families in the community.
- Availability of ground water as a secondary source of supply when surface water supplies are limited (see discussion on conjunctive use, above, for more details).

Can Rainwater Be Collected For Drinking?

This is a brief overview on the use of rainwater for drinking water purposes largely taken from U.S. Agency for International Development, *Determining the Need for Water Storage Technical Note No. RWS.S.P.1* (<http://www.lifewater.org/resources/rws5/rws5p1.pdf>). A more detailed discussion is provided in the section titled, "Rainwater Harvesting."

Rainwater needs to be collected and stored, if people are to use it for drinking. In order to plan for adequate storage and design, the most appropriate type of storage facility data on the following items should be collected:

- Amount of monthly rainfall
- Potential rainfall supply available each month
- The amount of water likely to be consumed by the family.

With this information, the size of the cistern can be estimated.

Data on average monthly rainfall can be acquired from a national weather agency, the military, or an airport. Data for a specific location may not be available, but regional data can be used for an estimate.

The potential available water supply depends on the amount of rainfall and the catchment surface area.

Ideally, cisterns and storage jars should be large enough to store water for the entire year. Where economic conditions prevent this, special measures, like the use of storage jars, should be taken. Water should be collected during the rainy season and stored for use during the dry season. Special care should be taken to prevent water loss through evaporation. When planning a cistern or storage reservoir, attempt to build a cistern either of adequate volume or as close to the desired volume as economic resources permit. This is necessary when no other water source of suitable quantity, quality, accessibility or reliability is available.

How Is Water Storage Capacity Determined?

Storage of surface water is necessary to provide sufficient quantities of water to the users. In some cases, a storage reservoir is not needed. When hand dug wells are installed in villages and water is extracted by buckets or hand pumps, no storage other than what the well holds are necessary. Where reservoirs are formed by dams, water sometimes can move from the reservoir to the users with no further storage. Usually, some sort of storage is required in systems where water is piped to the users (U.S. Agency for International Development, *Determining the Need for Water Storage Technical Note No. RWS.S.P.1* (<http://www.lifewater.org/resources/rws5/rws5p1.pdf>)).

To ensure that adequate storage capacity for the regional population is provided, proper planning of the storage capacity is necessary. The following factors should be considered in determining required storage capacity:

- Population served by the system taking into account population growth.
- Total daily demand for water in the community. This is found by multiplying the population to be served by the daily per capita consumption. Special consideration has to be shown for peak demand periods.
- Hourly demand and peak hour demand.
- The length of operation of the pump each day.

Next, the amount of water per day consumed by the population should be calculated. A general good approximation would be to assume that the average per capita daily consumption is 110 liters (although in most developing regions, the per capita daily consumption is lower). The peak hourly demand generally occurs in the morning, with a second smaller peak later in the afternoon. The peak demand ranges between four and five times the hourly demand.

The time length that the pump is in operation should be determined. In some cases, the pump may work for a few hours in the morning and a few in the afternoon or it may be operated continuously for eight to ten hours. In many cases, due to lack of electricity or other energy source, pumps are manual and activated on demand.

The storage capacity required is the sum of the excess supply of water after the pumping stops late in the afternoon, and the maximum volume required during the morning.

In summary, most water systems should have storage so that people can depend on a sufficient quantity, a certain quality and improved access and reliability (U.S. Agency for International Development, *Determining the Need for Water Storage Technical Note No. RWS.S.P.1* (<http://www.lifewater.org/resources/rws5/rws5p1.pdf>)). When rainwater roof run-off is used, storage is always necessary. For surface (and ground water), either storage is provided for at the source, or storage reservoir must be constructed. Most water distribution systems rely on man-made storage reservoirs.

The most important factor in planning for the use of storage is determining the capacity of the reservoir. Capacity should be sufficient to adequately meet all water needs of the users throughout the year. The minimum goal should be to provide sufficient storage to at least meet basic drinking needs. Given scarce resources, these minimal needs may be all that can get met. When determining storage needs for family or small community use, follow the procedures outlined below.

How Do You Determine The Water Storage Needs For A Family Of A Small Community?

The capacity for water storage needed by a family in a small community can be estimated filling out the data in the following form.

1. Identify water supply source: _____

2. If rainfall roof catchment, determine:
 - a. Area of catchment _____
 - b. Number of people to be served _____
 - c. Materials available for cistern or storage tank construction _____
 - d. Economic resources of family/community _____
 - e. Calculate capacity of storage reservoir _____
 - f. Find out how many people use the source for water supply and whether storage is sufficient to meet demand _____
 - g. Evaluate whether the community has sufficient resources to install some sort of storage _____
 - h. Determine storage capacity required _____
 - i. Choose the appropriate storage method for the community given resources and available materials (for example, tank, above or below ground reservoir)

3. If a surface water source:
 - a. Identify the supply source _____
 - b. Determine the number of uses and calculate demand for water using 110 liters per capita per day _____
 - c. Determine whether sufficient storage is already provided; for example, a dam and reservoir may hold sufficient water to meet demand _____
 - d. Determine whether storage is necessary or how much storage is required

 - e. Choose the most appropriate design given available materials and resources, needs and topographical features _____

It is desirable to project a storage capacity to meet needs caused by future population increases and water demand increases. This may require a substantial commitment of money and materials. This may not be possible because funds are not available or the money may be needed for more immediate community needs. A careful review will help to make the best engineering and management decisions. In any event, storage sites and facilities can be designed and built so that future expansion can be made readily and with least cost.

What Are The Water Treatment Processes Available For Surface Water Supplies?

To provide potable safe water for human consumption and reduce the water-borne diseases, there is need to treat the water. Water treatment techniques used in the developing world are discussed in more detail in sections that follow, including, Biosand filters, membrane filters, ceramic filters, and disinfection.

Appropriate technology options in water treatment include both community-scale and household-scale point-of-use (POU) designs (Wikipedia, *Water Treatment in Developing Countries*, http://en.wikipedia.org/wiki/Water_treatment#In_developing_countries). Military surplus water treatment units like the ERDLator are still seen in developing countries. Newer military style - Reverse Osmosis Water Purification Units (ROWPU) are portable, self-contained water treatment plants, which are becoming more available for public use.

In order for the decrease of waterborne diseases to have long-term effects, water treatment programs implemented by research and development groups in developing countries must be sustainable by their population. This can ensure the efficiency of such programs after the departure of the implementation team, as monitoring is difficult because of the remoteness of many locations.

A combination selected from the following processes is used for municipal/regional drinking water treatment worldwide (Wikipedia, *Water Treatment, Processes for Drinking Water Treatment*, http://en.wikipedia.org/wiki/Water_treatment#Processes_for_drinking_water_treatment):

- Pre-chlorination - for algae control and arresting any biological growth
- Aeration - along with pre-chlorination for removal of dissolved iron and manganese
- Coagulation - for flocculation
- Coagulant aids, also known as polyelectrolytes - to improve coagulation and for thicker floc formation
- Sedimentation - for solids separation, that is, removal of suspended solids trapped in the floc
- Filtration - removing particles from water
- Desalination - Process of removing salt from the water
- Disinfection - for killing bacteria.
- Biological means

There is no unique solution (selection of processes) for any type of water. Also, it is difficult to standardize the solution in the form of processes for water from different sources.

Treatability studies for each source of water in different seasons need to be carried out, in order to arrive to most appropriate processes.

The above mentioned technologies are well developed, and generalized designs are available that are used by many water utilities (public or private). In addition to the generalized solutions, a number of private companies provide solutions by patenting their technologies.

How Are Surface Water Supplies Evaluated And Monitored?

The following is taken from “Ten Steps to a Results-Based Monitoring and Evaluation System,” by J. Kusek and R. Rist, published by the World Bank (<http://www.oecd.org/derec/worldbank/35281194.pdf>). Results-based monitoring and evaluation (M&E) is a powerful management tool that can be used to help policymakers and decision makers track progress and demonstrate the impact of a given project, program, or policy. Results-based M&E differs from traditional implementation-focused M&E in that it moves beyond an emphasis on inputs and outputs to a greater focus on outcomes and impacts.

Building a Results-Based M&E System is not easy. It requires continuous commitment, time, effort, and resources but it is doable. Once the system is built, the challenge is to sustain it.

There are many political, organizational, and technical challenges to overcome in building these systems.

Building and sustaining such systems is primarily a political process, and less so a technical one. There is no one correct way to build such systems, and many countries and organizations will be at different stages of development with respect to good public management practices in general, and M&E in particular. It is important to recognize that results-based M&E systems are continuous works in progress.

The general definition of M&E is:

- *Monitoring* is a continuous function that uses the systematic collection of data on specified indicators to provide management and the main stakeholders of an ongoing development intervention with indications of the extent of progress and achievement of objectives and progress in the use of allocated funds.

- *Evaluation* is the systematic and objective assessment of an ongoing or completed project, program, or policy, including its design, implementation, and results. The aim is to determine the relevance and fulfillment of objectives, development efficiency, effectiveness, impact, and sustainability. An evaluation should provide information that is credible and useful, enabling the incorporation of lessons learned into the decision making process of both recipients and donors.

Monitoring gives information on *where* a policy, program, or project is at any given time (and over time), relative to respective targets and outcomes. It is descriptive in intent.

Evaluation gives evidence of *why* targets and outcomes are or are not being achieved. It seeks to address issues of causality. Of particular emphasis here is the expansion of the traditional M&E function to focus explicitly on outcomes and impacts.

Evaluation is a complement to monitoring in that when a monitoring system sends signals that the efforts are going off track (for example, that the target population is not making use of the services, that costs are accelerating, that there is real resistance to adopting an innovation, and so forth), then good evaluative information can help clarify the realities and trends noted with the monitoring system.

The essential actions involved in building an M&E system are to formulate outcomes and goals:

- Select outcome indicators to monitor
- Gather baseline information on the current condition
- Set specific targets to reach and dates for reaching them
- Regularly collect data to assess whether the targets are being met
- Analyze and report the results.

It is necessary to set key performance indicators to monitor progress with respect to inputs, activities, outputs, outcomes, and impacts. Indicators can provide continuous feedback and a wealth of performance information. There are various guidelines for choosing indicators that can aid in the process. Ultimately, constructing good indicators will be an iterative process.

A typical model relates to establishing performance baseline - qualitative or quantitative - that can be used at the beginning of the monitoring period. The performance baselines establish a starting point from which to later monitor and evaluate results.

It is important to build on the previous M&E and involve the selection of results targets; that is, targets can be selected by examining baseline indicator levels and desired levels of improvement.

Next is the need to include both implementation and results monitoring. Monitoring for results entails collecting quality performance data, for which guidelines are given. Then it is essential to deal with the uses, types, and timing of evaluation.

All the above should be summarized in a report of findings, which looks at ways of analyzing and reporting data to help decision makers make the necessary improvements in projects, policies, and programs.

Using findings is also important in generating and sharing knowledge and learning within governments and organizations.

A last step should cover the challenges in sustaining results-based M&E systems including demand, clear roles and responsibilities, trustworthy and credible information, accountability, capacity, and appropriate incentives.

DEVELOPING SURFACE WATER PROJECTS

Introduction

A surface water source requires some sort of impoundment and/or intake structure from which water is then delivered by trench or pipeline to a treatment system prior to delivery to the community or region.

A groundwater source will require a perennial spring, dug well or borehole in the ground that will allow groundwater to be pumped to the surface. Developing these sources of supply carries varying degrees of technical expertise, risk and cost.

Surface water and groundwater source development can be complex and will likely require sophisticated technical input. Whichever source type is selected, clubs should have adequate technical/engineering expertise associated with their project team to select the appropriate source of water supply and to insure a successful and sustainable project.

Note that rainwater harvesting, though technically a surface water source, is not discussed in this report. Instead, it is discussed in another Wasrag task force report.

What Constitutes A Surface Water Project?

Surface water sources include lakes, rivers and streams/creeks. By their nature, surface water sources may not be as convenient as groundwater sources and may require a distribution system constructed between the source water diversion and the point(s) of use. Surface water supplies may also require treatment and disinfection. The range of treatments available for a small community supply is necessarily limited by technical and financial consideration.

The most appropriate and commonly used treatments are abstraction, sedimentation, pre-filtration, sand filtration, coagulation, flocculation and sedimentation. Preliminary storage in a reservoir helps to guarantee a continuous supply of water despite variation in demand and in source-water availability. Storage may also provide an economical means of settling out some of the suspended solids. The reservoir may consist of a large tank or dam.

The microbiological quality of drinking water can be substantially enhanced by protecting the source and by treating the raw water. However, where raw waters are not of a consistently high quality, some form of disinfection is essential to ensure that the supply is safe from undesirable microorganisms (WHO, *Guidelines for Drinking Water Quality, Technical Interventions*, http://www.who.int/water_sanitation_health/dwq/2edvol3f.pdf). Disinfection provides the most effective means of reducing the microorganisms in drinking water. Disinfection methods may be either physical or chemical. Physical methods include boiling and ultraviolet (UV) irradiation; chemical methods include the addition of ozone or, most commonly, chlorine and its derivatives. Only chlorine has been widely applied in treating community water supplies.

Surface water systems may be more susceptible to drought than groundwater systems and for this reason may not provide a sustainable supply. Surface water sources can be more complex to develop than groundwater sources both in terms of initial construction and long-term operations. For this reason, careful consideration should be given by the sponsoring Rotary club to assess the project's sustainability.

What Are The Initial Design Considerations?

The key design considerations for the surface water source include site conditions, quality of water, constructability of affordable impoundment and/or intake structures, proximity of the community from the water source, and availability of construction materials. Obviously, the type of impoundment

structure to be designed will depend on the surface water source which must have a reliable supply of water. Major factors to be considered for the design of impoundment structure are the depth of soil/rock strata suitable for supporting the foundation load, spillway requirements and presence of floating or suspended solid.

The second consideration deals with community, including population to be served, community leaders' and/or users' commitment to provide maintenance of the project. All data are generated with engineering considerations (e.g. reliability, performance, efficiency, and sustainability). The following discussion assumes that the design will be primarily developed with an off-site source (stream or impoundment) and delivered to a central treatment facility before conveyance to community watering points. The system designs discussed herein are primarily for rural areas in developing countries where basic levels of service are practically non-existent.

What Are The Design Options?

The initial step in designing a surface water supply is identifying the point of diversion. This may be a lake or stream/river. Care should be taken to determine if this source is available all year round, as well as its susceptibility to drought or upstream contamination, which may have an impact on the design and location of the diversion structure.

Surface Water Diversion

Diversion structures may be a pump intake, a diversion dam or a side-stream diversion. Pump intakes can either be inside a small structure supported on piles or laid in the bottom of the surface water source with an associated off-stream pumping system. Also, the pumping system may be placed on a pier or caisson constructed into the surface water body. Off-stream pumping systems are generally better for river/stream sources because the pumping unit is protected from periodic flooding. Pier-mounted pumps are generally better for lake or pond sources, though off-stream pumps can be used for these sources. Off-stream pumping systems will require a special inlet structure laid in the bottom of the water source; these are specialty materials that may need to be imported.

Diversion structures consist of dams or side-stream facilities. Dams are technically complex to design and construct and are generally expensive to build properly. Dams on rivers or streams will have to be built to withstand periodic flooding and may require sophisticated spillway structures. Dams should be considered by Rotary clubs as a project of last resort.

Weirs or side-stream diversions usually consist of a concrete structure that diverts water from the pond or stream into either a pump station or an off-stream impoundment. These structures should have trash racks or screens to keep debris from entering the off-stream systems.

Off-Stream Impoundments

Off-stream impoundments are used to equalize flow between the water source and the point(s) of use, as well as to provide seasonal storage when the surface source may be limited in the dry periods. They can also protect the system from periodic flooding along the main source. Off-stream impoundments generally consist of a surface pond or reservoir. For smaller supplies, the impoundment might be a tank. The size of the impoundment will depend on the reliability of the surface water supply source and the size of the population served. Evaluating the size of the impoundment should be done on a project by project basis by an experienced engineer.

Water can move from the impoundment into the distribution system by either pumping or gravity flow. Gravity flow systems are generally more sustainable. Both systems will require a diversion structure between the impoundment and the transmission system. This could be a simple pipe laid in the bottom of the impoundment with a valve. It could also be a concrete structure with gates. If the

water cannot be delivered by gravity, a pump must be designed at the impoundment to get the water into the distribution line.

How Is Surface Water Distributed?

A water distribution system is used to move water from the surface water source or off-stream impoundment to the treatment facility. Water can be moved by way of an open trench or ditch or through a pipeline. The size of the pipe or ditch will depend on the population served and should be designed by an experienced engineer. Ditch systems may be easier and cheaper to build, but may be susceptible to damage by vehicles, animals, debris, or erosion. And, unless the ditch is lined, which is an expensive undertaking, water will likely be lost to infiltration and seepage.

Pipelines are generally the distribution method of choice, especially if the water must be pumped to the treatment facility. Though they are more expensive initially because of the cost of the pipe, they are more secure from damage and have virtually no maintenance once they are installed—PVC pipe is generally available around the world and is resistant to degradation over time.

What Are Typical Water Treatment Systems For Surface Water?

Water treatment systems can either be point-of-use or centralized, depending on the source of supply and the population served. Sustainable point-of-use systems usually consist of a biosand filter. However, biosand filters are limited in the degree of treatment that needs to be done to make the water potable. Point-of-use treatment systems are discussed in more detail in another WASRAG task force report.

Centralized treatment systems vary in complexity depending on the population served and the specific treatment that needs to be done. The type of treatment must be determined and designed by a qualified professional. Project sustainability may be at risk as the complexity and size of the treatment system increases.

Water is treated for various reasons. First, and probably foremost, water is treated to remove bacteria and viruses that do harm to humans. This type of treatment is called disinfection and can be done in a number of ways. The most reliable and readily available disinfectant is chlorine (such as commercially available bleach). Chlorine not only kills most bacteria and viruses on contact, but continues to kill organisms between the treatment plant and point of use (this is called residual disinfection). Other disinfectants are less reliable for both immediate and residual disinfection.

Surface water will also contain suspended sediment. Removing sediment can be done by sand or membrane filters. Sand filtration is less complex and thus more sustainable. For this reason, they are not recommended as Rotary projects. Sand filters are usually constructed as a concrete box structure with backflow capability to allow periodic cleaning of the sand. These structures must be designed by a qualified engineer and training must be done to insure long-term reliability of the system. Also, water that carries too much suspended sediment will reduce the chlorine disinfection residual, which in turn, could allow bacterial re-growth in the pipeline that carries the water to the point(s) of use.

Other contaminants may be in the water, such as nitrates (generally from human and animal waste), minerals (salts and metals), and toxic chemicals (e.g., pesticides). Removing these contaminants may require very sophisticated treatment systems that are both costly to construct and costly and difficult to operate and maintain. These systems must be designed by a qualified professional and the long-term operations must be monitored closely throughout the life of the project.

A more detailed discussion on point-of-use water treatment systems is provided in later sections.

How Much Do Surface Water Development Projects Cost?

The cost of developing surface water as a reliable, high-quality drinking water supply will vary considerably depending on the population served, the reliability of the water source, and the treatment required to make the water potable. For a village-sized system without complex treatment needs, the cost will likely be in the tens of thousands of dollars range. For a larger system and more complex treatment, the cost could be in the millions of dollars. The only way to know for sure is to utilize an experienced professional in the initial planning stage of the project.

Checklist for Using Surface Water Sources

Much more care must usually be taken when using surface water as a source of drinking water supply. It is usually turbid, which makes treatment more difficult. It also is more susceptible to climatic variations than ground water and may even disappear in the dry months. If a reliable surface water supply is available, then the following questions should be answered before finalizing plans for its use.

1. What is the yield of the surface water supply?
 - a. Monthly yield? _____
 - b. Annual yield? _____
2. Does the source have sufficient yield in the dry season to provide adequate water supply for the community or will storage need to be constructed or a secondary water supply (example, ground water or rainwater harvesting) be needed? _____

3. Will a conjunctive use program need to be implemented? _____
4. How much surface water storage will be needed? _____
5. What form will the surface water storage take (example, tanks or ponds)? _____
6. How far is the source of supply from the point of use? _____
7. Will a water conveyance systems be needed and if so, what form (pipeline, ditch)? _____

8. Are recent water quality analyses available for the source water? _____
9. What contaminants are in the water that will be of concern as a drinking water source?

10. What treatment systems are available to remove the contaminants of concern?

11. What is the population to be served? _____
12. How much water does the community need:
 - a. Daily demand? _____
 - b. Monthly demand? _____
 - c. Annual demand? _____
13. How much will each component of the surface water supply cost?
 - a. Water diversion structure? _____
 - b. Raw water conveyance system? _____
 - c. Raw water storage system? _____
 - d. Water treatment system? _____
 - e. Treated water storage? _____
 - f. Treated water distribution system? _____
14. How will your club monitor and evaluate the adequacy of the source of supply over the long term? _____

GROUND WATER

This section discusses ground water as a source of drinking water. In the following section, the development and construction of surface water and ground water projects will be discussed in more detail.

Why Is Ground Water Selected As The Source Of Water Supply?

Water pumped from the ground has some distinctive advantages, but some disadvantages over using surface water supplies. The advantages of using ground water are:

1. The ground water has been filtered by the porous media that it has passed through and therefore is more likely to have less physical and biological pollutants than surface water.
2. Ground water is plentiful in many areas of the world and it usually has a relatively cool temperature.

The disadvantages of ground water are:

1. Unconfined aquifers are easily polluted from contaminants that infiltrate and percolate down from the ground surface.
2. Dissolved chemical pollutants such as arsenic, as present in the ground water of Bangladesh, and fluoride, as present in the ground water from the Great Rift Valley, Kenya, can be present in ground water and are difficult to detect and to extract.
3. If the ground water source is extracted from an aquifer that has underlying saline or salt water, the pumping of the fresh water will cause a dramatic upward movement of the saline water that will pollute the fresh water source.
4. Ground water from any depth over 30 feet will require a submersible centrifugal pump that is run by electricity. This is an expensive option and many remote villages in developing countries are not supplied with electricity.

How Is Ground Water Found?

Ground water is found in unconfined and confined aquifers. Unconfined aquifers will likely be the source of ground water, which can be found in alluvial material, i.e., sand and gravels that have been washed down from the surrounding mountain or hillsides. Generally, ground water exists beneath our feet in all locations. However, determining if there is sufficient quantity and adequate quality is the overriding question. In the end, no matter how well one might guess in the absence of nearby water wells, one must drill a well and test it for quantity (pump test) and quality (using a laboratory). Having access to a hydrogeologist is a good way to take much of the guess work out of finding adequate ground water for the intended purpose.

How Is A Water Well Drilled?

Drilling a well can be done using an expensive electrical drilling rig or by a hand drilling rig. The depth of the well depends on the depth to the water table. Generally, the depth to the water table can be estimated by a hydrologist or hydrogeologist based on the surrounding topography, vegetation types and nearby water wells. Once you determine that ground water might be present, a well must be dug or drilled. People have been digging water wells for millennia. Drilling a water well is faster and usually results in a more sanitary completion. Drill rigs range from simple, hand-operated units to sophisticated units that require heavy equipment and several people to operate. Selecting the kind of drill rig to use

will depend on the depth to groundwater and underlying aquifers, the expected capacity of the well, how much money is available for the effort, and the availability of equipment in the region of the project.



Small capacity, shallow water wells can be constructed using manual drilling equipment, such as the electric drill on the left and a hand auger on the right.



More sophisticated drill rigs can be used for deeper, higher capacity water wells. The machine on the left is a rotary drill rig in common use around the world. The cable tool rig on the right is one of the oldest drill rig designs, dating back several thousand years. Cable tool rig drilling is generally much slower than rotary drilling.

Reference to drilling:

http://www.watersanitationhygiene.org/References/EH_KEY_REFERENCES/WATER/Drilling/Hand%20Drilled%20Boreholes/Design%20of%20a%20Low-Cost%20Drilling%20Rig%20%28Cranfield%20-%20Burrows%20G%29.pdf

How is the Quantity of Water Available in the Aquifer Determined?

It is difficult to determine and requires what is known as a pumping test. However, if the amount of water that is being withdrawn is only for household use and not for agricultural irrigation, the well should supply water into the foreseeable future. Generally, sandy soils that are deep (no near surface hard bedrock) will provide substantial storage for groundwater. In these conditions, if rainfall is seen to soak underground, ground water should be plentiful. If, on the other hand, the underlying geologic material is hard rock, then only limited groundwater will be available.

How is the Quality of Ground Water Determined?

It is important to know the quality of the water that is produced from the well. The water could be contaminated by physical, biological and chemical pollutants. The first effluent from the well should be sent to a certified water quality laboratory for analysis in order to determine the level of various pollutants that may be present in the water.

However, in general, sandy soils provide treatment for surface water percolating underground. Provided the well is located at least 100 meters away from latrines, drainage ditches that carry dirty water, or animal pens, and the water table is at least 10 meters underground, the well water should be of good quality. Specific physical contaminants that should be looked for include nitrates, fluoride, arsenic and salts (such as found in wells near the ocean).

How are Water Well Sources Secured?

There are five steps in the safe delivery of drinking water:

- Protection of the water source. The well should be encapsulated with a concrete cap that will keep ground surface pollutants from entering the well;
- Reducing the amount of sediment in the water if required;
- Filtration of the water if required (generally, if ground water is turbid, then something is wrong with the construction of the well or the well has not been sufficiently developed after it was drilled);
- Disinfection of the water if required; and
- Storing the water in a safe place so it does not become contaminated.

In the following sections, more detail is provided on how to construct surface water and ground water systems.

How is Ground Water brought to the Surface?

Many innovative methods have been developed to bring ground water to the surface. Unless the well is artesian and water is flowing out of the well at the ground surface, some sort of mechanism is needed to bring the water to the ground surface. For hand-dug wells, which are generally one to two meters in diameter, are often have a bucket attached to a rope and pulley system. Drilled wells are completed with a pump that is either operated by hand or electricity. Electric pumps have the advantage of pumping from a deep water table. Hand pumps are generally restricted to less than 30 to the water table in depth (but there are exceptions).

Rope, pulley and bucket systems are common around the world. They are cheap to build and maintain and simple in design. Their primary disadvantages are that water is brought up slowly and the

well can become polluted by contaminants that enter the well or by dirty buckets. This method is the least sanitary of the ground water extraction methods.



Hand-dug wells equipped with rope and bucket retrieval systems. Note how easily debris or wastewater/runoff can enter the well on the left. Placing a cover over the well when it is not in use would help.



A concrete base and elevated well head helps keep debris and contaminants out of the well. Hand pumps deliver water much faster than the rope and bucket method.

A better way to complete a hand-dug well is to place a concrete apron (2- to 3-meter diameter) around the base with an elevated base and then install either a hand pump or electric submersible pump in the well, such as in the photos below.

Hand pumps come in many designs, but most are of the positive displacement type (they lift water rather than suck it up the well). For a good overview of types, please visit Akvo.org at http://akvo.org/wiki/index.php/Community_pumps_-_general. The important thing to remember when selecting a hand pump is to evaluate the availability of spare parts and training of people to maintain them.

Electric pumps come in two varieties: submersible and line-shaft turbine. If a reliable and reasonably priced source of power is available at the well site then these might be considered. Power could come from a distant power plant, small generator, wind or solar. However, because these are complex machines, you must first consider if the community can afford their upkeep and training to use them. These pumps are not generally manufactured in the country you will be working, so spare parts might be an issue to consider. Only if there is a large population to serve and money and trained personnel are available should you consider this pump type. Please see Akvo.org's website for more on powered pumps: http://akvo.org/wiki/index.php/Powered_pumps_-_general.



A line-shaft turbine pump is on the left. A submersible pump (right) is installed down the well from where it pumps water up a pipe to the ground surface.

DEVELOPING GROUND WATER PROJECTS

Introduction

Three typical options, spring supply, a dug well or a borehole, are generally used to develop a groundwater source. During the planning process (ref. Section 2), the sponsoring Rotary club and/or its partners will gather the necessary design data pertinent to assessment of community and site conditions, including people to be served, hydrologic information, quantity of water required and selection of groundwater source, etc.

The design feasibility phase will involve visitation by the sponsoring Rotary club and/or its partners, accompanied by community leaders. They will observe the site conditions and gather additional data that are required to finalize the design of the planned project. In addition, they should discuss at a community meeting the nature of the project including water source, required labor and material, community involvement and commitment, security and maintenance requirements. The community should be in agreement regarding the shared cost and the on-going maintenance of the selected project.

The design phase will include finalizing the local and Rotary funding and the village approved design of the project. All data are generated with engineering considerations (e.g. reliability, performance, efficiency, and sustainability). The following discussion assumes that the design will be primarily developed as a central facility and/or community watering points/self-haul category. The conceptual system designs discussed are primarily for rural areas in developing countries where basic level of service is practically non-existent.

What Are The Design Considerations For A Ground Water Project?

The key design considerations for an enclosed spring, dug well or borehole may be divided into four categories. These considerations include site conditions, community commitment and participation, water quality, and construction resources.

The first consideration involves site conditions, including the presence of reliable supply of quality water and accessibility to the water source by the community. Access to water may be restricted in several ways, such as, seasonal fluctuations in availability or lack of supplies to remote areas.

Availability of such supply will ultimately depend on:

- Interactions between the climate and the geology of the region;
- The climate (rain, wind, sunlight and temperature): by determining whether an area is humid, that is where an average rainfall exceeds evaporation loss, or arid where evaporation exceeds rainfall;
- The geology (soil and rock conditions): by deciding whether water supply from the source will be adequate for the design life of the project.

In addition, natural factors governing quality of water obtainable at any spot include the direction of ground-water flow, the general geological arrangement of soil and rock strata (e.g., thickness, porosity and fissures), the amount of rainfall, and the elevation differences (and direction of flow) between the water source and the point of use.

The second consideration deals with the community, including population to be served, commitment and participation of the village leaders/or users to help pay for a portion of the construction so that “they own the project” and participate in the selection of the site and the maintenance of the project for its design life. Community involvement and commitment are the major considerations for the sustainability of the proposed project. Also, the selection of the group to undertake the design and the construction plans must be socially acceptable to the communities to be

served. Site conditions and community involvements influence the social and political appropriateness, technical feasibility and practicality, and the ultimate design.

The third consideration involves testing of water samples recovered from the source to confirm that water is of acceptable quality for human use (ref. Section 5). Of particular importance is the proximity of the water source to possible sources of contamination, including feed lots and corrals, human waste disposal areas, and chemical storage areas.

The last consideration is the availability of local construction materials, skilled labor and regional and/or national design guidelines. In addition, presence and experience of NGOs and any other organization related to the design options will greatly help assure a cost-effective sustainable project.

What Are The Design Options For A Ground Water Project?

The three conceptual design options that are described in this section include spring development, hand-dug wells and boreholes. The selection of development method depends on the availability of groundwater, cost of construction, etc. Determining the source of supply (e.g., groundwater), designing the extraction method (self-haul or central facility, or well with or without pumps), and designing the transport method (self-haul or pipeline) must be finalized during the initial design feasibility phase.

Spring Encasement Design

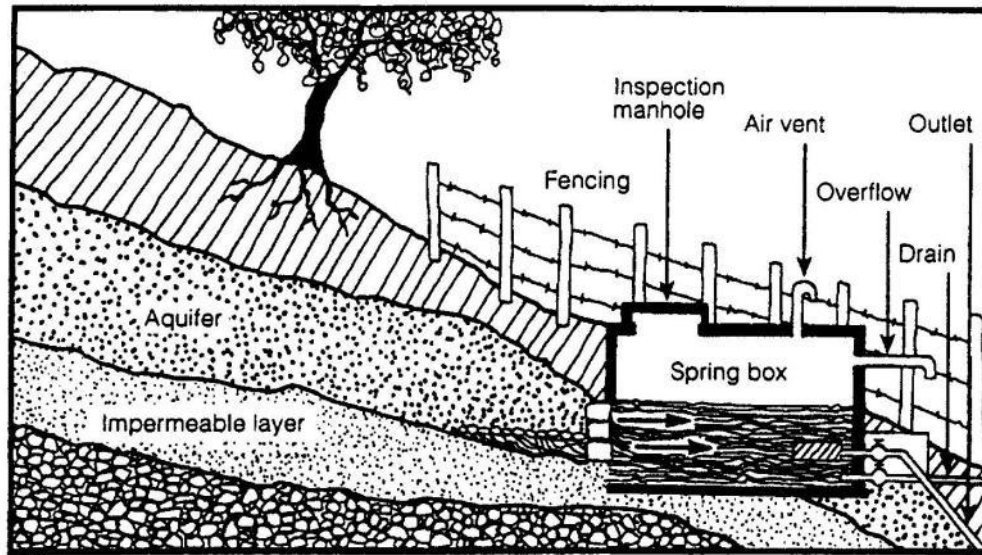
A spring typically flows out of the side of a hill above an impermeable consolidated soil or hard rock layer or where a stream crosses nearby. Water flow from the spring varies depending on the configuration of the aquifer and the size of the catchment area. In some areas, the spring flows year round and other areas, they stop flowing in the dry season. If a spring is to be used as a source of groundwater supply, it should be protected to preserve its quality and have adequate capacity to provide the required quantity and quality of water for its intended use throughout the year.

A spring encasement design consists of the following features (see Figure: Typical Spring Design):

- Spring box (watertight tank) which intercepts the source and extends downwards to an impermeable layer or a system of collection of pipes and a storage tank;
- A cover that prevents the entrance of surface drainage or debris into the storage tank;
- A protected overflow outlet;
- An impermeable layer (e.g. of concrete or brick wall or puddle clay) behind the box and above the eye of the spring to prevent the infiltration of contaminants;
- A connection to the distribution system or auxiliary supply;
- A drain pipe at the bottom of storage tank for cleaning the tank;
- An air vent to be fitted with mesh screen to keep animals and debris out of the spring box;
- A ditch around the storage tank to divert surface water;
- A fence around the tank to prevent the entry of livestock.

Exposed springs are vulnerable to contamination from human and animal activities. The usual method of protecting a spring is to collect water where it rises at the ground surface by enclosing the eye of the spring in a covered chamber or a box with an outlet near the bottom to allow water to flow away from the original site of the spring. In this way the natural spring is disturbed as little as possible. The exact collection system will depend on the type of spring (gravity or artesian) and the site of the spring. The hillside must be excavated to a sufficient depth to trap runoff and carry it away from the source. The location of the ditch and the points at which the water should be discharged are matters of judgment based on factors such as topography, subsurface geology, land ownership and land use. A typical simple spring water catchment design is presented in Figure: Typical Artesian Spring Design.

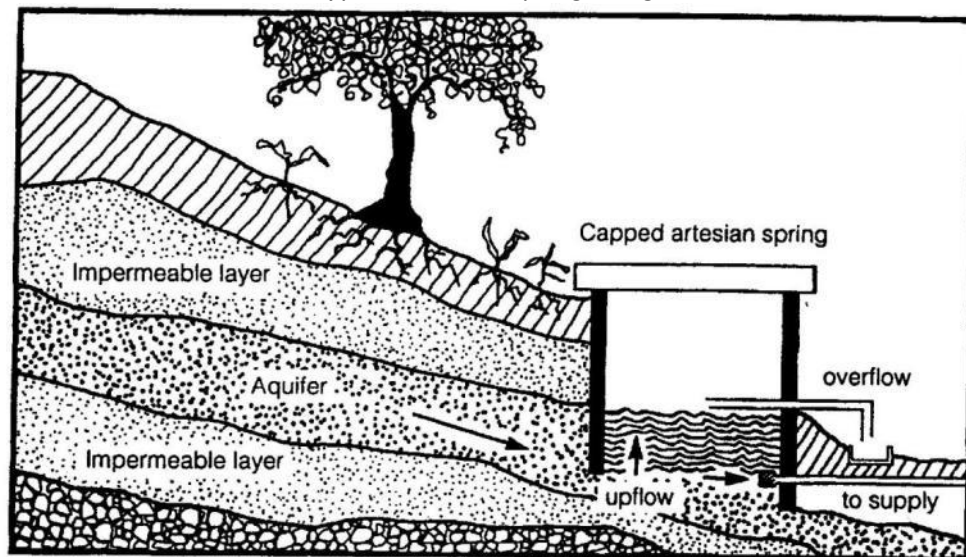
Typical Gravity Spring Design



Water from a protected spring may be supplied to small communities either directly or via a distribution system to a central location. A determination will have to be made, preferably during design, whether disinfection will be required. Where the spring-fed water supplies do require disinfection because of inadequate quality or as mandated by regulations, chlorine (the most effective readily available disinfectant) is added either as the water enters the pipe between the spring box and storage tank or as it leaves a storage tank to enter the distribution system.

Artesian springs should be protected by a box with walls extended above the maximum static head. When the recharge area and the aquifer are large and only a small number of wells penetrate the aquifer, the flowing artesian well produces fairly steady flow throughout the year.

Typical Artesian Spring Design



Dug Well Design

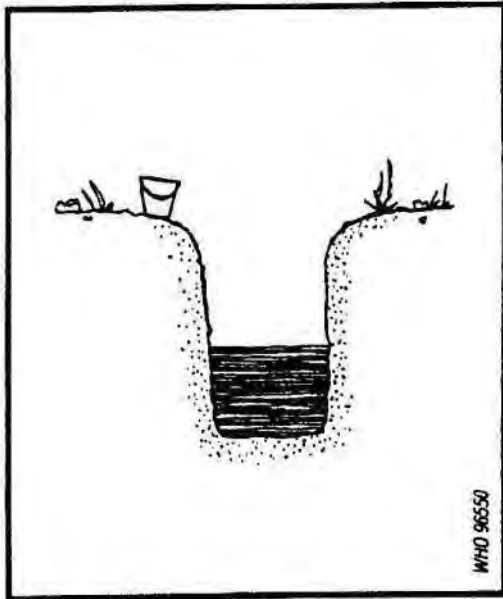
Many tens of millions of families in developing countries depend on private and public dug wells. Hand-dug wells have the advantage of being inexpensive to construct and they do not require complex equipment or skill to extract water. However, hand-dug wells have disadvantages. The hand-dug well can often become polluted by surface water contamination and/or by objects falling into them. In addition, hand-dug wells often go dry when the groundwater table drops in the dry season.

The most serious source of pollution is contamination by human and animal waste from nearby latrines and livestock pens, which results in increased levels of harmful microorganisms and nitrates. So, hand-dug wells should be constructed away from the latrines and sources of animal wastes. They should be constructed using bricks or concrete liners. The liner should extend above the ground surface in order to keep surface water from flowing into the hand-dug well. Bricks may be made locally or purchased. Also, concrete slips can be produced locally to use as liners.

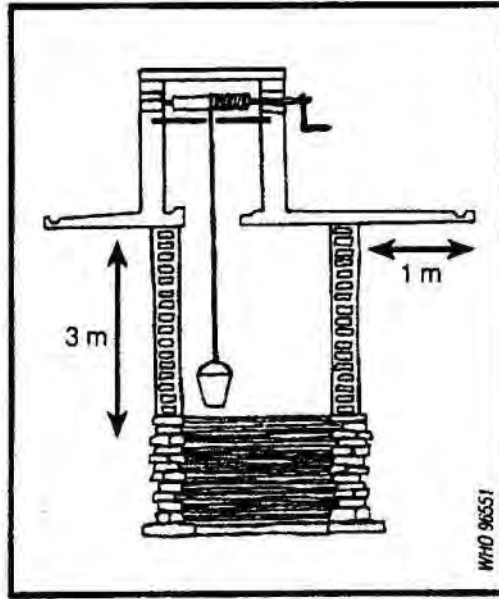
Digging hand-dug wells is labor intensive. Usually, hand-dug wells are excavated in the dry season so that they can be dug deep enough to provide water throughout the year. The critical site condition consideration to place a hand-dug well is the depth of groundwater table. If it is deep (greater than five meters), the hand-dug well can be fitted with a hand-pump, a concrete pad cover (two meters in diameter) on the ground surface around the well, as well as a concrete, steel or wooden lid on the top of the well. Sealing the hand-dug well protects it from contamination and eases the drudgery of pulling up buckets of water from the well. Various types of hand dug wells are presented in Figure: Typical Dug Wells.

Finishing the well pad and/or installing the hand-pump are good volunteer projects. For the purpose of this Task Force Report, hand-dug wells fitted with pumps and concrete aprons are called "Improved Traditional Wells." A typical hand-dug well with a hand pump installation is shown in Figure: Typical Dug Wells. Hand-pumps may be used where the depth of the groundwater table does not exceed 60 meters. Another option is to install shallow or deep tube wells with hand-pumps and proper protection. To ensure that the sanitary protection of a tube well is adequate, a reinforced concrete plinth should be built on the well head. Its diameter should be greater than that of the riser. The plinth should be sound and the hand-pump should be located and sealed in a sanitary manner above the surrounding plinth and ground level. A concrete cover (at least two meters in diameter) should be laid around and plinth and well head. Additional sanitary protection may be provided by fencing the well site to keep animals and unauthorized people out. Figure: Typical Tube Well with Hand Pump shows a typical tube well with a hand pump.

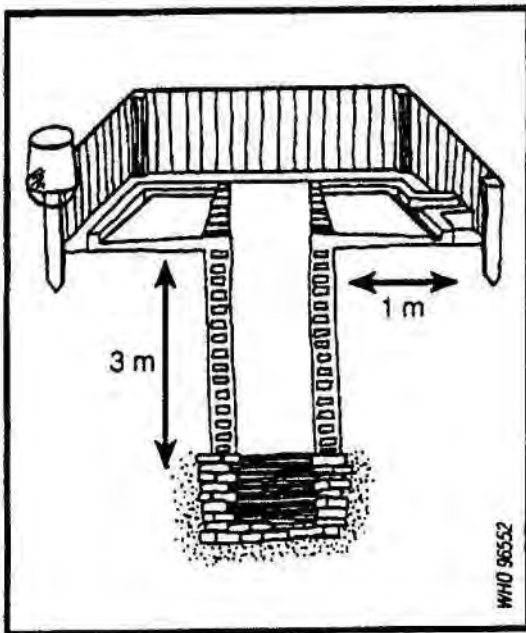
Typical Dug Wells



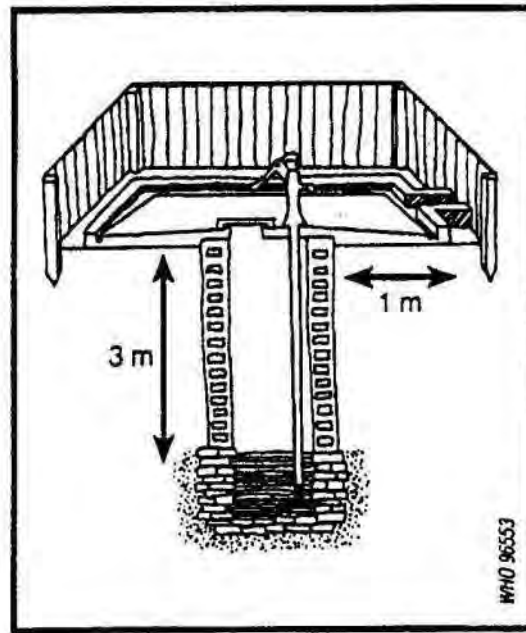
a) Unprotected Dug Well



b) Dug Well with Windlass

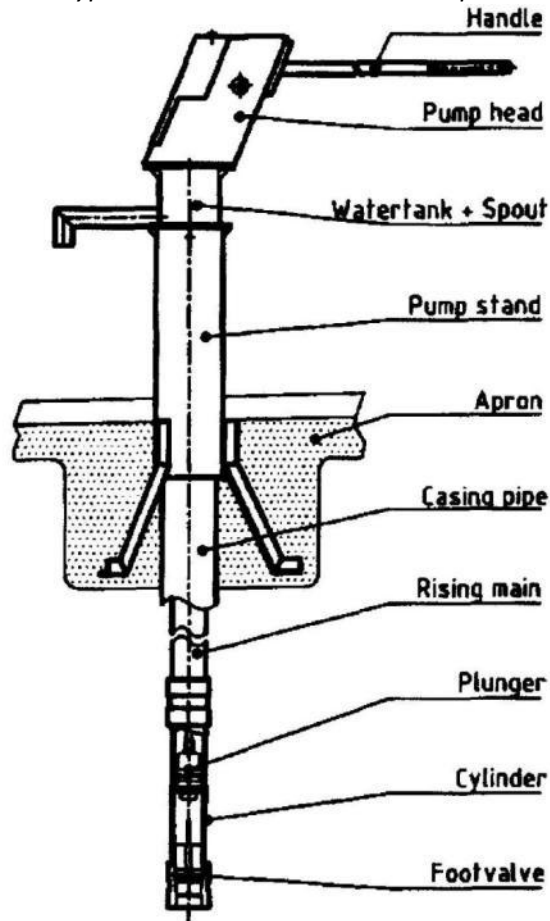


c) Protected Dug Well



d) Dug Well with Hand Pump

Typical Tube Well with Hand Pump



Drilled Borehole Design

Boreholes can be simple or complex depending on the local geology and water availability. A producing well is most successfully located through detailed examination of hydrogeologic conditions, including:

- Type, permeability, and position of soil and rock strata
- Characteristics of cracks, fissures and other large openings, and
- A study of performance records of other wells located in the area.

A professional hydrogeologist familiar with the region should be consulted during the preliminary stages when groundwater is being considered as a water supply source.

In all cases, wells must be located a safe distance from a potential source of pollution. In absence of any guidelines, wells should be at least 100 meters from the nearest source of pollution. Another important consideration is the direction of groundwater movement.

Drilling techniques are categorized as jetting, rotary drilling, percussion drilling, auguring and vibration. The choice of particular construction method for boreholes will depend on the location, scope and objective of the project, anticipated soil and rock conditions, size of well required, accessibility and transportability of equipment, and capabilities of local contractors.

Shallow Boreholes: A shallow borehole near a stream or river can be very effective in producing needed water supply to the community. Sandy soils between the stream and the borehole often filter

contaminants out of the water (though this should be verified during design). Also, groundwater is usually found at shallow depth (less than 60 meters), which allows boreholes fitted with hand-pumps to be used. Such shallow boreholes fitted with hand-pumps should also be properly protected from the surface water contamination.

Jetting is commonly used to construct smaller shallow wells in alluvial soils (sand, silt and clay) and has the advantage of relatively low cost. Also, the jetted machinery is easier to move into remote areas. However, this method of drilling is ineffective in consolidated soil and rock conditions, which will require rotary drilling techniques. Jetting is normally done with pipe in the size range 50-100 mm with a corresponding borehole diameter between 100-200 mm. A hand-pump or electric pump of about 2 to 8 H.P (1.5-6 KW), is generally adequate to extract water from a shallow borehole. Some Rotary clubs enjoy the adventure of drilling shallow wells using the jetting method. Many clubs find it easier and more convenient to partner with a regional NGO for drilling boreholes.

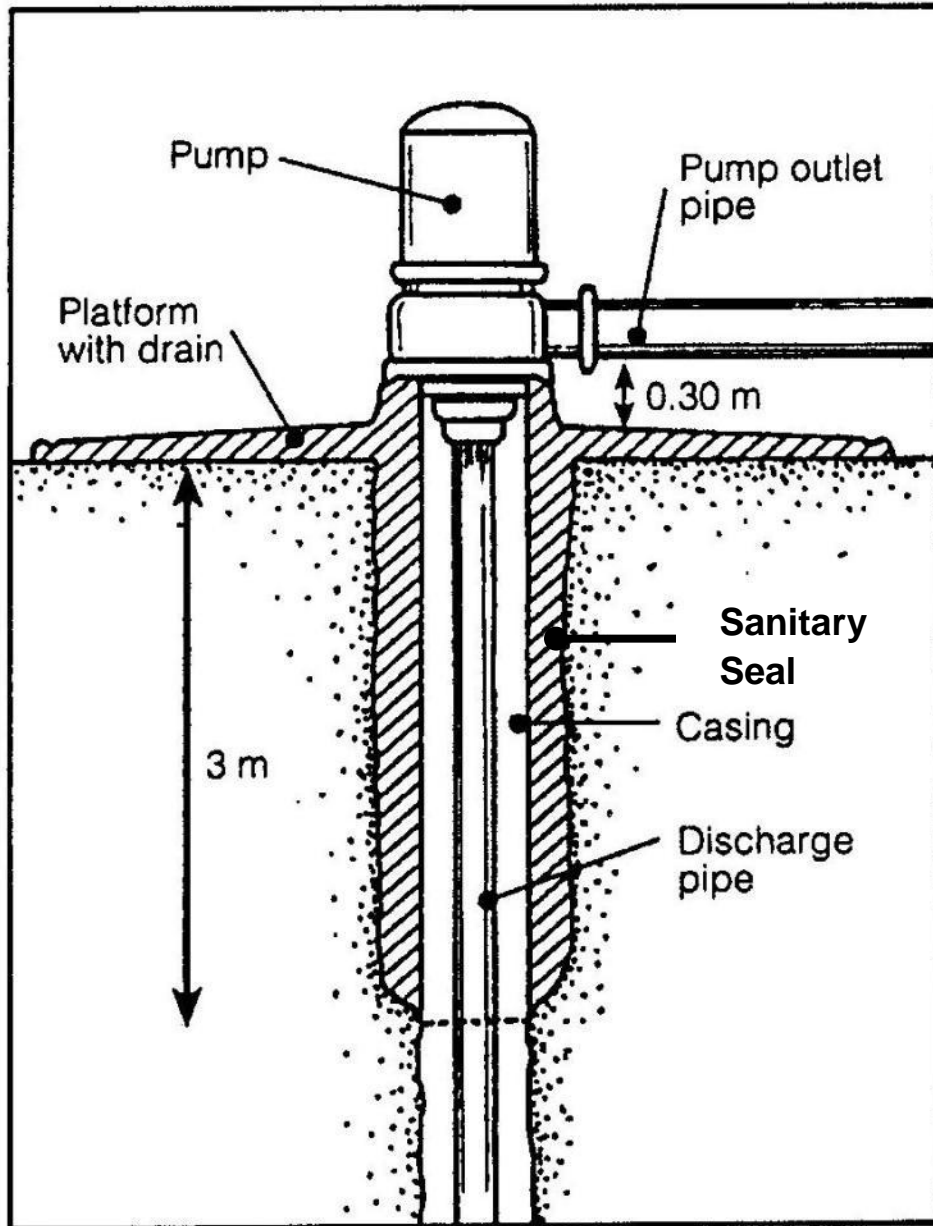
Deep Boreholes: Drilling a deep borehole is required to reach deep aquifers. Deep aquifers are less likely to contain pollutants originating from the land use or surface water in the area around the well head. This type of drilling is expensive and the driller needs to be experienced to be effective in the drilling operation. In addition, a pump and motor, pump house and a storage water tank are usually needed with a deep well. Pumps may be driven by solar-powered motors, windmills, or diesel- and gasoline-powered motors.

The diesel- or gasoline-power pumps require intensive maintenance in comparison to other pumping methods. However, diesel or gasoline engines may be readily available. They are commonly used when the electricity is not available in the region. The cost of diesel or gasoline engines varies depending on the size of distribution network and the type of reservoir (ground level or elevated).

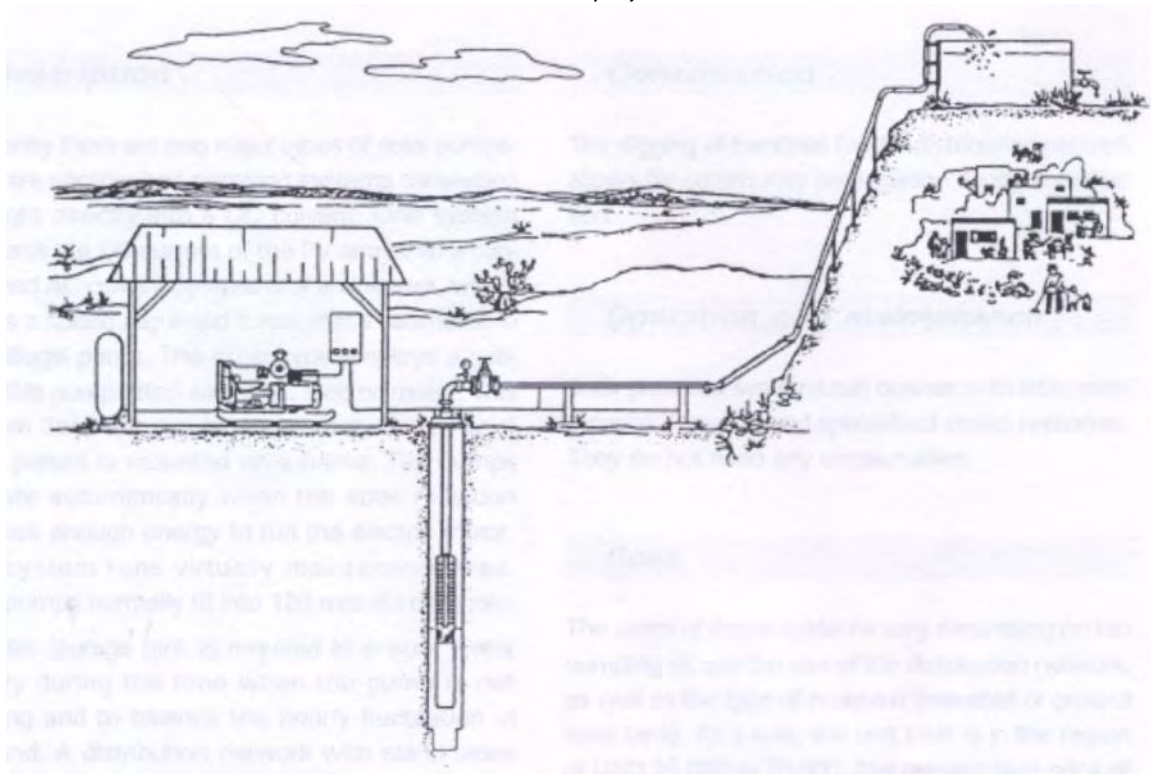
Water from deep boreholes is normally free from microbiological contamination and may be used by smaller communities without further treatment. However, this should be verified after the well is constructed. Certain structural precautions are essential when wells and the associated pumps are installed. The pump casing should extend from 30 cm above ground to below the expected pumping water level in the well. A concrete apron and platform should be constructed as required for shallow wells. A concrete sanitary seal should be installed in the space between the borehole wall and the well casing to help prevent contamination from entering the well (see Figure 3.5). Most sponsoring Rotary clubs hire professional contractors or NGOs experienced with the local site to construct deep boreholes with pumps and associated equipment.

Deep boreholes can provide the community with a lifetime of safe, clean drinking water. Maintenance will be required for the pump and motor assemblies. For sustainability of deep boreholes project, the sponsoring Rotary club and/or its partners should develop ways to train local people to maintain the wells and their associated equipment. They should also make sure that funds are availability from the community or local/ regional authorities to maintain the systems. Typical deep boreholes with various types of pumps are illustrated in the following figures (Typical Deep Borehole With Pump, Typical Deep Borehole With Pump, Electric Pump System, Solar Pump System, Windmill Pump System).

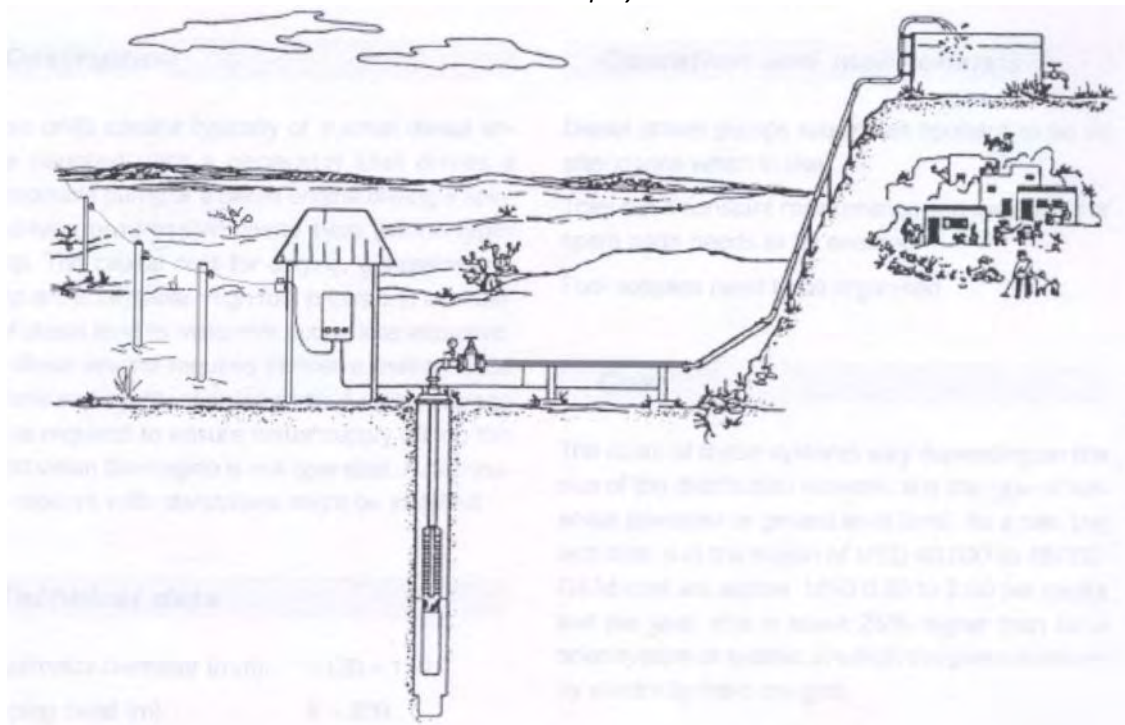
Typical Deep Borehole With Pump



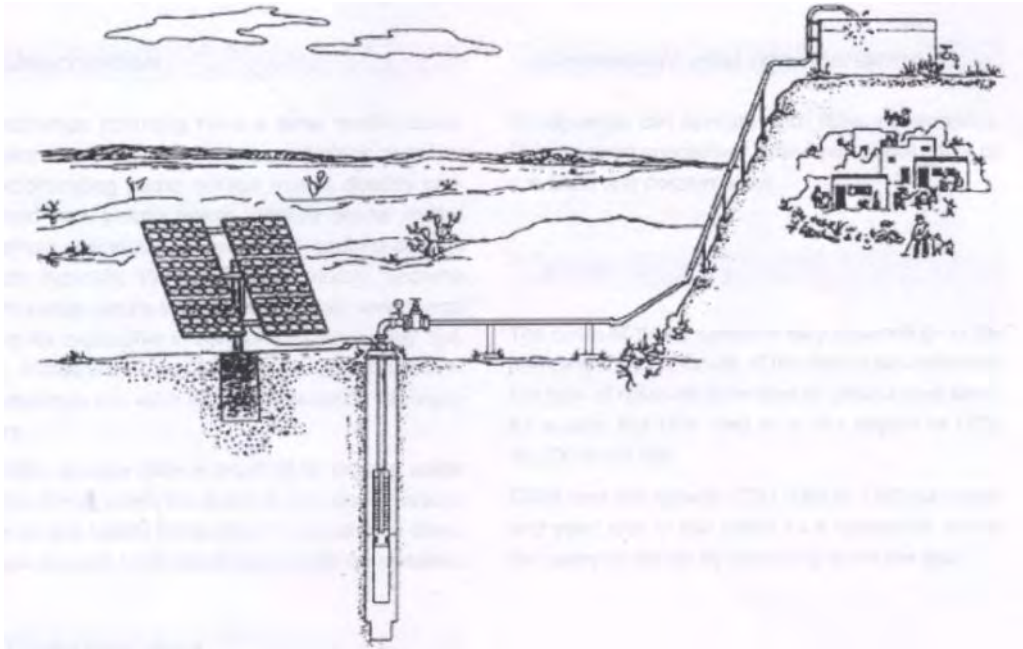
Diesel Pump System



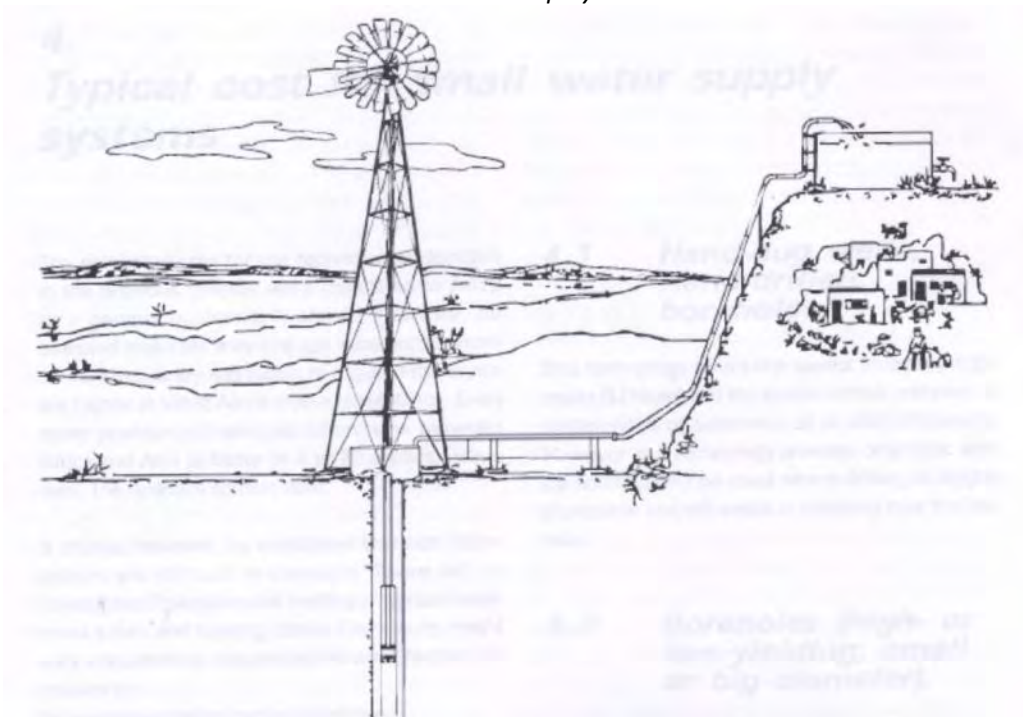
Electric Pump System



Solar Pump System



Windmill Pump System



What Are The Cost Of Ground Water Projects?

Estimating the cost of the proposed project is required to develop any project early in the design to ensure that the Rotary club and its partners are prepared to continue with the project to completion---even if cost overruns occur. This is particularly true if TRF matching grants are used. Cost is most important in the development of community water source and supplies where local capacity to finance operation and maintenance is limited. Where the planning stage recognizes long-term funding issues with the local community, it is vital that national and regional authorities are informed so that the situation will have adequate support for operation and maintenance programs.

Checklist for Using Ground Water Sources

Tapping ground water sources is often more difficult than using surface water sources because it often takes expensive, specialized drilling equipment to reach it. However, ground water is usually more draught resistant as a source of supply than surface water and it comes out of the ground with little or no turbidity, which makes treatment, if it is needed, much easier.

One must determine several things before selecting groundwater as a source and supply for water. First, is groundwater readily available? Second, is it of sufficient quantity for the intended purpose? Third, is it of adequate quality for the intended purpose? Finally, how the water system is completed and operated must be considered. When considering ground water as a source of supply the following steps should be considered.

Is ground water available?

1. Are any hydrology or hydrogeology reports/maps available for the region from universities or the government? _____
2. Are there wells in the vicinity, and if so,
 - a. How were they dug or drilled? _____
 - b. Who drilled them? _____
 - c. How deep are the wells? _____
 - d. How much do they pump? _____
 - e. What is the water quality (any problems)? _____
 - f. Do the wells every run dry? _____
3. If wells are not in the vicinity, what is the geology like?
 - a. Is hard bedrock exposed at or near the village? _____
 - b. Is sand and gravel common for the ground cover? _____
 - c. Is there a stream or river running through the area? _____
4. Do you have the means to dig or drill a well and complete it?
 - a. Is there a drilling contractor nearby willing to drill a well? _____
 - b. Is there a source of material needed to drill a well (for example, well casing, perforated pipe, gravel backfill, cement, etc.)? _____
 - c. If no drilling contractor is available, is the village willing to dig a well to sufficient depth to supply the community (often over 30 meters deep)? _____
5. Given the answers above, what is the best way to drill the well, who should drill it, and what will it cost to complete? _____

What is the population to be served and how much water do they need (per capita)?

6. How many people need to be served? _____
7. Is this a stable population or is the population transient? _____
8. If the population is transient, what is the annual variation in population? _____
9. How much water do people need:
 - a. Daily to drink? _____
 - b. Daily to Bath? _____
 - c. Daily for Agriculture? _____
 - d. Daily for other purposes? _____
 - e. Total Daily Demand? _____

Is sufficient ground water available?

10. If wells are nearby, how much do they reliably pump on a daily basis? _____

11. To determine the number of wells needed, divide the daily demand (see #9e) by the amount pumped from nearby wells (#10). _____
12. If no wells are nearby, then a test well will need to be drilled. This is risky because money will be spent with no guarantee that sufficient water will be found.

Does the well produce water of adequate quality?

13. If wells are nearby, have water quality samples been taken and analyzed by a reliable laboratory? _____
14. Are there any constituents in the nearby ground water that need to be treated before use?

15. Is the drinking water from these nearby wells treated before used, and if so, how?

16. If there are water quality problems with nearby wells, then you should expect similar problems, and therefore need to plan for them.
17. If treatment is needed, what type of treatment process do you need?
 - a. If ground water is to be delivered to a central kiosk, is it to be treated there, and if so, what type of treatment would work best (see sections on water treatment)?

 - b. If ground water is delivered to individual homes or if water from a central kiosk is not treated, what type of point-of-use treatment would work best (for example, bio-sand filter, membrane filter)? _____

Where should a new well be located?

18. Determine the best place based on geology. Drilling a well on thick sandy soil rather than bedrock is preferred. If bedrock is located on high ground and thick sandy soil is located in the low ground, drill in the low ground. Drill near an intermittent or perennial stream (stay at least 50 meters away from the stream).
19. Keep wells at least 100 meters away from potential sources of contamination, such as latrines, animal pens, and surface drainage systems.

How should the well be completed?

20. If the water table (water level standing in the well after drilling) is greater than 15 meters deep, then a concrete seal (called a sanitary seal) should be installed above the perforated well pipe to the ground surface to stop contaminated surface water from leaking down around the well casing to the water outside the well. If the water table is shallower than 15 meters deep, then as much sanitary seal as possible should be installed.
21. An elevated concrete pad at least five meters in diameter should be installed around the well head to help stop contaminated water from entering the well.
22. All potential standing water should be drained away from the well head.
23. After hand pump or electric pump is installed, the well head should be sealed.

Is some sort of storage needed?

24. If some sort of storage needed? An elevated tank will provide pressure to a central kiosk or to a water distribution system that supplies homes. _____
25. If storage is needed, how much storage is needed (at least one day's supply for the population served, or several day's supply is even better)? _____

26. How will the storage be constructed (for example, concrete or plastic tank on a hill overlooking the village, or a steel or plastic tank on an elevated tower)? _____
27. Are materials to build the tank locally available? And from whom? _____

Have you planned for long-term operations and maintenance of the water well?

28. Is money being collected for well maintenance? _____
29. Has someone been trained to look after the well and maintain it if necessary? _____
30. Are there spare parts available for the pump? _____
31. How will you periodically monitor the long-term performance of the water well? _____

RAINWATER HARVESTING

Introduction

Rainwater harvesting has been practiced by a variety of ancient civilizations around the world and appears to have originated in Asia and the Middle East several thousand years ago. Examples of traditional water collection for both domestic and agricultural use dating back more than 4,000 years have been documented all over India, from the Himalayan mountains to the eastern coastal plains. Rainwater utilization also has a long history in Sri Lanka, Nepal and Bangladesh where use of harvesting systems are still common today.

In the last 20 years, there has been a renewed and growing interest in the ancient practice of rainwater harvesting as a potential water source. In simple terms, rainwater harvesting is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments. The collected rainwater can be used for a variety of purposes, including household drinking water, agriculture, flood control, backup supply during dry spells or breakdowns, and emergency water supply in the case of disasters.

Large scale water projects using wells or dams have been built in the past few decades which have displaced rainwater as an option for a water source. It has recently been recognized that traditional rainwater harvesting can be used as an important tool in managing water resources. Countries like China and India have made great strides in using traditional methods to ensure that limited water resources are being well managed.

It is worth noting however that rainwater harvesting is not the answer for all household water problems. There is a complex set of interrelated circumstances which have to be considered when selecting an appropriate water source. Cost, climate, technology, hydrology, social, and political elements all factor in the eventual selection of a water supply for a given situation (Development Technology Unit, Email: dtu@eng.warwick.ac.uk, 1999).

While rainwater harvesting may not always be the ideal solution for all situations, it can play a particular niche role and offer an alternative source of water supply that complements others.

There was a decline in rainwater utilization in many parts of the world in the middle of the twentieth century when there was a great focus placed on large-scale water supply and distribution projects, such as dams and piped systems. However since the 1980s, there has been a renewed and growing interest in the traditional practice of collecting rainwater for domestic use in both rural and urban areas of developing countries, particularly in Africa and Asia.

The adoption and expansion of rainwater harvesting systems can be attributed to a variety of factors, including:

- Severe ground and surface water shortages in some regions.
- Increasing pressure on limited water resources.
- Poor ground and surface water quality (e.g. arsenic contamination, salination).
- Failure of conventional water supply systems.
- Growing use of impervious roofing materials, like tiles and corrugated iron, replacing traditional grass and thatch.
- Development of effective, low-cost tank designs (e.g. Thai ferro-cement jars).

In rural areas the number of rainwater tanks with volumes greater than 1 m³ is estimated to be many tens of millions worldwide. Most of these have been constructed since 1980, primarily in the developing countries. This is not surprising considering that in 2002 only 72 percent of rural residents have access to any improved water supply; this figure is only about 45 percent in sub-Saharan Africa (WHO/UNICEF JMP, 2005).

In Asia, several tens of millions of people are dependent on rainwater supplies, most significantly in north-east Thailand, central China and India. These countries in particular have seen an increasing willingness by some national and many local government authorities to invest in the promotion and implementation of rainwater harvesting technology. In Thailand alone, more than 10 million ferroement rainwater tanks have been built since 1983.

Other countries such as Indonesia, Bangladesh, the Philippines, Nepal and Sri Lanka are also beginning to use rainwater technology, although to a lesser extent.

There are several benefits of collecting and storing rainwater in towns and cities, including providing:

- Supplementary supplies for households with limited access to water for domestic use.
- Emergency, safe water in case of disasters.
- Flood control during periods of heavy rainfall.

However, there are some constraints to collecting rainwater for domestic use in urban settings, such as poorer water quality due to air pollution, shortage of space, and the high cost of land.

There are several benefits to rainwater harvesting for domestic use in developing countries, including:

- Rainwater is a free resource.
- Complements other water sources and utility systems.
- Improves household water security and water conservation.
- Relatively simple to construct, install and operate.
- Flexible and adaptable to a variety of local and environmental conditions.
- Allows households to enjoy improved water supply and quality.
- Emphasizes small-scale, community-based, self-help development.

The scope and size of rainwater systems can generally be subdivided into small, medium and large-scale. **Large-scale systems** which do not need filtering:

- Flood waters are diverted using bunds, diversion structures and small dams for spate irrigation, groundwater recharge and flood control. See an example of this work go to: <http://www.youtube.com/watch?v=SbIlZKRIBnk> for part 1 which is RVM: Water Harvesting Part one: Rotary International and http://www.youtube.com/watch?NR=1&feature=endscreen&v=V_SBp74FVU which is RVM: Water Harvesting Part two: Rotary International videos.
- Runoff Farming where water is harvested for crops.

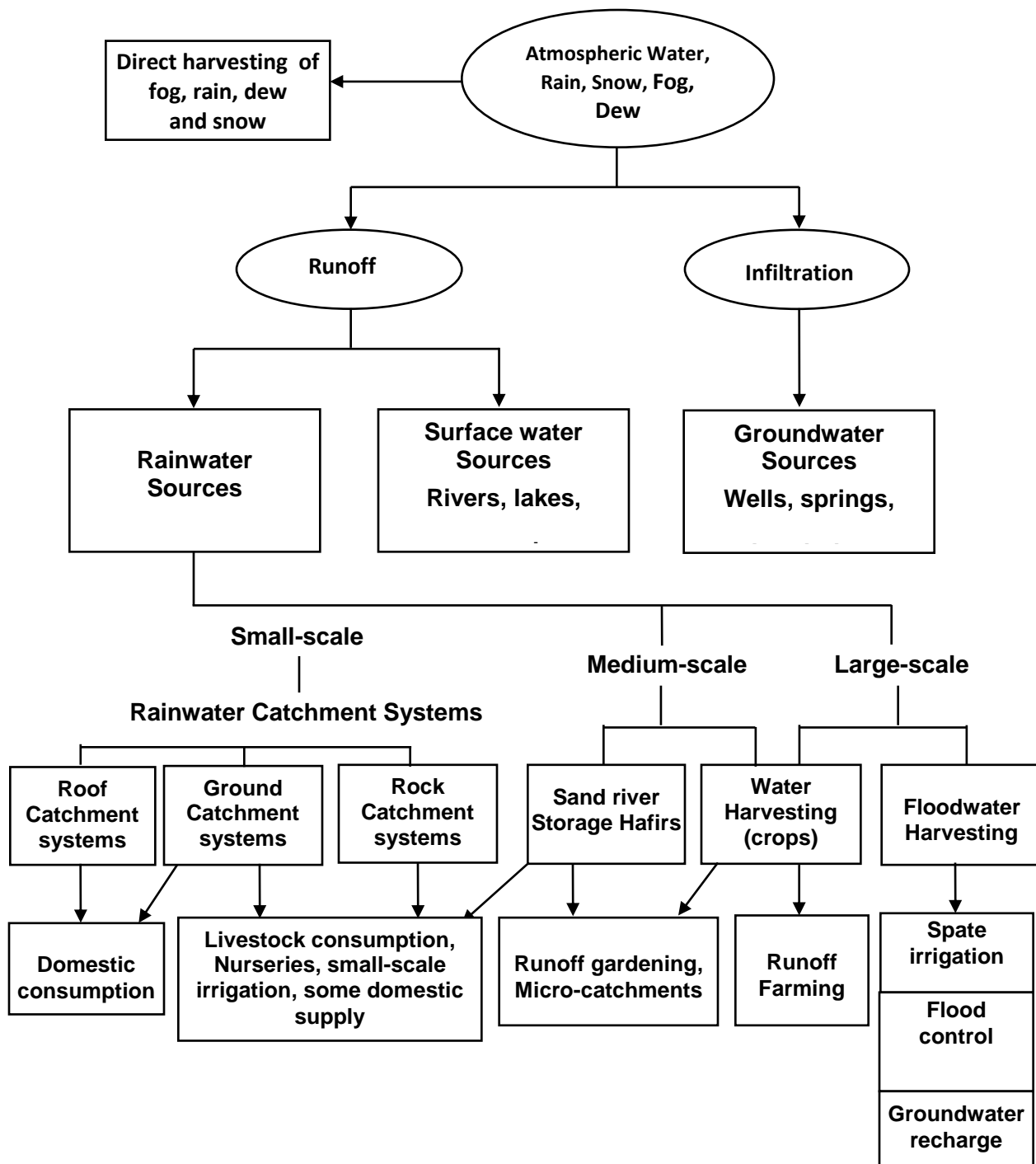
Medium-scale systems which do not need filtering:

- Micro-catchments and smaller water harvesting structures designed for runoff gardening, household subsistence farming, domestic gardening and individual trees.

Small-scale systems which do need some kind of filtering. Types of filtering are dependant on the type and degree of contamination collected.

- Direct collection of rainwater from roofs and other purpose-built catchments, small constructed or natural surface catchments, and rock catchments.

The flow chart on the next page shows sources of water and the context of rainwater catchment systems.



*Sources of water and the context of rainwater catchment systems
(Adapted from Gould and Nissen-Petersen, 1999)*

What Is A Roof Catchment System?

Roof catchment systems are best suited for providing water to individual households, provides a direct water supply, can be used with an existing structure (e.g. house or building), efficient in collecting rainwater due to high runoff coefficient and provides relatively good quality water.

Typical roofing materials that are most appropriate for rainwater harvesting include corrugated galvanized iron sheets, tiles and asbestos sheets (DTU, 2002).

The pictures below are examples of the three different types of catchment systems used.



Debris, dirt and dust will collect on the roof catchment area and when the first rainfall arrives this unwanted material will be washed into the storage tank. To avoid this, the system should incorporate a system for diverting this “first flush” water so that it doesn’t enter the tank and affect the water quality. There are a number of simple first flush devices which are commonly used, and there are also more complex systems. The simple ideas are to manually move the downpipe away from the tank inlet and then replace it once the initial flush has been diverted.

Roof catchments may also use filtration systems and settling tanks to help remove debris and sediment at the inlet and outlet of the storage tank. Similar to the first flush devices, the level of sophistication for filters varies from rudimentary to complex technology.

Key features of any storage tanks are that it should be watertight, durable, affordable, and designed to not contaminate the water in any way. There are two types of tanks that can be used to store water: Surface tanks are the most commonly used to store rainwater captured from rooftops made of ferrocement, bricks, reinforced concrete, metal, plastic, fiberglass or wood. Sub-surface tanks using ferrocement, concrete, brick and traditional clay linings are sometimes used.

The lid of a water storage tank should be as tight as possible to prevent insects and contaminants from entering.

Gutters are most commonly used for diverting water from roofs and come in a wide variety of shapes and forms, ranging from factory made polyvinyl chloride (PVC) pipes to locally made bamboo or folded sheet metal gutters. Guttering is usually fixed to the building just below the edge of the roof. In developing countries, gutters are often the weakest link in the rainwater harvesting system.

Glides are sometimes used instead of guttering and are slanting ridges made of metal, brick, stone, or wood constructed on the roof to direct runoff towards the storage tank.

The top of the downpipe needs to have a fine mesh screen to prevent mosquitoes and other insects from entering into the storage tank.

Towards the bottom of the storage tank there should be a discharge pipe with a shutoff valve for periodic cleaning. Above the discharge pipe would be the access pipe with a shutoff valve. This pipe should be high enough to allow for all sized fetching buckets.

Additional filtering in most cases is not needed for it to be potable drinking water

Example of a Roof Catchment System in Rural India

The very simple method of catching rainwater with a saree is practiced in the heavy rainfall areas of Kerala and Kamataka. The traditional technique is used for three months during the monsoon season and where the available water supply is not potable.

There is hardly any hesitation to drink rainwater in these areas. However, families using the saree system typically boil the water before drinking it. Some households keep the water in small storage vessels for their weekly drinking needs. Each household usually has one saree harvesting system and it is generally sufficient to supply enough drinking water for the family. (Padree, 2004)

What Is A Ground Catchment System?

Ground catchment systems use the land surface to collect rainwater and are best suited for several households or a community. The catchment can be specifically built to collect rainwater or it may already exist for another purpose, e.g. threshing floor, playground or a road.

Main Advantages:

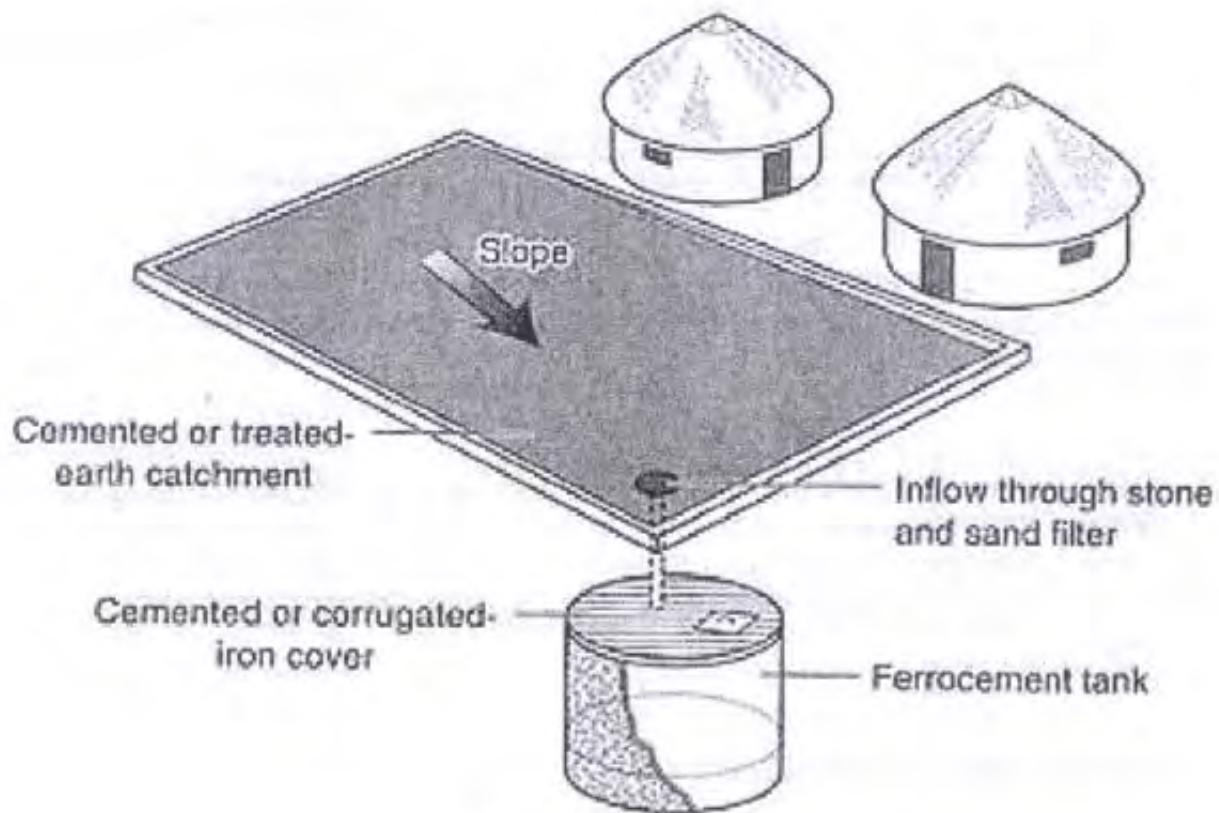
- The larger catchment area can collect more rainwater than a roof system.
- Large quantities of rainwater can be harvested for a community supply.
- Collects a considerable amount of water in areas where rainfall is very scarce and other sources are unavailable.

Main Disadvantages:

- Collected rainwater is usually of poor quality since it can become easily contaminated by pollutants and excrement from animals and children.
- Ground surfaces are not normally as efficient as roofs for collecting runoff (i.e. they have a lower runoff coefficient).
- People still need to fetch water and sub-surface tanks make it more inconvenient to withdraw water for use.

Since the rainwater collected from these catchments is generally of poor quality it should be treated if it is intended for drinking. Rainwater from this type of collecting is best for secondary purposes like watering livestock or gardening.

The picture below is an example of a ground catchment system.



(Gould and Nissen-Petersen, 1999)

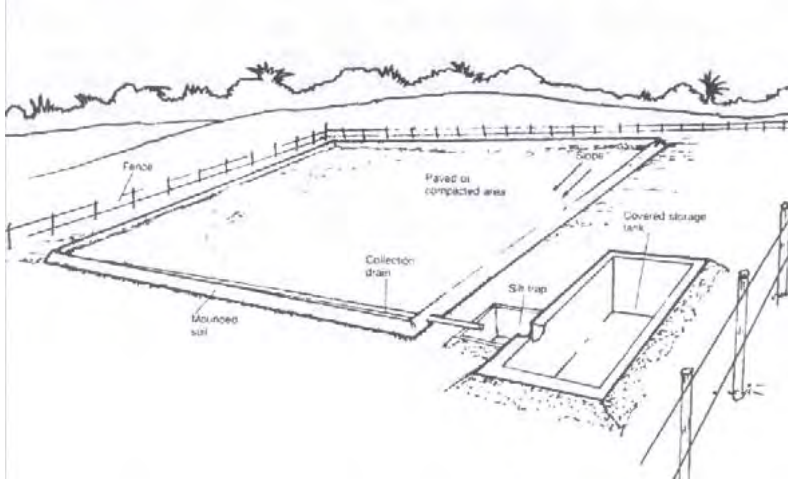
Rainfall runoff can be collected from a natural surface, however many soils have a high infiltration capacity and a low runoff coefficient. There are three approaches to help reduce infiltration and increase the amount of rainwater runoff collected from a natural ground catchment surface.

1. Covering – Natural surfaces are covered with an impermeable material such as butyl rubber, plastic sheeting, tiles, and metal sheets. While these materials give a higher runoff coefficient and reduce contamination, they are expensive and may not be available locally.
2. Treatment – Materials are added to soil surfaces to try to seal them including cement, lime, paraffin wax, oil, bitumen, asphalt, sodium salts, silicone or clay. Treating surfaces is a cheaper alternative to increase the runoff coefficient, although the cost can still be substantial.
3. Compaction – Natural soil surfaces are compacted and shaped using manual labor or earth-moving machinery. Threshing floors and compounds around rural households often have a compacted surface which can make for a useful catchment surface. The water quality is generally poorer than covered or treated surfaces and excess sediment may need to be removed from the collected water.

For smaller ground catchment systems, such as threshing floors, the floor normally slopes so the rainfall flows to a storage tank inlet. For larger systems, such as a road, a network of drains and channels is needed to direct the runoff. For example, in semi-arid areas of Kenya, rainfall runoff is diverted from road surfaces for crop irrigation using diversion channels and a canal system (Kirimu, 1999)

How Can Rainwater BE Stored In Reservoirs For Community Use?

The collected runoff can be stored in various systems to be used as required. Storage reservoirs can be of many different types. They can be located on the surface of the ground or below the surface. Sub-surface tanks can be made from local materials using ferrocement, concrete, brick and traditional clay linings. If suitable to the application, water could be drawn off the reservoir by way of a drain, filtered and stored in a covered tank.

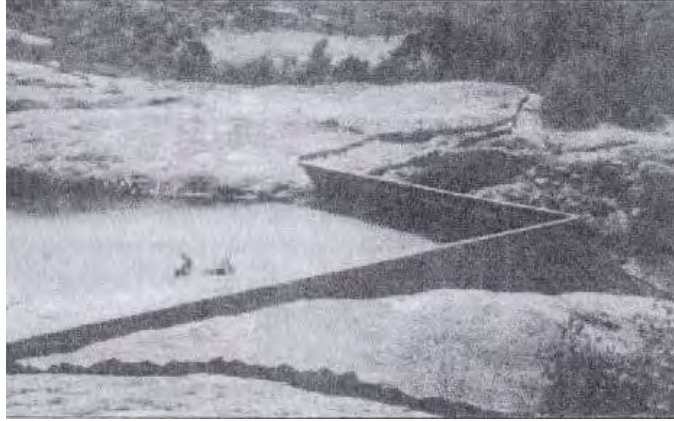


Pen surface reservoirs can hold large amounts of water, but they are subject to evaporation and contamination. Open surface reservoirs can also have excessive sedimentation, and become a breeding ground for insects, and thus insect-borne disease (such as malaria)

Usually some sort of inlet filter is needed to prevent sediment and debris from entering the storage tank. It is also important that sub-surface tanks have a cover to prevent children and animals from falling into them. Proper fencing around the reservoir is also highly recommended.

What Are Rock Catchments?

Rock catchments can be constructed in natural valleys or hollows by constructing a rubble/stone/masonry dam to contain the water. The least expensive, where suitable sites exist, are naturally occurring rock catchments. They require impermeable, exposed, unjointed bedrock able to hold rain water. Granite rock forms (sometimes called inselbergs) are an ideal rock catchment. Some of these large rocks have natural concave surfaces and can actually hold the water, if the surface is more convex on top, the water running off can be collected into a barrel at the point(s) of greatest runoff. Rock catchment, earth dams, hafirs, check dams, and sand dams are some of the most effective and cheapest types of rainwater storage systems but the collected rainwater is usually of poorer quality since it can become easily contaminated by pollutants and excrement. It is recommended that the rainwater be treated using a household treatment technology if it is intended for drinking. Regular inspection, cleaning, maintenance and occasional repairs of the ground catchment are essential for its long-term success.



This is a picture of a rock catchment system at Kaseva, Mutomo in Kitui District, Kenya. (Picture furnished by: Gould and Nissen-Peterson, 1999)

Another type of rock catchment used in more mountainous areas is to tap into a rock spring and to pipe the water down to the village using PVC pipe. The spring water can be put into a tank and even piped into the schools and individual homes with shutoff valves. This method is more expensive to build and the PVC pipe and fittings may not be locally available but the water will not have to be filtered for drinking.

Training a local villager to do regular inspections, cleaning and to do maintenance when needed is a must when using PVC pipe and shutoff valves to keep this type of system sustainable.

Please watch this video:

<http://www.youtube.com/watch?v=HGiHU-agsGY&feature=youtu.be>

Most of the material presented is from Household Rain Water Harvesting manual produced by: CAWST Centre for Affordable Water and Sanitation Technology, Calgary, Alberta, Canada.

What Are Some Of The Sources Of Rainwater Contamination?

The following table summarizes some of the sources that can contaminate rainwater and the health risks associated with the contamination.

Types and Sources of Rainwater Contamination

Contaminant	Potential Sources	Health Risk
Pathogens such as bacteria, viruses and protozoa	<ul style="list-style-type: none"> • Roof catchments: Bird or animal feces. • Ground catchments: Human, bird or animal feces. 	<ul style="list-style-type: none"> • Greatest water quality concern. • Roof catchments: Reports of illness are infrequent. • Ground catchments: Usually poor water quality and should be treated before drinking.
Dust and ash	<ul style="list-style-type: none"> • Volcanic activity • Bushfires 	<ul style="list-style-type: none"> • Does not pose a health risk. • Can affect turbidity, taste and color.
Heavy metals : (e.g. lead, copper, zinc, manganese, cadmium)	<ul style="list-style-type: none"> • Old roofs constructed with lead flashing and lead based paint. • Severe air pollution in urban areas from industry and vehicles. 	<ul style="list-style-type: none"> • Serious contamination is rare under normal circumstances. • Risk is minimized by avoiding lead flashing and lead based paint.
Sulphur dioxide (SO ₂), nitrogen oxides (NO and NO ₂), hydrocarbons	<ul style="list-style-type: none"> • Air pollution in urban areas from industry and vehicles. 	<ul style="list-style-type: none"> • Increasing concern in urban areas. • Insignificant risk in rural areas.
Pesticides and herbicides	Agricultural practices, such from industry and vehicles.	Increasing concern in areas of intensive farming.
Asbestos	Old roofing materials	Although asbestos fibers are dangerous to inhale, it is not believed that asbestos in drinking water poses a health risk.
Mosquito larvae	Mosquitoes laying eggs in gutters, tanks or ground catchments	<ul style="list-style-type: none"> • Particular concern in tropical areas where mosquitoes act as vectors for diseases, such as dengue fever, yellow fever and malaria. • Risk minimized buy using tank inlet screens and not allowing water to pool in gutters.

(Gould and Nissen-Petersen, 1999, Government of Australia, 2004; Mosley, 2005)

Checklist for Using Rainwater Harvesting

Rainwater Harvesting is commonly accomplished by collecting water from the roofs of houses, schools and other structures as a source for household drinking water. Rainwater harvested from roofs can contain human, animal and bird faces, dust, urban pollution, pesticides, etc. The highest level of pollution occurs in the first rain of the season or after a dry period. Therefore, the system should be designed to divert the first few millimeters of any rainfall and the collected water should be treated with disinfection or boiled. Also, the roofs should be cleaned as much as possible at the end of any prolonged dry period. The following questions should be considered during the planning stages for rainwater harvesting.

1. Determine Quantity of Rainwater Available

- a. What is the average monthly rainfall in the demand area where the water is to be collected?

- b. If these data are not available, what is the average monthly rainfall of several nearby rain gauges? _____
- c. Are there extended dry periods during the year or does the rainfall occur year round? If so, how long? _____
- d. Are there houses, schools or other structures in the demand area whose roofs are adequate to support attached rainwater gutters? If so, name them. _____
- e. What is the roof area (horizontal projection) of all of the structures that are going to be used for the collection of rainfall?
- f. Calculate the total amount of water available each month by multiplying the average monthly rainfall times the total roof area (horizontal projection). _____

2. Determine the Water Demand

- a. How many people are going to be served by the rainwater catchment system(s)?

- b. How much water does each person consume daily for drinking? _____
- c. How much water will each person consume daily for cooking? _____ For bathing?
_____ For other? _____
- d. Determine per capita monthly water demand by adding drinking water demand to other demands calculated above and then multiply by 30. _____
- e. Determine how much storage is needed per capita by multiplying the monthly water demand per person times the number of months during the dry season, and then multiply that number by 1.5 or 2.0, depending on the likelihood of prolonged drought for the region.

3. Determine Availability of Construction Materials

- a. Are rain gutters, PVC pipes and water storage tanks available locally for purchase or will they have to be constructed from local sources? _____
- b. Will any parts needed for the project need to be imported? If so, what and at what cost?

- c. What size of water storage plastic containers or cisterns will have to be purchased or constructed to provide sufficient water during any dry periods (multiply the number of people in the home served by the per capita storage calculated in number 2e, above)?

4. Determine the need for disinfection

- a. What form of disinfection is readily available (for example, chlorine)? _____
- b. Do the people reject the use of chlorine in their drinking water (refuse to use it in the long term) because of taste? _____
- c. If the answer is yes to 4b, then consult an expert (for example, Wasrag's "Ask an Expert")
- d. What disinfection should be used before the water is consumed? _____

WATER QUALITY

What Are Water Quality Standards?

Governments and regulatory bodies impose drinking water standards to ensure that their citizens can be assured of safe potable water. However, the presence of a national Water Quality Standard does not ensure public safety as demonstrated in many developing countries. This public safety aspect is entirely dependent on the scope, frequency and location of water quality testing and the focus on maintenance and operation of treatment facilities. Finances, culture and work ethic frequently work against the successful delivery of water that meets the Water Quality Standards..

Water treatment to bring raw water up to the “standard” is usually done at a “facility” from which it is then distributed (sold) in containers (bottles or bags) or by piped networks delivering it to households. This “facility” may be a municipal water treatment plant or a private water marketing company selling bottled water. Water Quality Standards generally apply where water is provided by a level of government to its citizenry or by an entity selling water to the public.

The philanthropic sector deals with access and safety of the water and may not consider national Water Quality Standards or feel they need to consider them.

For example, access to improved sources may mean that a pipe is installed from a distant water source – reducing time spent getting water to the home but not necessarily changing its quality. Often a small fee is necessary to pay for maintenance or pumping energy (electricity or fuel).

Where families and villages are self-reliant (using their own wells or other sources, rainwater capture, filtration and disinfection systems and processes) philanthropic entities supplying household water treatment systems may do so on a “best efforts” basis given technological limitations or local culture.

For those working in the philanthropic sector, such as Rotary International, this is an ethical rather than a legal issue.

What Is The Difference Between A Standard And A Guideline?

Standard: a mandatory limit that must not be exceeded, reflecting a legal duty or obligation.

Guideline: a recommended limit that should not be exceeded; guidelines are not intended to be standards of practice or to give rise to a legal duty or obligation, but in certain circumstances they should assist in evaluation and improvement.

In 1982, WHO shifted its focus from ‘International Standards’ to ‘Guidelines’. The main reason for the shift is the advantage provided by the use of a risk-benefit approach (quantitative or qualitative) to the establishment of national standards and regulations. Specifically, the application of the Guidelines to different countries should take account of the socio-cultural, environmental and economic circumstances particular to those countries.

Many countries have consulted these Guidelines and developed their own Water Quality Standards based on them. Other countries, such as Canada, have developed National Guidelines which individual provinces must then meet or exceed within their own local legal standards.

WHO Drinking Water Quality Guidelines:

http://whqlibdoc.who.int/publications/2011/9789241548151_eng.pdf

Canadian Water Quality Guidelines:

http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/2010-sum_guide-res_recom/index-eng.php#a8

Nigerian Water Quality Standards:

http://www.unicef.org/nigeria/ng_publications_Nigerian_Standard_for_Drinking_Water_Quality.pdf

What Water Is Being Treated For?

The potential health consequences of microbial contamination are such that its control must always be of paramount importance and must never be compromised.

WHO 2011

This section is taken largely from: Centre for Affordable Water & Sanitation Technology (CAWST) (www.cawst.org). While the water treatment focus must always address the microbial aspect, disease may also result from consumption of water containing toxic levels of chemicals. The health burden is most significant for two chemicals: arsenic and fluoride.

Arsenic contamination of drinking water sources is being found in increasing numbers of water supplies world-wide and in Asia in particular. The total disease burden is as yet unknown, but in Bangladesh, the country with the most widely reported problem, between 35 and 77 million people are at potential risk (Smith *et al.*, 2000).

Fluoride is also a significant global problem and WHO (1999) suggest that over 60 million people are affected by fluorosis in India and China and suggest the total global population affected as being 70 million.

Water Quality Standards are frequently divided into sectors which are described in detail below – Acceptability, Microbial, Chemical.

Acceptability

WHO Guidelines for Physical Parameters

The appearance, taste and odor of drinking water should be acceptable to the consumer. The table below shows the WHO Guidelines for Drinking Water Quality for physical parameters.

WHO Guidelines for Drinking Water Quality: Physical

Parameters	Available Range	WHO Guideline
Colour	Colour less (acceptable)	15 TCU (True Colour Unit)
Odour	Odourless (acceptable)	No health based value is proposed
Temperature	Cool water (acceptable)	No health based value is proposed
Turbidity	Less than 5 NTU	Less than 5 NTU

(WHO, 2007)

Potential Health Effects from Physical Contaminants

Physical contaminants do have not direct health effects themselves; however, their presence may relate to a higher risk of biological and chemical contamination which may be harmful to human health. For example, increased turbidity levels are often associated with higher levels of disease causing pathogens such as viruses, parasites and some bacteria (WHO, 2007). Also, if the turbid water is disinfected with chlorine, the chlorine is taken up by the suspended solids and may not have the ability

to sufficiently kill bacteria and viruses. Therefore, some attempt should be made to treat water so that it is physically clear before attempting to disinfect it.

Microbial

WHO Guidelines for Biological Contaminants

The WHO Guidelines for Drinking Water Quality recommends that all water intended for drinking should have non-detectable faecal contamination in any 100 mL sample. However, many countries have developed their own water quality standards which may differ from the WHO Guidelines. For example, in 2007 Nepal developed national drinking water standards where total coliform should be zero at least 95% of the time.

According to the WHO, the risk of faecal pollution using *E. coli* as an indicator is shown in the following table. Many relief agencies also use these values to determine when water treatment is required in emergency situations (adapted from Médecins Sans Frontières, 1994).

Faecal Pollution and its Associated Risk

<i>E. coli</i> level (CFU per 100 mL sample)	Risk¹	Recommended Action²
0-10	Reasonable quality	Water may be consumed as it is
10-100	Polluted	Treat if possible, but may be consumed as it is
100-1000	Dangerous	Must be treated
> 1000	Very Dangerous	Rejected or must be treated thoroughly

(¹ WHO,1997, ² Harvey, 2007)

Routine water quality testing techniques are not available for viruses, protozoa and helminths. The WHO Guidelines recommend protection of the source and treatment techniques to ensure their absence. The degree of treatment required is a function of the source water (i.e. ground or surface water) and level of fecal contamination of the source.

To ensure the absence of viruses, the WHO Guidelines recommend that the following conditions for chlorine disinfection be met:

- Residual free chlorine ≥ 0.5 mg/L
- Contact time ≥ 30 minutes
- pH < 8.0
- Median turbidity ≤ 1 NTU
- Maximum turbidity = 5 NTU

Potential Health Effects

The majority of human infections associated with water can be categorized depending on the source of the pathogen and the route by which we come into contact with the pathogen.

Diseases Associated with Water Contaminated with Pathogens

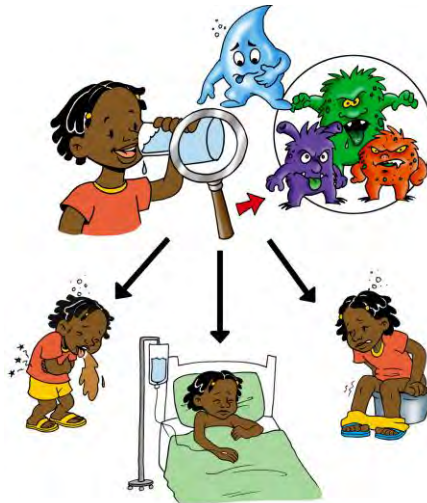
Source	Route of Human Contact with Pathogen	Associated Diseases	Appropriate Interventions
Water-borne	Primarily from drinking microbial contaminated water.	Diarrhea, cholera, typhoid, shigellosis hepatitis A and E.	Improve drinking water quality by removing or killing pathogens.
Water-washed	Caused by contact with microbial contaminated material.	Trachoma, skin sepsis, scabies, fungal infections.	Improve availability of water for hygiene, improve hygiene practices.
Water-based	Caused by parasites which either penetrate the skin or are ingested	Schistosomiasis, guinea worm.	Reduce contact with infected water, remove parasites from water.
Water-insect vector	Diseases are not acquired from water but rather from vectors, usually mosquitos, whose life cycles depend on access to water.	Mosquitoes (malaria, dengue, yellow fever, filariasis) Black fly (river blindness) Tsetse fly (sleeping sickness).	Protect water from insect breeding, control insects, and prevent insects from biting.

Pathogens found in water can also be divided into four main categories: bacteria, viruses, protozoa, and helminthes (worms).

Bacteria

Bacteria are the most common microorganisms found in human and animal feces. Drinking water contaminated by feces is the primary cause of water-borne infections. This is often called the fecal-oral route of transmission since the source of the pathogens is human or animal feces. With some bacteria, only a few are needed to make us sick.

The most common water-borne diseases caused by bacteria are diarrhea (also known as gastroenteritis), cholera and typhoid. About 1.8 million people die every year from diarrheal diseases, including cholera (WHO/UNICEF, 2005). It is estimated that 88% of diarrheal disease is caused by unsafe water, inadequate sanitation and poor hygiene (WHO, 2004).



Cholera remains a global threat and is one of the key indicators of social development. While cholera is no longer a threat to countries with basic hygiene standards, it remains a challenge in countries where access to safe drinking water and adequate sanitation is limited. Almost every developing country in the world faces cholera outbreaks or the threat of a cholera epidemic (WHO, 2007).

Similar to cholera, typhoid is prevalent in countries that lack access to safe drinking water and sanitation. There are an estimated 17 million cases of typhoid worldwide resulting in 600,000 deaths (WHO, 2007).

Viruses

Viruses are the smallest of the pathogens. Viruses are unable to replicate by themselves and must invade a host cell to make more viruses. This disrupts the functions or causes the death of the host cell. It is more difficult and expensive for us to study viruses so we know less about them than other pathogens.

Viruses that are transmitted by water can cause diarrhoea, hepatitis A and E. However, viruses generally produce milder symptoms than bacteria. Hepatitis A occurs sporadically worldwide and is common throughout the developing world with 1.5 million cases every year (WHO, 2004).

There are other viruses that are transmitted by vectors that depend on water to survive. For example, mosquitos spread diseases such as Malaria, Dengue Fever, Rift Valley Fever, Japanese Encephalitis, West Nile Fever, Ross River Fever, Equine Encephalitis, and Chikungunya. Most of these diseases occur in tropical and sub-tropical areas.



Human immunodeficiency virus (HIV) and viruses that cause the common cold cannot be transmitted through water since it doesn't provide a suitable environment for the viruses to survive.

Protozoa

Protozoa are single celled organisms and some can stay alive without a host. Some protozoa are able to form cysts which allow the organism to stay dormant and survive in harsh environments. The protozoa cysts become active once the environmental conditions become more favourable.

There are several different types of protozoa that may cause illness, such as amoeba, cryptosporidium and giardia. On a worldwide basis, infections of amoebic dysentery are the most

common resulting in about 500 million cases each year. These protozoa live predominantly in tropical areas.

Malaria is also a parasitic infection that is passed on by mosquitos. Approximately 1.3 million people die each year of malaria, 90% are children under the age of five. There are estimated to be 396 million episodes of malaria every year, most of the disease burden is in sub-Saharan Africa (WHO, 2004).

Helminths

Helminths, more commonly known as worms or flukes, require a host body to survive and are generally passed in human and animal faeces. Both helminths and protozoa are considered to be parasites. They spend part of their life in hosts that live in water before being transmitted to humans. Many types of worms can live for several years and weaken their host by using up their food.

Common types of helminths that cause illness in developing countries include round worms, pin worms, hook worms and guinea worms. The WHO estimates that 133 million people suffer from intestinal worms each year. These infections can lead to severe consequences such as cognitive impairment, severe dysentery or anaemia, and cause approximately 9,400 deaths every year (WHO, 2000).

Schistosomiasis, also known as bilharzia, is caused by the trematode flatworm. This is widespread disease that affects about 200 million people worldwide. Although it has a relatively low mortality rate, schistosomiasis causes severe symptoms in millions of people. The disease is often associated with large scale water resource projects, such as the construction of dams and irrigation canal which provide ideal breeding grounds for the flatworm.

Infectious Dose

The infectious dose is the minimum number of pathogens needed to cause an infection. The presence of a microorganism in drinking water does not always mean that it will make us sick. We must take in more microorganisms than the infectious dose to cause illness. The infectious dose is different depending on the type of pathogen. Generally, viruses, protozoa and worms have lower infectious doses than bacteria.

Those most susceptible to and more likely to die from water related diseases are infants, young children, the sick and elderly. For these people, the infectious dose is usually much lower than for the average adult. For instance, over 90% of deaths from diarrhoeal diseases in the developing world occur in children under 5 years old. (WHO/UNICEF, 2005)



Indicator Organisms

Testing for every conceivable pathogen in water would be both time consuming, complicated and expensive. Alternatively, the presence or absence of certain bacterial indicator organisms is used to determine the safety of the water. The use of bacteria as indicators dates back to 1885 where they were used in the first routine bacteriological examination of water quality in London, England (WHO, nd). Since then indicator tests have been found to be cheaper, easier to perform and yield faster results, compared to direct pathogen monitoring.

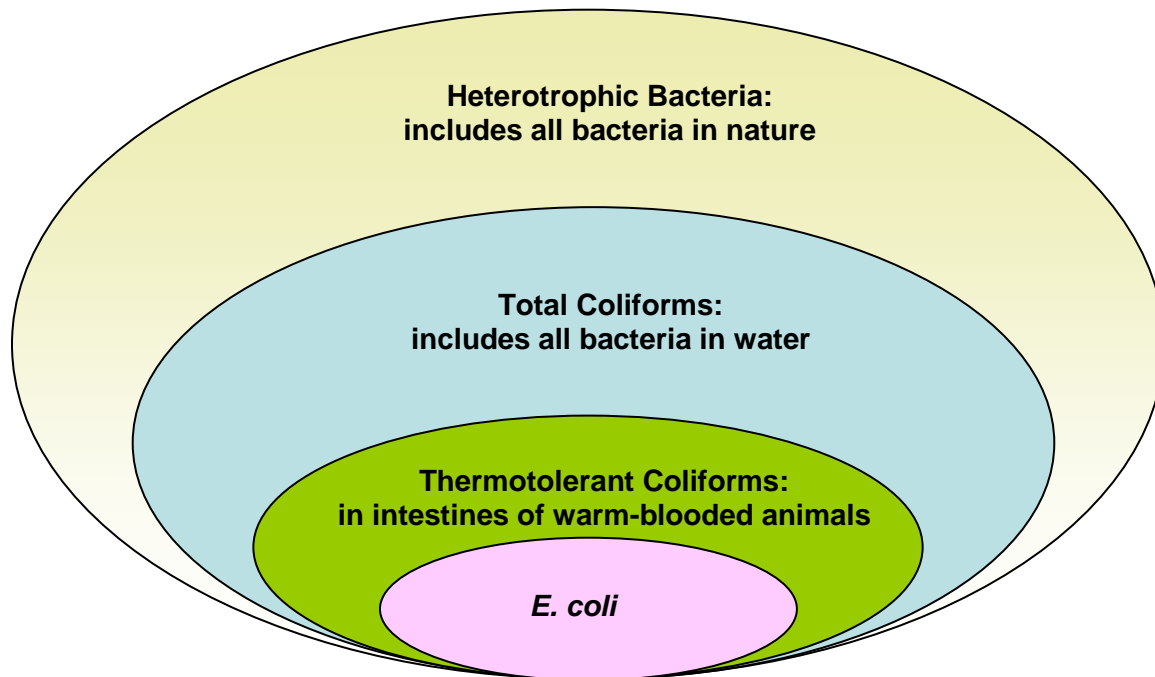
Indicator organisms should ideally possess the following characteristics:

- Present whenever pathogens are present
- Present in the same or higher numbers than pathogens
- Specific for fecal or sewage pollution
- At least as resistant as pathogens to conditions in natural water environments, and water purification and disinfection processes

- Non-pathogenic
- Do not multiply in the environment

There is no universal indicator to ensure that water is pathogen free, but there are several different types, each with certain characteristics. The choice of indicator depends on the relationship between the indicator and pathogens. Coliform indicators are most commonly used because they exist in high ratios to pathogens making them easier to detect in a water sample. However, some bacterial pathogens (such as *Yersinia*) may not correlate with coliform indicators. Besides coliform indicators, fecal streptococci and enterococci have also been proposed as indicators of water quality.

Total coliforms, thermotolerant coliforms and *Escherichia coli* (more commonly referred to as *E. coli*) are the main coliform indicators. As shown in the following diagram, thermotolerant coliforms are a sub-type of total coliforms and *E. coli* is a member of the thermotolerant group.



Important Note:

The presence of bacterial indicators does not always correlate with the presence of protozoa or viruses in drinking water, and vice versa. There are many cases of waterborne disease outbreaks in which the drinking water met all requirements for bacteriological water quality (as well as process efficiency indicators and other water quality parameters).

(BCCDC Environmental Health Laboratory Services, 2006)

Total Coliforms

Total coliforms have been used as an indicator of drinking water since the early 1900s (EPA, 2006). There is some debate internationally about the public health significance of this bacterial indicator group since they are not specific indicators of fecal pollution. An understanding of the basic definition of this group of bacteria, however, is important to assessing possible risks as poor drinking water quality is associated with the presence of these organisms.

Originally, total coliforms included 4 groups of bacteria: *Escherichia*, *Klebsiella*, *Enterobacter* and *Citrobacter*. These 4 groups are found in feces of warm-blooded animals, including humans. However, recent scientific evidence has shown that total coliforms actually include a much broader grouping of bacteria than the 4 original groups. In fact, to date there are now 19 recognized groups of bacteria that fall under total coliforms, of which only 10 of these groups have actually been associated with feces. Several environmental species included as total coliforms, are associated with soil, vegetation, or water sediments. Thus, not all total coliforms represent bacteria coming from the feces.

Moreover, recent research has also demonstrated that some groups of total coliforms that are found in the feces of animals are also capable of replicating in nutrient rich environments. This makes it difficult to assess whether the water in which total coliforms were detected was contaminated with feces or not.

Overall, the total coliform group has become a less specific measure of public health risk. In fact, the group violates the two basic criteria for a good indicator, these being the requirement for the microorganism to only be associated with the feces of animals and to be incapable of replicating in the environment. (Source: BCCDC Environmental Health Laboratory Services, 2006)

Thermotolerant (Faecal) Coliforms

Thermotolerant coliforms are a sub-group of the total coliform group. They used to be commonly referred to as faecal coliforms since they are found in warm-blooded animals (i.e. birds and mammals). Historically, faecal coliforms have been extensively used as bacterial indicators of faecal contamination. Among the coliforms in human faeces, 96.4% are faecal coliforms. They are distinguished from total coliforms by their ability to grow at higher temperatures (42°C - 44.5°C), a useful trait for the laboratory. When compared to the presence of total coliforms, the presence of faecal coliforms in a water sample adds significant weight to a possible health risk.

With respect to total coliforms, thermotolerant coliforms are a more specific indicator of fecal contamination than total coliforms (EPA, 2006). More recently, *E. coli* has replaced faecal coliforms as the preferred indicator since it is a more specific indicator of contamination by human or animal feces. (Adapted from BCCDC Environmental Health Laboratory Services, 2006)

Escherichia Coli (*E. coli*)

E. coli is the most important indicator used in drinking water quality testing and has been used for over 50 years. It is a coliform bacteria found predominantly in the faeces of warm-blooded animals. The majority of *E. coli* is harmless; however there are some strains (such as O157:H7) that are known to cause severe diarrhoea and other symptoms.

E. coli has similar biochemical properties to the other coliforms and is distinguished by the presence of the enzyme β -glucuronidase and galactosidase. Many different water testing methods make use of the presence of this enzyme for detection of *E. coli* in water samples. Over 95% of *E. coli* tested to date possesses this enzyme. Of note, most strains of O157:H7 do not produce this enzyme and is one of the very few that cannot be detected by β -glucuronidase-based methods. However, the likelihood that O157:H7 being the only *E. coli* strain present in a faecally contaminated water sample is remote.

E. coli has an extremely limited ability to survive and replicate outside the host. Thus it is the most appropriate indicator of faecally contaminated water and the key bacterial indicator for public health. The research shows that *E. coli* cells are able to survive at least 10 days in biofilms even under high levels of disinfection (EPA, 2006).

Fecal Streptococci and Enterococci

Parallel to the research conducted on coliforms, a group of bacteria known as fecal streptococci were also being investigated as important indicators. The enterococci are a subset of fecal streptococci group. Four key points in favor of the fecal streptococci were (WHO, 2001):

- Relatively high numbers in the excreta of humans and other warm blooded animals.
- Presence in wastewater and known polluted waters.
- Absence from pure water and environments having no contact with human and animal life.
- Persistence without multiplication in the environment.

Fecal streptococci and enterococci are generally absent from pure, unpolluted waters having no contact with human and animal life, with the exception being growth in soil and on plants in tropical climates. Thus for water quality purposes, they can be regarded as indicators of fecal pollution, although some could originate from other habitats, making them less reliable than *E. coli* as an indicator. They are also not as good a fecal indicator when pathogenic protozoa are present (US EPA, 2006).

**Microbial Indicators Excreted in the feces of Warm Blooded Animals
(average numbers per gram wet weight)**

Groups	Thermotolerant Coliforms	Fecal Streptococci
Farm Animals		
Chicken	1,300,000	3,400,000
Cow	230,000	1,300,000
Duck	33,000,000	54,000,000
Horse	12,600	6,300,000
Pig	3,300,300	84,000,000
Sheep	16,000,000	38,000,000
Turkey	290,000	2,800,000
Domestic Pets		
Cat	7,900,000	27,000,000
Dog	23,000,000	980,000,000
Humans	13,000,000	3,000,000

(Adapted from WHO, 2001)

Important Note:

Bacterial indicators, such as *E. coli*, are not intended to be absolute indicators for the presence of pathogens. Rather the presence of these bacterial indicators in a water sample is consistent with the fact that the water was likely contaminated with feces and at a higher risk for causing disease.

Water contaminated by fecal material may or may not have pathogenic microorganisms in it. Consequently, drinking bacterially-contaminated water may or may not cause disease. The concept of using bacteria as indicators of water quality and public health safety is based on risk by association.

(BCCDC Environmental Health Laboratory Services, 2006)

Chemical

WHO Guidelines for Chemical Contaminants

“Pure” water does not actually exist in nature, as all water contains some naturally occurring chemicals that have leached from the surrounding physical environment. In most cases, the levels of naturally occurring chemicals are either beneficial, or minimal and of little consequence. There are also many human made chemicals that can contaminate water and affect its usability. Sources of chemical contaminants can be divided into the following five groups.

Sources of Chemical Contamination

Sources of chemicals	Examples	Chemicals
Naturally occurring chemicals	Rocks and soils	Arsenic, Barium, Boron, Chromium, Fluoride, Manganese, Molybdenum, Selenium, Sodium, Sulphate and Uranium
Chemicals from agricultural activities	Application of manure, fertilizer and pesticides; intensive animal production practices	Ammonia, Nitrate, Nitrite, DDT
Chemicals from human settlements	Sewage and water disposal, urban runoff, fuel leakage	Nitrate, ammonia, heavy metals, pesticides, other organic chemical
Chemicals from industrial activities	Manufacturing, processing and mining	Antimony, Cadmium, Cyanide, Lead, Nickel, Mercury
Chemicals from water treatment and distribution	Water treatment chemicals; corrosion of. And leaching from, storage tanks and pipes	Aluminium, Chlorine, Iodine, Silver, Zinc

(WHO, 2004)

The risks associated with chemically contaminated water are identified through the comprehensive analysis of water samples. Once a contaminant has been identified it is possible to establish the implications it will have on human health using previously conducted research. However, most developing countries do not have the resources to acquire this knowledge.

The WHO drinking water guidelines were recommended on the basis of a tolerable daily intake (TDI) of contaminants. A dose of TDI is varied on the weight of body and quantity of daily drinking water consumption (WHO, 2006).

Using valid water related research and experiments the WHO was able to establish a set of drinking water guidelines, recommending the maximum chemical contaminant concentrations for drinking water. Despite the WHO Guidelines for Drinking Water Quality, standards vary among countries and regions. There is no single approach that is used worldwide. Adoption of the WHO Guidelines varies from country to country due to differences in governments, policies, available resources and local needs.

The WHO does not include some chemical parameters such as iron, calcium, sodium, magnesium and zinc in the drinking-water guidelines since research indicates that these chemical poses no health risk or aesthetic problems at the level generally found in drinking water.

WHO Guidelines for Drinking Water Quality: Chemical

Chemical	Maximum Level
pH	No health based value is proposed
Ammonia	No health based value is proposed
Antimony	0.02 mg/L
Arsenic	0.01 mg/L
Barium	0.7 mg/L
Boron	0.5 mg/L
Cadmium	0.003 mg/L
Chlorine (free)	0.5 mg/L
Chloride	0.7 mg/L
Chromium	0.05 ppb
Copper	2.0 mg/L
Cyanides	0.07 mg/L
Fluoride	1.5 mg/L
Iron	No guideline value proposed
Lead	0.01 mg/L
Manganese	0.4 mg/L
Mercury	0.006 mg/L
Molybdenum	0.07 mg/L
Nickel	0.07 mg/L
Nitrates	50 mg/L
Nitrites	3 mg/L
Silver	No guideline value proposed
Selenium	0.01 mg/L
TDS	No health based value is proposed
Uranium	0.015mg/L

(WHO, 2006)

Potential Health Effects

The effect of the contaminant on human health depends largely upon the type of contaminant, its concentration, the length and frequency of exposure. The user's age, physical health condition and immunity can also have a large influence on the resulting health effect. A list of chemical contaminants, the health impacts they pose, and potential contamination sources are provided in the following table.

Potential Health Impacts of Chemical Contamination

Chemical	Potential Health Effect from Ingestion of Water	Source of Contamination
Ammonia	Ammonia in drinking-water is not of immediate health relevance. No health based guidelines.	Sewage, wastewater disposal sites or animal waste for agriculture activities
Antimony	A skin disease which makes skin itching, and become sore, rough and broken (eczema and dermatitis can cause due to long and regular contact with antimony.	High concentrations of antimony may occur in acidic drainage from mining areas and active volcanic areas.
Arsenic	Skin disease (Melanosis and Keratosis), circulatory system problems, hypotension and vascular disease can cause	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes

Chemical	Potential Health Effect from Ingestion of Water	Source of Contamination
<u>Barium</u>	It is out of danger for health. The principal route of excretion of barium in humans is faecal. 20% is excreted in the faeces and 7% is excreted in the urine within 24 hours.	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Boron	It may indirectly influence bones and metabolism. Boron is very difficult to remove from water and is not usually encountered of high concentration.	Boron concentrations may commonly exceed drinking-water in ground water in areas with volcanic rocks.
Chlorine	The effects are not likely to occur at levels of chlorine that are normally found in the environment. High dose of chlorine irritates the skin, the eyes, and the respiratory system.	Monitoring is necessary; this would usually be at the treatment works.
Chloride	Several studies have suggested that the chloride ion may play a more active and independent role in kidneys function and nutrition	Chloride is widely distributed in nature, generally as the sodium (NaCl) and potassium (KCl) salts.
Chromium	No significant effects have been attributed to the ingestion of highly chromium contaminated drinking water	Most soils and rocks contain small amounts of chromium in different form
Cadmium	High dose of cadmium causes kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Calcium	There is no evidence of adverse health effects specifically attributable to calcium in drinking water	The concentration of calcium in water depends on the residence time of the water in calcium-rich geological formations.
Copper	Copper is an essential element in human metabolism. Although the intake of large doses of copper has resulted in adverse health effects, the levels at which this occurs are much higher than the permissible limit.	Copper and its compounds are widely distributed in nature, and copper is found frequently in surface water and in some groundwater.
Cyanide	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Erosion of natural deposits; discharge from fertilizer and aluminum factories; High concentrations of fluoride may occur in groundwater in areas with acid volcanic, sodium-rich (alkaline) igneous or volcanic rocks, and in some sedimentary and metamorphic terrains.
Iron	No health impact up to 2 mg/l does not have a hazard to health	Iron is generally present in surface waters as salts when the pH is above 7. Most of those salts are insoluble and settle out or are adsorbed onto surfaces
Lead	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits

Chemical	Potential Health Effect from Ingestion of Water	Source of Contamination
Manganese	No specific adverse health effect. As with iron, the presence of manganese in water may lead to the accumulation of microbial growths in the distribution system.	The weathering products of manganese deposits on the surface contribute only slightly to the manganese content of river and sea water.
Mercury	Long-term daily ingestion of approximately 0.25 mg of mercury as methyl mercury has caused the onset of neurological symptoms and kidney damage	High concentrations of mercury may occur in groundwater and surface water supplies in gold-mining areas where mercury has been used for gold extraction.
Molybdenum	High dose of molybdenum causes liver dysfunction and joint pains in the knees, hands and feet	It is a relatively rare element in the Earth's crust. High concentrations of molybdenum may occur in groundwater in mining areas where sulfide ores contains.
Nickel	Higher chances of lung cancer, nose cancer, birth defects, allergic reaction, heart disorders	Available in industrial waste (nickel plating). Monitoring is essential if specific source of pollution were known.
<u>Nitrate (measured as Nitrogen)</u>	Infants below the age of six months who drink water containing nitrate in excess could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Potassium	In healthy individuals, adverse effects due to potassium are unlikely. Potassium intoxication by ingestion is rare, because large single doses usually induce vomiting.	Potassium occurs in various minerals, from which it may be dissolved through weathering processes. A number of potassium compounds, mainly potassium nitrate, are popular synthetic fertilizers.
Sodium	No adverse health effect.	Compounds of sodium are widely distributed in nature. Weathering of salt deposits and contact of water with igneous rock provide natural sources of sodium
Total Dissolved Solids (TDS)	Although there are no direct health concerns, high concentrations may be objectionable through taste.	Primarily consists of inorganic salts. Erosion of natural deposits; runoff
Uranium	No evidence of harmful effects by the ingestion uranium in drinking water	Uranium is widely distributed in the geological environment but concentrations are high in granite rocks and sulphide minerals.
Zinc	No adverse health effect. Zinc is an essential element for the human growth.	Industrial and domestic emissions contribute a considerable quantity of zinc to the air and water environments.

(WHO, 2006)

Chemicals of Concern in Developing Countries

Arsenic

Arsenic is a naturally occurring, toxic element found in groundwater and is one of the greatest chemical problems in developing countries. High levels of arsenic can be found in water from deep wells

in over 30 countries. In south Asia alone, it is estimated that 60 to 100 million people are affected by unsafe levels of arsenic in their drinking water. Bangladesh is the most severely affected, where 35 to 60 million of its 130 million people are exposed to arsenic contaminated water.

The initial health effect of drinking arsenic contaminated water for a few years is melanosis. Melanosis is light or dark spots that show up on people's skin, often on the chest, back, or palm. Afterwards, keratosis and other lesions may occur. Keratosis is hardening skin bulges on palms and feet. Drinking arsenic contaminated water over the long-term may lead to lung, bladder, kidney, skin, liver, and prostate cancer. Arsenic is also known to cause vascular diseases, neurological effects, and infant developmental defects.

There is currently no effective cure for arsenic poisoning. The only prevention is to drink arsenic-free water.

Fluoride

Fluoride which comes from natural geological sources can also contaminate groundwater. The concentration of fluoride varies with the type of rock that the water flows through and a person's exposure depends mainly on where they live.

Small amounts of fluoride are generally good for our teeth. But at higher doses over time, it increases a person's risk of dental fluorosis where their teeth are destroyed by spotting and pitting. Eventually, chronic exposure to fluoride over the long-term increases the risk of skeletal fluorosis where it accumulates in the bones, leading to crippling skeletal damage.

Infants and young children are most at risk from fluoride contamination since their bodies are still growing and developing.

Nitrates and Nitrites

Nitrate and nitrite are naturally occurring compounds in the environment that are part of the nitrogen cycle. Nitrates are also used widely as fertilizers and nitrites are used mainly as food preservatives, especially in cured meats.

The nitrate concentration in ground water and surface water is normally low but can reach high levels as a result of leaching or runoff from agricultural fertilizers or contamination from manure or domestic sewage (WHO, 2006)

High levels of nitrate in drinking water can cause serious illness and sometimes death. The main health concern is methaemoglobinaemia, or blue baby syndrome, that occurs in infants that are usually bottle fed. Symptoms include shortness of breath and their skin turning blue due to the lack of oxygen. Blue baby syndrome can become severe when the infant's health rapidly declines over a few days (US EPA, 2006).

Lead

Lead contamination usually comes from human rather than natural sources. Lead pipes are still common in old houses in some countries, and lead solders have been used widely for joining copper tubing. Using lead pipes can result in elevated lead levels in drinking water, especially in areas with soft or acidic water (i.e. low pH). Whenever possible, lead pipes should be replaced to prevent contamination of drinking water.

Long-term exposure to low lead levels can cause adverse neurological effects, especially in infants, young children and pregnant women. Lead exposure is most serious for infants and young children because they absorb lead more easily than adults and are more susceptible to its harmful effects. Even low level exposure may harm the intellectual development, behavior, size and hearing of infants (Environment Canada, 2004).

Radioactive Materials

Radiation comes from both naturally occurring and human sources. The largest proportion of our exposure to radiation comes from natural sources. Radioactive materials in drinking water can come from:

- Naturally occurring uranium in underground rock that releases radon into ground water;
- Industrial processes that involve naturally occurring radioactive materials (e.g. mining and processing of mineral sands, or phosphate fertilizer production);
- Nuclear fuel cycles; and
- Improper medical and industrial use and disposal of radioactive material (WHO, 2006).

There is evidence that radiation exposure at low to moderate doses may increase the long term incidence of cancer. However, this type of hazard in drinking water is rarely a public health issue. No harmful health effects are expected from drinking water if the concentration of radionuclides is below the WHO guidance levels. Due to the low levels of radioactive materials typically found in drinking water supplies, acute health effects of radiation are also not a concern (WHO, 2006).

Checklist for Considering Water Quality

Determining the quality of the water source is vital to the long-term sustainability of your water project. The following questions should be asked before going any further with the planning of your water project.

1. What are the health issues in the community and are they related to the water supply?

- a. What are the health issues in the community to be served by the water project?

- b. Are any of these health issues caused by waterborne organisms, and if so, what?

- c. Are any of these health issues caused by organic inorganic chemical contaminants, and if so, what? _____

2. What are the health standards?

- a. Are there official health standards for water quality in the country? _____
- b. Do you have a copy of the standards? _____
- c. Who administers them? _____
- d. Does anyone monitor the health of the people in the community on a routine basis? _____

3. Are recent water quality analyses available?

- a. Are recent water quality analyses available and do you have a copy of them? _____
- b. Who analyzed the samples and are they a reliable laboratory? _____
- c. Is the laboratory identified in #9 available for your use in the future? _____
- d. What constituents are problematic as a drinking water supply? _____
- e. Do you know of an appropriate treatment technology for the community that would mitigate the contaminants of concern? _____
- f. If recent water quality analyses are NOT available, are you prepared to take samples from your intended water supply source?
 - Have you identified a reliable laboratory of the analyses? _____
 - Do they have sample containers for your use? _____
 - Has the lab showed you the proper way to take and store the samples required?

 - Have you taken precautions to check if the laboratory is “dry labbing” you (faking the analysis or making mistakes unintentionally)? This is done by submitting a sample of clean (bottled) drinking water or water for which you know the quality in advance. _____

4. Have you made arrangements to have the water supply periodically sampled and analyzed after the project is completed? _____ By whom? _____ How often? _____

OVERVIEW OF TREATMENT TECHNOLOGIES

Introduction

Rotary clubs that engage in water projects may feel overwhelmed by the technologies available today to treat water to drinking water levels. Probably the single most-asked question of Wasrag is, “What kind of treatment system/device should we use?” The answer to that question is not an easy one. It depends on many factors, including:

- a. What contaminants need to be removed?
- b. How much water needs to be treated per day?
- c. Is it to be used out in the community or in individual households?
- d. Does the system require higher pressure to operate?
- e. Does it require electricity to operate?
- f. Is more than one treatment step required, such as filtration followed by disinfection, to reach drinking water quality?
- g. Are local technicians available to operate and maintain the system?
- h. What can the community afford to operate and maintain?

These questions illustrate that there are no easy answers. In general, however, simpler is better than complex.

But, even though a technology may seem simple (or claimed to be so by the manufacturer), it may not operate as intended. For example, a membrane filter may be able to operate at low pressure, but in so doing, it does not have a small enough pore diameter to remove viruses and some bacteria; therefore, some sort of post filtration disinfection will be called for, like adding chlorine. Now the treatment process is more complex and is open to misuse by the end user because they ran out of chlorine or don't like the taste of chlorine. The result: Project Failure!!!

In the subsequent sections more detailed discussions are provided for the commonly used point-of-use water treatment systems: biosand filters, ceramic filters, and membrane filters. These sections are followed by a section of water disinfection. Read them carefully and weigh the simplicity of the technology to operate day-to-day, as well as in the long term against its cost and its acceptance by the community. If, after reading these technology overviews, the reader still has questions, seek out the “Ask an Expert” program at Wasrag’s website, www.StartWithWater.org.

Comparing & Contrasting Water Treatment Technologies

The following four pages provide an overview of the relative effectiveness of various household and municipal water treatment technologies. It is copyrighted by Program for Appropriate Technology in Health (PATH) (2010). Use of this document has been granted to Wasrag for educational or non-commercial purposes. Rotary thanks PATH for allowing it to use this excellent resource.

Global Landscape of Household Water Treatment and Safe Storage Products

Overview

Safe drinking water is essential to good health. However, in resource-poor settings, water often comes from unsafe sources and carries deadly pathogens. The World Health Organization estimates that 1.8 million people die each year from diarrheal diseases, many of which are attributed to unsafe water. Safe drinking water is one of the United Nations Millennium Development Goals—by 2015, the United Nations hopes to decrease the proportion of people without sustainable access to safe drinking water by 50 percent.

To increase access to safe water, PATH's Safe Water Project is exploring the potential for commercial enterprises to target low-income populations with household water treatment and storage (HWTS) consumer products. We are working to identify, adapt, and develop appropriate HWTS products and business models with the goal of enabling market-based forces to take on production, distribution, sales, and maintenance to low-income households.

The Safe Water Project is spending some of its efforts to catalyze changes within the HWTS product category, specifically to benefit low-income populations. We are continually assessing and reviewing the state of technology and research, as well as development activities aimed at producing HWTS products available in the developing world.

The matrix on the following pages portrays a global landscape of technologies both presently existing and under development by numerous researchers and manufacturers. The assessment is not weighted nor does the matrix provide

a final ranking value. The colors demonstrate an informed judgment based upon internal usability testing, field testing with users, outsourced laboratory testing, and published literature, especially for the parameters addressing public health impact and treatment efficacy. Overall, the matrix reflects the complexity of making choices regarding the use of HWTS in various geographies with variable source waters and user needs.



Wendy Stone

Technology assessment of household water treatment and safe storage (HWTS) products*

Analysis as of May 2010

- Parameter negative or with a higher level of concern
 Parameter strongly positive
 Parameter weakly positive or with moderate concern
 Insufficient information available

Household Water Treatment and Safe Storage (HWTS) Product† Description	Examples of Manufacturers and/or Advocates‡
Ceramic water pot + durable safe storage vessel	Potters for Peace; Potters Without Borders; International Development Enterprise (IDE); Rural Development Institute (RDI); Thirsting to Serve
Carbon block filter + bromine + durable safe storage vessel	HaloSource & Eureka Forbes Ltd. (AquaSure)
Carbon block filter + chlorine + durable safe storage vessel	Hindustan Unilever (Pureit)
Rice husk/ash filter	Informal market with support from academic institutions and nonprofit organizations
Rice husk/ash filter + silver treatment + durable safe storage vessel	Tata (Swach)
Higher-quality ceramic candles + durable safe storage vessel	Doulton; Katadyne
Lower-quality ceramic candles + durable safe storage vessel	Rama, Butterfly, OK Industries, Neelam
Higher-quality hollow fiber membrane (+virus)	Vestergaard Frandsen (LifeStraw Family)
Lower-quality hollow fiber membrane + carbon filter + durable safe storage vessel	Kent (UF Membrane Water Purifier)
Household biosand (slow-sand) filtration	Center for Affordable Water and Sanitation (CAWST); BushProof; Samaratin's Purse; HydrAid
High-quality hollow fiber membrane (+virus) + carbon filter	LifeSaver Systems (LifeSaver Bottle)
Chlorine (liquid—sodium hypochlorite) + durable safe storage vessel	WaterGuard, AquaGuard, Population Services International (PSI), Center for Disease Control and Prevention (CDC) Safe Water System
Chlorine (tablet—NaDCC)	Medentech (Aquatabs); Hydrachem
Coagulant/flocculant + disinfectant	Bishan Gari; Ion Exchange (Jalshudhi Water Purifier - Zero B); Thanh Mai; Nissei Trading Co.
Coagulant/flocculant + adsorptive ingredients + disinfectant	Proctor & Gamble (PUR)
Other natural coagulants/flocculants	Informal markets (moringa seeds, alum, prickly pear cactus); Kemira Kemi AM (alum); Nippon (polyglutamic acid)
Metal disinfectants (liquid and/or controlled release media)	AquaSalveo
SODIS or similar solar-based system	Swiss Federal Institute for Environmental Science and Technology (EAWAG)
Ceramic filtration via siphon pressure	Basic Water Needs (Tulip, CrystalPur)
Filter cartridge with brominated media	In research and development stage
Lower-quality ceramic candles + disinfectant + durable safe storage vessel	In research and development stage
Adsorptive media (nanotechnology) incorporated into filter element	In research and development stage
Core chlorination unit amendable to user-supplied durable safe storage vessel	In research and development stage
Chlorine (NaDCC) tablets + durable safe storage vessel	In research and development stage
Ultra violet (UV) light emitting diodes (LEDs)	In research and development stage
Household scale mixed oxidants—solar powered	In research and development stage
Ceramic filtration via siphon pressure + durable safe storage vessel	In research and development stage

* Cells without color indicate insufficient data to determine a ranking. Colors are not weighted and represent an informed judgement based upon internal user testing, outsourced laboratory results, user testimonials, and other sources.

† All products do not require plumbed water connection or mains electricity to treat water.

‡ Assessments for items labeled as "Research and development" are projections from available data and knowledge.

		Filtration	Adsorption	Disinfection	Bacteria	Viruses	Protozoan cysts	Protection against recontamination	Turbidity	Other contaminants	Evidence level of efficacy	Media toxicity	Quality control	Incorrect use	Technology readiness	Acceptability by user	Capacity of product	Acquisition cost	Maintenance costs	Uptake and continued use	Supply chain	Training and support
	Source of pressure	Treatment mechanism			Primary treatment efficacy			Other factors affecting treatment efficacy			Public health impact	Safety			Primary technology factors					Secondary technology factors		
	Gravity	✓																				
	Gravity	✓	✓	✓																		
	Gravity	✓	✓	✓																		
	Gravity	✓	✓																			
	Gravity	✓	✓	✓																		
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	Gravity	✓																				
	Gravity	✓	✓																			
	Gravity	✓																				
	Gravity	✓																				
	Gravity	✓																				
	Mechanical pump	✓	✓																			
OC)	Not applicable			✓																		
	Not applicable			✓																		
	Not applicable	✓		✓																		
	Not applicable	✓	✓	✓																		
id)	Not applicable	✓																				
	Not applicable			✓																		
	Not applicable			✓																		
	Siphon + gravity	✓																				
	Gravity			✓																		
	Gravity	✓		✓																		
	Gravity	✓	✓																			
	Gravity			✓																		
	Not applicable			✓																		
	Not applicable			✓																		
	Not applicable			✓																		
	Siphon + gravity	✓																				

sting in India, and published literature (primarily for public health impact and treatment efficacy).

Glossary

Term	Definition
Acceptability by user	Acceptability is a combination of reported and projected acceptability. Reported acceptability represents a limited subset of data (e.g., flow, function, maintenance, aesthetics) from both an informal user testing study in India and an extended user testing study (product placement inside households) in Andhra Pradesh, India. Projected acceptability represents in-house testing of numerous factors including, but not limited to, product assembly, cleaning procedures, maintenance procedures, flow rate, and filling and dispensing procedures.
Acquisition cost	To compare fast-moving consumer goods or FMCGs (sachets and/or small bottles of consumable treatment products) against durable goods, acquisition cost was compared between an FMCG-calculated cost for a four-month period against a durable good because many durable goods require replacement components starting at four to six months into product life.
Adsorption	The process by which molecules collect on the surface of another substance, which is also referred to as surface adhesion. The adsorptive capacity is highly dependent on surface area. Adsorptive affinity is a function of charge density.
Capacity of product	The capacity of product is representative of the volume of water treated before replacement components are required due to expired media, breaking clogged pores, or other factor.
Coagulation-flocculation	The process is defined as one in which coagulants destabilize (offset the charge) the colloidal mixture while the flocculants aggregate/clump. The process is followed by sedimentation (settling by gravity) and/or filtration to remove the aggregate material.
Disinfection	Disinfection methods include thermal/heat, chemical, and/or irradiation processes.
Evidence level of efficacy	The term is intended to include products with demonstrated and documented (e.g., Health Impact Study) reductions in disease burden (e.g., diarrheal disease or helminthic infections) the product is within a shared technology class/group with documented public health impact (e.g., health impact or epidemiological study).
Filtration	Filtration includes mechanical, membrane/gradient, and/or biological filtration methods.
Incorrect use	Incorrect use is an assessment of the likelihood of and implications for incorrect use of the technology and all components.
Maintenance costs	The assessment of ongoing costs (maintenance costs) includes the frequency and cost of replacement parts due to media exhaustion, clogging, or breakage.
Media toxicity	Media toxicity is noting whether or not a potential risk exists or could exist for the introduction of toxicity by the technology to the consumer's drinking water due to the use of media for treatment.
Membrane filtration	The process of membrane filtration includes those methods that utilize pressure, electrical potential, and concentration gradients to remove dissolved constituents and colloidal materials. Membrane filtration includes no pressure (forward osmosis), low-pressure (microfiltration and ultrafiltration), and high-pressure (nanofiltration and reverse osmosis) systems.
Other contaminants	The technology is capable of addressing non-microbiological contaminants such as fluoride, arsenic, nitrates/nitrites, volatile organic carbons (VOCs), or other contaminant of concern.
Protection against recontamination	Recontamination of treated water with microbial contaminants is mitigated by the use of chemical residual or inclusion of a safe storage container or other protective barrier/agent.
Quality control	Both quality-control and quality-assurance practices are noted for manufacturers, whether large commercial entities or smaller artesanal groups.
Supply chain	Assessments of supply chains included barriers to transportability (volume, fragility, weight) as well as availability.
Technology readiness	Technology readiness includes commercial availability, manufacturing capability/capacity, and the stage of research and development (R&D).
Training and support	The training and support analysis depicts the level of training and/or support needed to operate the technology correctly, including assembly, cleaning, and maintenance.
Turbidity	Turbidity is cloudiness or opacity in the appearance of a liquid caused by solids, particles, and other pollutants. Turbidity measurement is typically done in either nephelometric units (NTUs), formazin turbidity units (FTUs), or visible height using a disk or tube (translated into approximate NTUs or FTUs through a table). The measurement provides an indication of the clarity of water and serves as a proxy for water quality.
Uptake and continued use	The assessment included a search for the demonstrated uptake (published literature, anecdotal evidence, observational evidence, etc.) and continued use by persons within the base of the (economic) pyramid (BoP) segment. According to the World Resources Institute and depicted in the World Economic Pyramid, the persons at the BoP consist on those populations (~4 billion people) living on less than \$2 per day per person for more than 50 years and represent the "survival market."

BIO-SAND FILTERS

What Is A Biosand Filter?

Biosand filters (BSF) are an adaptation of traditional slow sand filters - a centuries old technology for community water treatment. Slow sand filters are typically large, 1 to 2 meters (~3 to 7 feet) deep, and use a column of sand with a thick biologically active layer to remove suspended solids and undesired impurities. Water percolates slowly and continuously through the sand while microorganisms growing in a bacteriological purification zone remove harmful pathogens.

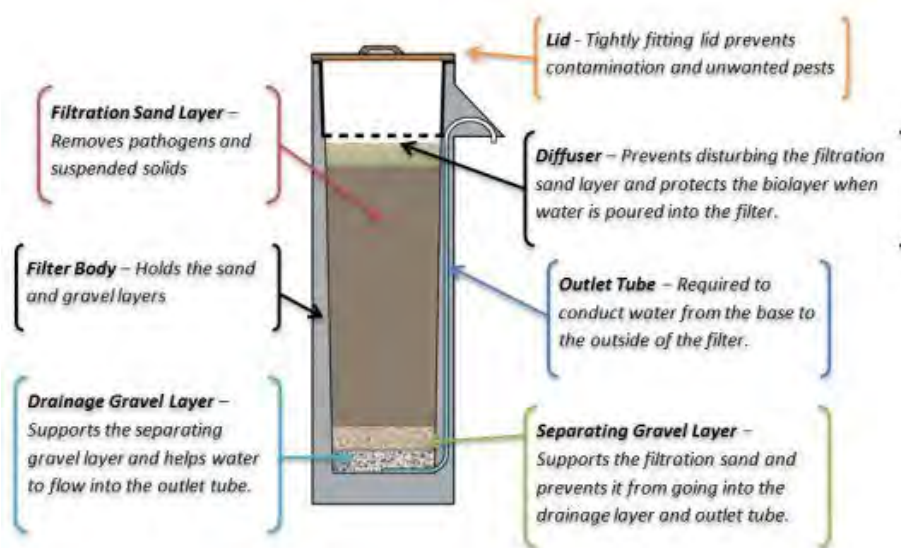
BSFs are smaller, household-scaled filters, which are adapted for intermittent non-continuous use so they are suitable for 'point-of -use' service. Like slow sand filters, biosand filters are non-pressurized, do not need electricity, or chemicals to operate. Compared to other point of use systems (such as chlorination or solar disinfection), BSFs are easier to operate, harder to misuse, and less expensive, which makes them a good alternative, especially in developing countries.

What Are The Components Of A Biosand Filter?

Most biosand filters consist of similar components. The filter container can be made of concrete, plastic or any other water-proof, rust-proof and non-toxic material.

At the top of the filter there is a tightly fitted lid to prevent contamination and unwanted pests from entering the filter. Below the top reservoir is a diffuser plate to prevent disturbance of the filtration sand layer and protect the biolayer when water is poured into the filter.

Next is the filtration sand layer of cleaned and sieved fine sand. This size and depth of this layer is important and has been determined over 10 years of empirical experimentation in field use. The sand should be 0.7mm (0.027 inches) or smaller, and 543mm (21-1/2 inches) deep.



The next layer is support gravel of 6mm (1/4 inch) diameter, and 50mm deep (2 inches).

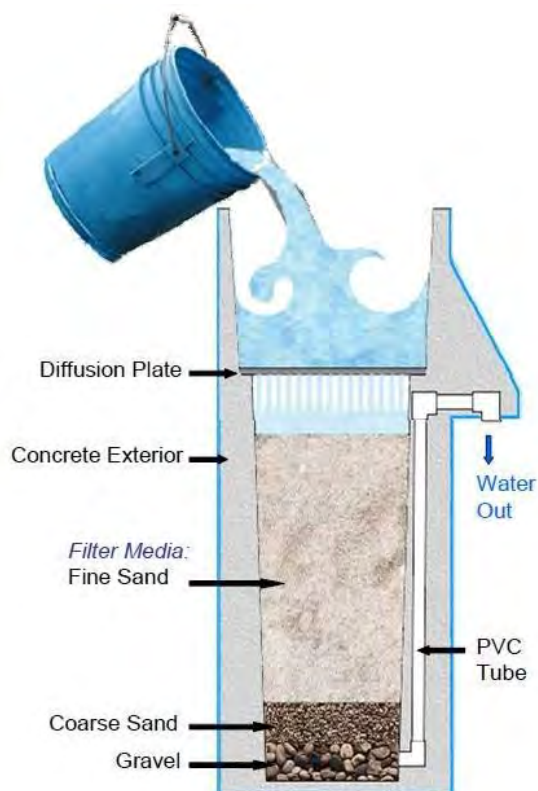
The bottom layer is drainage gravel of 12mm diameter (1/2 inch), also 50mm (2 inches) deep.

The outlet tube standpipe is built so that the drain height is about 50mm (2 inches) above the sand level. This assures a water depth over the filter column to keep the filter wet, but shallow enough that oxygen from the air can diffuse to the biologically active layers and keep them alive and active.



How Do You Use A Biosand Filter?

Once set up and in operation, you simply pour a bucket of raw water into the top of the filter. Water flows through the filter and is collected in another bucket or container at the base of the spout. Flow rate through the filter will slow as the water level in the inlet reservoir drops and lowers the pressure head, and it normally takes some minutes for the entire bucket to make its way through the filter. There are no valves or moving parts and the design of the outlet system ensures that a minimum water depth of five centimeters (2 inches) is maintained over the sand when the filter is not in use.



How Much Water Does A Typical Filter Treat?

Depending on the size of the unit, a typical household biosand filter holds about 12 to 15 liters (3 to 4 gal.) of water and can be flushed with raw water up to 4 times per day. The optimal rate water to flow through a BSF is about 0.7 liters/min (about 3 cups/min.), so it usually takes about 20 minutes for a full flush of water to work through the filter. With four flushes per day, a BSF can treat 48 to 60 liters/day (12 to 16 gallons/day), which is sufficient to supply clean drinking water for a family of 4 or 5 each day. A BSF can be flushed more often, but filtration efficiency and pollutant removal decreases. With normal use, the flow rate will decrease over time as the filter becomes clogged, but can be restored with cleaning (see below).

How Does A Biosand Filter Work?

Pathogens and suspended material are removed from water through a combination of biological and physical processes:

1. **Mechanical trapping, or filtration.** Sediments, cysts and worms are removed from water by becoming trapped in the spaces between sand grains.
2. **Adsorption** or attachment: Viruses can be adsorbed, or become attached to sand grains. Once attached, they are metabolized by organisms in the filter or are inactivated by antiviral chemicals produced by the biologically active layer. Certain organic compounds are also adsorbed in the sand and removed from the water.
3. **Predation - BIOLAYER:** Bacteria and other pathogens in the water are consumed by microorganisms in a gelatinous biofilm that is formed in the top few millimeters of fine sand during the first 10–20 days of operation. This biological layer consists of [bacteria](#), [fungi](#), [protozoa](#), [rotifera](#) and a range of aquatic insect larvae. As the biolayer ages and grows, more algae tend to develop and larger aquatic organisms may be present including some [bryozoa](#), [snails](#) and [Annelid](#) worms. In the scientific literature, this biolayer is called a '*schmutzdecke*' - the German word for 'dirty layer'. The biofilm layer merges with deeper fine sand in a continuing zone of biological activity where other microorganisms also help to consume and trap other microorganisms. However, bacterial activity is most pronounced in the upper part of the filter bed, and gradually decreases with depth as oxygen and food becomes scarcer to sustain life.
4. **Natural death:** Food scarcity for pathogens, combined with sub-optimal temperatures and the relatively short life span of most pathogens, causes them to die off and become nutrients for other micro-organisms. Most pathogens prefer temperatures close to body temperature (37°C, or 98.6°F), and do not thrive at temperatures below about 30°C (86°F).



How Well Does A Biosand Filter Work?

Under ideal circumstances, a well-managed Biosand filter can produce drinking water of exceptionally good quality. BSFs have been shown to remove 5.00-64.00% of heavy metals such as iron, and ~95% of turbidity, 98.5% of bacteria, 99.9% of protozoa, as well as reducing viruses. BSFs also help to reduce discoloration, odor, and unpleasant taste. Studies have also shown a decrease in the occurrence of diarrheal disease of up to 40%, and an increase in general health correlated with the use of BSFs.

However, optimal performance cannot always be assured or guaranteed due to variations in the construction, installation, and maintenance of a filter. These filters do not sufficiently remove dissolved compounds such as salt and fluoride, or organic chemicals such as pesticides and fertilizers. If a water source is contaminated with organic and inorganic industrial and agricultural toxicants, Biosand filtration by itself is not the best appropriate water treatment technology. And BSF's do not remove the smallest viruses, so it is often recommended that a small amount of Chlorine be added to the outflow collection bucket.



How Long Does A New Filter Take To Start Working Well?

The biofilm and biological zone typically develop within two to three weeks. It may take up to 30 days depending on the temperature and the biological content of the raw water. The filter will require daily fillings during the biofilm growing period, but water from the filter can be used during those first few weeks while the biolayer is being established if a safer water source is not available. However, chlorination to kill pathogens in the water taken out is recommended at least during this time period.

Later, after the filter has been in use over time, the flow rate may decrease as the biolayer becomes too thick and dense, requiring periodical maintenance or cleaning (see Cleaning below).

How Do You Keep A Biolayer Working?

Biofilm effectiveness relies on the following critical points:

- A constant wet environment with pretty consistent water flows
- Sufficient food to keep the biolayer active
- Oxygen for the biolayer microorganisms
- proper temperature, not freezing nor too hot



The biolayer is thin, only about 1cm, (1/2 in.) thick, and to survive and thrive it needs water, oxygen, and food. So to keep the filter working at its best, the filter needs to be used as consistently as possible

without large or frequent variations in operation and raw water supply. Raw water has to be fed in intermittently with a fairly consistent daily regimen. For most commonly sized units this means at least one 5 gallon (20 liter) bucket of water should be added over a day's time with a minimum pause period of 1 hour, and a maximum of 48 hours, between large feedings.

Why Is A Pause Period Between Water Feeds Important?

A pause time, or idle period, is needed to allow time for the micro-organisms in the biologic layer to consume pathogens contained in the water. Biosand filters are most effective and efficient when operated intermittently and consistently. Typically, idle time amounts for more than 80% of daily use time. A pause period of 6-12 hours is a suggested time, with a minimum of 1 hour and a maximum of 48 hours after a charge of water has stopped coming out the outlet tube.

If too much water is fed in too quickly, filtration will be insufficient since a big load of contaminants takes more time to be 'eaten up', and some contaminants will pass through. However, if the pause period is extended for too long, microorganisms will eventually consume all of the food supply and die off reducing the filter's treatment efficiency when it is used again.

Temperature Restraints

Filtration and pathogen removal depends on the health of the biolayer which needs to be protected from near freezing temperatures. Temperatures below about 6° Celsius (43° F) start to hurt performance, and an alternative water treatment method will be required below 2° Celsius (36° F).

What Other Limits Are There On Biosand Filters?

Turbidity, or muddy water. Biosand filters are not able to handle high turbidity - greater than 50 NTU (see next paragraph). In some locations BSF's may become clogged and ineffective during monsoon or rainy seasons. High amounts of suspended particles present in the turbid water settle in the top sand layer causing a rapid loss in flow rates. Turbidity also requires the filter to be cleaned frequently which involves disturbing the biological layer and leads to delays in putting the filter back into service.

Turbidity Measurement: Nephelometric Turbidity Unit (NTU). For most water treatment use, Turbidity is measured in NTU. Water with 1 mg. of silica in 1 liter has an NTU measurement of 1. Most North American water standards call for portable water to have a measurement of 1, and certainly less than 5 NTU. If the raw water turbidity is greater than 100 NTU, the water should be pre filtered before it goes through the biosand filter. A simple test to measure the turbidity is to use a 2 liter clear plastic soft drink bottle filled with water. Place this on top of large print. If you can see it, the water probably has a turbidity of less than 50 NTU.



How Do Users Misuse A BSF And Stop It From Working Well?

- Let it freeze.
- Never clean it properly (see below), or use wrong cleaning procedures.
- Run much more water through it than the maximum good operating rate.
- Let it dry out, or stop feeding in water regularly. In this case the biolayer may be rejuvenated by resupplying the influent water on a daily basis and letting the biolayer get reestablished.

- Introduce chlorine down through the filter box. This will kill the active biolayer. If this happens, the sand and gravel have to be removed from the BSF box, the box needs to be cleaned out and new sand and gravel installed. However, chlorine can be used to clean the outlet by careful use as described in the web linked PDF noted in the cleaning section below.
- Clean the sand too aggressively. If a user aggressively digs up the fine sand while cleaning, the biolayer will be inoperable. In this case, the biolayer may be restored by letting the top layer of sand settle down for a day or two and then start over with influent water and the 2 to 3 week period to establish a biolayer. However, the BSF cannot be allowed to dry out during this time period.

Why Does A Biosand Filter Need Cleaning?

Eventually the surface of the sand in the filter will become plugged, particles will accumulate in pore spaces between sand grains, and water flow will decrease to less than 0.1 liter/min (about 1/2 cup/min).

Time between cleanings will also greatly depend on the amount of turbidity in the raw water that comes from particulate sources - whether organic or mineral material. If the raw water is relatively clean (turbidity less than 30 NTU), many users run for several months without cleaning.

Both time needed to clean a filter, and the effect on performance, is minimal provided cleaning is performed in a correct fashion. A BSF may be cleaned as often as required without negatively impacting filter performance. Deep cleaning or "Harrowing" should not be practiced on a biosand water filter (see below),

What Is "Harrowing" And Should It Be Used To Clean A Biosand Filter?

Harrowing is a cleaning process used in larger slow sand filters and involves lowering the water level to just above the biolayer, and vigorously stirring the sand to suspend any solids held in that layer and then running that water to waste. Although Harrowing is suggested by some proponents of biosand filtration. Dr. David Manz of the University of Calgary who developed this technology and who invented the BSF, is adamant that harrowing not be used for a BSF since the biolayer would be disrupted.

How Is A Filter Cleaned And Maintained?

Biosand filters slowly lose their performance as turbidity is deposited and as the biolayer grows and reduces the rate of flow. Eventually it is necessary to clean the filter. Time between cleanings will depend on the amount of turbidity in the source water, but the impact of cleaning the filter on performance is minimal provided cleaning is performed in the correct fashion. A simple stirring or skimming of the top layer of sand, called "Swirl and Dump," is usually sufficient to restore optimal flow.

Step by step detailed instructions in a PDF format on cleaning a BSF can be found at:

<http://www.manzwaterinfo.ca/documents/guidance/BSF%20Maint%20and%20Cleaning%20Jan%202009.pdf>

The basic steps are:

- Add water, remove lid and diffuser
- Agitate the sand surface to about 1/2 cm (1/4 inch) with fingers or a small brush
- Let the sand settle
- Decant the messy water with a cup or ladle



- Reassemble the unit

Every year (or several months, depending on the turbidity of raw water), a more thorough cleaning and 'scraping' and washing of the top 5 cm (2 inches) of sand might be required. After this process, the filter will need time to reform its biolayer before it is fully active once again.

Proper BSF maintenance does require some training and attention. Inefficient filtration can be caused by user error, and/or failure to wait until the biolayer is re-established.

Also note that the outlet, lid and diffuser should be cleaned regularly. The outlet especially should be kept clean using soap and water, or a chlorine solution.

How Many Biosand Filter Units Are In Use Globally?

Researchers reporting in Water Research, have estimated that well over 300,000 BSFs are in use worldwide.

What Is The Expected Lifespan Of A Biosand Filter?

The estimated lifespan is 30+ years. Existing filters are still performing satisfactorily after 10+ years. Lids and diffusers may need replacement more often.

Are There Controversies And Conflicting Claims Regarding Biosand Filters?

Some well-meaning writers have extrapolated the optimal flow rates (0.7 liters/min., or about 3 cups/min), for a normal sized filter, and calculated that a single filter could process 30 liters/hour (8 gal/hr) all day long, or as much as 285 liters/day (75 gal) with nearly 20 flushes a day. As noted above, a user could not push that much water through a BSF without very dramatically decreasing the quality of the outlet water.

Microbiological and chemical studies have confirmed that four flushes of 12 to 15 liters (3 to 4 gal) evenly spaced over a day will optimally produce 48 to 60 liters (12 to 16 gal) per day - a far cry from 285 Liters/day.

If greater quantities are needed, a user will have to install multiple units.

Another area of controversy between providers of advice and equipment is with the cleaning methods, as noted above. Again, scientific and evidence based results in practical field use have shown that the "Swirl and Dump" method is superior overall to "Harrowing" methods, and is more easily learned and maintained by end users.

There are also natural conflicting claims for superiority between manufacturers and suppliers of filter designs and hardware, but in general the engineering and scientific community agrees that - while each may have some definite advantage or disadvantage in a specific region or application - the various filters do work pretty much the same and give essentially the same microbial reduction performance. A review of available filters follows.

Who Are The Major Suppliers Of BSF Units?

There are three major suppliers of BSF boxes: Aqua Clara International; CAWST; and HydrAid, in addition to several minor suppliers (see also tivawater.com). Each of these BSF boxes has unique



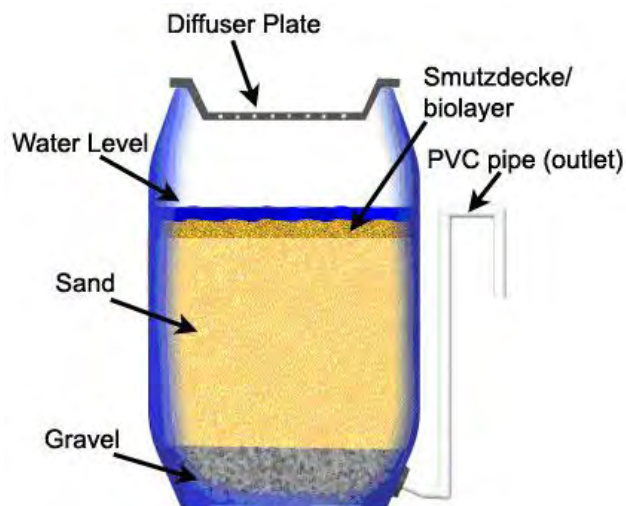
characteristics and costs; however, once filled with sand and gravel, they essentially work the same, and produce about the same amount of filtered water per day.

The individual characteristics and differences between each of the major BSF boxes are discussed in the following paragraphs:

Aqua Clara International (ACI) [aquaclara.org]

The ACI concept is to build BSF units from PVC pipes or plastic barrels, "whatever type is locally available in the village". However, in addition to a plastic barrel and PVC piping, fittings and gaskets are needed to complete the assembly of the BSF.

These BSF boxes may be tall and thin or short and fat, however they need sufficient depth of sand and gravel to adequately filter water; that is, the standard depth of sand and gravel, as discussed above, has to be maintained for effective operation. The sand and gravel has to be locally available, preferably from a nearby quarry, and then sieved to the required three sizes and washed, as needed.



The advantages of the ACI BSF are:

1. The BSF box is relatively inexpensive and can be produced in villages, as needed;
2. A local industry may be formed to produce them and train people on their proper operation;
3. The BSF is light in weight, so the BSF boxes can be easily transported using mules to difficult sites, such as remote villages.

The disadvantages of the ACI BSFs are:

1. There is a potential for a leak to occur if a proper seal is not maintained where the discharge line exits from the bottom of the plastic filter box, especially if the chosen plastic is brittle;
2. Manuals and specification for the size and depth of sand and gravel are not available on the company's web site, but can be obtained upon request.

Centre for Affordable Water & Sanitation Technology (CAWST) [cawst.org/]

CAWST, located in Calgary, Canada, was the organization founded by the original developer of household BSFs, Professor David Manz of the University of Calgary. The CAWST BSF box is made of concrete using a steel mold (form). Details on how to construct this mold is presented in the CAWST BSF Manual, which can be downloaded from their web site. CAWST does not produce or install BSFs in developing countries, but is a teaching organization. They conduct BSF workshops not only in their headquarters in Calgary, but in developing countries throughout the world.

The advantages of CAWST's concrete BSFs are the following:

1. The organization has a track record of 10 years, with over 300,000 of their BSFs installed in numerous countries around the world.



2. CAWST provides extensive and complete manuals that can be downloaded for free from their webs site.
3. Their design, particularly the depth and sieve sizes of the recommended sand and gravel currently for their BSF Version 10, has been fined tuned to ensure that the highest level of water quality is obtained.
4. A local industry can be developed to produce the concrete BSFs and sell them at a profit.

The disadvantages of the CAWST BSFs are cost and material availability.

1. Their heavy weight: The empty concrete filter box weighs 95 kg (209 lbs), which makes transportation to remote sites difficult and expensive.
2. Since the concrete BSF box does not contain reinforcing bars or chicken wire, it can be rather fragile and break if transported over rough terrain.

HydrAid [hydraid.org]

Unlike the BSFs of Aqua Clara International and CAWST, whose BSFs are constructed at the user site, the HydrAid BSF is a plastic box, constructed in Grand Rapids, Michigan, by Cascade Engineering and distributed by Triple Quest. HydrAid has an agreement with the U.S. Navy providing that if a filter is purchased and shipped to San Diego, California, the U.S. Navy will forward ship them for free to selected ports around the world.



The advantageous of the HydrAid BSF are:

1. They are light weight and are made of a very sturdy plastic, which travels well;
2. They have a very attractive appearance as compared with the CAWST type concrete BSF and the various plastic barrels of Aqua Clara International;
3. Extensive manuals are available on the HydrAid web site.

The disadvantages of the HydrAid BSF are:

1. They are expensive - it cost \$1,000 to have 15 of the HydrAid plastic boxes, complete with the sieved and washed sand and gravel, shipped from Grand Rapids, Michigan, to the U.S., Navy in San Diego, California;
2. The recipient country must have a port that is friendly to the U.S. and can accommodate and allow a U.S. Navy ship to dock there;
3. It may be necessary to pay import duty and tariffs for the BSF boxes to enter the country (in Kenya the tariff is 16%);



- There may be transportation costs from the country's port of entry to the village where the BSF units are to be used.

Other web sites of interest:

- http://en.wikipedia.org/wiki/BioSand_Filter
- <http://www.biosandfilter.org/biosandfilter/index.php/item/229>

SUMMARY OF BIOSAND FILTERS

MANUFACTURER	CAWST	AQUA CLARA INT'L	HYDRAID
Web Site Link	http://www.cawst.org/	http://aquaclara.org/	http://www.hydraid.org/
NGO Location	Calgary, Canada	Holland, Michigan	Grand Rapids, Michigan
Filter Box Type	Concrete Box	Plastic Barrel--various sizes	Plastic Barrel--one size
Manuals Available	On Web Site	Available from ACI	On Web Site
Flow Rate: Liters/min	0.7	0.8 to 4.0 depending on size	0.7
Manufacturing Site	ON SITE	ON SITE	CASCADE ENGR., MI
Aprox Sand & Gravel Cost	\$38 (as seen in Honduras)	Varies depending on size	15/\$1,000 Delivered to San Diego = \$67.00 each
Weight without sand & gravel (kg/lb)	95/209	Varies depending on size	3.6/8
Weight with sand & gravel (kg/lb)	155/340	Varies depending on size	63.5/140
Transporting BSF	Heavy & fragile concrete	Light plastic	Light plastic
Media Sizes			
Lower Drainage Gravel	6 - 12mm (1/4" - 1/2")	Similar to CAWST	Pre-sieved and washed color
Support Gravel	0.7 - 6mm (0.03 - 1/4")	Similar to CAWST	coded sand & gravel bags are
Sand	<= 0.7mm (0.03")	Similar to CAWST	supplied with the biosand filter box
Media Depths			
Lower Drainage Gravel	50mm (2")	Similar to CAWST	Pre-sieved and washed color
Support Gravel	50mm (2")	Similar to CAWST	coded sand & gravel bags are
Sand	543mm (21.4")	Similar to CAWST	supplied with the biosand filter box
Ease of Maintenance	Swirl & Dump	Swirl & Dump	Swirl & Dump
Ergonomics of Use	Heavy to move	Light weight when empty	Light weight when empty
Expected Service Life	10 years+	10 years+	10 years+
Ease of Rejuvenation	Moderate	Moderate	Moderate
Best Choice for Rotarians	1st Choice unless weight is a consideration	2nd Choice	3rd Choice
NOTES	See Note #1	See Note #2	See Notes #3 and #4

NOTE 1: Sand & Gravel from local sources must be sieved and washed on site.

NOTE 2: Sand & Gravel can be provided by ACI or sieved and washed on site.

NOTE 3: HYDRAID delivered to San Diego, CA can be shipped to many ports in the world by the US Navy.

NOTE 4: HYRAID provides the sand & gravel, which is shipped with the plastic boxes from Michigan

CERAMIC FILTERS

What Is Ceramic Water Filtration?

The word "ceramic" comes from the Greek word *keramikos*, for pottery. Ceramic water filtration uses porous ceramic (fired clay) to filter microbes or other contaminants from drinking water. This method relies on small pores in the ceramic material that allow water to pass through while stopping unwanted material and bacteria on the surface and within the porous filter.

In general, the smaller the pore size of a filter - and the more complicated the path the water takes through the ceramic medium - the more effective it is at removing particles from water. Ceramics can be manufactured with a small and complex pore structure, making them an ideal filter medium.

Ceramic filtration technology, is a proven household water treatment and safe storage (HWTS) method, and is considered among the most promising options for developing countries.

This document summarizes the key characteristics of the ceramic filtration process and provides perspective on the costs, efficacy, major suppliers and other issues of likely interest to potential users and buyers.

Is This New Technology?

No. Ceramics started to become widely used for the filtration of drinking water in the early 19th century. Cholera and typhoid epidemics were a common occurrence in London, and in 1835, Queen Victoria

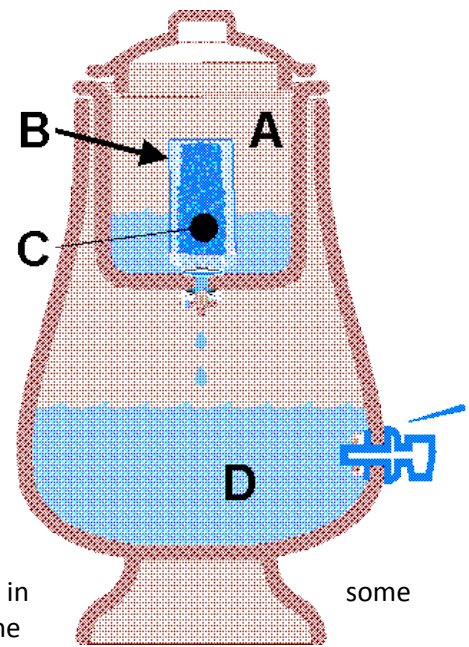
commissioned the Dalton Company to produce water purifiers for the Royal household. They created a gravity fed stoneware fitted with a clay filter element for bacteria removal.



What Are The Components Of A Ceramic Filter?

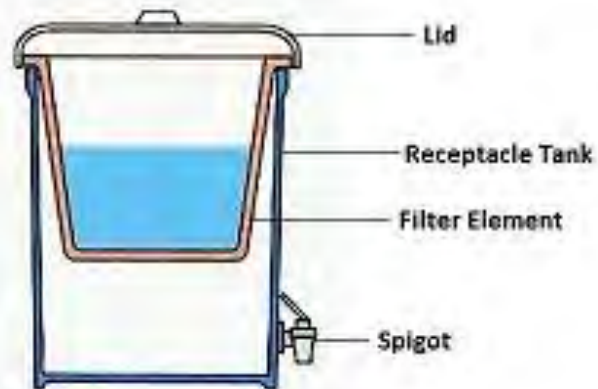
In most commercially produced household filter units, there is an upper reservoir (A) into which the user pours raw water. Water then passes by gravity through the ceramic filter element (B) and also in many commercial units, through an internal activated carbon inner filter element (C) before falling into a lower reservoir of treated water (D).

The ceramic filter element is usually 'candle' shaped, but can also be manufactured in a variety of disk or semi-spherical shapes. Candle shaped elements are hollow which can allow addition of an inner charge of activated carbon (see below). The bottom of the element is fused to a small threaded pipe, which with appropriate fittings seals the element to the upper chamber. This configuration allows the filter to be easily removed for cleaning or replacement, and in also allows the user to change the charge of activated carbon within the ceramic 'candle.'



Clay 'Pot' Filters

Over the last few decades, several simple design ceramic filter types have been developed that can be manufactured locally in developing areas using local facilities and labor. These have a flowerpot shaped filter element made from a porous ceramic material. Water poured into the filter percolates through the pot material, and is collected in a second container.



There are many variations of these ceramic filters: some are made entirely from ceramics such as the Potters for Peace filters (see supplier section below), some have a ceramic pot hanging in a plastic container such as Filter Pure (Agua Pure, see below). Frequently, a colloidal silver coating is added to the ceramic filter. Some ceramic pot filters also include activated charcoal in the clay.

How Are Ceramic Filter Elements Made?



The starting point for a ceramic filter is clay. Many glassy white commercially produced filters are made from diatomaceous earth, a geological clay formation formed millions of years ago from single celled algae deposited on the bottom of ancient lakes and lagoons.

Other locally produced filters start with local clay. The makers look for a smooth, plastic clay, and mill and sieve it to remove impurities such as sand and organic material. Then they mix the clay with a pulverized combustible "burn out" material like sawdust, peanut shells, wheat flower, or rice husks before forming it into the desired shape. The dried clay form is then fired in a



kiln at high heat to vitrify the material. During firing, mixed-in material burns out leaving fine pores and microscopic channels through the finished ceramic element.

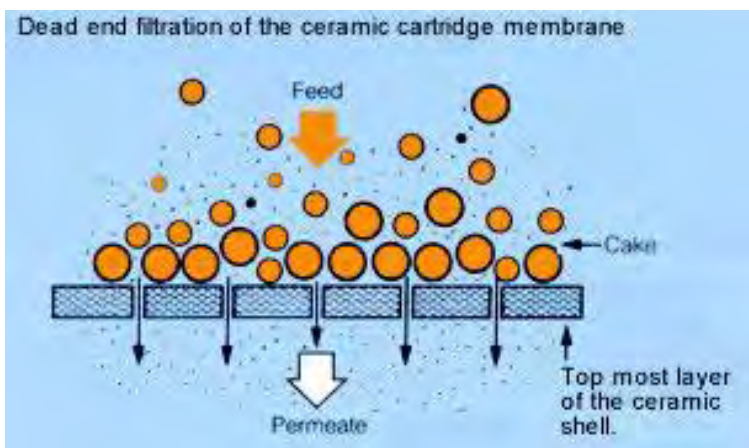
A very detailed 187 page document on manufacturing ceramic pot filters can be found at:

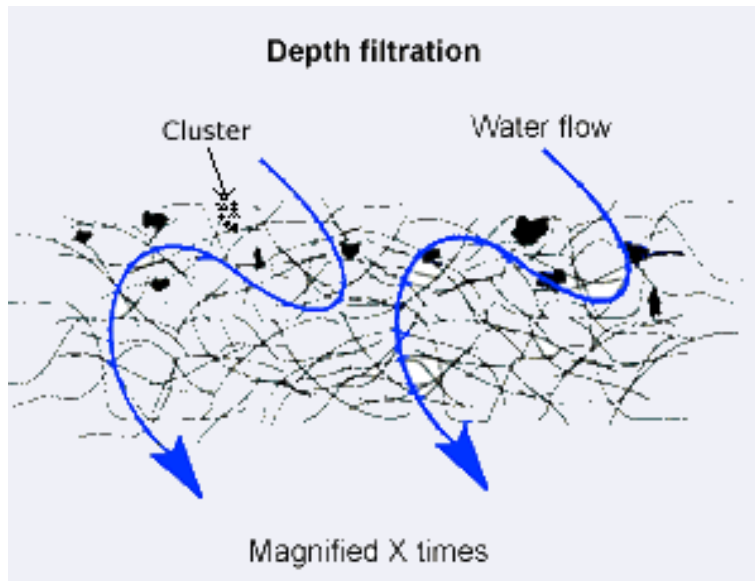
<http://waterinstitute.unc.edu/media/Best%20Practice%20Recommendations%20for%20Manufacturing%20Ceramic%20Pot%20Filters%20June2011.pdf>.

How Do Ceramic Filters Work?

Ceramic filters work with a combination of "dead-end filtration" and "depth filtration."

Dead end filtration works when a particle in the raw water runs into a filter surface pore that is smaller than the particle itself. Particles can also be intercepted when they 'bridge' across a pore adhering to each other. Bridged particles might not plug the pore, creating even smaller pores and gradually forming a "filter cake" which creates finer filtration, but also decreases the flow rate through the filter.





Source: Doulton USA, <http://doultonusa.com/HTML%20pages/technology.htm>

Depth Filtration happens inside the filter element when particle laden water has to navigate through the intricate maze of twists and turns within the ceramic material.

Flow paths have to follow a complicated labyrinth of sharp angles and jagged pores, and particles that may have penetrated the topmost filter layers become trapped within the structure.

Other effects occur as particles combine with other particles to form clusters large enough to become trapped as a group, and some particulate material becomes chemically attracted to the filter material and is adsorbed

Why Add Silver To The Treatment Process?

Given favorable conditions, bacteria could accumulate and grow on and in a filter unless prevented by some means. To primitive life forms, silver is as toxic as the most powerful chemical disinfectants. And since it is relatively harmless to mammals, silver has great potential as a disinfectant.

Free silver ions (Ag^+) have a toxic effect on micro-organisms even in relatively low concentrations and provide a highly fungicidal, bactericidal and algacide effect. Medical studies describe silver ions as a catalyst that disables the enzymes that microorganisms depend on to "breathe."

How Is Silver Added?

Some commercially produced candle filter elements are manufactured with a small amount (about 0.07%) of pure silver added into the clay mixture before forming and firing. Some of the non-commercial pot filter makers also add colloidal silver diluted in water or silver nitrate to their dry clay mixture. Others dip the fired filter element in a silver solution, or brush it onto the surface.

What Is 'Activated' Carbon, And Why Add It?

Ordinary charcoal has a very porous surface, and is a very effective material to capture and remove some taste, odor, and color causing chemical constituents in raw water. 'Activated' carbon is even more effective. Activated carbon is heat processed to be riddled with small, low-volume pores that greatly increase the surface area available for adsorption and chemical reactions. Due to the high micro porosity, just one gram of activated carbon has a surface area in excess of 500 sq. meters (or 2.5 million

sq. ft. for one pound). Carbon can be obtained from a variety of sources such as coconut shell, wood or coal, and all of which are readily available practically everywhere in the world. The activation process is also quite simple and can be done with an industrial oven.

How Effective Are Ceramic Filters?

How effective any ceramic filter is at removing bacteria, viruses, and protozoa depends on the production quality of the ceramic filter, and the uniformity and size of its pores. A well-made ceramic filter can have pore sizes small enough to remove virtually all bacteria and protozoa down to 0.2 microns (μm), yielding treated water with up to 99.99% less *E. coli* versus untreated water. A 60-70% reduction in diarrheal disease incidence has been documented in users of these filters.

Most bacteria have nominal sizes of 0.2 microns to several microns. One micron is equivalent to 1/1000 of a millimeter. A millimeter is 1/1000 of a meter. Although most ceramic filters are effective at removing bacteria and the larger protozoa's, they are not good at removing viruses. Viruses, which can also cause various health problems, have dimensions far less than 0.2 microns and must be dealt with separately, by other disinfection means (chlorine, etc.). Also, since use of a filter alone does not provide chlorine residual protection, it is important that users be trained to properly care for and maintain the ceramic filter and receptacle to prevent recontamination.

The efficiency of a given filter with water throughput will, of course, vary with the size and hydraulic capacity of the filter element, as well as time between cleanings.

Typically, ceramic filters meet the new “interim” category of protection developed by the World Health Organization (WHO). Table 1 shows the log reduction levels (LRV) called for in the new WHO protocol:

Table 1 – WHO protocol LRV requirements¹

Target	Log Reduction Value: Bacteria	Log Reduction Value: Viruses	Log Reduction Value: Protozoa
Highly Protective	≥ 4	≥ 5	≥ 4
Protective	≥ 2	≥ 3	≥ 2
Interim	Achieves “protective” for 2 classes of pathogens		

What Are The Benefits, Drawbacks, And Appropriateness Of Ceramic Filters?

This section is taken from Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases (http://www.cdc.gov/safewater/PDF/Ceramic_2011-final.pdf). The benefits of ceramic filtration are:

- Proven reduction of bacteria and protozoa in water
- Produces a range of 1 to 11 liters/hr. (1/4 to 3 gal.) depending on size
- Simplicity of use and acceptability - minimal training or behavior change needed
- Proven reduction of diarrheal disease incidence for users
- Long life - if the filter remains unbroken
- Slow to clog, easy to clean
- A low one-time cost
- Simple design, can be manufactured locally
- Small, lightweight. Can be carried by a child

¹ WHO, “Evaluating Water Treatment,” 2011.

- No change in water taste - acceptable chemical free treatment
- Pretty and attractive addition to any house

The drawbacks of ceramic filtration are:

- Generally not effective against viruses
- No chlorine residual protection - can lead to recontamination if treated water is stored unsafely
- Variable quality control for locally produced filters
- Filters can break over time - need for spare parts
- A low flow rate of 1-3 liters per hour for non-turbid waters
- Filters and receptacles must be cleaned regularly, especially after filtering turbid water
- A cracked filter may be undetectable, but still have a negative effect on capability
- Turbid water can plug up the filter pores
- Cleaning can remove some types of silver layers over time, necessitating replacement of the filter

Ceramic filtration is most appropriate in areas where there is capacity for quality ceramics filter production, a distribution network for replacement of broken parts, and user training on how to correctly maintain and use the filter.

What Are The Economics And Scalability Factors?

Locally manufactured ceramic filters range in cost from \$7.50-\$30. Distribution, education, and community motivation can add significantly to program costs. Ceramic filter programs can achieve full cost recovery (charging the user the full cost of product, marketing, distribution, and education), partial cost recovery (charging the user only for the filter, and subsidizing program costs with donor funds), or be fully subsidized such as in emergency situations. If a family filters 20 liters of water per day (running the filter continuously) and the filter lasts 3

years then the cost per liter treated (including cost of filter only) is 0.034-0.14 US cents.



Commercially available ceramic filter systems range in cost from tens to hundreds of US dollars, depending on where they are manufactured and purchased, and the quality of the ceramic filters. The economics and the sustainability of commercial product-based projects depend on donor funding and subsidy, as well as follow-up to ensure replacement parts are accessible to the population using the filters.

When And How Should A Ceramic Filter Element Be Cleaned?

Ceramic filters capture most particles within about 0.1mm (.005 of an inch) of its surface, so it's easy to brush away clogged pores and expose new ones. However the elements themselves are fragile and require careful handling. If the time it takes for the water to filter into the lower chamber substantially decreases, it is time for cleaning. Also, if the "clean" water side of the ceramic membrane is brought into contact with dirty water, hands, cleaning cloths, etc., then the filtration will be ineffective. If such contact occurs the filter should be cleaned, and sterilized if possible, before reused.

For pot type filter elements, contaminants will be retained in the top half of the unit, and this can be cleaned by brushing the inside with a soft brush and rinsing it out. Candle elements can be removed and rinsed under clean running water while scrubbing lightly with a scouring pad or small brush. Cleaning should be performed evenly by working from the threaded mount down.



Cleaning the filter can restore the flow rate, but is also a possible pathway for recontamination of treated water (e.g. if a dirty cloth is used)

What Else Should Be Done To Maintain The System Properly?

The lower chambers should be cleaned about once per month with soapy water. In areas with hard water, calcium scale may build up on spigot and chambers after prolonged use. To remove, soak affected part(s) in vinegar or a 50-50% mix of vinegar and water for about 15 minutes. Wipe away calcium scale with a scouring pad or soft brush then wash with soapy water and rinse.



When Should A Filter Element Be Replaced?

A candle should be replaced when the candle element shows a significant change in diameter of the ceramic after cleaning. Also for a pot type or a candle type, anytime a crack in the ceramic occurs, the integrity has been lost and the filter must be replaced.

The major risks to success of all forms of ceramic filtration are hairline cracks and cross-contamination. If the unit is dropped or otherwise abused, the brittle nature of ceramic materials can allow fine, hard to see cracks, and can allow larger contaminants through the filter.

Do Ceramic Filters Remove Beneficial Minerals?

No. Although some ceramic 'candles' with internal activated carbon will remove some minerals, chlorine, and other dissolved chemicals. Most other ceramic filters including most 'pot' types allow dissolved minerals and salts to pass through.

Where Have Ceramic Filters Been Used?

Ceramic filtration programs have been implemented in over 20 countries. [Potters for Peace](#), (PFP) is a United States and Nicaragua based non-governmental organization (NGO) that promotes the flower-pot ceramic filter design by providing technical assistance to organizations interested in establishing a filter factory. PFP has assisted in establishing filter-making factories in many countries. Once the filter factory is established, the factory markets the filters to NGOs who then incorporate the filter into their own water and sanitation programming.

The first PFP filter factory, in Managua, Nicaragua, was constructed using private donations. From 1999-2005, the filter factory was a self-financed recognized micro-enterprise in Nicaragua. NGOs paid \$10 per filter, and transported the filters themselves to project locations. Despite the fact that 23,000 filters were made and sold in Nicaragua from 1999-2004, the factory was not financially sustainable and was sold in 2005 to a private investor who increased the price of each filter.

One of the largest ceramic filtration programs is in Cambodia, where two NGOs both worked with PFP to establish filter factories. [Resources Development International](#) distributes the filters through unsubsidized direct sales, distribution through local vendors, and community-based subsidized programs. [International Development Enterprises](#) distributes the filters nationally through vendors. Both NGOs sell filters to government agencies and other NGOs. The project has successfully distributed over 200,000 filters and has been extensively studied.

[Thirst-Aid \(thirst-aid.org\)](#) is now directing in Myanmar, one of the most successful ceramic water filter (CWF) interventions in the world. As of today they have helped establish eight private CWF producers who employ over 150 people. In the last 11 months, these producers have manufactured and distributed over 90,000 CWFs, providing a population of nearly half a million with sustainable clean drinking water.



Who Are The Major Suppliers?

The major suppliers include ProCleanse, Potters for Peace, FilterPure, Doulton, Katadyn, and Basic Water Needs.

ProCleanse [procleansefilters.com]

The ProCleanse™ Water Filter is the “first of its kind” to provide a two-chamber device that uses a proprietary blend of porous ceramic particles and a mixture of positively charged biocide materials to significantly reduce harmful micro-organisms.² Contaminated water is poured into the device and passes through a debris strainer that filters out large sediment. Gravity moves the water through the ceramic media, filtering and deactivating harmful microorganisms. The result is clean, safe water for drinking on the first day of use. The filter does not require any assembly and replacement parts, is lightweight and easy to transport and uses no chemical additives.³ The units offer residual disinfection benefits due to presence of metal ions in treated water, and competitive pricing of \$.001 per liter over the expected lifecycle of ten years. ProCleanse filters reduce E-Coli by more than 99.999 percent. Testing is ongoing to demonstrate significant impact on cysts and viruses.



Potters for Peace [pottersforpeace.com]

Potters for Peace does not manufacture filters, but instead helps local communities establish independent filter workshops produce and sell the filters. Tens of thousands of filters have been distributed worldwide by organizations such as the Red Cross, Doctors Without Borders, UNICEF, and Oxfam.⁴ The filter design, similar to process described above was developed in Guatemala in 1981 by Dr. Fernando Mazariegos of the Central American Industrial Research Institute (ICAITI). Dr. Mazariegos' goal was to make bacterially contaminated water safe for the “poorest of the poor” by developing a low-cost filter that could be fabricated at the community level.⁵ The filters have been proven to eliminate approximately 99.88 percent of most pathogens.

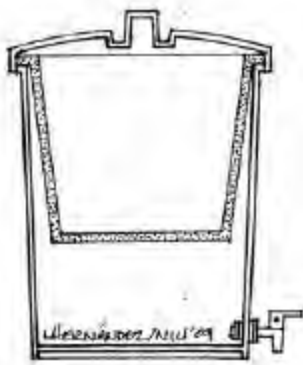


² <http://www.procleansefilters.com/media/faq-sheet.pdf>

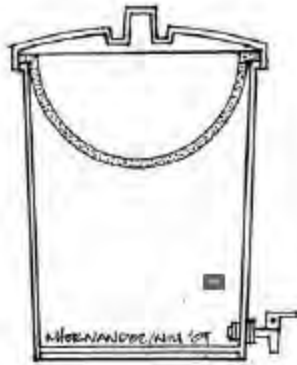
³ <http://www.procleansefilters.com/>

⁴ <http://www.water.info/home.ceramicfilters.pottersforpeace.html>

⁵ http://pfp.he207.vps.webenabled.net/?page_id=8



Potters for Peace
(7-11 liters)



Thirst-Aid
(10 liters)



FilterPure
(6 liters)

FilterPure [filterpurefilters.org]

FilterPure is an organization with a mission: Manufacture and distribute an improved and inexpensive “point of use” water filtration device which is producible in developing countries. FilterPure is a non-profit organization (U.S. tax-exempt) and is committed to providing safe drinking water to the at risk populations of the developing world.



The FilterPure design is a round-bottom ceramic pot is made from a mixture of clay, a combustible material (sawdust or rice husks), and colloidal silver. During the firing process, about ½ inch of charcoal is produced within the filter to improve taste and color.

Doulton [doulton.com]

Doulton ceramic water filters have a highly effective barrier to pathogens and particles. The ceramic pore structure has an absolute filtration rating of 0.9 microns (less than 1000th of a millimeter) making it capable of filtering sub-micron particles and bacteria from drinking water. Ceramic filters contain trace amounts of silver incorporated within the ceramic shell. The silver inhibits bacterial growth and makes the filters self-sterilizing. In addition, the ceramics are made from 100 percent natural elements, and do not add anything to the filtered water. Doulton filters allow beneficial minerals to pass through the water and the gravity filters do not require any plumbing or electricity.



Katadyn [katadyn.com]

Katadyn manufactures several lines of large and small scale ceramic filters. These range from individual 'backpacking' and 'water bottle' sized units to larger household units. These are supplied with a micro porous structure with impregnated silver which delays the growth of bacteria. The pore size of Katadyn ceramic filters is 0.2 micron. Bacteria typically ranging in size from 0.2 to 5 micron and like protozoa (1 – 15 micron) are efficiently filtered out.

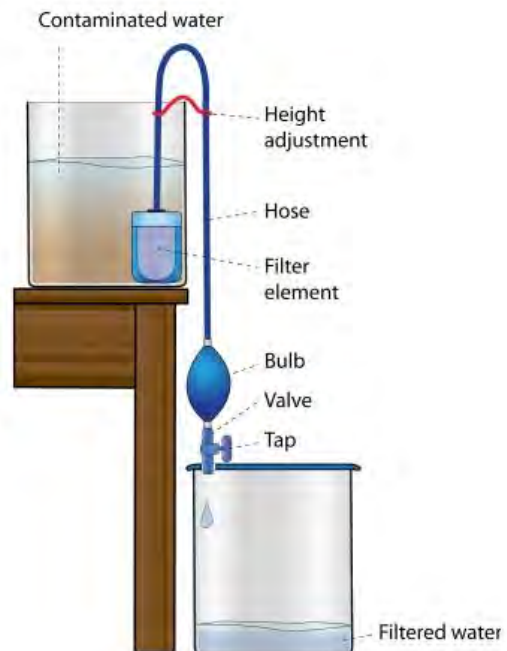
Basic Water Needs [basicwaterneeds.com]

From the Netherlands, Basic Water Needs BV developed the 'Tulip' siphon water filter. This is a candle filter which uses gravity siphon pressure to force water through the ceramic filter element.

It is a compact system since most locally available water storage containers can be used, and the filter only weighs about 500gm, or one pound.

The Tulip treats 4 to 5 liters per hour. The filter element is infused with nano silver in order to increase bacterial removal efficiency.

More than 150,000 of these filters are used successfully in more than 15 countries. During the cholera epidemic in Zimbabwe, of all of 58,000 people using the Tulip filter, no person was infected by the disease.

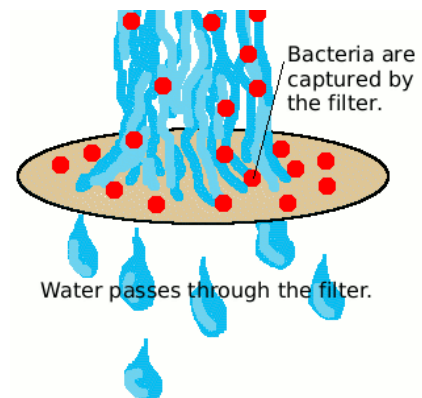


MEMBRANE WATER FILTRATION

What Is Membrane Water Filtration?

Membrane water filtration is a method to remove bacteria and other contaminants from water by passing raw water through a micro porous membrane.

As with other forms of filtration, the contaminants stay on the 'dirty' side and treated water passes through and is collected for use on the filtered side.



What Are The Membranes Made Of, What Do They Look Like?

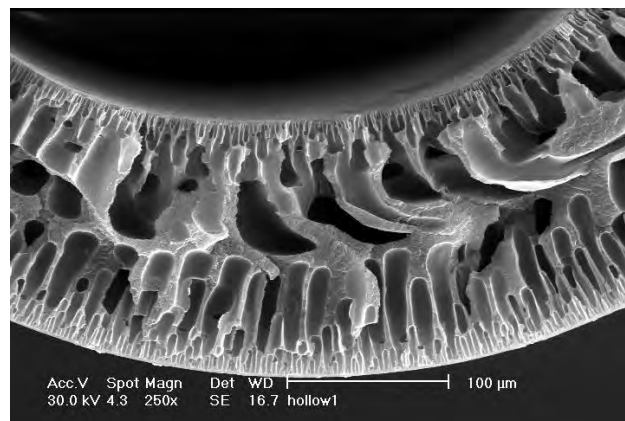
Most membrane filters for drinking water start with thin semi-permeable materials made from a synthetic polymer - manufactured as flat sheet stock or as hollow fibers. Many individual small membranes are then bundled and formed into one of hundreds of different types of membrane modules. These modules vary greatly in size and in shape - from U-shapes to spiral-wound to various cylindrical shapes. Module construction typically involves sealing the membrane material into an assembly, with inlet and outlet connections.



Various forms of hollow tube membranes



A typical hollow-fiber module may consist of several hundred to over 10,000 membrane fibers as shown in this array of industrial sized membranes for waste water treatment.



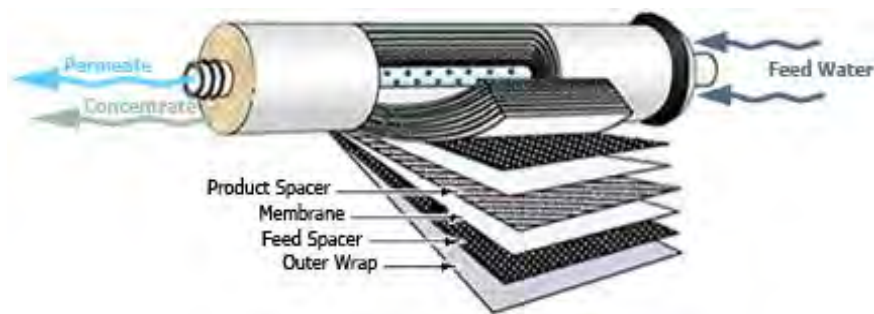
Micro-photograph of the cross section of a hollow tube membrane wall showing porosity.

Other membrane filters can be very small, like the 'straw' filters used by hikers and outdoor enthusiasts to purify raw water.



Still other configurations, made for household or small commercial use, look like the filters often seen in kitchens and in domestic refrigerators.

Spiral wound membrane modules are encased in a pressure vessel. In these, the raw feed flows through a wrapped flat membrane into a spacer, and then out to the outlet.



Is This New Technology?

Membrane filters for water were first commercially produced in 1927 in Germany, and were used during World War II to produce municipal water. Membrane filters of various forms and types are used in thousands of commercial and industrial processes, from chemical and food production to waste water treatment. Some types, specifically Reverse Osmosis (see below) filters have seen increasing use in recent decades to produce drinking water from sea water. Also in the last few decades, newer designs of membrane filters have been developed that do not require high pressure pumping systems to push water through, and their use for drinking water treatment in developing areas has grown.

How Do Membrane Water Filters Differ From One Another?

Most importantly by pore size. Pore size determines what size (and type) of contamination is filtered out. Membrane filters are also differentiated by capacity, configuration, shape, connections, need for pressure (pumping systems), manufacturing materials, and quality (mostly uniformity of pore size).

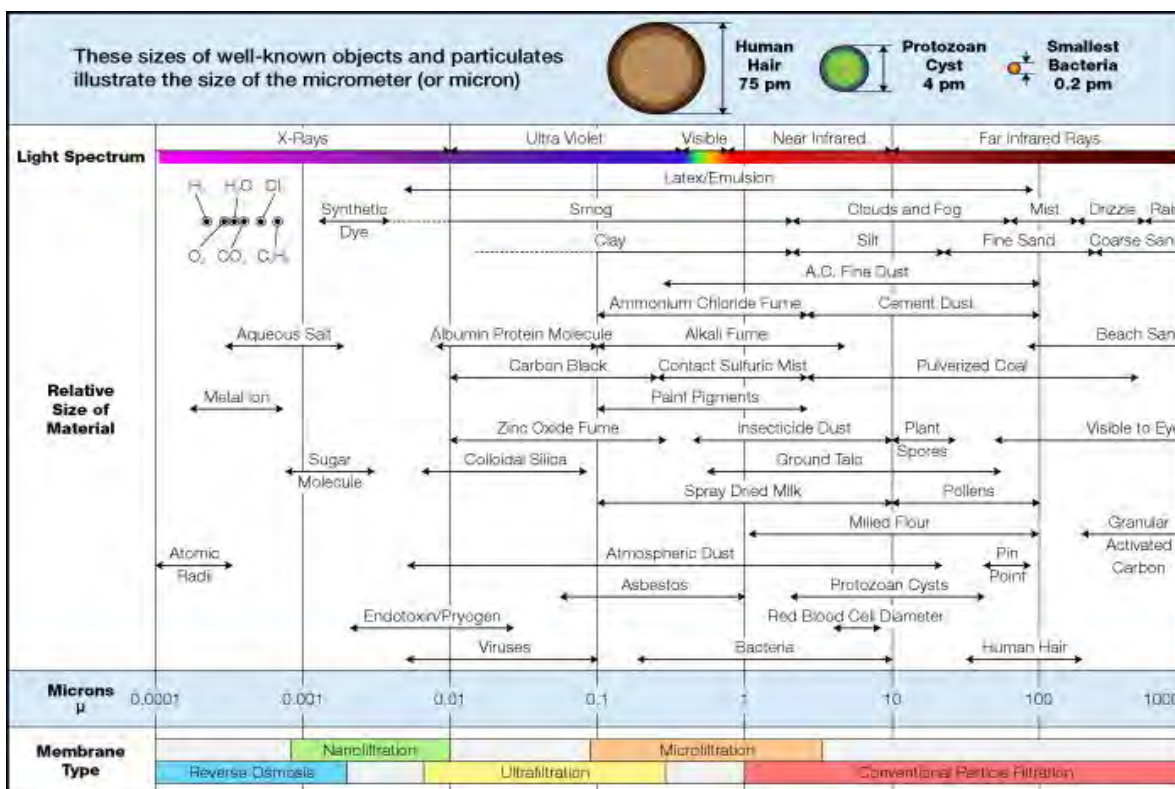
What Is Most Important When Selecting A Membrane Filter?

Determine what chemical contaminant and/ or biological constituent needs to be removed. This will indicate what membrane pore size and filter configuration will do the job. For example, turbidity and sediment is more easily separated than large bacteria and protozoa, while viral contamination requires much tighter filtration under pressure, and contaminants like salt generally require specialized membranes and pressure systems.

Testing, in the lab or field, or both, will be required to assure good treatment. In some cases a membrane filter alone is insufficient, and the best solution can be a combination with another form of treatment (e.g., bio-sand filters) or with the addition of a secondary treatment method (such as post-treatment chlorine).

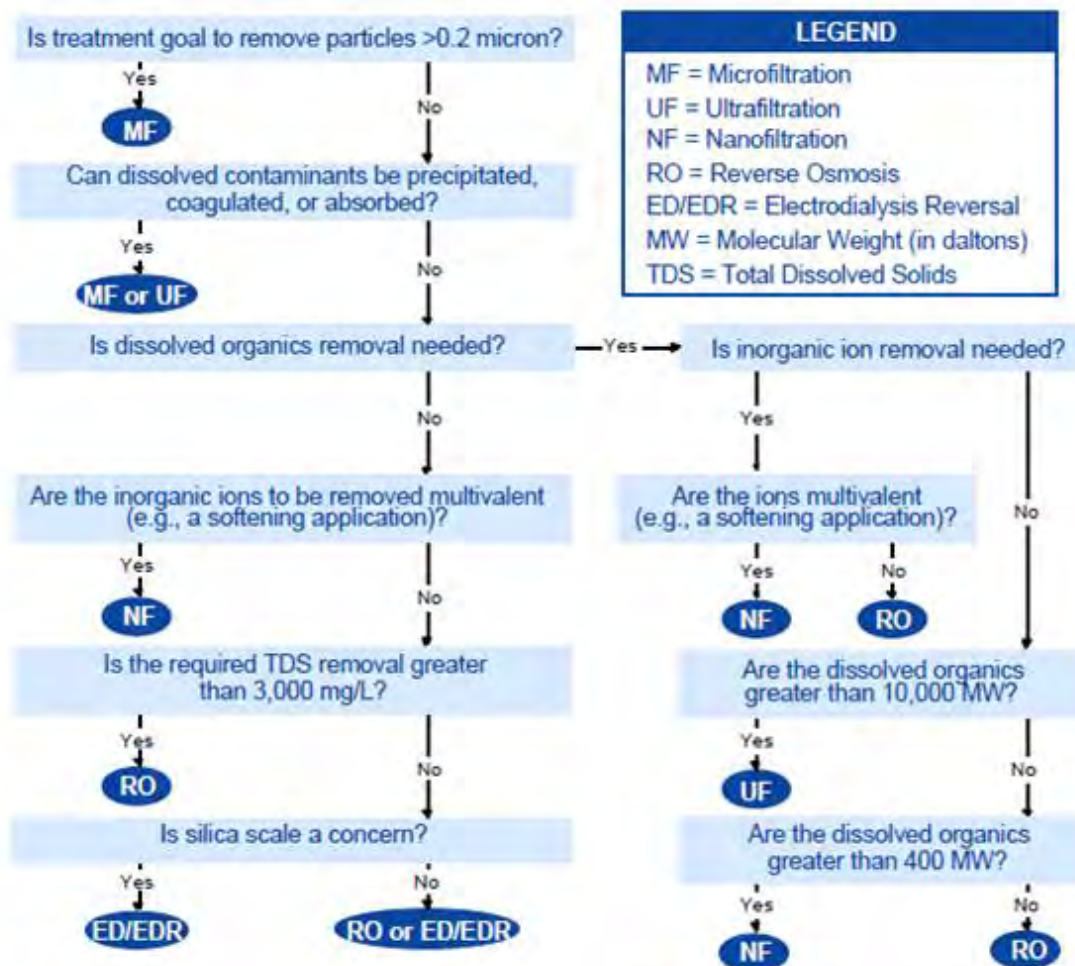
What Are The Different Classifications Of Membrane Filters?

Membrane filters are classified by pore size, and therefore what size of contaminant is filtered out of the water stream. See the tables below for more complete information on classification. Membrane classifications include: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO).



Source: h2odistributors.com

Generalized Membrane Filter Selection Chart



NOTE: This simplified chart is based on common assumptions and should not be applied to every situation without more detailed analysis.

ASSUMPTIONS	
A. Relative Cost <ul style="list-style-type: none"> MF < UF < NF < RO or ED/EDR If TDS removal > 3,000 mg/L, RO or ED/EDR may be less costly 	B. Removals <ul style="list-style-type: none"> MF—particles > 0.2 Micron UF—organics > 10,000 MW, virus, and colloids NF—organics > 400 MW and hardness ions RO—salts and low MW organics ED/EDR—Salts Particles include <i>Giardia</i>, <i>Cryptosporidium</i>, bacteria, and turbidity

Reprinted from Proceedings of the 1993 Membrane Technology Conference, by permission. Copyright © 1993, American Water Works Association.

Are Membrane Filters Appropriate For All Developing Areas?

Large-scale membrane filter systems are complicated, expensive, energy intensive (require pumping), and require specialized training for operation and maintenance. Of the four main membrane classifications, Microfiltration, however, can be suitable in specific situations.

Microfiltration, with pore size ranging from 0.1 to 1 μm (0.00004 inch), can separate most normal bacteria and protozoa, and in small applications does not require a pump or high pressure system to push water through the filter.

Is A Pump, Or Pressurized System, Required For Microfiltration?

Microfiltration, differs from other membrane processes - like reverse osmosis and nanofiltration - because those systems need higher pressure to force water through the filter (see next table), and while some microfiltration systems use pressurized inlet flows, the systems most commonly used for developing area water treatment do not need to include pressure.

Due to limited available energy in many developing areas, the water pressure needed to drive raw water through a membrane filter is usually provided by use of elevated water tanks rather than high-pressure pumps. This differs, of course, with the level of treatment that is required. For example removing salt from sea water requires far more pressure than removing silt from water. Since there are practical limits on how high a supply tanks can be elevated, the filtration process is limited to pressures required by microfiltration and ultrafiltration water systems. The trade-off is that the treated water may not remove all mineral or biological constituents that are present in the raw water.

How Is The Microfiltration Pressure Requirement Met?

For microfiltration, the required water pressure head (the distance between the bottom of an elevated storage tank and the top of the filtration system) is 0.7 to 10.5 meters (2 to 35 feet). For ultrafiltration, the required water pressure head is 7.0 to 70.3 meter (23 to 230 feet). For most developing area installations, builders can provide up to about 10 meters (33 feet) of pressure heads from elevated tanks.



How About The Small Straw Type Filters Used By Hikers?

There are several manufactures of point-of-use microfiltration devices for individual users, for example Sawyer and Life Straw (see links below). However, these microfiltration water filters have limited flow rates and are not suitable for providing community supplies for large populations in their current configuration. They should probably be considered as an interim intervention until more suitable, sustainable water treatment systems can be developed.



Who Manufactures Small, Community-Sized Membrane Filter Systems?

Few manufactures provide microfiltration or ultrafiltration systems with the capacity to serve at the community level. This may be because of the low demand of these filters, as compared to the RO membrane filters, which are in greater demand in the developed world and, therefore more profitable to manufacture.

One example of an ultrafiltration membrane filter that is suitable for large community use is the SkyHydrant, manufactured by SkyJuice, a nonprofit foundation located in Sydney, Australia. This product can supply 600-1,000 liters of clean water per minute with a head of 5 meters. SkyJuice™ has supplied over 900 water filtration units since January 2005, and has a good track record for sustainability.

The advantages of scaled-up ultrafiltration systems, such as SkyHydrant, are that they can deliver large flow rates suitable for communities with large populations. However, because the pore size of ultrafiltration systems is not adequate to remove some bacteria and most viruses, a post-filtration disinfection system should be considered, especially if the treated water is to be stored for more than a day or two before used. The SkyJuice website is:

<http://www.skyjuice.com.au/skybox.htm>.



How Are Membrane Filters Maintained?

After a time, all membrane filters will start to clog as the retained contaminants fill pore spaces. Most membrane filters are cleaned with a reversed filtration process called Backwashing with clean water. In many cases the backwash is done with higher pressure (usually about 2 times the forward flow pressure) to increase the velocity of water and blast clogged particles off the filter. Although the process for every filter is specific to the design, materials, and configuration of the filter, the principle is the same. Users must carefully adhere to the manufacturers recommended cleaning procedures.

Occasionally, a filter might need chemical cleaning to remove fouling that backwashing doesn't. The manufacturers' information will have these procedures and recommended products.

How Often Does A Filter Require Backwashing?

Cleaning frequency will vary with every filter and installation. Frequency of cleaning depends on how dirty the raw water stream is, and what flow rates are used. With extremely turbid or muddy water, backwashing may be required as much as 100 times more often than with relatively clear water. Nevertheless, for most membrane filters, backwashing is an extremely simple process and takes only a short time and no special training.

Can You Backwash With Dirty Water?

No. Were this were done by error a large volume of water would have to be run through the filter and dumped before once again filtering water for consumption.

How Much Water Can Be Filtered/Purified Per Day?

The capacity of every filter installation will vary. With every manufacturer, each pore size, material, configuration, etc. will be different. However, flow rates in general are determined by a combination of four variables:

- Head pressure (The distance from the top of the water source to the filter)
- Altitude (The higher the altitude, the slower the flow rate)
- How clean the filter is
- The filter itself (there are slight variations between filters)

Should A Pre-Filter Be Used Ahead Of The Membrane Filter?

In areas where the raw water is turbid, or muddy, a pre-filter is recommended and will greatly increase flow rates and time between required backwashing. Several simple pre-filter types can be used including simple cloth and bucket filters, and settling tanks.

Will Most Membrane Filters Remove Chemicals, Pesticides Salt, Or Heavy Metals Like Arsenic?

Only Reverse Osmosis membrane filters will remove these chemicals. Larger pore sized filters common for household use will not remove these chemicals.

Membrane Types, Properties And Applications

Membrane pore size determines how effective it will perform in removing various contaminants. Determine what needs to be removed from the water supply to make it drinkable and then select the appropriate pore size. Once pore size is identified, one can select the appropriate filter. Note that in some cases, the water treated with a membrane filter must be disinfected to remove very small viruses and bacteria. The following tables were developed by Professor Kara Nelson, UC Berkeley School of Civil Engineering.

Category	Size range	Typical constituents removed	Typical Applications		Removal mechanism
			Drinking Water	Wastewater	
Microfiltration (MF)	0.1-1 μm	TSS, turbidity, protozoan cysts (e.g., crypto, giardia), bacteria	TSS, turbidity, particles, cyst removal	Membrane bioreactor (MBR), pretreatment for disinfection (particles or DBP precursors with PAC) or NF/RO	Straining
Ultrafiltration (UF)	0.01-0.1 μm	Macromolecules, colloids, some viruses			Straining
Nanofiltration (NF)	0.001-0.01 μm (1-10 nm)	Small molecules, divalent ions (e.g., hardness), viruses	Softening, DBP precursors (NOM), disinfection	Softening, disinfection	Straining and some exclusion
Reverse Osmosis (RO)	0.1-1 nm	Very small molecules (e.g., color), ions (e.g., hardness, sulfates, nitrate, sodium)	Desalination, synthetic organic compounds, DBPs, nitrate, demineralization	Removal of specific compounds before reuse	Exclusion (water permeability > solute permeability)

Membrane Types, Pressure Requirements, Flows, And Utilities

The smaller the pore size, the more pressure that is needed to push a given amount of water through the filter.

Category	Pressure, psi	Pressure Meters of water	Flux, gal/ft ² -d	Flux, gal/ft ² -d	kWh/ 1000 gal	Recovery, %
Microfiltration (MF)	1-15	0.7-10.5	10-40	10-40	0.1 (@ 15 psi)	94-98
Ultrafiltration (UF)	10-100	7.0-70.3	10-20	10-20	0.8 (@ 75 psi)	70-80
Nanofiltration (NF)	75-150	52.7-105.7	5-20	5-20	1.4 (@ 125 psi)	80-85
Reverse Osmosis (RO)	125-1000	87.9-703.1	8-12	8-12	2.7 (@ 225 psi)	70-85

Source: Professor Kara Nelson, UC Berkeley School of Civil Engineering

Links To Further Membrane Filter Information

The following links are provided for more information on membrane filter operations, as well as manufacturers of membrane filters commonly used in the developing world.

http://www.epa.gov/ogwdw/disinfection/lt2/pdfs/guide_lt2_membranefiltration_final.pdf

Koch Membrane Systems

mrwa.com

katadyn.com/

sawyer.com

espwaterproducts.com

vestergaard-frandsen.com

skyjuice.com.au

lenntech.com/

vichemgroup.com

aboutmembranefiltration.com/

DISINFECTION OF WATER

What Is The Disinfection Of Water?

The disinfection of water is the removal of the biological pollutants. Water can be contaminated with physical, chemical and biological pollutants. Disinfection removes the biological pollutants, or pathogens, which are viruses, bacteria, and parasites such as helminthes, protozoa and worms. Many of these biological pollutants, especially viruses, may not be removed by the previous steps of sedimentation and filtration.

What Techniques Can Be Used To Disinfect Water?

Four most commonly used methods for the disinfection of water are chlorination, ultraviolet light, ozone and solar water disinfection (SODIS).

What Is The Chlorination Of Water And Why Is It Used?

The process of adding chlorine (Cl_2) to water is called chlorination. It is a method of purifying water in order to prevent the widespread of waterborne diseases, especially those caused by bacteria, viruses and amoeba.

Chlorine is one of the most widely used disinfections. It is very applicable and very effective for the deactivation of pathogenic microorganisms. Chlorine can be easily applied, measured and controlled. It is fairly persistent and relatively cheap.

Chlorination has been widely used in urban water supplies, especially those with long extended distributions systems because of the residual chlorine that is required at the end of the pipeline.

Those who grow up as children with chlorine in their drinking water are used to the odor and the taste of chlorine. However, when it is added to the drinking water supplies of developing countries, where the adults have never tasted nor smelled chlorinated water, the users are often reluctant to drink the chlorinated water and may revert back to drinking from their commonly used polluted water sources.

Furthermore, people are often concerned about the health effects associated with chlorinated water. Chlorine can react with naturally occurring organic compounds found in water sources and produce byproducts which may be carcinogenic. Other disadvantages include that the additions of chlorine to water supplies requires technically trained personnel and a continuous supply of chlorine.

Chlorine is the main disinfectant in the USA, because it is relatively cheap. In the U.S. national drinking water standards state that the maximum residual amount of chlorine is 4 mg/L.

The WHO drinking water standards state that 2-3 mg/L chlorine should be added to water in order to gain a satisfactory disinfection and residual concentration. The maximum amount of chlorine one can use is 5 mg/L. For a more effective disinfection the residual amount of free chlorine should exceed 0,5 mg/L after at least 30 minutes of contact time at a pH value of 8 or less.

Why Is Ultraviolet Light (UV) Used As A Disinfection Of Water?

Ultraviolet light (UV) is a disinfection method that can be used to purify water as it kills pathogens including viruses and bacteria. The UV is delivered via a lamp as shown in the figure above. UV water treatment devices can be used for any water sources whether it is from wells or other surface water sources.



UV treatment compares favorably with other water disinfection systems in terms of cost, labor and the need for technically trained personnel for operation. UV treatment works best when the water is pretreated using sedimentation and filtration.

Why Is Ozone Used As Disinfection For Water?

Ozone is a powerful oxidizing agent that can disinfect most waterborne organisms such as pathogens. Ozone is made by passing oxygen through UV light. The advantage of using ozone is that it produces fewer dangerous by-products and has no taste or odor problems. Furthermore, it leaves no disinfectant residual in the water such is the case with chlorination. The disadvantage of ozone is that it must be created on-site. Then it is added to the water that is to be purified by bubble contact. This may be difficult in developing countries.

Why Is SODIS Used As Disinfection For Water?

Solar Water Disinfection (also known as SODIS) is a simple but free and effective method of disinfecting water by only using sunlight and plastic, PET type, bottles. The treatment methodology only requires the filling of recycled plastic water bottles from local water sources and leaving them to be exposed to sunlight for 24 hours. The treatment method is decentralized and can be applied at the household level.



Source: Wikipedia, Solar Water Disinfection,
(<http://en.wikipedia.org/wiki/SODIS>)

The exposure to sunlight, and its solar radiation, has been shown to deactivate diarrhea causing pathogens and therefore reducing pollution in drinking water. Studies have shown that this is one of the most effective and inexpensive methods of treating drinking water in developing countries. The advantageous include the recycling of plastic bottles and the low cost of setting up the racks for holding the water bottles.

CHECKLIST FOR SELECTING WATER TREATMENT SYSTEMS

In any water project, selection of the most appropriate treatment technology can only be made once the preliminary information discussed in previous sections above has been gathered and analyzed.

Before deciding "How" the "What" must be known: What is in the water? What must be removed? What quantity of treated water is needed each day? Therefore, the following questions must be answered before selecting a treatment method:

1. Has the Checklist for Considering Water Quality (above) been answered? _____
2. What are the community health issues & water standards? _____
 - a. What chemical and biological contamination is in the water? _____
 - b. What is the turbidity level in the water? _____
 - c. What do people expect from water? Odor? Chlorine smell? Color/Cloudiness? _____
 - d. Do the people object to chlorine taste to the point that they won't use water disinfected with chlorine? _____
3. Is the raw water source adequately studied and defined? _____
 - a. Quality? _____
 - b. Quantity? _____
 - c. Variability/ Seasonable changes? _____
4. Are recent and reliable water quality analyses available? _____
5. Are there good estimates for the number of people, and households, to be served? _____
6. Are available power sources well understood? _____
 - a. Is reliable electrical power available and what is its source? _____
 - b. What is the cost of electrical power? _____
 - c. Can the community afford the power for their water system? _____
7. Is there good Local economic and demographic information? _____
 - a. What can the community afford to operate and maintain? _____
 - b. Are technically trained people available for operation and maintenance of the water system? _____
 - c. Does small business/entrepreneurial culture exist? _____
 - d. Is micro-financing available? _____
 - e. Are contractors available for community size water projects? _____
 - f. Are building materials available and affordable? _____
 - g. Are spare parts available and affordable? _____

Selecting Appropriate Filtration Technology

Selection of the most appropriate filtration technology depends primarily on the contaminants to be removed, the levels of turbidity in the raw water, and the size or capacity of the requirement.

Secondary, but also very important considerations include the cost, complexity (and required maintenance) of the system, and how easily the target community will adopt and sufficiently use the technology. Finally, is the treatment system going to be centrally located in the community or will it be established in each household?

Centrally Located Treatment Systems

For centrally located treatment systems, membrane filters are probably the best to consider. The complexity of central treatment systems is far more than that of a household treatment system, and for this reason, an expert should be called upon to assist in the design. For these systems, the following should be considered?

1. Is filtration and particle removal at the level of about 1 micron adequate? That is, removal of protozoa and large bacteria? _____
 - a. If yes, then conventional filtration can be applied.
 - Inexpensive 'pot' ceramic filters
 - Rice husk/ash filters
 - Low quality ceramic filters
 2. Is removal of smaller particles, down to 0.2 microns necessary? _____
 - a. If yes, then bio-sand filters, microfiltration membranes, and better ceramic filters can be used. These will remove the smallest bacteria, but cannot guarantee virus removal.
 3. Is viral contamination removal a goal? _____
 - a. If yes, then either ultrafiltration membranes must be applied with their required complex higher pressure systems, or a post-filtration sterilization technology must be applied in addition to a filtration system.
 4. Are pesticides and/or other chemical contaminants (including arsenic) to be removed? _____
 - a. If yes, then the filtration devices described above will not work alone; a carbon filter, ozone, ion-exchange, or other specialized removal process must be applied. See an expert to design a system.
 5. Are dissolved salts, fluoride, or minerals to be removed? _____
 - a. If yes, then as above, a specialized system must be applied. This could involve use of a reverse osmosis system or precipitating, flocculating, or adsorbing the contaminant to separate it from the water stream.
 6. How is the membrane pressurized? _____
 - a. Pumped from source? _____
 - b. An elevated tank? What tank elevation is needed to supply the proper pressure at the membrane? _____
 7. How is the water distributed? _____
 - c. Distributed at the filtration plant? _____
 - d. Pumped to a secondary elevated tank(s)? _____
 - e. Pumped into a water distribution system that goes to kiosks within the community or directly to homes, schools, clinics? _____
 8. How much water needs to be treated on a daily basis? _____
 9. What is the capacity of the filtration system, based on daily demand? _____
 10. Have you planned for redundant filter paths so that filtration can continue while back flushing is being done in parts of the plant that are down? _____
 11. If line power is the primary source of power (if needed), is there a backup power supply so that water can continue to be treated? _____
 12. If treated water is delivered into a distribution or storage system, has it been disinfected with a disinfection agent that has residual disinfection capacity (example, chlorine)? _____
-

Household Water Treatment Systems

Selecting a household water treatment system will depend on the type of contamination that is anticipated in the source water supply (based on water quality analyses taken for the source). For lightly contaminated water with low turbidity, any of the filtration methods discussed in preceding sections will work well. Here are some questions to ask when selection a treatment method:

1. What is the type/size of contaminant to be removed? _____
 - a. Is filtration and particle removal at the level of about 1 micron adequate? That is, removal of protozoa and large bacteria? If yes, then conventional filtration can be applied. _____
 - Inexpensive 'pot' ceramic filters
 - Rice husk/ash filters
 - Low quality ceramic filters
 - b. Is removal of smaller particles, down to 0.2 microns necessary? _____
 - If yes, then bio-sand filters, microfiltration membranes, and better ceramic filters can be used. These will remove the smallest bacteria, but cannot guarantee virus removal.
 - c. Is viral contamination removal a goal? _____
 - If yes, then either ultrafiltration membranes must be applied with their required complex higher pressure systems or a post-filtration sterilization technology must be applied in addition to a filtration system.
 - d. Are pesticides and/or other chemical contaminants (including arsenic) to be removed? _____
 - If yes, then the filtration devices described above will not work alone; a carbon filter, ozone, ion-exchange, or other specialized removal process must be applied. See an expert to design a system.
 - e. Are dissolved salts, fluoride, or minerals to be removed? _____
 - If yes, then as above, a specialized system must be applied. This could involve use of a reverse osmosis system or precipitating, flocculating, or adsorbing the contaminant to separate it from the water stream. None of these is appropriate for a household system.
2. How Turbid (muddy) is the raw water? _____
 - a. Does the raw water have turbidity greater than 50 NTU? _____
 - Some membrane systems will handle high turbidity, but these usually require mechanical pumps for operation. Ask the manufacturer.
 - Some high quality ceramic filters will tolerate high turbidity but will need more frequent cleaning.
 - Most other filters discussed in the sections above will rapidly clog with high turbidity, and the raw water should have a pre-filter of some sort to reduce turbidity. Pre-filter examples are:
 - Simple sand filter
 - Cloth filtration
 - Settling basins
 - Complex flocculation and precipitation basins
 - b. Note that high turbidity can also affect sterilization systems, especially ultraviolet (UV) light or sunlight. Turbidity should be reduced as much as possible before disinfection is done.
3. What system size is needed? _____
 - a. Is demand on the level of about 50 liters (14 gallons) per day or less per household?
 - A household, point-of-use, filter can be appropriate.
 - Bio-sand filters
 - Household ceramic filters
 - Small membrane filters
 - b. Is demand greater than 50 liters/day? _____

- A larger, centralized community service may be required.
 - A community-sized membrane filter can be used, but space restrictions may be a problem. An elevated tank or power may be required to pressurize these larger systems.
 - Multiple smaller filters arranged in parallel might be appropriate.
4. What are some of the other, secondary considerations that are also important? _____
- _____
- a. Is the need immediate? _____
 - If yes, then a bio-sand filter which can take several weeks to become effective might not be the best immediate solution.
 - Small, point-of-use, individual ceramic filters or membrane filters might be appropriate.
 - b. Does the projected system require pressure to operate? _____
 - Would gravity head be possible? _____ Sufficient? _____
 - c. How easy is the system to operate and maintain? _____
 - d. Does the system require electricity to operate? _____
 - e. Is more than one treatment step required? _____
 - Filtration followed by disinfection, to reach drinking water quality?
 - Pre-filtration to reduce turbidity?
 - f. Is the best system too complicated and expensive for the community? _____
 - g. Is an associated water storage system required? _____
 - What kind? _____ How big? _____
 - How is sterility maintained? _____
 - How is treated water distributed? _____
 - i. What forms of disinfection are readily available? _____
 - Chlorine liquid? Tablets? _____
 - Solar based (SODIS)? _____
 - Coagulants and flocculants with other disinfectants? _____
 - Ultraviolet light? _____
 - Ozone? _____
 - j. Are local technicians available to operate and maintain the system? _____
 - What level of training is required? _____
 - k. What can the community afford to operate and maintain? _____
 - l. Do people reject the taste of chlorine in their drinking water? _____
 - m. Are there specific climatic or other considerations that could affect the long-range viability of the equipment and system? _____
 - n. Are there alternative sources for spares and replacement parts? _____

Disinfection for Water Supplies

Keeping water clean and safe to drink may require disinfection as a secondary step after filtration or as a protection for unfiltered ground water. The following steps for supplying clean and safe water are:

1. Protect the source of supply from unnecessary contamination
 - a. Build a box around a spring to keep people and animals out of the water.
 - b. Construct water wells at least 100 meters from sources of contamination, such as latrines, dirty drainage ditches, animal pens, and industrial areas.
 - c. Construct a concrete apron around well head and cover the well head.
 - d. For open dug wells, don't allow dirty buckets to be lowered into the well; use a dedicated bucket suspended on a rope.

2. Filter the water before disinfection to remove sediment and any easily destroyed pathogens.
3. When applying a secondary form of disinfection, determine if the water will be used immediately or will remain in storage for a time before use (such as in a storage tank).
 - a. For water that will be used immediately, secondary disinfection may not be needed unless very small pathogens, such as viruses, are suspected. If disinfection is needed for small pathogens, then the disinfected water should sit for at least 20 to 30 minutes before it is consumed to allow the disinfectant to work.
 - b. If water is to be stored for any length of time after initial treatment, then a secondary disinfectant should be used that has residual disinfection capacity, such as chlorine.
 - c. Note: Ozone and ultraviolet light do not have residual disinfecting capacity.

WATER PROJECT CONSTRUCTION

Introduction

Rotary club members are always challenged to use their talents to serve others on projects, whether it is time, talents, or treasuries. Water projects are an excellent opportunity to use all of these talents to serve the needs of the poor around the world. This section reviews the some of the important aspects of the construction phase of work, from mobilization to project closure. The most important decision for the sponsoring Rotary club to make is the extent to which they wish to participate in actual construction.

Active participation can occur in several ways. Alternatives include:

- Sponsoring Rotary club conducts the project alone, from planning through construction using the clubs resources (labor and money)
- Work with a host Rotary club to hire a local contractor
- Partner with a local or international NGO to implement the project

As a rule of thumb, here are a few strengths and weakness of each idea:

Topic	Work as a club project	Hire a contractor	Partner with or hire an NGO
Ease for sponsoring Rotary club to undertake a project	May take a lot of work organizing volunteers.	Straight forward if host or sponsoring Rotary club finds a good contractor at a good price	NGO often has experience setting up & implementing projects
Finding In-country host Rotary club	Usually relies on on-going relationship with host Rotary club	Host Rotary club may steer the project to a good contractor.	NGO often has existing relationship with host Rotary club
Funding a project	High interest at sponsoring Rotary club level	sponsoring Rotary club and district go through normal fund-raising process.	NGO may be able to share in the cost or contribute funds from a partner
In-country oversight	Requires a volunteer(s) to travel to the location for pre-project inspection.	Usually supervised by sponsoring Rotary club or a volunteer from the host Rotary club	NGO may be located in-country and also provide a liaison with both sponsoring & host Rotary club
Buying supplies	Sponsoring Rotary club needs to either ship material or buy locally.	Contractor buys all material.	NGO arranges for materials.
Project reporting	Requires a strong commitment from one or more sponsoring or host	Requires good communication between representatives of	A good NGO provides good and regular reports. There still

Topic	Work as a club project	Hire a contractor	Partner with or hire an NGO
	Rotary club members	sponsoring Rotary club and host Rotary club.	needs to be a strong commitment from one or more sponsoring or host Rotary club members.
Working with people who live at project site	Relies on relationship with sponsoring Rotary club or local people	Usually delegated to host Rotary club and contractor	NGO often times has existing relationship with local people
Building sustainability	Sponsoring Rotary club needs to send teams back into area on a regular basis	Contractor needs to work with village, host and sponsoring Rotary club.	NGO needs to work with village, host and sponsoring Rotary club
Training local people	Sponsoring Rotary club needs to send volunteers. Volunteers usually need to be trained.	Contractor may provide the training or the sponsoring Rotary club sends volunteer(s).	NGO arranges for the training and/or works with host and sponsoring Rotary club volunteer(s).

Working As A Club Project?

Many Rotary clubs enjoy the hands-on approach to a project. They rise to the challenge of organizing volunteers, raising the funds, and working with overseas partners. Many of the volunteers come back with lifetime relationships with overseas friends as well as with their own club members. In addition, going on project trips will challenge club members to be active, promoting growth within their club and their district.

The key to a successful project for these sponsoring Rotary clubs is to ensure that the elements of what it takes for the long-term sustainability of the project is defined and the entire club and project partners have made the commitment to carry out the plan.

On the other hand, some clubs may feel overwhelmed with the idea of actually doing a water project. They may feel that they lack the technical skills, the time and/or the people to properly complete the project. For these clubs, it may be best to become a “cooperating” or “participating” club with other clubs or to partner with an appropriate NGO that can provide assistance in carrying out the requirements outlined in this document. As a participating club, the club and its members can be a valuable support organization with both financial and in-kind staff support services. Being a major partner in a successful project does not require your club to be the leader of the planning, design or construction phases of the project.

Project Initiation/Mobilization

The on-site responsible authority needs to be identified prior to moving forward with the implementation phase of the project. In addition, a considerable number of approvals from all involved groups will be required in order to obtain the support of the local community, supporting Rotary club(s) and ultimately the financial commitment, including matching grants. As previously stated, any water and

sanitation project will be orders of magnitude more complex than any other projects undertaken by Rotary International and its clubs. To initiate the project, the participating clubs and partners will have to be committed to the short- and long-term funding of the project. However, this will only be achieved following the approval of the project design by all concerned. Such approvals, including a commitment to the project schedule, will be required from the following participants:

- Participating Rotary club(s)
- Village or Community
- Local and/or National Government
- Involved NGOs
- The Rotary Foundation (If Foundation funding is used)

How Is An NGO Selected?

Many international and in-country NGOs have a depth of experience for water-development projects and many of the NGOs work in many countries. Often times, these NGOs already have a relationship in the sponsoring Rotary club's area of interest. These NGOs can also open doors for finding host Rotary club partners. In addition, NGOs usually have an acute awareness of the local water and sanitation problems and local politics, and they can recommend a good project in which the sponsoring Rotary club can undertake.

Finding a good NGO is usually built on relationships. An international NGO may make a presentation to the sponsoring Rotary club. The NGO builds an awareness of the need for clean water and the sponsoring Rotary club will begin to develop an emotional attachment with the people in need. The NGO suggests a course of action and the sponsoring Rotary club may decide to contribute funds and other club resources to the project. This method of "interview" is a good way for the sponsoring Rotary club to evaluate the qualifications and demonstrated success of the NGO with similar projects in the country of interest.

Other times, the sponsoring Rotary club (or sponsoring Rotary district) wants to do a project but doesn't know how to find a good NGO. In these circumstances, the district water committee or grants committee may be a good resource. In addition, WASRAG may be able to provide recommended criteria and a possible list of NGOs doing the type of work in the area of interest (ref. WASRAG web site at www.StartWithWater.org).

The design process will also include an outline of the mobilization procedure and identify available local labor and materials, the material which will have to be obtained from outside the project site, the availability of local manpower and the skill level available both for construction and supervision. The selection of a suitable NGO may be useful for this process.

How Is A Contractor Selected?

In almost all parts of the world, there are contractors available for water development projects. The host Rotary club often has recommendations for contractors and/or drillers. However, unless the host club's membership includes experience water professionals, it is important to confirm the qualifications of both NGO and contractors that they will be relying on as their financial and construction partner many hundreds of miles away.

Contractors work based on a contract. Therefore, the contract must set clear expectations for permits (if needed), costs, design standards, results, and reports. Both the sponsoring Rotary club(s) and the host Rotary club(s) will need to assign someone to monitor the contractor, inspect the results, and obtain the reports. The sponsoring Rotary clubs are encouraged to send a team for a post-project evaluation and meeting with the host Rotary club.

Project Completion/Closure

The final project design must also indicate the schedule for completion, when tests to be completed to indicate closure and when the project is handed over and to whom. If the project is funded by a global grant, the sponsors are required to submit a progress report to the Foundation within 12 months of receiving the first grant payment and every 12 months thereafter. A final report must be submitted within two months of completing the project.

Checklist for Water Project Construction

The larger and more complex a water project is will determine whether or not a Rotary club partners with other Rotary clubs to implement the project.. Partners may by other Rotary clubs within their district, or Rotary clubs in the host country. Sometimes a project requires the assistance of an outside non-governmental organization (NGO). Having the right partners will help the construction process go smoothly. Answering the following questions will help the Rotary club during the construction process.

1. Is the project being funded by more than one Rotary club? _____
2. Do Rotary club members have the professional expertise to plan and design a water project and the ancillary needs of sanitation and health and hygiene? _____
3. Who in your Rotary club will manage the planning and construction process? _____
4. Does the club have sufficient number of club members to travel to the project site and complete the project? _____
5. If more than one club is participating in the project, what are the roles for each club?

6. If the club(s) does not have the expertise to plan, design or construct the project, who will be called upon to assist with the needed expertise? _____
7. If an NGO is needed to assist with the project:
 - a. What role in the project do you expect them to participate? _____
 - b. What are their credentials for fulfilling their role in the project? _____
 - c. Has the NGO working this country or region within the country before? _____
 - d. Who will be the contact from the NGO? _____
8. Is a contractor needed to complete the project? _____
9. If a contractor is needed:
 - a. Does he have references for doing quality work on similar projects? _____
 - b. Does he have the right equipment to complete the project on budget and schedule?

 - c. Is he available at the time your team will be available to travel to the country? _____
10. What action will designate the completion of the project? _____
11. What steps will be to take place to close out the project?
 - a. _____ Establish the community water committee.
 - b. _____ Close out NGO contracts.
 - c. _____ Pay contractors.
 - d. _____ Train operation and maintenance technician and supply him with tools, manuals and spare parts.
 - e. _____ Set up contact points between sponsoring Rotary project team, Regional Team and community water committee.
 - f. _____ Establish long-term evaluation and monitoring program.
 - g. _____ Complete TRF grant paperwork.

DRINKING WATER SYSTEM OPERATION AND MANAGEMENT

Introduction

During project planning, development and construction, it is very important to involve the leaders of the community that will be served by the project(s). They should be involved in the planning and construction in so far as possible in order to assure their commitment to the project and its long-term successful operation. This includes the requirement to set and collect annual tariffs by the local water committee to ensure that funds will be available to pay for maintenance and repairs of the installed system and to help ensure that it remains in good operating condition. This section discusses items to consider for achieving community 'buy-in' and the long-term sustainable success of the project.

How Vital Is Community Leader Involvement?

The involvement of community leaders in the water system project cannot be overstated. Whether the sponsoring Rotary club or its partners are dealing with a tribal chief, another Rotary club, or a community government, involvement and approval from the highest level is vital to the success of the project. The leaders must first be involved in the planning of the project to be sure they agree that the selected project is the highest priority need of the community.

Community leaders must also be involved in the design and construction phases of the project so that the project location, methods of construction and materials of construction are familiar to them and approved as a long-term solution to their problem.

Finally, and perhaps most important, the leaders must be aware of and approve the long-term operation and maintenance requirements, including cost of the improvement and the collection of tariffs to pay for on-going repairs and maintenance. Only with this high level involvement and approval can any project expect to succeed and remain viable over its projected life.

Why Is System Operation And Maintenance Important?

No matter what type of water supply improvement is selected for the proposed project, the operation and maintenance procedures must be documented in writing using the village's customary ways of entering into contracts.

People from project area must be selected to operate and maintain the system and they must be trained in the correct operation and maintenance (O&M) procedures, including the frequency of sampling and testing and frequency of various maintenance activities. Establishing these standard operation and maintenance procedures and setting an annual tariff for use is critical to the system being sustainable over the life of the facility.

Each project will require a customized manual of procedures to fit the specific application. The sponsoring Rotary club, the host Rotary club or NGO will also need to provide monitoring on a regular basis during the start-up years to assure the project remains sustainable. Any problems discovered during monitoring activities must be acted upon quickly to return the project to a viable status (see Project Monitoring and Feedback, below).

Is Tariff Assessment And Collection Important?

Early in the project, an appropriate tariff on system users should be identified that will be adequate to pay for materials and labor required to operate and maintain the system over its projected life. A procedure and mechanism for collecting the tariff should also be developed. Community leaders must be convinced that the selected system has the resources to allow it to have a sustainable future and that the only way to equitably do that is for the users to contribute their fair share for its maintenance. .

Can Changes In Water Quality Be Expected After The Project Is Operational?

Water quality issues may be present from the initial development of the proposed project or they may occur after some period of operation. Water quality degradation may range from color and odor problems to more serious problems, such as bacteria, dangerous chemicals, or heavy metals. For this reason, periodic monitoring of water quality both at the source and point of use is vital. If changes are found, determine if they have a potential negative effect on the population served and, if so, take immediate steps to mitigate the problem, such as provide additional protection at the source or provide improvements/modifications to the treatment system.

How Important Is Supply Chain Of Spare Parts Inventory And Security?

A critical spare parts inventory should be left with the project at the conclusion of construction. These may include spare pumps, gaskets, pipe fittings, etc. These parts should also be made secure from theft. The Rotary club should also help encourage the private sector in the region to stock appropriate supplies and be available to contract repairs as an alternative to placing this need on the village members themselves. The host Rotary club or NGO should occasionally check the private sector supply chain and inventory to make sure that it is available for the village when they need them for repairs.

Should Project Monitoring & Feedback Be Implemented?

Project monitoring and feedback was previously mentioned as a critical part of on-going operation and maintenance in order to ensure a sustainable project. Each project should be monitored on a regular basis (e.g., annually) by qualified technical persons to determine if the project is functioning as it was originally intended. This should be done by qualified members of the sponsoring Rotary club, host Rotary club or NGO.

Reports of the monitoring effort should be made to the sponsors and NGO, the community leaders, and the local staff responsible for the system operation and maintenance. Should problems be discovered, the report should include a positive plan for improvement that will result in re-establishing sustainability.

It is very important that positive monitoring results are shared with all parties, including the system operators and local authorities. It is at least as important that any necessary improvements be shared with the operators, including procedures required to improve the system and return it to one that is sustainable.

Checklist for Drinking Water System Operation and Maintenance

Failure rate of water projects constructed by service organizations in developing countries has been high (greater than 50%) for a number of reasons. The two most common causes are:

1. building inappropriate technology for the community, and
2. not developing community buy-in before the project is constructed or developing continuing community participation after the project is constructed.

Answering the following questions will assist a Rotary club in making its project sustainable.

1. Who from your club will periodically monitor the sustainability and performance of your project? _____
2. Who from the Regional Team will be your club's contact for assisting with project monitoring?

3. Does the community have an effective community water committee? _____
4. Does the community water committee need help in becoming more effective? _____
5. Who in the community will be the contact for your Rotary club and the Regional Team?

6. How will your Rotary club, the Regional Team and the community water committee communicate with one another after the project is completed? _____
7. Who from the community will be responsible for operation and maintenance (O&M) of the project? _____
8. Does the O&M technician have the tools and spare parts to effectively maintain the project?

9. How will tools and spare parts be secured? _____
10. Who will be responsible for acquiring and paying for spare parts? _____
11. How will the Rotary club hold the O&M technician responsible for his tools and the storage of spare parts? _____
12. Does the community water committee have a tariff system in place to pay for long-term operation and maintenance of the project? _____
13. Who will be responsible for and manage the money collected for O&M? _____
14. If water quality of the source water is expected to change seasonally or over time, who will be responsible for taking a water quality sample and having it tested? _____
15. If water quality changes over time, who will determine any changes in treatment process?
