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PRO-WASH
Practices, Research and Operations in Water, Sanitation and Hygiene

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PRO-WASH Guide to Sustainable Water Point Infrastructure:

A SYSTEMS-BASED APPROACH

EXECUTIVE SUMMARY

This guide aims to improve the sustainability and resilience of water points in rural areas of low-income countries. Lack of safe drinking water is a major cause of sickness and death, particularly in children. Safe drinking water needs investments in water point infrastructure, along with the supporting social, financial, and institutional systems. Yet around a third of water point infrastructure fails within a few years of installation[1]. Communities and their development partners cannot afford this loss. Even small improvements in water point infrastructure sustainability can save a lot of time and money, and many lives.

This guide is aimed at those who make decisions on how, when, and where to install water point infrastructure, what infrastructure to install, and how to keep it working. This guide is aimed at decision-makers in implementing partner organizations in Africa, particularly resilience food security activities (RFSAs) supported by USAID BHA. It is also aimed at development partners in international NGOs and aid organizations.

Water point infrastructure in rural parts of low-income countries is a paradox: on one hand, the technologies themselves are chosen for their simplicity, ruggedness, and reliability. On the other hand, the systems and institutional arrangements needed to keep them going, including regular operation and maintenance, can be surprisingly complicated and fragile. Climate change is increasing uncertainty, both in terms of the physical circumstances in which the infrastructure must operate and the changing needs and priorities of user communities. Future conditions are increasingly unknowable.

Good water point infrastructure and its institutional context should be sustainable (i.e., persist for long periods using available local systems and resources) and resilient (i.e., absorb shocks and changes without breaking down). There is no such thing as the perfect system, and compromises and trade-offs are needed. Arguably, water point infrastructure is more of a political-economy problem than an engineering or hydrology problem (even though engineering and hydrology are very important).

Since almost all rural water point infrastructure in low-income countries relies on groundwater, this guide begins with an overview of groundwater characteristics (Section 2). Section 3 describes the different basic types of water point infrastructure such as spring protections and boreholes, and some characteristics of each. Sections 4 and 5 discuss sustainability and resilience, respectively. Section 6 details why water point infrastructure is a classic "complex problem" and the systems thinking that can help with better solutions. At the end of the guide is a list of useful references, most of which can be freely downloaded from the **FSN Network** or elsewhere.

While this guide provides some practical guidelines and specifications in the reference sections, it is not a comprehensive guide to planning, designing, building, and running water point infrastructure. Instead, this guide lays out some of the over-arching issues and challenges around water point infrastructure in support of better planning and wider safe drinking water coverage.

1 See p8.

CONTENTS

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ACRONYMS AND ABBREVIATIONS

BHA	USAID Bureau for Humanitarian Assistance
CIS	Climate Information System
IWRM	Integrated Water Resource Management
NGO	Non-governmental organization
O&M	Operation and Maintenance
PE	Political Economy
RFSA	Resilience Food Security Activity
RO	Reverse Osmosis
SDGs	Sustainable Development Goals
USAID	United States Agency for International Development
WASH	Water, Sanitation, and Hygiene

1. INTRODUCTION

Water point infrastructure and good operations and maintenance (O&M) is important for USAID Bureau for Humanitarian Assistance (USAID/BHA)- funded Resilience Food Security Activities (RFSAs) and other programs working on WASH. Water infrastructure and O&M support better health and nutrition, economic development, poverty reduction, women's empowerment, and environmental sustainability.

This guide aims to support RFSA partners to improve initial design, sustainability, and reliability, recognizing challenges may include poor water quality and addressing environmental concerns including impacts from climate change. It addresses the issues in three ways:

1. By introducing some of the main issues that influence the sustainability and resilience of water point infrastructure;
2. By showing that these issues can combine in sometimes unexpected ways to determine overall infrastructure sustainability and resilience, and that this is why a systems approach to infrastructure is recommended;
3. By linking to further resources on the aspects of infrastructure introduced in this guide. These resources go into more detail on many of the topics, and are easily available and accessible.

This guide complements other USAID guidance, such as those for **Water Quality Assurance Plans** and the **Technical Brief** series.

The main intended audience for the guide are senior and mid-level RFSA staff who make decisions about water point infrastructure, O&M models, and water governance, and who might need an overview and a quick reference that links to diverse information in a clear and accessible way. A secondary audience consists of colleagues in NGOs, USAID, and partner organizations, who are addressing problems with water infrastructure, and making planning decisions about allocating resources and funding.

This guide is divided into seven sections. After a discussion of groundwater (Section 2), this guide describes the different basic types of water point infrastructure such as spring protections and boreholes, and the advantages and disadvantages of each (Section 3). Section 4 looks at the question of sustainability and its implications for the planning, operation, and maintenance of water point infrastructure. Section 5 focuses on how to improve water point resilience in the face of a changing climate. Section 6 discusses why water point infrastructure is a complex problem, and the need for systems thinking. The Conclusions sum up and suggest some ways forward.

At the end of the guide is an appendix with links to useful reference material and further reading relevant to each section, most of which is freely available from the **FSN Network** or elsewhere.

WHAT'S THE PROBLEM?

About 2 billion people worldwide lack safely managed drinking water services, and about 1.7 billion people have no access to safely managed sanitation[1]. Poor sanitation and unsafe water together cause much disease and suffering. Despite these challenges, progress is slowly being made in water, sanitation, and hygiene (WASH) provision globally[2].

1 See the **Joint Monitoring Program** for this data, and more.

2 For example, according to the **Joint Monitoring Program**, in the year 2000, 62% of people had access to safely managed drinking water, and today that figure is about 74%.

HOW DOES INFRASTRUCTURE HELP?

Delivering safe water and adequate sanitation requires infrastructure—built or manufactured structures such as pumps, pipes, toilets, wells, or buildings. Infrastructure can also mean systems made from these components, and which include the necessary human and financial resources, such as water treatment plants.

This guide concentrates on water point infrastructure and the operations and maintenance (O&M) of this infrastructure. This mostly means physical structures and systems such as pumps, wells, tanks, spring protection boxes, or pipes that help us to get water from an environmental source such as an aquifer or a spring and make it available in the right quantity and quality at the right place. Additionally, O&M of infrastructure includes regular maintenance, repairs, checks, and adjustments. O&M requires financial, human, and institutional resources. Without O&M, *all infrastructure will fail*. For example, around a third of water infrastructure in low-income countries fails after only a few years[3]—a big loss in places where such infrastructure is already scarce (see **Section 4**). Designing and installing infrastructure with O&M in mind is a good investment (see **Section 4**).

GENDER EQUALITY AND SOCIAL INCLUSION IN WATER INFRASTRUCTURE

As women and children are the most likely to collect and use water at the household level (cooking, cleaning, caregiving), it is important to consider gender equality and social inclusion within all water infrastructure activities. Social inclusion means that all members of society should have the same opportunities and security and be treated with the same level of dignity. Gender inequality is a particularly common form of exclusion worldwide. Social exclusion and gender discrimination makes it harder for women and girls to access education and job opportunities, disempowering them and exposing them to the threat and reality of violence. Lack of opportunities for women and girls not only causes suffering and lower earning power, but also risks serious economic and health costs for their communities and countries.[4] This is why investing in girls and women is essential for development and for WASH.

Water point infrastructure should take special consideration of the needs of women and girls, as well as other marginalized members of the community. This means involving women (in all their diversity) at all stages of the project and ensuring that their voices are heard and their needs are met. It is not enough just to condemn gender and other forms of discrimination—concrete plans and strategies should be formulated to guarantee participation. It is essential that women participate equally in all discussions of water related to sustainability and climate resilience. For example, women use household water infrastructure the most, know when it breaks down, and how it reacts to shocks such as droughts. Without women's full participation, water infrastructure may be designed without proper consideration of how it is actually used, or who uses it. For more information, visit the PRO-WASH resource page on **Integrating Gender Equality and Social Inclusion in WASH and IWRM**.

3 Figures vary between countries, and depend on the definition of "functional". See **Carter (2021)** for more detailed discussion, including the results of the UPGRO "**Hidden Crisis**" project.

4 Wodon, Q., Onagoruwa, A., Malé, C., Montenegro, C., Nguyen, H., & de la Brière, B. (2020). How Large Is the Gender Dividend? Measuring Selected Impacts and Costs of Gender Inequality. The Cost of Gender Inequality Notes Series. Washington, DC: The World Bank. Available to download **here**.

SIMPLICITY VERSUS COMPLEXITY

What if you needed transport, and were given a choice between a Mercedes Benz and a bicycle? You'd pick the Mercedes, wouldn't you? Are you sure? What if the roads were very rough and the car would get stuck or damaged? What if there were no fuel, and so once you'd finished the first tank, the Mercedes would be useless? In those circumstances, a bicycle might be more useful. It's the same with infrastructure—it must fit the circumstances where it will be used.

But simple, low-tech solutions aren't always better in low-resource, rural settings: there is a trade-off between technical complexity and organizational or institutional complexity (Figure 1). Imagine a rural area with twenty villages, each supplied with water by its own diesel-powered well. Each well must be inspected and refueled monthly, and overhauled annually. It takes a lot of time and money for a team of technicians to visit each well every month. Sometimes in the rainy season, they can't travel at all because the roads are too muddy. The O&M is mechanically fairly straightforward but logistically complicated.

An engineering firm proposes to supply all twenty villages with a single large electric pump and water treatment plant at a nearby river, plus a system of pipelines. They argue that the new system would be expensive to build, but once installed it will be easier to maintain because there is only one pump to worry about. Also, the pump and treatment plant are all in one place. They say that the installation of the new system will be paid for over time with the savings made by not traveling to the twenty original wells, and the savings on diesel fuel.

This new system will be mechanically more complicated (pump, treatment plant, and pipeline network) but won't have the logistical challenges of visiting all twenty villages regularly. The new system has more complex O&M requirements—for example, maintaining the treatment plant, or fixing the electric pump if it breaks down. Also, a failure at the pump or treatment plant would mean that water would not be available for all twenty villages—whereas in the past if a village pump failed, only that village would be without water. The electric pump is more reliable than the old diesel-powered pumps but if it breaks down it takes longer to fix because it needs a qualified electrician and costly spare parts. This is what is meant by trade-offs, which are emphasized throughout this guide.

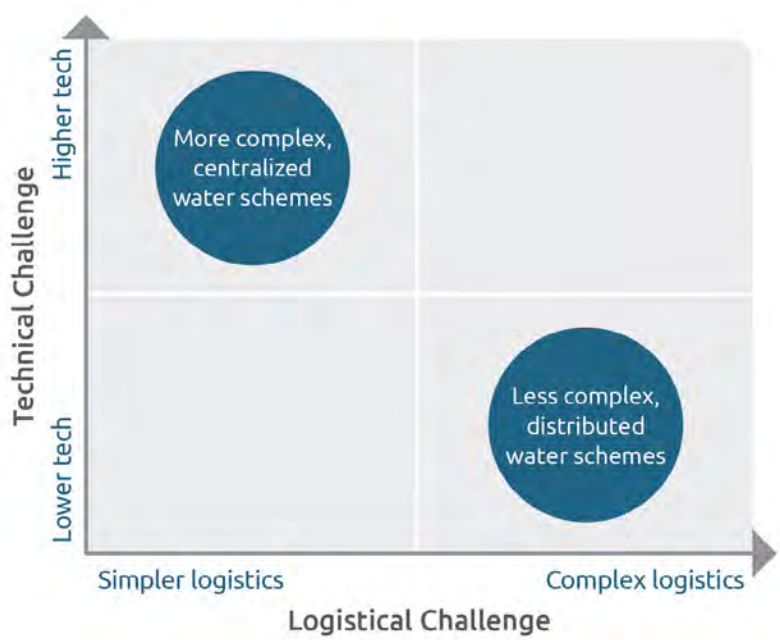

FIGURE 1: Big regional schemes may substitute technical complexity for small schemes' logistical challenges[5]

5 Figure after Gibson, J. (2011). Is it worth building regional schemes? Presentation to the 6th International Rural Water Supply Network Forum. Kampala, Uganda, 29 November – 1 December 2011.

CASE STUDY FROM BANGLADESH

In some places, a higher level of technology can be the most appropriate solution. For example, the RFSA Nobo Jatra (New Beginning), implemented by World Vision in southwest Bangladesh, tackled the problem of saline water in community supply boreholes by installing electrically powered reverse-osmosis (RO) plants to help ensure safe and reliable domestic water supplies. RO technology requires relatively complex arrangements for operations and maintenance (O&M), including a steady income stream to pay for the running costs and spare parts. Nobo Jatra were able to address the technological, financial, and management aspects of RO plant operation, including through training plant caretakers, implementing an innovative cashless payment system, and training water vendors to make water deliveries. The high levels of reliability achieved in turn made people more willing to pay extra for the convenience of the high quality water—a virtuous circle. Other factors for success included tailored business plans for each RO plant, close collaboration with government departments, and diverse and inclusive water management committees[6].

An RO plant in Bangladesh.

6 For more information, see this **briefing note** on Nobo Jatra's work.

2. ALL ABOUT GROUNDWATER

WHY FOCUS ON GROUNDWATER?

This guide focuses on water point infrastructure that uses groundwater such as spring protections and wells. Groundwater is the main source of domestic water for most rural people in Africa and south Asia.[7] In general, the large volumes of groundwater stored in aquifers make it drought-resistant, and the natural quality of most groundwater is usually good.[8] These make groundwater a good option for water supplies in low-income areas. Across much of rural Africa, Asia, and South America, groundwater is the only realistic option for meeting dispersed rural demand, and most RFSAs depend on this resource.[9]

BOREHOLE OR WELL?

In many countries in Africa and Europe, the word borehole is used to describe a narrow diameter well (around 150 mm or 6 inches) usually between 10 and 100m (30' to 300') deep, that is drilled with a machine called a drilling rig. Structures with diameters that are about a meter or wider (about 3' or wider) are known as dug wells, or just wells. In North America, the term "well" covers both boreholes and dug wells. In South Asia, the word tubewell is often used[10].

Drilling a borehole is usually done by a drilling contractor, operating a drilling rig. Rigs vary in size, from machines weighing many tons and carried by large trucks to much smaller and more portable designs. In some areas, simple hand-powered equipment can drill boreholes. The size and type of drilling rig used depends on the depth and diameter of the borehole, on the geology and ground conditions, and on the time available. There are many considerations and tradeoffs when deciding what type of rig and what method of drilling to use. These depend in turn on what conditions are expected and on the final design of the borehole. It is important to get professional advice from a groundwater specialist or hydrogeologist when planning drilling, since this will save time and money in the long-run. Contracting with the driller is important, covering issues like who pays if a borehole is dry, if equipment is lost or broken, or if the final borehole construction is not to specification.

FIGURE 2: Drilling rigs working in Nigeria (left) and in South Africa (right)

7 According to the **World Bank**, about three quarters of poor people still live in rural areas and rely on agriculture.

8 But all groundwater should be tested to make sure it is safe to drink.

9 For more details, see MacDonald, A., Davies, J., Calow, R., Chilton, J. (2005). *Developing Groundwater. ITDG Publ. Warwickshire. Available to download* **here**.

10 There are several other types of groundwater delivery structures, such as qanats, infiltration galleries, or adits, each with advantages, drawbacks, and sometimes with distinctive cultural contexts.

Groundwater is found in underground aquifers so it has some unique characteristics and can behave differently compared to water in rivers and lakes. Groundwater usually moves very slowly (normally less than a meter (3') a day), for example, and can even flow in directions that don't follow the local topography. Understanding how the groundwater resource exists—where it is, how much is there, how deep it is, its quality, where it is moving and how fast, and how it is recharged—is essential in planning water point infrastructure. Even today, a lot of water infrastructure is still designed and planned without considering all of the characteristics of the groundwater resource on which it relies. Understanding a few basic groundwater terms and concepts can help to clear up any mysteries[11]:

SOME IMPORTANT THINGS ABOUT GROUNDWATER

Aquifers are bodies of rock or sediment that contain groundwater (in cracks or in the spaces between grains, for example) and also allow the groundwater to move within the aquifer. In other words, the cracks or spaces in the aquifer have to be big enough, and connected enough, to allow groundwater to move through the aquifer at a reasonable rate (e.g., towards the intake of a well). The amount of groundwater that an aquifer can store is called its porosity—this means the amount of space in the aquifer made up of all the cracks and spaces between grains combined. For example, if a fractured limestone aquifer has a porosity of 5%, when that aquifer is saturated with groundwater, about 5% of the volume of the aquifer is groundwater and the other 95% is limestone. Usually, the more porosity an aquifer has, the better.

Permeability describes how easily groundwater moves through an aquifer—i.e., through the interconnected cracks and spaces between grains. The more permeable an aquifer, the more easily water can move through it. Imagine a rock with isolated pockets of space that are not connected—this rock could store groundwater (porosity) but would not transmit if very well (permeability). Normally, the more permeable an aquifer, the better.

The aquifers most useful for water supplies are typically associated with loose (unconsolidated) sediments such as sands and gravels, and with sandstones or fractured and weathered limestone. But aquifers can be found in almost all types of rock, even ones that seem unpromising, such as granites. Aquifers may be as small as a few tens of meters wide and a few meters deep, such as a buried riverbed, a layer of gravel, or some locally weathered granite—or they may take up whole continental regions and be hundreds of meters thick. All countries have hydrogeology maps at national or regional scale that show the locations and properties of aquifers but the quality and accuracy of the maps varies from country to country (see **Figure 9**). It's a good idea to consult all available maps before considering groundwater-based water supplies—see the sub-section on hydrogeologists and hydrogeological maps below.

When a well is dug or drilled into an aquifer, the water in the well usually settles at a certain level below the ground. This level is called the water table. Below the water table, the pore spaces in the aquifer are fully saturated. There is often water in some of the pore spaces above the water table too, but they are not all full, and this zone is known as the unsaturated zone. The water table may be very close to the ground surface or hundreds of meters below it, depending on the aquifer and the location. The water table is usually not flat, but varies with the topography—it is usually further from the ground surface beneath hills, and closer to the surface in valleys (see **Figure 4**). In some places the water table intersects with the ground surface—these areas usually form wetlands, springs, marshes, rivers, or lakes.

11 A good text that includes introductions to basic groundwater concepts is the book **Developing Groundwater** published by Practical Action Publishing.

Groundwater does not stay still in most aquifers, but moves from areas where the water table is higher to areas where it is lower. This is one reason why it is important to know where the water table is, and how it varies over a project area—it can tell us which way the groundwater is flowing. Monitoring of groundwater levels through simple measurement of depth to water table helps us to understand groundwater sustainability, flow direction, threats to quality, and other important things (Figure 3).

FIGURE 3: Hydrogeologists monitoring a groundwater level in a newly drilled borehole in Nigeria

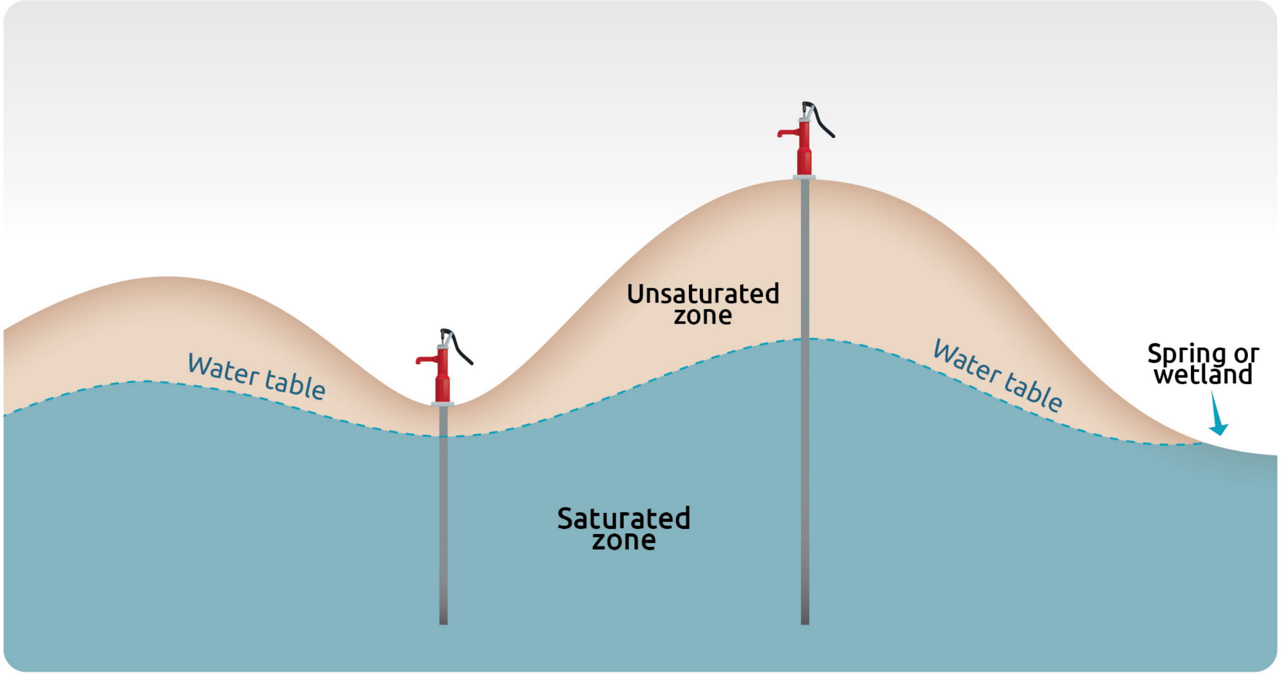

FIGURE 4: The water table is often a subdued reflection of the topography

Some of the rain that falls percolates down into the ground and finds its way to the water table. This is called recharge. Surface water bodies such as rivers and lakes can also recharge groundwater. Under natural conditions, groundwater flows from areas where it is recharged to areas where it discharges (e.g., at a river or the sea). This can take a long time—tens or even hundreds of years—and is part of the water cycle (see **Figure 5**). Recharge in any particular region can be described as a percent of the total rainfall in that region. Recharge can vary from about 5% or less of total rainfall in semi-arid areas, to more than 30% in other places. Many hydrogeology maps include an estimate of recharge for the various aquifers or areas shown.

Sustainable use of groundwater is an important topic—ideally, groundwater abstractions should not cause unwanted impacts such as the drying of wetlands or excessive lowering of the water table. Linked closely to this is the issue of groundwater data. For example, without knowing how the water table is changing (i.e., how "full" the aquifer is), it's hard to know what management measures to take.

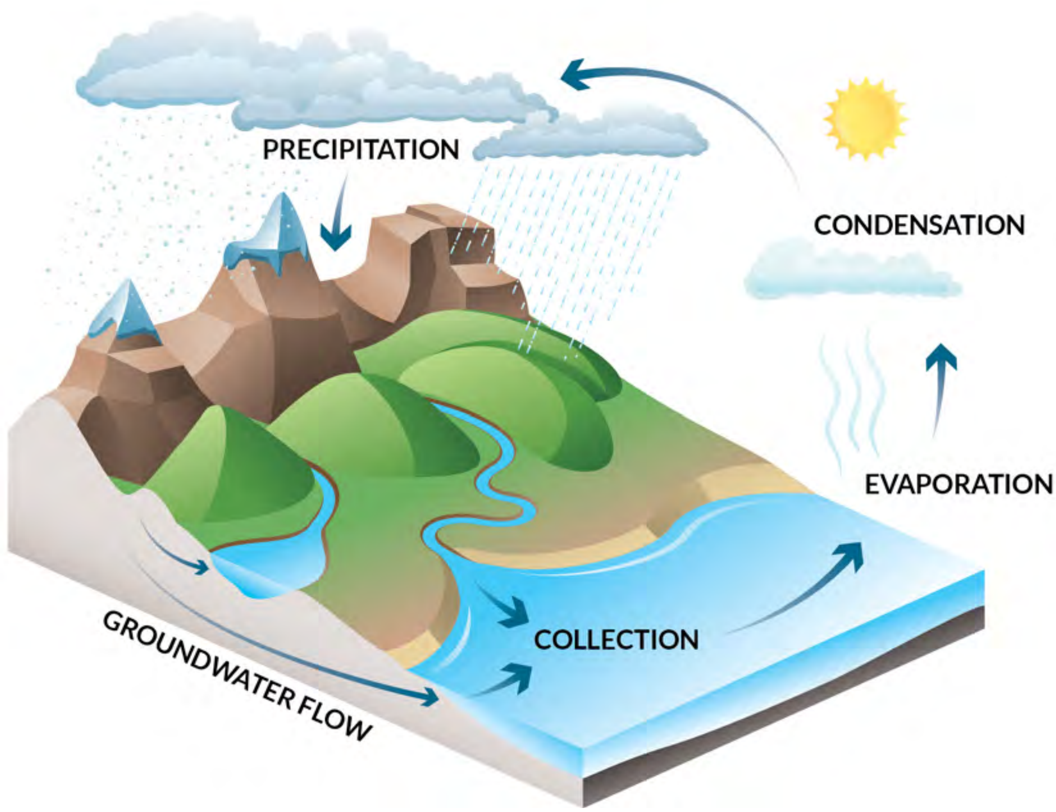

FIGURE 5: The Water Cycle[12]

GROUNDWATER YIELDS

Very roughly, a yield of about 0.5 liters per second (L/s) (or about 8 US gallons per minute) is needed to support a hand-pump on a borehole—and even this low yield can be hard to find in some areas. Lower yielding aquifers may still support a large-diameter well, which can slowly fill up overnight. Public water-supply boreholes (e.g., those supplying whole villages or towns) often yield around 20 L/s (about 315 US gallons per minute). Irrigation boreholes in (for example) the unconsolidated sediments of south Asia (**Figure 6**) or the dolomites of southern Africa can yield twice this, or more. Low or declining yields may not always be the fault of the aquifer, but are often due to infrastructure issues such as poor borehole construction, blockages, poor pump specification, pump problems, or deterioration of materials (especially corrosion).

12 Figure adapted from the PRO-WASH training course on Drinking Water Quality Monitoring

FIGURE 6: A borehole in Bangladesh yielding about 80 L/s

(Photo: Jeff Davies)

When water is pumped from a borehole, the level of water in the borehole drops until an equilibrium is reached. The level of water in the aquifer around the borehole drops too, most steeply near the pumping borehole, forming a conical shape. This is called a cone of depression, and its dimensions can be calculated before pumping starts if the properties of the aquifer are known. The lowered water level in the borehole and surrounding aquifer is called the drawdown.

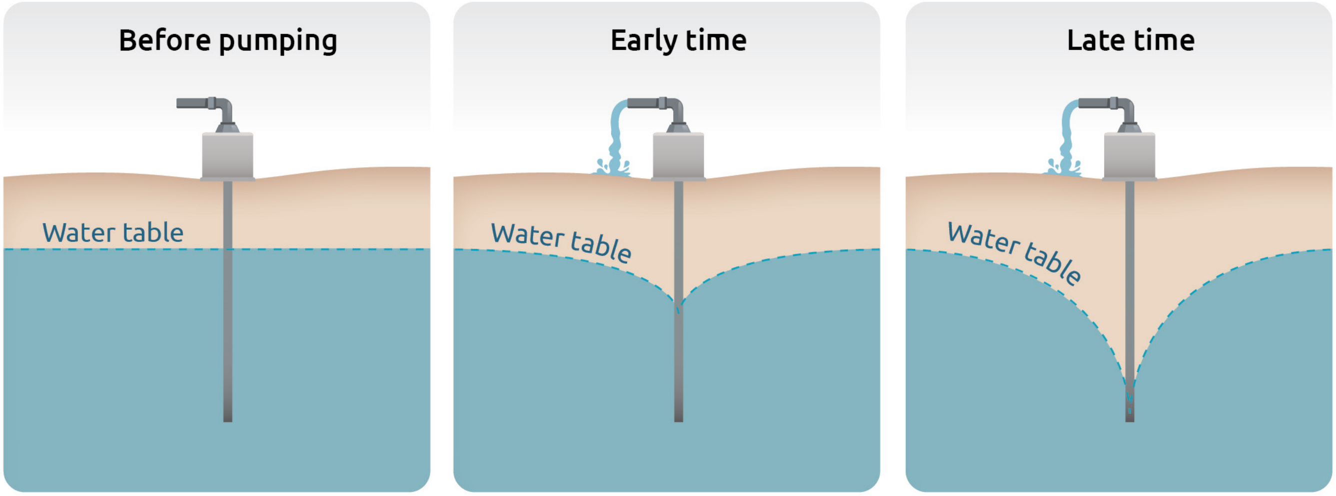

FIGURE 7: Development of a cone of depression in the water table

HYDROGEOLOGISTS AND HYDROGEOLOGICAL MAPS

The study of groundwater is called hydrogeology, and a hydrogeologist is a person who studies groundwater. She or he will often have training in geology, as well as graduate studies in hydrogeology. Hydrogeologists can assess groundwater volumes and quality, design infrastructure such as boreholes, interpret hydrogeological data, read hydrogeological maps, site boreholes, and make recommendations for the sustainable supply of groundwater.

A basic hydrogeological study would include a desktop assessment that uses existing data and information to get a general idea of the groundwater conditions and potential in an area. This can normally be done in a few days or less at reasonable cost, and is usually a wise investment whenever groundwater is being considered for water supply. More detailed groundwater studies can involve surveys of existing water points, the drilling and testing of new boreholes, water sampling, and mathematical modeling of the groundwater flow and quality. These studies can take months or longer and are more expensive, but provide more information.

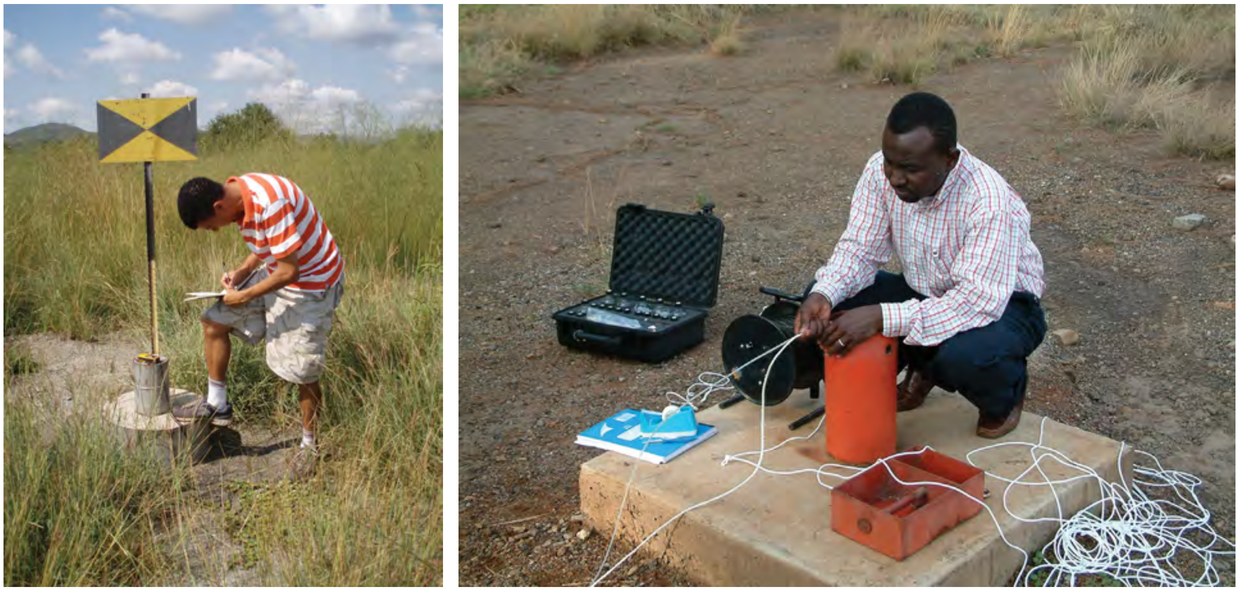

FIGURE 8: Hydrogeologists at work

The geology in any particular area has a huge influence on the types and properties of aquifers – and so geology maps that show the rock types are very important to hydrogeologists. Hydrogeology maps are special geology maps that show aquifer types and properties, as well as often the level of the water table, the groundwater quality, the rate of recharge, and other information. Hydrogeology maps at detailed (large) scales are most useful for siting boreholes and understanding local groundwater, but smaller scale maps that cover larger regions are also very useful (**Figure 9**).

Most parts of the world are covered by at least one hydrogeology map, and some countries have very detailed maps and even groundwater atlases of local areas. Many hydrogeology maps are available on-line for free, along with groundwater reports, data and other information. See the PRO-WASH's **summary guide** to groundwater resources for more information.

It is a good idea to consult a hydrogeologist on all aspects of groundwater planning and abstraction. The information she or he gives can save a lot of time and money and help with project sustainability. Hydrogeologists should be properly qualified and experienced in the particular area of interest. Hydrogeologists often work closely with engineers, project managers, health experts, gender specialists and others to ensure that a groundwater supply is tailored to the requirements of a project, and that any infrastructure installed is appropriate and cost-effective.

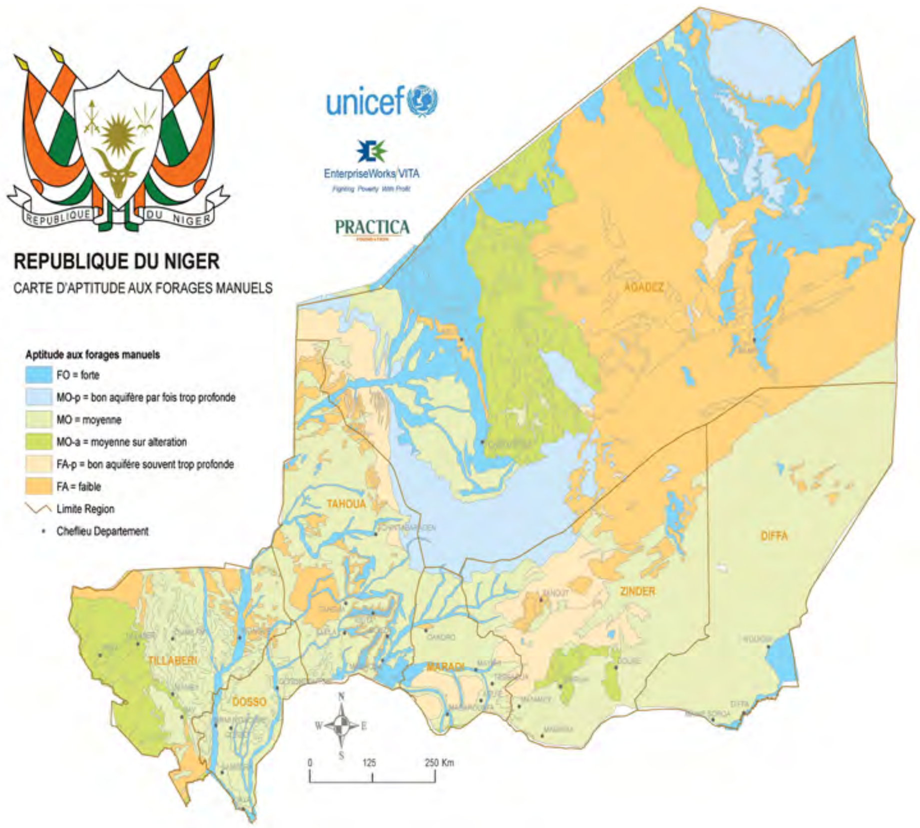

FIGURE 9: Example of a national hydrogeology map (Republic of Niger)[13]

GROUNDWATER QUALITY, AND PATHOGENS AND PROTECTION ZONES

The quality of groundwater depends on several things, including the type of aquifer rock and how long the groundwater has been in the aquifer. In general, microbiological contaminants such as bacteria and parasites do not survive long in aquifers and unlike river water, groundwater often does not need to be treated before being used or drunk. However, groundwater should always be tested before being accepted as safe to drink. Groundwater can become polluted too—another reason why groundwater should be tested. Some groundwater quality parameters (such as salinity, arsenic content, or E. coli bacteria) can be tested at the source, while other parameters need a laboratory[14]. Some groundwater pollutants (such as pesticides or hydrocarbons) can be very difficult and expensive to clean up.

Pathogenic organisms such as bacteria tend to die off at a known rate in aquifers, and few can survive underground for more than about 50 days[15]. The groundwater travel time between a potential contaminant source such as a pit latrine, and the intake of a well, should be long enough to minimize the risk of infection. It is wise to establish a protection zone around any groundwater source used for drinking water supply. No polluting activities and no animals are allowed into this zone, and it is sometimes fenced off. Mathematical groundwater models can be used to calculate the more complex size and shape of protection zones in places

13 Map accessed at the British Geological Survey's **Africa Groundwater Atlas**.

14 See the PRO-WASH **Technical Guide** on Drinking Water Quality Monitoring, and **Training Course**, for more details.

15 Pathogen survival rates in groundwater depend on many factors. See the **ARGOSS manual** for more details.

with varied topography and hydrogeology. However, there are also basic methods that can be used to lessen the risk that local pollution will contaminate groundwater sources. In a more detailed study, hydrogeologists would typically look at the source of pollution, the pathway that it takes, and its destination (or receptor), in assessing groundwater contamination risk (see the **ARGOSS manual** for example). It is much easier to protect groundwater quality than it is to clean it up once it has become polluted.

CASE STUDY FROM ZIMBABWE

The Amalima Loko RFSA works across five Districts of Matabeleland North Province in north-western Zimbabwe. This is a part of the country with erratic rainfall, and groundwater resources are important for sustainable irrigation, stock watering, and domestic water supply. The Kalahari Sands aquifer underlying part of the RFSA area is composed of fine-grained sands and silts, and it is difficult to stop boreholes from clogging up with the fine material. The sand and silt also wears out pump components prematurely. In response, Amalima Loko are investigating different borehole designs, including those that use special gravel packs, to keep the problem to a minimum. The RFSA also keeps records of borehole locations and construction, so that previous technical issues and possible solutions are documented and can be applied to new infrastructure design. The RFSA also works with local drilling companies to source appropriate materials, and use better drilling methods, to help ensure that groundwater infrastructure in the Kalahari Sands is as resilient as possible.

SOME WATER TREATMENT BASICS

Surface water, such as water from a river or lake, usually goes through four basic steps to make sure it is safe for humans to drink:

1. Removal of large particles and debris with a strainer as water is pumped from the river or lake;
2. Addition of chemicals (flocculants) to make smaller suspended particles (mud, clay, etc.) in the water stick together (to form flocs) and sink to the bottom (sedimentation);
3. Filtration of the water to remove the flocs—the water should now be clear, but it may still have invisible microbiological contaminants such as viruses or bacteria in it;
4. Disinfection (often using chlorine) to kill any microbiological contaminants. Residual chlorine in the water helps to keep it disinfected as it is sent through pipes or collected in containers by people.

If the water is polluted (e.g., with pesticides, nitrates, algae, etc.) then further treatment steps are needed. Particle removal (first three steps) is important for step 4 to work. Water treatment uses energy (e.g., for pumps), and chemicals (e.g., chlorine and flocculent), and the treated water needs to be regularly tested by trained people to ensure the treatment process is working.

Groundwater can usually skip the first three steps in this process because the aquifer filters the water, but most public water supplies that use groundwater and send it through pipes disinfect it with chlorine (or another method) as a precaution. In some cases, groundwater may be filtered too. Stand-alone groundwater sources such as springs and boreholes usually have no treatment at all, and this is why it is so important to make sure they do not get contaminated in the first place, and that they are constructed properly to protect them from contaminated surface water.

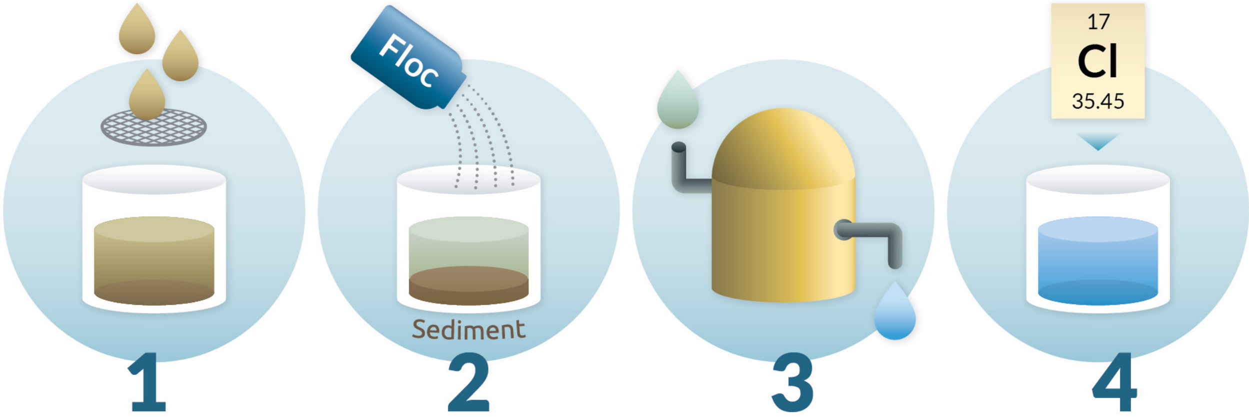

FIGURE 10: Basic steps in water treatment

FIGURE 11: Sand filters (treatment step 3) at a small town water supply in South Africa

3. TYPES OF WATER SUPPLY INFRASTRUCTURE

BOREHOLES, WELLS, AND TUBEWELLS

The two most common types of infrastructure used to supply groundwater for domestic use are boreholes[16] and spring protections. A borehole is a specialized piece of infrastructure for pumping groundwater to the surface. A borehole's design and construction hugely influences how long it lasts, how efficiently it operates, and the safety of the groundwater it delivers. There is no single borehole design—boreholes should be designed and constructed based on the groundwater conditions and the aquifer type, and on their intended use. Borehole design and construction is one of the most overlooked issues in water infrastructure, and is often the root cause of many frustrating problems such as poor yields, unreliability, contaminated groundwater, or high operating costs.

A borehole is a long, narrow hole: most water supply boreholes are around 100 to 250 mm (4 to 10 inches) in diameter and usually between about 10 m and 100 m deep (33' to 330') deep. Imagine a 150 mm (6') diameter drainpipe that is the length of a football field, and you have a rough idea of a borehole's real dimensions. Boreholes are drilled to a suitable depth into an aquifer below the water table, usually by drilling rig.

All boreholes need support for at least some of their depth with a cylindrical lining of metal or strong plastic tubing to keep them open. This tubing is called casing. The casing has slots or holes at places where groundwater is expected to flow into the borehole. This special slotted casing is called a screen. Screen is more expensive and fragile than casing, and an important part of the design of any borehole is where to place the screen, and where to place the casing.

The circular gap or space between the outside of the screen or casing, and the inside wall of the drilled hole, is called the annulus. This space is normally filled with gravel or other material called formation stabilizer where it is adjacent to solid casing. Near the ground surface, special clay or cement grout should be used to form a sanitary seal.[17] A sanitary seal prevents contaminated surface water and contaminated shallow groundwater from getting into the borehole. A well-engineered sanitary seal helps to ensure good water quality and is a vital part of borehole design. The space between the borehole screen and the borehole wall is usually filled with a special mix of gravel called a gravel pack. The gravel pack helps to filter the groundwater as it flows into the borehole, as well as supporting the screen. The diameter of the gravel in a gravel pack should depend on the grain size and other characteristics of the aquifer—not all gravel packs are the same. The gravel pack should also be clean and should not harm the quality of the groundwater. Some boreholes, drilled into hard, stable rock formations, do not need screen or gravel pack and these are left "open hole" below a shorter length of surface casing plus the sanitary seal (see **Figure 12**).

16 Boreholes are called "wells" in North America and "tubewells" in parts of Asia.

17 Also known as an annular surface seal, or just a surface seal.

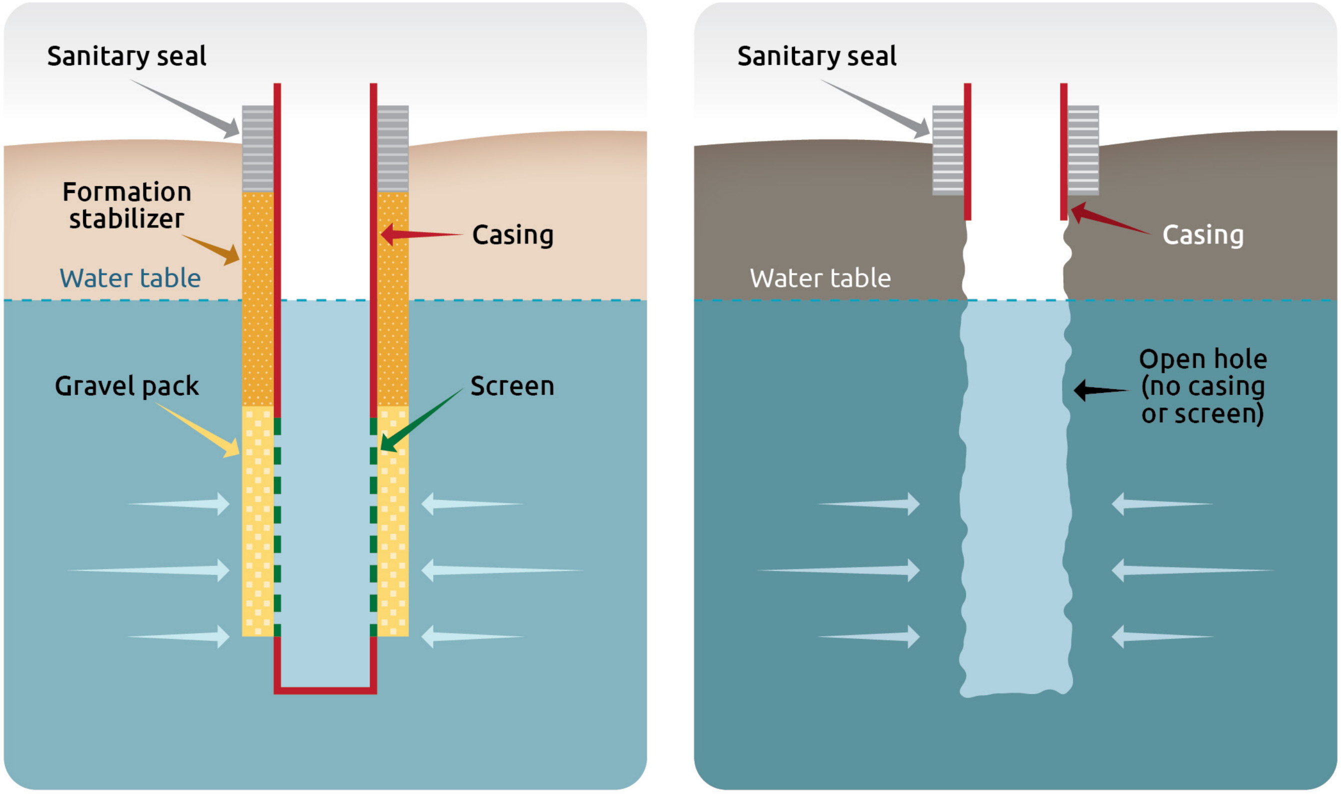

FIGURE 12: Borehole design for unstable geological formations (left) and for stable formations (right) (not to scale)

The borehole designs in Figure 12 above are not drawn to scale—if they were, the figures would need to be about 2 m (6 feet) high!

Designing a borehole depends on the hydrogeological conditions, and this is one reason why collecting data during drilling is so important. Designing and constructing boreholes is often left to sub-contractors, with little time, money, or supervision allocated, even though poorly designed or constructed boreholes can fail prematurely and are more susceptible to contamination. Research by the **UPGRO project** found that poor siting and construction was the most significant contributory factor to water point failures in a study done in Uganda. Many of the water points were sited with limited technical investigation and supervision. Professional borehole design and construction, using appropriate materials, can greatly extend the life of water points and is strongly recommended. See chapter 6 of the book **Developing Groundwater** for more detail on designing and constructing boreholes.

FIGURE 13: A geophysical team siting a borehole in Nigeria.

DATA COLLECTION DURING BOREHOLE DRILLING

All drilling results in useful hydrogeological data, including details of the local geology, the depth to groundwater, the groundwater quality, and so on (Figure 14). The drilling contract should specify that this information is collected and passed to the client. Sometimes, managers may not be aware that dry boreholes that yield no water still yield useful data (see **Section 7**). Hydrogeologists can compile this data to help predict groundwater conditions to make water supply infrastructure in the area more reliable and less costly. In some countries, drillers are legally required to submit details of all boreholes drilled to the authorities. A correctly drilled borehole is the foundation of a reliable groundwater infrastructure asset. Essential data to collect includes:

- Description of geology (logging and photos of drill cutting samples taken every 1m / 3')
- Water strike and fracture zone depths
- Final blow yield of borehole
- Static water level
- Step test and pumping test results
- Water quality measurements made on site, such as EC and pH
- Well construction (total depth and diameter, lengths and positions of all casing and screen, casing and screen material, details of grout and gravel pack)

FIGURE 14: A hydrogeologist in Tanzania logging drill cutting samples (L), and a driller collecting drill cuttings in Ghana (R)

(Photos: Jeff Davies)

SPRING PROTECTIONS

Springs are places where groundwater emerges from the ground naturally—such as where the water table intersects with a slope, or where groundwater is forced to the surface by geological structures. Springs may not be safe to drink from without treatment because of microbial pollution or other contamination, unless they are protected (by keeping animals away, for example). A spring protection system consists of a brick or concrete box around the spring eye, sometimes with stones to filter the water and a removable lid allowing cleaning (Figure 15). The spring water can then be piped away from the spring under gravity, to a storage tank and standpipe so that people can access the water. A spring protection should also include a fence or wall to keep people and animals away from the area around the spring, and trenches, drains or berms to stop surface runoff from getting into the spring.

Larger spring protections may serve several villages, depending on the flow rate of the spring and its seasonal variability. A spring's flow rate (i.e., how much water it delivers) is important in deciding how many people it can serve. The hydrogeological setting of a spring controls how much water it delivers, and also how that rate might vary over the year or following dry spells. Long-term records of spring flow and local rainfall volumes are very useful, and local community knowledge can be vital. Land-use changes, such as planting trees above a spring or using pesticides and fertilizers near a spring, can impact its flow rate or quality.

FIGURE 15: A spring protection being installed in South Africa

DUG WELLS

Wells that are dug by hand and are more than about a meter (about three feet) in diameter are called dug wells. Dug wells are normally (but not always) much shallower than boreholes. They are laborious to construct, but this work can be done with basic tools. Dug wells are usually lined with stones, bricks, concrete rings or other material to stop them collapsing. A dug well that is open to the elements is easily contaminated, but they can have lids fitted and concrete aprons constructed to protect them. Dug wells can also be contaminated when buckets and ropes are lowered into them to withdraw the water, and so some dug wells are covered over and fitted with pumps (see **Figure 16**).

Dug wells can be more vulnerable to drought than boreholes because they are shallower and do not penetrate as far below the water table. If the water table falls below the base of the well, the well will go dry. On the other hand, in low-yielding aquifers the storage of a dug well can be a bonus—they fill up slowly overnight, allowing people to collect water in the morning.

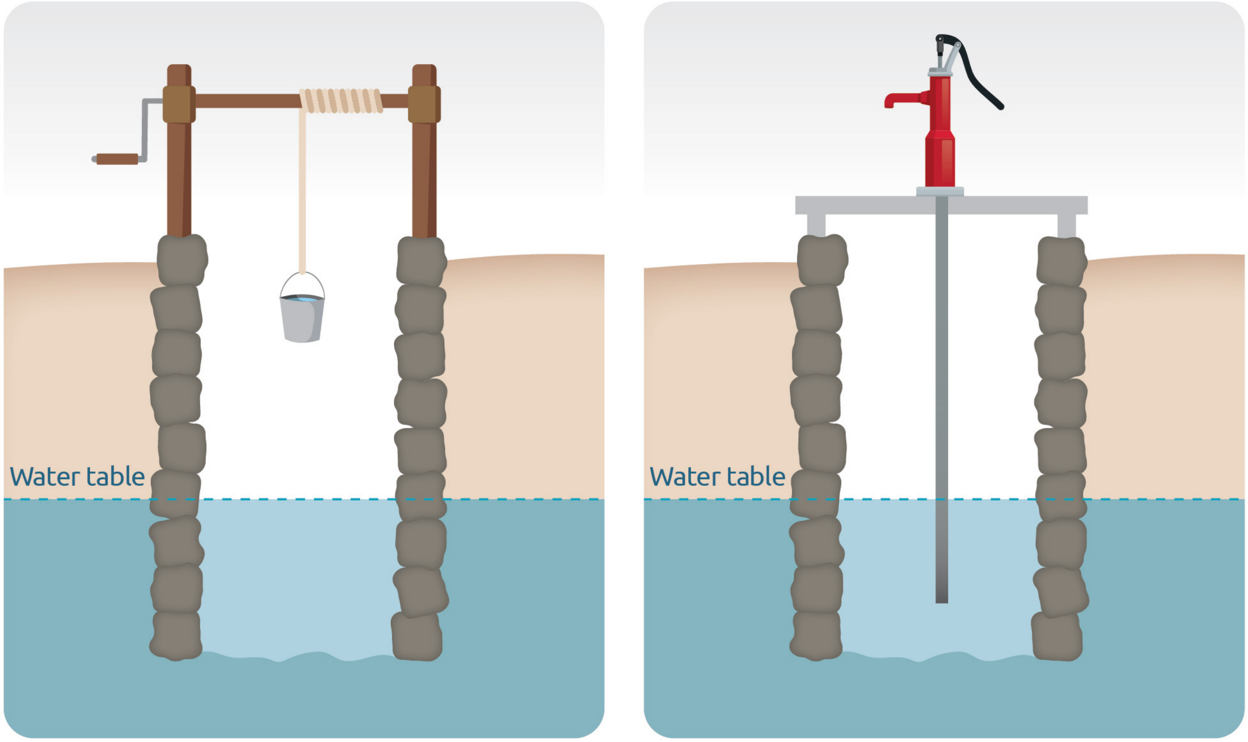

FIGURE 16: A basic dug well (left), and an improved dug well (right) protected from surface contamination

SAND ABSTRACTION SYSTEMS

Sometimes, a sandy riverbed or even an artificial sand dam can be a source of water. It is possible to construct a system of pipes or drains in the sand below the water table that can yield water. Alternatively, shallow boreholes called wellpoints can be installed. Sand abstraction systems can take advantage of irregular water flows down dry river beds or wadis (sometimes called sand rivers) which sporadically recharge sands and other sediments along the river bed. Water stored in sand, like other groundwater, is much less susceptible to evaporation. Sand abstraction systems can be relatively cheap and quick to construct, and may only need basic tools. They are especially useful where no other aquifers are found nearby. The thicker and wider the sand deposits, the more groundwater they can store. When planning a sand abstraction system, it is important to understand the dimensions of the sand body, the level of the water table and the amount of annual recharge. Clogging of equipment by silt and fine sand can be a problem in these systems, but good design can overcome this—for example by using special geotextile membranes around screens to filter out fine particles. Stephen Hussey's[18] book on sand abstraction systems gives practical advice for RFSAs on the different types of systems and how to construct and maintain them.

18 Stephen Hussey is an engineer with Dabane Water Trust, an NGO and RFSA sub-partner in Zimbabwe.

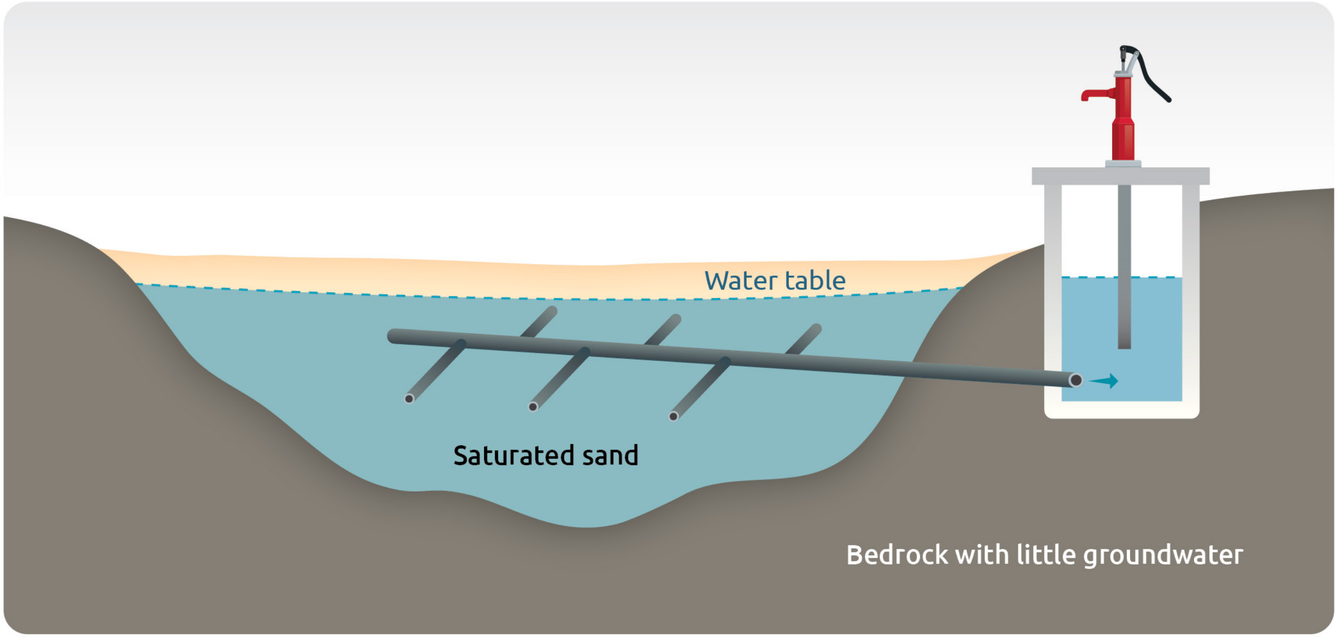

FIGURE 17: Example of a sand abstraction system

MECHANIZED PUMPING

Human Powered: The simplest devices for lifting groundwater to the surface are human powered, such as rope pumps, treadle pumps, or hand pumps (e.g., Afridev, Bush Pump, India Mk2). Each of these technologies has its own advantages and drawbacks. The final choice will depend on the cost of the equipment, the O&M strategy, how much water is required, the preferences of the users, spare part availability, cost recovery potential, and other things (see **Section 4**). In many places, a particular brand or design of hand pump is normally used, or may even be a legal requirement. For example, in Zimbabwe, the government specifies a particular type of hand pump called a Bush Pump (Figure 18). Sticking to a single type of hand pump can mean fewer problems with spare parts and make it easier to train pump technicians.

FIGURE 18: A Bush Pump in Zimbabwe (left), and an Afridev Pump in Ghana (right)

(Photos: Jeff Davies)

Motorized: Water is heavy, and it is often preferable to have a motorized pump to do the work of getting water to the surface. Most motorized pumps used for water supply have rotating impellers that move the water. Many of these pumps are designed to be used underwater (e.g., near the bottom of the borehole below the water table) where they are kept cool and don't need to be primed. These submersible pumps come in many different sizes, and choosing the right one for the volume of water it will be moving and the height which it will lift the water (the head) is very important (see below).

MOTORIZED PUMPS AND PUMP CURVES

Motorized pumps should be selected for a particular head (or lift height) to lift water against and a desired flow rate, known as the duty point. Manufacturers of borehole pumps publish information sheets called pump or performance curves for their products. These pump curves show the performance of the pump at various heads (lift) and flow rates. The point on a pump curve where the pump is most efficient is called the best efficiency point, and ideally the pump should be operated close to this point.

Just as each pump has a unique pump curve, so each pipeline has a unique "system curve." The pipeline system curve describes how the friction losses in a pipeline increase at higher flow rates. The pump performance curve and the system curve can be plotted on the same chart. The system duty point is where these two lines cross. The selection of a pump for a given duty point should also consider the best efficiency point of the pump. When a pump duty point is close to the best efficiency point it will operate most efficiently, reliably, and have the longest possible life.

When the aquifer conditions, yield requirements, water table levels, above ground lift, and pipeline specification (length, diameter, material) are known (or estimated), the pump and system curves help us to choose the best pump for the job.

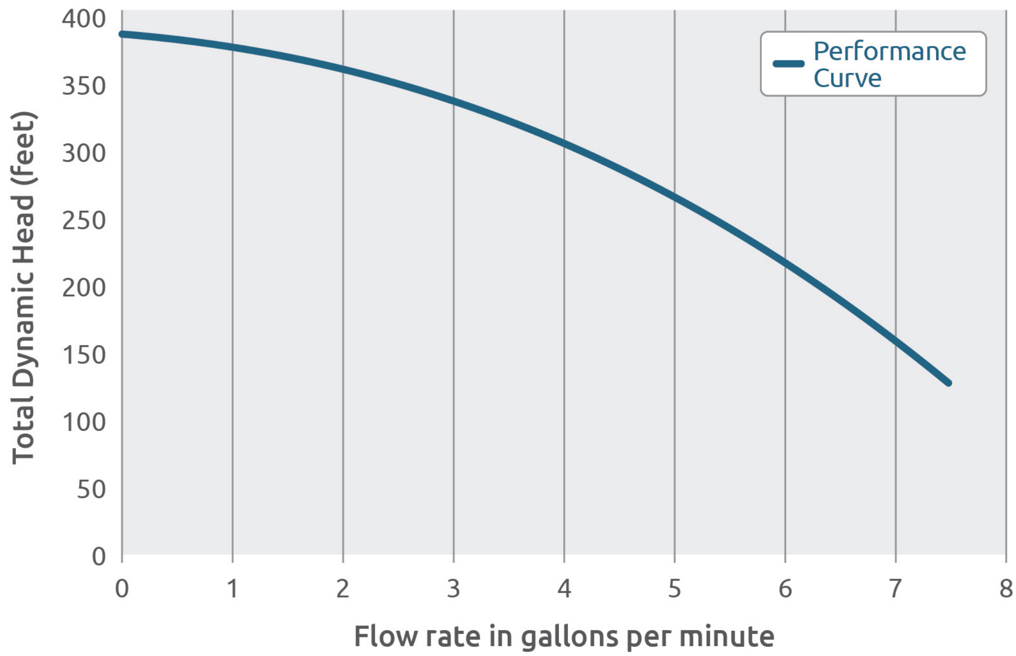

FIGURE 19: Example of a pump curve for a Grundfos 5SQ07-230 submersible borehole pump[19]

19 Diagram after the Grundfos SQ Submersible Pump **Manual**.

All motorized pumps need a source of energy to operate them, often from a diesel engine or by electricity. The choice of energy is usually determined by what is available and what it costs. In many rural areas, there is no grid electricity and diesel generators may be the only option. Some pumps are even powered directly by diesel engines via a belt drive or a rotating vertical shaft. Solar-powered pumps are becoming more popular today as designs improve, and in a few cases, wind pumps are still used. Lower-yielding solar and wind pumps are often designed with a storage tank nearby—the low pumping rate fills the tank slowly, but people can get water from the tank quickly when they need it.

One way of comparing motorized pumps is to consider how much energy is used to lift a given volume of water. Another consideration is the frequency of pump failure or breakdown—i.e., how often the pump needs to be repaired. A cheaper pump that needs many repairs can be more expensive in the long term, as well as inconveniencing water users. The availability of spare parts is also important.

It is essential to consult a qualified person with expertise in pump selection and maintenance when choosing a motorized pump. Many pumps are chosen based on the biggest size that will fit down the borehole, or other arbitrary criteria, and this leads to early failure and high costs. All other things being equal, a low pumping rate for longer periods of time leads to less drawdown for the same volume of water abstracted, keeping costs lower. Ensure that the pump choice also fits with the O&M strategy and the wider context (see **Section 6**).

MULTIPLE USE WATER SYSTEMS

A multiple-use water system (MUS) is not a type of pump, but rather an approach to water supply provision that has implications for the technology chosen. A MUS is designed to supply both domestic water and water for productive uses, such as irrigating a garden or crops, raising livestock, or running a small business. Many systems that were designed only for domestic use are in fact used for many other purposes, and are already multiple-use water systems. The MUS approach means that the various uses are taken into account at the planning stage, and the MUS infrastructure is designed to be able to support these various uses. By enabling people to earn money using their water, such as through farming or a small business, the MUS approach can mean that more money is available to maintain the infrastructure, in turn meaning that the water supply, including for domestic use, is more reliable. Communities often prefer MUS for this reason, and multiple-use water requirements should be taken into account in modern water supply planning.

MUS can present a more complex set of challenges than water services designed for domestic use only. For example, a MUS often uses more water than a domestic-only system, and the aquifer needs to be able to supply this. Some activities that use the water (such as using fertilizers on irrigated crops) may even harm the quality of the groundwater. MUS may also make issues like cost recovery and management cooperation more complex, since community members may not all derive the same benefits from the MUS. A mixture of hydrogeological, engineering, and social issues need to be take into account when planning a MUS if the system is to be successful.

4. SUSTAINABILITY AND WATER INFRASTRUCTURE

WHAT IS SUSTAINABILITY?

Sustainability implies that water point infrastructure should not only be well engineered and functional, but should also fit well with the local people, economy, and the environment, and not harm future prospects. Such infrastructure would be less likely to break down, run out of water, go bankrupt, or have undesirable impacts. It would also be more likely to be cared for and to improve WASH outcomes. Sustainability is sometimes said to have three “pillars”—the environment, the economy, and society. We need to consider all three of these things when planning sustainable infrastructure (sometimes called the “triple bottom line”).

Sustainability is a core expectation of RFSAs, in particular the sustainability of project activities. Work done by USAID on project sustainability found that three factors are critical: (1) a sustained source of resources, (2) sustained technical and managerial capacity, and (3) sustained motivation (of beneficiaries and service providers). Information on USAID’s effective sustainability and exit strategies is available **here**. Both wider project sustainability, and the narrower sustainability of water point infrastructure, have various dimensions (political economy, gender, institutions, etc.), which are discussed below.

Water supplies that are sustainable are less likely to move downwards or regress on the JMP Drinking Water Ladder (see **here**) (Figure 20). The aim is to move up the ladder, and stay there.

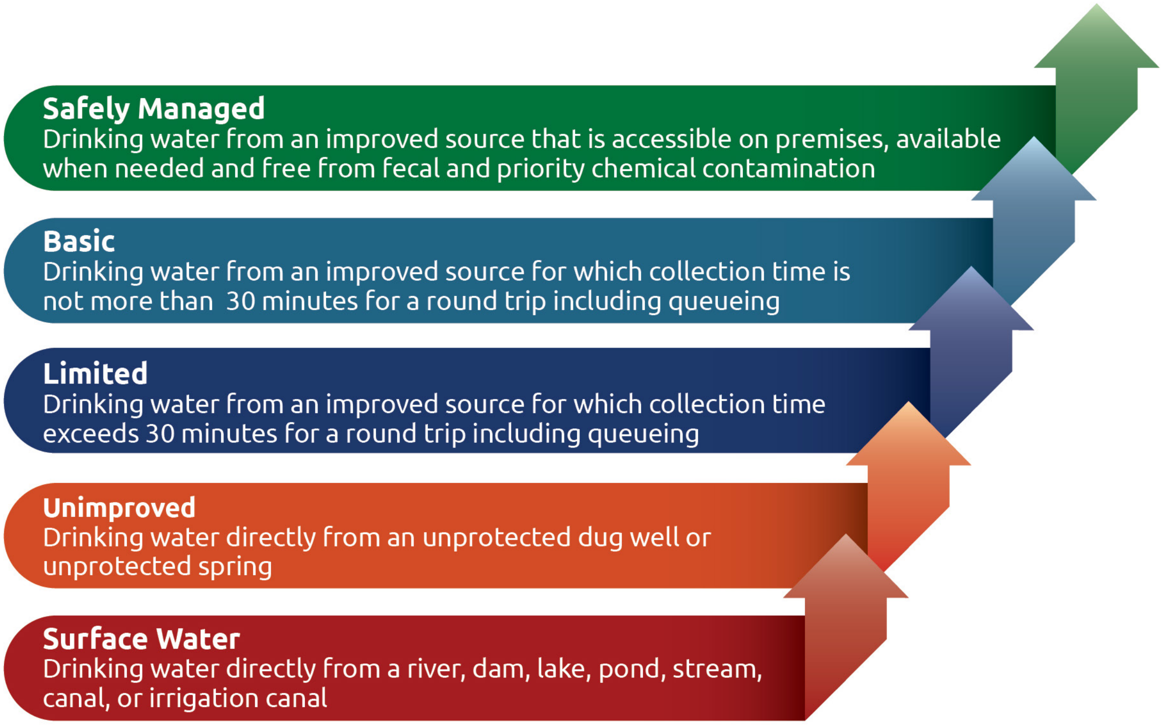

FIGURE 20: The JMP Drinking Water Ladder[20]

20 Diagram after the WHO/UNICEF JMP Drinking Water Ladder, available at the **JMP website**.

Today's focus on sustainability came about partly in reaction to earlier development models or projects that did not always take enough account of the local communities and environments in which they operated. When these projects ended (or collapsed), the costs of cleanup and the fallout from unemployment and loss of other livelihoods were sometimes considerable. In some cases, local communities were worse off after the project than they had been before it started.

The Sustainable Development Goal Six (SDG6) focuses on clean water and sanitation. However, wider issues such as pollution, consultation, ecosystem protection, and sanitation have an impact the sustainability of a supply of safe drinking water. The rest of this section will discuss some of the ways in which water point infrastructure is planned, operated, and maintained, taking into account wider issues of the environment, economy, and society.

STAKEHOLDERS AND POLITICAL ECONOMY ANALYSIS

Different groups of people, or stakeholders, with an interest in a water point can include the user community, an NGO, the state or regulator, the private sector, and others. These can be broken down further, for example into different community groups or into various private sector service providers. A stakeholder analysis is an attempt to understand who these stakeholders are, their interest in the water point, their priorities and motivations, and their roles and responsibilities. Water points work best and are most sustainable when it is in everyone's best interest to support and maintain the water point.

A political economy analysis is an attempt to understand the stakeholders in the context of the wider political, social, institutional, technical, and financial conditions. A political economy analysis looks at problems that affect a water point, and then tries to understand why the problems are there and what can be done by investigating the drivers or causes of those problems[21]. Almost any development can have winners and losers, or those who benefit, and those who might have to make concessions.

A full political economy analysis can be a lengthy and complicated exercise, but the basic steps are quite simple (after Manghee and Poole, 2012):

1. What are the problems or challenges?
2. What are the institutional arrangements, and how effective are they? Do informal institutional arrangements sometimes take priority (e.g., patronage networks)? Why are things this way? How are they changing with time?
3. What can be done, or what actions can be proposed, to improve the situation?

The key point is to understand the water point problem in terms of the stakeholders and their interactions and motivations (e.g., financial, legal, customary, religious, etc.). When problems with water points are considered in this holistic way, it is often possible to identify courses of action that make a sustainable outcome more likely. Ideally, a political economy analysis would be done before a final decision about water point infrastructure is made, so that the infrastructure choice can be tailored to the institutional environment. The RFSA refinement period after the project award can be a good opportunity to revisit the political economy of a RFSA project area, and how its characteristics might impact the success and sustainability of water point infrastructure. BHA expects RFSAs to make stakeholder consultation and community visioning/consultation a core part of RFSA programs.

21 See e.g. Manghee, S. and Poole, A. (2012). Approaches to Conducting Political Economy Analysis in the Urban Water Sector. World Bank Water Paper 74742. World Bank Group, Washington DC, USA. Available **here**. For examples of political economy analysis, see the **World Bank's document**.

While PE analysis usually focuses on the country or region where the infrastructure work is carried out, funding or donor partners and countries have political economies too, and the assumptions and decisions made by those designing or evaluating infrastructure programs are also influenced by political economy. Information on this is usually clearly laid out in policy documents, technical briefs, white papers, and on donor websites.

To some extent, the final water infrastructure that is approved and installed must satisfy the PE requirements of the receiving country AND the donor country. If the infrastructure doesn't accord with the receiving country's PE, then it is unlikely to work very well, and if it doesn't align with the donor country's PE, then it's unlikely to be funded. The infrastructure specifications required by the donor country or organization should be taken into account early on, since it is likely to influence all aspects of the infrastructure choice, installation, and functioning. This is why a PE analysis of the donor as well as the receiver is useful, since both impact the available choices and the resilience of the system.

FIGURE 21: Possible solutions should take both donor and receiver political economy into account

The extent to which PE influences infrastructure engineering considerations is still underappreciated. Some might still argue that infrastructure should be designed mainly for the objective physical conditions, using best global practice and the best materials that fit the project budget. But any complex problem, including water infrastructure, is influenced by the assumptions and questions of those working on the problem. Ignoring the over-arching political economy that mediates our choices and shapes our values risks missing an important part of the picture—and this in turn can reduce infrastructure resilience just as much as a bad engineering design or a poor material choice.

GOVERNMENT POLICY AND REGULATIONS, AND THEIR IMPACT ON INFRASTRUCTURE

Governments are very important stakeholders because they set the policies and rules that govern water point infrastructure. It is governments—at national, regional, or local levels—who ultimately decide on many key issues, such as what designs of pumps are allowed, how much duty should be paid when importing spare parts, who is allowed to drill boreholes, or how much funding should be allocated to rural water supplies. Governments also set standards for infrastructure design and construction, and for water quality. Even in remote areas where government assistance may be minimal and local communities are expected to carry out repairs, following government regulations and standards is necessary for sustainable infrastructure. For example, the Zimbabwean government specifies that the Bush Pump should be the hand pump used by rural communities, so that skills training and spare parts networks are more efficient than they would be if different types of pump were used, each with its own maintenance and spare parts needs. In countries such as Ethiopia, local government representatives sit on village water supply committees, and take part directly in village-level water supply planning.

WATER COMMITTEES, PROFESSIONALIZATION, AND ACCOUNTABILITY

Communities today may manage their water supplies via a volunteer water committee which is elected or supported by the community. This committee then works with community members as well as outside service providers and partners, to ensure the sustainable operation of the water supply. This model can have problems—for example, token engagement of women, volunteers lose interest, conflicts arise, or some community members may not want to pay for water. To fix some of these shortcomings, there is an emphasis on professionalization. This means that the committee and its activities should be more formal and structured, such as by adopting codes of practice or by formally contracting with service providers. More emphasis is now given to governance and accountability, including defining formal stakeholder roles and responsibilities, better financial management, outside investment, longer-term planning, and performance targets.

BUDGETING FOR OPERATION AND MAINTENANCE

As introduced in Section 1, operation and maintenance (O&M) combines the typical ways in which a water source is used (e.g., operation of a pump handle) with the routine activities that keep the system working (e.g., tightening of bolts, lubrication, replacement of worn components, minor repairs, etc.). The maintenance requirements of a source partly depend on how a source is used/operated—and the way it is operated partly depends on whether it is maintained.

O&M means all the tasks that keep a system working satisfactorily and serving the community. O&M is not just the physical tasks of using and maintaining a water source, but also about the institutional, physical, social, and political context of the infrastructure—we need spare parts, skilled people, and a legal mandate, as well as funding (see Figure 22). For example, to replace a simple pump component costing a dollar, the right person with the right training and the right tools must be on site at the right time, with the appropriate mandate and permission. That person must be paid, have adequate transport, have access to spares and tools, and have support in case things go wrong. Thus systems for O&M can be surprisingly complex, even where the repair or maintenance itself might seem very simple, quick, and cheap.

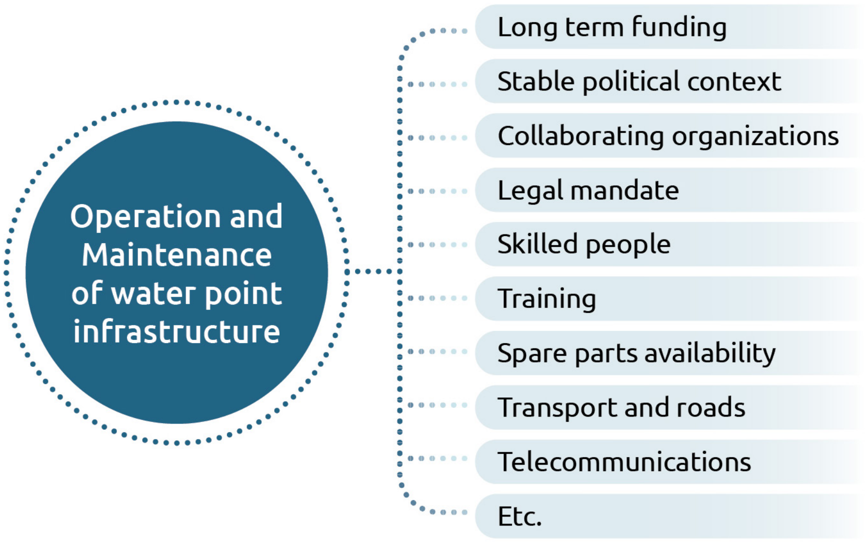

FIGURE 22: Examples of key elements of operation and maintenance (O&M)

Funding for O&M is very important. Without reliable, regular O&M funding, all water supplies fail sooner or later. It is expensive to replace or rehabilitate sources that have failed, and there are also the costs of not having the source while it is being replaced.[22] O&M funding is an investment and an insurance policy—it is better to pay to keep a system running smoothly than to pay to replace it every time it fails. It is also cheaper—in a cost-benefit study of groundwater supplies for rural areas in developing countries, a study carried out in 2012 found that the value of water infrastructure increased by between three and five times if there is a suitable operation and maintenance (O&M) program in place[23].

O&M budgets are sometimes vulnerable because they might seem less important than budgets for capital projects or for emergencies. A well-run O&M program can also sometimes appear wasteful—why are funds being spent when the system never seems to give any problems? This is why O&M budgets, and the various systems needed for O&M, need to be ***institutionalized—in other words, they must become part of a set of recurring practices and behaviors protected by rules, customs, and laws.***

Water utilities, municipalities, private sector providers, and even some village water committees often divide their budgets into different components, as follows:

- Operating expenditure (OpEx): this is the money spent on day-to-day operations, salaries, and on routine, regular tasks such as maintaining a pump.
- Capital expenditure (CapEx): this is money spent on one-off, capital items, such as a new pump or a new water treatment plant, that should last longer than a year.
- Capital Maintenance Expenditure (CapManEx): this is the cost of renewing, replacing or rehabilitating components to keep a capital asset working—for example, replacing a pump motor. CapManEx is for things that only need infrequent and irregular replacement or repair—routine maintenance falls under OpEx. CapManEx is essential to O&M, but these funds can be difficult to budget for, since they fall somewhere between OpEx and CapEx.

All three parts of a budget are important, even if we sometimes mainly think about the purchase and installation costs (CapEx). All water points need regular funds for routine servicing and operation (OpEx). And when a major part of a water supply system needs to be replaced (e.g., a pump that has worn out), it's important that CapManEx is also available—otherwise the system won't work.[24]

Some proportion of the total cost of a water scheme usually needs to be met by the users of the water source, and user fees are often the biggest source of income for a scheme. It is essential that fees charged to users are affordable and acceptable to the users. Ability to pay is related to household income levels as well as to several other factors.[25]

Life-cycle costs are important to analyze so that implementers and entities responsible for infrastructure management understand the true expected cost of maintaining an infrastructure system throughout its entire expected life, as well as realistic annual operating costs. IRC WASH and Water for People have developed a Lifecycle costing tool to enable detailed budget estimates and planning (**see useful resources**).

22 These costs are not just economic, but can include hardship, illness and death in the community.

23 Whinnery, J. (2012). A Well Construction Cost-Benefit Analysis: For Water Supply Well Guidelines for use in Developing Countries. Unpublished paper, Oregon State University, USA. It can be downloaded **here**.

24 Other costs are also sometimes discussed, such as the cost of interest payments on loans, and these depend on the characteristics of the infrastructure.

25 This topic is beyond the scope of this guide, but is nevertheless very important. As **Carter** (2021:6) puts it, "A fundamental difficulty with both community-managed and private operator-run services in low- and middle-income countries is the ability and willingness of water users to cover the full costs of providing the service."

CASE STUDY FROM ETHIOPIA

The Strengthen PSNP4 Institutions and Resilience (SPIR) was a Resilience Food Security Activity (RFSA) with activities in two Ethiopian regions: Amhara and Oromia. In order to improve water point functionality, SPIR took political economy and government policy into account in designing systems to improve tariff collection, enhance the participation of low-income households in water management committees, improve private sector capacity to carry out operation and maintenance, and introduce financial innovation such as local insurance products for water points. This work was done in collaboration with local government and with private sector stakeholders, and initial results suggest that this approach has paid off, with better O&M response times and higher water point functionality. Some of the lessons are transferable to other RFSAs, whilst other strategies were tailored to the Ethiopian context by SPIR. Results have included the establishment of five private sector O & M small businesses, each with between five and ten members. Collectively, they have provided maintenance services to more than 200 water schemes, as well as providing a source of income for members[26].

Water point maintained as part of the SPIR RFSA's work. Photo Credit: SPIR RFSA, Ethiopia

O&M HELPS KEEP WATER QUALITY SAFE, TOO

Good O&M also helps to keep water supplies clean and free from pollution. For example, a concrete hand pump base that is not maintained will often crack and surface pollution (e.g., nitrates, microbes, or pesticides) can get down into the groundwater via the cracks. A diesel storage tank that is not maintained and checked can leak diesel and cause serious groundwater pollution (see **Figure 23**). Good O&M can also detect when systems that keep water safe are close to failure (e.g., when the chlorine supply in a chlorine dosing system is running low, or when a diesel storage tank starts leaking). In these ways, O&M helps ensure good water quality, as well as keeps water point equipment working. Since it is usually more difficult and expensive to clean up pollution (especially underground pollution) than it is to prevent it, good O&M for water quality management makes sound financial sense too.

26 For more information, see **this project brief** on SPIR's work.

FIGURE 23: Borehole head works contaminated by diesel fuel (left) and agricultural runoff (right)

Work done on the UPGRO research program (2013-2020) confirmed that more than 30% of groundwater-based supplies break down within a few years of construction. Researchers found that sustainability depends on several factors, including groundwater resources; water point siting, design and construction; financing; management; external support and community arrangements; and demand pressures. These factors can combine in complex ways (see **Section 6**), making sustainability of water infrastructure a challenge.

5. RESILIENCE, CLIMATE CHANGE AND WATER INFRASTRUCTURE

WHAT IS RESILIENCE, AND HOW IS IT DIFFERENT TO SUSTAINABILITY?

Resilience means the ability of a system to recover from stresses or shocks. A resilient system is one that can endure or adapt to hardships and stresses and still function[27]. Resilience in water infrastructure has become more important recently because the natural conditions under which water supply systems must function are becoming more variable due to climate change. Resilience can refer to the engineering infrastructure itself (e.g., stronger materials, deeper boreholes), and it can refer to the various financial, social, and institutional systems that support the infrastructure.

Sustainability on the other hand means infrastructure that fits well with the local environment and community, and can persist using the inputs, systems, and raw materials that are available and will be available indefinitely. An infrastructure system can be sustainable under one set of climatic or socio-economic conditions, but could break down (and be unsustainable) under another set of conditions. A resilient system might be able to adapt to both sets of conditions, but could still be unsustainable if, for example, it needed financial or engineering resources that were unavailable over the longer term. Ideally, all water point infrastructure needs to be both resilient *and* sustainable.

WHAT IS CLIMATE CHANGE, AND WHY IS IT IMPORTANT TO RESILIENCE?

Climate change means a long-term change in average weather conditions, such as rainfall and temperature. The abnormal changes in the global climate recorded in the last few decades are mainly caused by the burning of fossil fuels. Climate change can seriously harm our natural environment, and it can make growing crops and securing water supplies more difficult. Disasters such as storms, droughts, heatwaves, landslides, and floods may become more common and more dangerous. Warmer weather and changes in rainfall patterns can also increase insect-borne diseases such as malaria.

Climate change is a serious threat to development worldwide, impacting WASH, food security, migration, and conflict. Low-income communities are often the hardest hit. Climate change influences water point infrastructure directly through physical changes such as falling water tables or flooding, and also indirectly through changes and threats to people's livelihoods, incomes, communities, and customs.

Resilient water supply infrastructure can absorb climate-related changes or shocks[28] and adapt to new circumstances. Therefore, designing and building more resilient infrastructure is a priority for climate change adaptation. For example, a hand pump could be designed so that flooding did not damage it, and it could be drilled deeper to handle more severe droughts. These physical or engineering changes go together with better strategies for adaptive governance, in which institutions are made more flexible and systems, such as O&M, more responsive to changes[29].

27 USAID's definition of resilience is: The ability of people, households, communities, countries and systems to mitigate, adapt to and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth." USAID's **Strategic Framework** for Early Recovery, Risk Reduction, and Resilience provides guidance to partners on approaches and programming in the areas of early recovery, risk reduction, and resilience (ER4).

28 Water and climate are closely linked - according to USAID's **Technical Brief 13**, "Water solutions are climate solutions".

29 USAID's 2022-2030 **Climate Strategy** has results areas and suggested actions for confronting the climate crisis.

GREEN INFRASTRUCTURE AND THE POWER OF NATURE-BASED SOLUTIONS

Green infrastructure means any engineered intervention that uses vegetation, soils, and natural processes to manage water and create healthier built environments for people and the natural resources that sustain them. Green infrastructure can range in scale from small scale technologies such as rain gardens and green roofs to regional planning strategies targeting conservation or restoration of natural landscapes and watersheds[30].

Green infrastructure has potential advantages over carbon-intensive "grey" infrastructure, including having multiple functions—for example, reforestation may not only prevent soil erosion, but it can also deliver food, fuel, habitat, recreation, and shelter. A wetland reduces flooding, improves water quality, and provides fishing and useful plants.

Most water points use concrete, steel, and other "grey" materials, but they can often be combined with green infrastructure elements to improve resilience. For example, re-vegetation in the catchment area of a well or borehole can promote groundwater recharge, slow down runoff, and limit the movement of pollutants. A "living fence" made of thorn trees around a spring can not only protect the spring, but may also provide firewood, be less susceptible to theft, and even repair itself if damaged. Banana trees planted at the end of a hand pump drainage apron prevent stagnant water pooling, and also provide fruit and shade (Figure 24).

FIGURE 24: Banana palms planted at the end of a hand pump drainage channel in Malawi

CLIMATE CHANGE, RESILIENCE, DATA, AND INFRASTRUCTURE DESIGN

Water point infrastructure is designed for a particular environment and set of circumstances. For example, a borehole should be deep enough to reach the water table during the dry season. The pump components should tolerate the chemistry of the groundwater to limit corrosion. And the water point should deliver enough water to meet demand. But as the climate changes, these circumstances might change too. For example, the water table may drop further than expected during longer dry seasons, drier weather might result in more saline groundwater, and migration of people and animals looking for grazing might place higher demand on the water source. Infrastructure choice and design parameters need to consider anticipated future conditions. With climate change, the past is not a good guide to future conditions.

30 See USAID's **Green Infrastructure Resource Guide** for more information.

Climate data and information can help to predict likely future conditions when designing water point infrastructure. After all, there is no point in building something designed for today, when tomorrow may look very different. One way to boost resilience of water point infrastructure is to use information from climate information systems (CIS) when designing and operating the infrastructure. Modern climate information systems need physical data on the environment from satellites or river gauges, but they also rely on people and organizations to turn this data into useful knowledge products such as forecasts, advisories, or reports[31].

Water infrastructure is a part of a bigger physical and institutional system (see **Section 6**) whose characteristics depend partly on local circumstances (physical, social, institutional, hydrological, etc.). We need to understand these circumstances to reduce risk and to improve resilience. One example would be understanding the likelihood, duration, and impact of droughts at the local level. This is another reason why better data and information, at good resolution, is important to resilience planning[32].

CASE STUDY FROM THE SAHEL

The USAID TerresEauVie Activity in Niger and Burkina Faso started in 2019 and builds on previous USAID-funded work in the Sahel. This activity is part of USAID's Resilience in the Sahel Enhanced (RISE) 2 initiative. In this semi-arid part of Africa, food and water insecurity, persistent poverty, poor governance, and high population growth rates combine with recurrent climate shocks to threaten development and hold communities in persistent poverty and insecurity. TerresEauVie has three components: improved water security; enhanced sustainable productive land use; and improved management of shocks, risks and stresses. Working across forty rural communes in the two countries, the project has adopted a multi-faceted approach that includes improved monitoring and management of resources, conflict management, social and behavior change, and climate information services to improve social and ecological risk management. A practical example of this work is the 2021 partnership with a local NGO to train community members in easily applicable land reclamation and water and soil conservation techniques such as runoff management and reforestation. The use of berms and other structures to reduce runoff improves soil moisture and groundwater recharge, and revegetation improves watershed water quality by filtering fine material and breaking down pollutants. This work has been put into practice on more than 600 hectares of land in Niger so far. For more information on this activity, see the **project website**.

SUMMING UP – ENSURING RESILIENCE

To improve water point resilience, it is useful to think through the various factors that make a system resilient. These include the physical infrastructure itself, any supporting physical infrastructure (including green infrastructure), the users of the infrastructure and their preferences and livelihoods, and the systems for operating and maintaining the infrastructure (including funding arrangements). Information on future climate conditions and climate shocks is also important. Ideally, every infrastructure asset would have a checklist of these things as part of the funding or project process. Resilience should not be planned for once and then forgotten, because resilience means a system that is flexible and adaptable. Infrastructure upgrades, together with the institutions that support the infrastructure, should have flexibility and adaptability built in. Investments in resilience, and in systems for ensuring resilience, are cheaper than dealing with infrastructure that has failed because it was not resilient enough.

31 For more information, see **PRO-WASH's brief** on Climate Change, Risk and Resilience in WASH and Agriculture Projects.

32 USAID's Climate Strategy (2022-2030) recommends "Ensuring widespread availability of reliable and appropriate climate vulnerability data and information, including traditional knowledge, particularly for communities facing the greatest risks."

6. A SYSTEMS APPROACH TO WATER INFRASTRUCTURE

THE WIDER CONTEXT

Installing, operating, and maintaining water supply infrastructure and ensuring its resilience is closely linked to the wider social, political, and economic context. For example, a funding model for O&M may depend on community income from selling crops or livestock. If prices fall, then incomes drop and water point functionality declines as payment for water services (and O&M spend) falls. Value judgements also affect the debate: what exactly is "successful" water supply infrastructure in the first place? What particular balance of cost, service level, community involvement, water quality, and water use is best? Does everyone agree? Who gets to decide?

COMPLEX OR WICKED PROBLEMS

Problems with many factors that influence each other, such as installing water infrastructure, are called complex or "wicked" problems.[33] Complex problems are often difficult to define and separate from other problems, and are hard to find solutions for. It is also not always clear when a complex problem is solved, and the solution may well involve qualitative or value-based judgements (i.e., is the solution "good" or "bad"?). The solutions that are then chosen for complex problems can influence the problem itself, or give rise to other problems[34]—as in the example in the paragraph above. And because each complex problem is unique, the solutions are unique too – what works in one place may not work elsewhere. This makes solving such problems more difficult.

So what does all this mean for water infrastructure planning? How can we make the right infrastructure choices? The following principles can help us to focus on the wider systems problem as a whole:

- Take political economy into account—good design and engineering are necessary but not sufficient for successful water infrastructure;
- Consult widely with all stakeholders—complex problems are unique and depend on the local area and people, so what may have worked somewhere else might not work here;
- Try to anticipate secondary or indirect impacts of the infrastructure and consider these in the plan;
- Take care of the basics such as using proper design and building standards, having a solid plan for O&M and community engagement, ensuring stable O&M funding, reviewing the groundwater resource characteristics, and using available data on how the situation might change as the climate does;
- Think about preconceptions and blind spots. For example, how might ideology impact the project, and might it be constraining options?;
- Expect changes to the situation, and to your plans, as the project develops—it might be necessary to iterate and be flexible to ensure resilience;
- The "solution" to a water infrastructure problem may not suit everyone. It may even be the "least bad" outcome. Don't let the perfect be the enemy of the good.
- Take a systems approach

33 See Rittel, H. & Webber, R. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences 4* (2), 155-169, which can be downloaded **here**.

34 According to Rittel and Webber (1973: 165), "Every wicked problem can be considered to be a symptom of another problem."

SYSTEMS THINKING AND OSTROM'S DESIGN PRINCIPLES

Systems thinking means trying to see water infrastructure holistically as a set of linked "systems," in which changes in one area may impact another area. The important thing is to look not just at the various aspects of a water supply installation in isolation (e.g., the hardware choice, the water point committee, the hydrogeology, the O&M arrangements, the health impacts, etc.) but to also look at the relationships between these things. The ways we organize ourselves socially, economically, communally, and politically also have a big influence—but this influence is not always obvious. People interact with each other following informal norms, cultural values, formal rules, and other institutions. They also interact with and are influenced by government departments, NGOs, aid agencies, and other organizations.

At the same time, it's important to realize that complex systems often have difficult-to-predict outcomes, and so flexibility is vital. This is why it is important to take a systems approach to water point infrastructure. Keep looking at the bigger picture where possible. This can be more difficult than it sounds, for example, when different specialists need to communicate, agree, and prioritize.

It is possible to analyze these interactions in the same way as we study physical and engineering characteristics. One way to do this is to use a framework of attributes that seeks to define the characteristics of institutions, developed by the political scientist Elinor Ostrom. According to Ostrom's framework, a communally managed resource such as an aquifer (as well as the infrastructure that abstracts water from it) is more likely to be resilient if the resource is important to a group of users who understand and value it, who trust each other, who have a degree of autonomy, and who have experience in organization and leadership[35]. Experience shows that if one or more of these attributes is missing, then the resource and its infrastructure are less likely to be governed well, and are therefore less resilient.

The IRC has done extensive work on WASH infrastructure as part of a socio-technical system and have proposed nine sub-systems or building blocks of WASH systems that can be used in a practical way to reduce complexity to a manageable level and to support WASH Systems Strengthening. Their **report** goes into detail on each of these building blocks, and describes their links with each other. The IRC's building blocks are depicted in **Figure 25**.

35 For more on Ostrom, please see the Appendix of references at the end of this guide.

FIGURE 25: The IRC's WASH System building blocks

LEARNING FROM FAILURE

Part of a systems approach is also learning and adaption, including learning from failure. Nobody likes to fail, but the reality is that failures do happen with complex water infrastructure projects. Wells or boreholes can yield too little, or even be dry. Water quality may be unexpectedly poor. Financial flows may be less than expected. It is tempting to make some rapid assumptions about the reason for the failure (or even to blame others for it), try to avoid the subject or move on quickly. But failures can teach us a lot if we are prepared to look. Failures also warn others and can save them and their organizations a lot of time and money. It is important to have systems in place to carry out valuable failure analysis work. The results of a failure analysis may even compensate for the cost of the original failure.

To conclude this section, successful and resilient water point infrastructure needs a systems approach for the best results.

7. CONCLUSIONS: INFRASTRUCTURE CHOICE, DESIGN AND MAINTENANCE

This guide has introduced some of the main issues that can make water infrastructure successful— or cause it to fail. As outlined in the previous section, there is no one-size-fits-all approach to designing and installing water infrastructure, but there are some useful principles. Perhaps the most important of these is to start planning early, taking into account all of the different interlocking aspects. Water infrastructure is a complex problem, and solving it needs a systems approach. At the same time, water infrastructure is often urgent, requiring installation in a hurry—particularly in emergency contexts. These two competing priorities need to be balanced.

Mistakes made in the design and installation phase are difficult to correct later, and early planning and careful consideration of the various aspects can save a lot of effort as the project develops. If planned well, expenses in the construction phase can be recouped over the lifetime of the infrastructure, in lower operating costs, shorter downtime, and so on. The installation cost of infrastructure is nowhere near the true long-term cost, although this mistake is often made. In the end, the desired outcome and the project budget need to be considered, and tradeoffs will usually have to be made. Infrastructure should be "fit-for-purpose," or adequately designed and engineered.

One strategy is to start planning for water infrastructure before it is needed. Organizations can analyze aspects of water infrastructure sustainability, and make some basic decisions, even before budgets are approved. What are the characteristics of the community, and their livelihoods? What is the water source, and its quality? What kinds of financial arrangements will need to be made, to ensure sustainability? What is the project (or RFSA) theory of change, and how can water infrastructure support it? Given the changing climate, how might the physical circumstances change? These questions, and many others, help to narrow down options and avoid pitfalls, well before the project design phase. It's always helpful to remember that wide consultation is part of -planning and of resilience: infrastructure that is installed to meet the preferences of a minority is not likely to last as long or be as effective as infrastructure with wide community support.

Another issue to consider is how choices made today will impact overall infrastructure functioning in years to come. This can get very complex, since it involves not just longer-term changes to the natural environment such as water availability, but also questions of economic development, nearby infrastructure that has not yet been built, people's movements and preferences, political developments, and so on. However, some thought about what the area or community that the infrastructure will serve is likely to look like in five, ten or twenty years' time is still useful because even small improvements can help make the infrastructure work better and serve more people reliably.

APPENDIX: RESOURCE LINKS FOR THE PRO-WASH GUIDE TO SUSTAINABLE WATER POINT INFRASTRUCTURE

Books and practical guidelines

Resource libraries and websites

Background discussion, policy, and theory

SECTION 1: Useful Resources on O&M, Management, and Complexity

Books and practical guidelines

- The **International Water Association** (IWA) has an **Operation and Maintenance Network** with useful resources including **this manual** on O&M of urban water supply systems
- The **Whole Building Design Guide** provides a good introduction to Operation and Maintenance, including the steps to **compiling an O&M manual** for a particular building or infrastructure asset. The guide contains best practices on general O&M steps relevant for many kinds of infrastructure assets.
- This **Water Paper** by the **World Bank** gives an overview of the capital and O&M requirements of water infrastructure, with a focus on water utility funding
- The United Nations Children's Fund (**UNICEF**) produced **this manual** on the O&M of a refugee camp water supply system

Resource libraries and websites

- The **United States Environmental Protection Agency** has compiled resources on **effective utility management practices**
- **WaterAid** has a library of publications **here** on various aspects of water supply and WASH in low income countries
- The International Federation of Red Cross and Red Crescent Societies (**IFRC**) has **information** on water, sanitation, and hygiene (WASH), as well as a **resource** for WASH practitioners.

Background discussion, policy, and theory

- The **Water and Development Research Group** at Aalto University in Finland has a **discussion page** on the role of maintenance in sustaining rural water supplies in Africa.
- In 2021 PRO-WASH convened a series of **eight webinars** on different aspects of the O&M of WASH infrastructure, and these are available to download and view.
- Charles Perrow's book *Normal Accidents* on technology complexity and failure, published by in 1984 by Princeton University Press is available **here**. It describes how seemingly trivial failures can propagate to threaten whole systems.

SECTION 2: Useful Resources on Groundwater

Books and practical guidelines

- PRO-WASH has assembled a selection of useful references, guidelines, and more on groundwater into a handy summary guide that can be downloaded **here**.
- A good introductory guide to groundwater and its use in development is the book *Developing Groundwater* published by Practical Action Publishing. It is available to read or download **here**
- The United States Department of Agriculture's *National Engineering Handbook* has a chapter on groundwater investigations which describes types of investigations (from reconnaissance to detailed), and methods and equipment. The chapter is available **here**.
- The **Groundwater Project's** book *Hydrogeologic Properties of Earth Materials and Principles of Groundwater Flow* can be read and downloaded **here**. Their book on fluoride in groundwater is available **here**, and their book, *Groundwater Microbiology*, is **here**.
- The British Geological Survey's ARGOSS manual (*Assessing the Risk to Groundwater from On-Site Sanitation*) is a practical guide to the problem of how to make sure that boreholes are not contaminated by pit latrines and other sanitation facilities. It can be downloaded **here**.
- The International Association of Hydrogeologists (IAH) has produced a **Strategic Overview series** of briefing documents on many aspects of groundwater use, including many translated into Spanish, Portuguese, French, Chinese and Hindi.
- PRO-WASH's "Technical Guide on Drinking Water Quality Monitoring" is available here (and in French **here**), and is specifically aimed at USAID Bureau for Humanitarian Assistance (BHA) funded partners seeking to improve drinking water safety as part of Resilience Food Security Activities (RFSAs). PRO-WASH has also produced videos showing **how to take a water sample**, and what happens once that water sample arrives at a **water laboratory**.

Resource libraries and websites

- The website of the African Groundwater Network (AGW-NET), which includes resources, literature and tools, is **here.**
- The African Groundwater Atlas prepared by the British Geological Survey contains freely accessible information on African groundwater and is available **here.**
- CAWST's library of material on drinking water quality testing can be found **here**.
- The **Water Point Data Exchange** is a platform for sharing and harmonizing water point data world-wide

Background discussion, policy, and theory

- One of the classic textbooks on groundwater and hydrogeology, *Groundwater* by R. Allan Freeze and John A. Cherry, can be downloaded from **The Groundwater Project**, along with a series of other guides to many aspects of groundwater studies and hydrogeology.
- A recent paper by MacAllister et al. on the contribution of physical factors to hand pump borehole functionality in Africa can be downloaded **here**.
- The World Health Organization's *Guidelines for drinking-water quality: Fourth edition* can be downloaded **here**.

SECTION 3: Useful Resources for Water Supply Infrastructure

Books and practical guidelines

- The USAID-funded LoWASH project produced **these** engineering design guidelines for rural water supply systems.
- The Rural Water Supply Network's **guide** for the Procurement and Contract Management of Drilled Well Construction is a useful guide for project managers. Their **guide** to Supervising Water Well Drilling is aimed at supervisors, geologists and engineers. RWSN have also developed a **Code of Practice** for Cost Effective Boreholes is aimed at optimizing value for money.
- UNICEF and the SKAT Foundation produced **this** toolkit on Planning, Contracting and Management of Borehole Drilling.
- The Construction Standards Working Group of the Global Shelter Cluster have produced **a manual** on common standards for construction projects in humanitarian settings, as well as other resources and toolkits.
- The **Groundwater Project's** book *Water Well Record Databases and Their Uses* can be read and downloaded **here**.
- The pump manufacturer Grundfos offers a **free online course** on the basics of pump curves.
- The International Water Management Institute (IWMI) produced **these** guidelines for community-led multiple use water services.
- Stephen Hussey's book *Water from sand rivers: guidelines for abstraction* discusses sand abstraction systems in detail, and is available to read or download **here**.

Resource libraries and websites

- The Rural Water Supply Network has a good resource library **here**, with many guidelines and manuals related to rural WASH infrastructure. For example, in 2022 RWSN collaborated with USAID on a **report** on new and innovative water supply technologies for rural areas such as small villages and dispersed settlements.
- Engineering for Change has a library of resources **here** focusing on low income countries.
- **Akvopedia** is a free, open-sourced water, sanitation & hygiene resource, with water and sanitation portals.
- The SKAT Foundation has a resource library **here,** which includes information on groundwater technologies, materials choices, and other aspects of rural water supply infrastructure.

Background discussion, policy, and theory

- A special edition of the *International Journal of Water Resources Development* focused on all aspects of water infrastructure. Abstracts of the chapters are available **here**.
- PRO-WASH and SCALE produced **this** short briefing note in 2021 on Multiple Use Water Systems.
- The International Water and Sanitation Center produced **this** guide in 2009 on multiple use water systems and poverty reduction.
- Bonsor HC, Oates N, Chilton PJ, Carter RC, Casey V, MacDonald AM, Etti B, Nekesa J, Musinguzi F, Okubal P, Alupo G, Calow R, Wilson P, Tumuntungire M and Bennie M. 2015. A hidden crisis: strengthening the evidence base on the current failures of rural groundwater supplies. Paper presented at the 38th WEDC International Conference, Loughborough University, UK. Available for download **here**.

SECTION 4: Useful Resources on Sustainability and Water Infrastructure

Books and practical guidelines

- The **International Water Association** (IWA) has an **Operation and Maintenance Network** with useful resources including **this manual** on O&M of urban water supply systems.
- The **Whole Building Design Guide** provides a good introduction to Operation and Maintenance, including the steps to **compiling an O&M manual** for a particular building or infrastructure asset. The guide contains best practices on general O&M steps relevant for many kinds of infrastructure assets.
- The Sustainable WASH Systems Learning Partnership recently produced **these** ten factors for viable rural water services, and **these** maintenance approaches to improve the sustainability of rural water supplies.
- WaterAid's 2022 guidance "Integrating Gender Equality into Water, Sanitation, and Hygiene Projects: Guidance for NGOs and Implementing Partners" describes how gender-responsive processes and objectives can be embedded into the design of WASH projects. It can be downloaded **here**.
- PRO-WASH's "Integrating gender equality and social inclusion in WASH and IWRM: A quick guide for WASH and IWRM practitioners". It can be downloaded **here**.
- Prof. Richard Carter's 2021 book *Rural Community Water Supply: Sustainable services for all* can be read and downloaded **here**. This book discusses many aspects of rural water supply, including a chapter on what's changing in the field of rural water supply.
- In 2021, Sally Sutton and John Butterworth published the book *Self-Supply. Filling the gaps in public water supply provision*, which can be read and downloaded **here**. This book focuses on those areas and communities where public provision of water services does not reach.
- The IRC's The **WASH Systems Academy** has courses and tools aimed at supporting water and sanitation systems strengthening.
- The IRC's report "Mobilising finance for WASH: getting the foundations right" presents real examples of creating an enabling environment for finance in WASH can be found **here**.
- The RWSN have compiled a useful and practical guide to "Women's Empowerment through Rural Water Supply Activities," which can be downloaded **here**.
- Manghee and Poole's 2012 World Bank paper on conducting political economy analysis in the urban water sector can be found **here**

Resource libraries and websites

- The UPTIME project develops results-based contracts to sustain and scale resilient rural water services globally. Their website includes some useful resources and can be found **here**.
- USAID's **Sustainable WASH Systems learning partnership** includes a collection of resources on professionalized maintenance, collective and collaborative approaches, and systems understanding and engagement.
- The **SSWM Toolbox** is a library of knowledge on sustainable sanitation and water management, including technologies, methodologies, behavioral change approaches and planning tools.
- The **Africa Water Facility** facilitates water projects investment in Africa, and has news and information on current projects.
- The IRC has developed a suite of life cycle costing tools for WASH systems strengthening, alongside a self-paced online **Costing sustainable water services course**.

Background discussion, policy, and theory

- In 2021, PRO-WASH convened a series of **eight webinars** on different aspects of the O&M of WASH infrastructure, and these are available to download and view.
- The World Bank's policy research working paper "Governance Drivers of Rural Water Sustainability: Collaboration in Frontline Service Delivery" which focuses on collective management of water infrastructure can be found **here.**
- In 2020, researchers from Oxford University in the United Kingdom published **this paper** on rethinking the economics of rural water supply, including recommendations to make services more sustainable.
- A copy of the Brundtland Report of the United Nations' World Commission on Environment and Development can be found online **here**
- Bonsor, H.C., Oates, N., Chilton, P.J., Carter, R.C., Casey, V., MacDonald, A.M., Etti, B., Nekesa, J., Musinguzi, F., Okubal, P., Alupo, G., Calow, R., Wilson, P., Tumuntungire, M., & Bennie, M. (2015). A hidden crisis: strengthening the evidence base on the current failures of rural groundwater supplies. Paper presented at the 38th WEDC International Conference, Loughborough University, UK. Available for download **here.**
- The IRC discusses the question of sustainability through water utility versus community management models, using examples from Uganda, **here**.
- The IRC's briefing note describing the life-cycle costs approach and why it was developed can be found **here**.

These two journal papers explore the issue of community management of water infrastructure in Africa:

- Whaley, L., MacAllister, D.J., Bonsor, H., Mwathunga, E., Banda, S., Katusiime, F., Tadesse, Y., Cleaver, F., & MacDonald, A. (2019). Evidence, Ideology, and the Policy of Community Management in Africa. *Environmental Research Letters 14* (8): 085013. Available **here**.
- Whaley, L., Cleaver, F., & Mwathunga, E. (2021). Flesh and Bones: Working with the Grain to Improve Community Management of Water. *World Development* 138: 105286.Avalible **here**.

SECTION 5: Useful Resources on Resilience in Water Infrastructure

Books and practical guidelines

- USAID's 2022-2030 Climate Strategy, and other resources on the climate crisis, can be found **here**.
- PRO-WASH's 2021 guide to "**Climate Change, Risk, and Resilience in WASH and Agriculture Projects"** introduces climate information systems and provides some examples and practical resources.
- USAID's 15-page Technical Brief on climate-resilient, low-emissions water security and sanitation can be found **here**.
- WaterAid's 2021 **Programme Guidance** for Climate Resilient WASH discusses how to design and implement a climate resilient WASH project or program.
- USAID's 2017 **Toolkit** for Climate-Resilient Water Utility Operations provides methodologies for water utilities to improve climate resilience.
- USAID has published fact sheets and maps on early recovery, risk reduction, and resilience (ER4), available **here.**

- UNICEF has a **collection of case studies** showing different methods for establishing safe, sustainable water supply and sanitation for communities affected by climate change.
- USAID's BeSecure Project published **these** guidelines and lessons on Climate Resilient Water Infrastructure
- USAID's brief on water resources management (WRM), including information on nature-based solutions, can be found **here**.
- USAID's Green Infrastructure resource guide, aimed at providing USAID practitioners involved in the planning and development of sustainable infrastructure projects with a better understanding of green infrastructure, can be found **here**.
- USAID's Environmental and Natural Resource Management (ENRM) Framework is intended to coordinate, unify, and elevate environment, climate change, and natural resource management work across USAID. It can be found **here**.
- The Nexus Environmental Assessment Tool to quickly identify issues of environmental concern before designing longer-term emergency or recovery interventions can be found **here**.
- The Green Recovery and Reconstruction: Training Toolkit for Humanitarian Aid (GRRT) can be found **here**.
- The Nature Conservancy's *Blue Guide to Coastal Resilience*, concentrating on using green infrastructure in coastal areas, can be found **here**. They have other resources on nature-based solutions **here**.
- The WWF has a guide to *Natural and Nature-Based Flood Management*, aimed at supporting local communities using natural and nature-based methods for flood risk management, **here**.
- The **United States Environmental Protection Agency** (EPA) has information on **Operation and Maintenance considerations for green infrastructure**

Resource libraries and websites

- NASA's Earth Science Data Resource page is **here**, intended for a global user community for interdisciplinary use.
- The website of the United Nations body for assessing the science related to climate change, the Intergovernmental Panel on Climate Change (IPCC), can be found **here**. It includes various reports for download. Their 2022 report "Climate Change 2022: Impacts, Adaptation, and Vulnerability" can be found **here**.
- USAID's Environmental Procedures Hub, with resources on environmental good practice, can be found **here**.
- In 2017 UNICEF and the Global Water Partnership produced this **Strategic Framework** for WASH Climate Resilient Development.

Background discussion, policy, and theory

- In 2022 WaterAid produced **Water, Sanitation and Hygiene**: The Foundation for Building Resilience in Climate-Vulnerable Communities.
- This **scoping study** written by the Overseas Development Institute (ODI) and the British Geological Survey (BGS) draws together research on the links between climate change and water.
- USAID's Environmental and Natural Resource Management Framework can be found **here**.
- In 2022, WaterAid produced a guide called "**Groundwater: The World's Neglected Defence Against Climate Change**," which shows how groundwater can contribute to resilience in the face of climate change.

- A paper entitled "Resilience by Design: A Deep Uncertainty Approach for Water Systems in a Changing World" by authors from the University of Massachusetts and the World Bank can be found **here**.
- The World Bank has published a "Resilient Water Infrastructure Design Brief" which guides users on how resilience can be built into the engineering design of their project. It can be downloaded **here**.
- The 2016 book by Cervigni R and Morris M *Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience* published by the World Bank and Agence Française de Développement can be found **here**.
- World Vision carried out a study analyzing shock-response approaches used by World Vision Zimbabwe and partners (WVZP) to build resilience in Zimbabwe, available **here**.
- Dethier, J., & A. Effenberger. (2012). Agriculture and Development: A Brief Review of the Literature. *Economic Systems 36*(2), 175–205. Download this paper **here**.
- Steffen W., Rockström, J., Richardson, K., Lenton, T., Folke, C., Liverman, D., Summerhayes, C., Barnosky, A., Cornell, S., Crucifix, M., Donges, J., Fetzer, I., Lade, S., Scheffer, M., Winkelmann, R. & Schellnhuber, H. (2018). Trajectories of the Earth System in the Anthropocene. Proceedings of the National Academy of Sciences, August 2018, 115(33): 8252–59. This paper can be downloaded **here**.
- World Bank. 2016. High and Dry: Climate Change, Water, and the Economy. World Bank Group, Washington DC. This report can be downloaded **here**.
- Niang I., Ruppel, O.C. , Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., &Urquhart, P. (2014). "Africa." In: Climate change 2014: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. Download **here**.
- CONFER's policy brief "Integrating Diverse Knowledge Types in the Development of Climate Services for Improved Agro-pastoral Community Resilience" can be found **here.**
- The IRC published **this** policy paper on climate resilient WASH at different levels in Ethiopia, with key implications for policy and planning.
- The IRC's working paper on Climate change, water resources and WASH systems can be found **here**.
- The World Bank published **this** policy research paper in 2012 by Stephane Hallegatte titled "A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation," which makes a powerful argument for better climate information systems, and includes cost-benefit estimates.
- Trenberth, K.E., Marquis, M., & Zebiak, S. (2016). The vital need for a climate information system. *Nature Climate Change6*, 1057-59. This paper can be accessed **here**, but it is unfortunately not free to download.
- The United States' **Congressional Research Service** published **this** statement on the viability of incorporating natural infrastructure into US water management systems
- The Overseas Development Institute (ODI) has a discussion paper on green infrastructure in fragile states **here**, which looks at costs, poverty reduction, employment, and other factors.

SECTION 6: Useful Resources on Systems Approaches

Books and practical guidelines

- An example of Elinor Ostrom's approach can be found in her paper "**A Polycentric Approach for Coping with Climate Change**," which emphasizes systems thinking, trust, and collective action.
- The World Bank presents eight good practice cases of problem-driven political economy analysis in a 2014 report **here**, and a guide to the use of political economy analysis in advancing more effective food and nutrition policies **here**.
- The Overseas Development Institute (ODI) has a short "how-to" guide on political economy analysis **here**.
- **This manual** by the Wildlife Conservation Society, although focused on fisheries management, introduces the social-ecological systems framework developed by Elinor Ostrom.
- The 2021 book, *Self-Supply: Filling the gaps in public water supply provision*, can be read and downloaded from the Practical Action Publishing **website**.
- The IRC has published a book entitled *Community water, community management : from system to service in rural areas* which concentrates on social problems as the main obstacle to the successful operation and installation of the water supply system. It can be downloaded **here**.
- The IRC's book *Supporting rural water supply: moving towards a service delivery approach* looks at success factors in rural water service delivery, and can be found **here**.
- The United Nations Children's Fund (**UNICEF**) produced **this guide** to Developing Water, Sanitation and Hygiene (WASH) Finance Strategies, focused on achieving the SDGs in middle- and low-income countries.
- The 2005 book, *Water Rights Reform: Lessons for Institutional Design*, covers a range of issues considering equity, water rights, and water governance. It can be downloaded **here.**

Resource libraries and websites

- The website **Globalwaters.org** is a good resource for information and material on various aspects of WASH and water supply infrastructure.
- The **international think tank IRC** has many useful resources on WASH sustainability on its website, including **this** discussion on a systems approach to a WASH problem, and **this** report on taking a systems approach.

Background discussion, policy, and theory

- **This paper** by Chester and Allenby (2019) "Infrastructure as a wicked complex process" discusses complexity in infrastructure specification and recommends managing infrastructure as a systems problem, as well as finding solutions that are acceptable to all parties.
- The IRC's working paper on strengthening WASH systems, "Understanding the WASH system and its building blocks: building strong WASH systems for the SDGs," can be found **here**.
- A World Bank paper "**Can Islands of Effectiveness Thrive in Difficult Governance Settings?** The Political Economy of Local-level Collaborative Governance" discusses collaborative governance and political economy, drawing on Ostrom's analytical framework.
- Rittel and Webber's 1973 journal paper on wicked problems, "**Dilemmas in General Theory of Planning**," explains the difficulty of searching for solutions to problems that include social policy.

SECTION 7: Useful Resources on Consultation, Trade-offs, and Learning from Failure

Books and practical guidelines

- The RWSN Directory of rural water supply services, tariffs, management models and lifecycle costs can be downloaded **here**.
- The World Bank has produced **this guide** to better stakeholder communication and engagement in Public-Private Partnership (PPPs) involving communities, the government, and the private sector.
- The International Finance Corporation produced **this guide** to good practice for stakeholder engagement for companies doing business in emerging markets.

Resource libraries and websites

- The IRC has compiled a compilation of guidelines, methods and tools for use in processes of planning and dialogue for improved water governance at local and governorate level, which can be found **here**.
- This **web page** has a great section with case studies of WASH failures, and what we can learn from them.
- This **blog** talks honestly about failure in the WASH sector too.

Background discussion, policy, and theory

- **Here** is a short Harvard Business Review article on strategies for learning from failure.

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BACKGROUND TO THIS GUIDE

Discussion with BHA led to a desk mapping and consultation exercise carried out by PRO-WASH in 2020 and 2021. This work included key informant interviews with representatives from five RFSAs in Africa and one in south Asia, their development partners working on WASH infrastructure planning and installation, and PRO-WASH Steering Committee members. PRO-WASH also discussed infrastructure choice and sustainability with specialists from the public and private sectors working on WASH infrastructure installation and operation in Africa. The work also drew on PRO-WASH's **webinar series** on different aspects of operation and maintenance of WASH infrastructure.

ABOUT PRO-WASH

PRO-WASH (Practices, Research and Operations in Water, Sanitation and Hygiene) is an initiative funded by USAID's Bureau for Humanitarian Assistance (BHA) and led by Save the Children. PRO-WASH aims to improve the quality of activities, strengthen the capacity and skills of BHA implementing partners in WASH, and improve the level of knowledge and practices around WASH.

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