Compendium of Water Supply Technologies in Emergencies

1st Edition

GERMAN WASH NETWORK

n|w University of Applied Sciences and Arts Northwestern Switzerland

WASH Cluster Water Sanitation Hygiene

sustainable sanitation alliance

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Foreword

Monica Ramos
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Access to safe water is a necessity to sustain life and is critical to reducing the burden and spread of disease. It also underpins human rights, dignity and well-being, and sustainable development. With the Covid-19 pandemic, the benefit of access to safe water, as a key preventative measure to reducing public health risks is crucial, now more than ever.

Today, 2.2 billion people lack access to safe water and are forced to rely on potentially contaminated sources or purchasing water from unregulated water vendors – putting their health and safety at significant risk. This is only further exacerbated in humanitarian settings and fragile contexts, due to increased attacks on water infrastructure, public health outbreaks and impact of climate change on natural disasters. It also further hampers the sector's capacity to guarantee the safe water chain, including collection, handling, storage, treatment and consumption.

The complexity of this issue requires a comprehensive and systematic approach to the application and use of appropriate water supply technologies in humanitarian settings and fragile contexts. The technical guidance on water supply technologies provided in this publication plays a pivotal role in building capacity and promoting evidence-based decision making for the sector. It also speaks greatly to the vision of the cluster, acting as a driver for improved coordination and optimises the use of a common tool to deliver an accountable and high-quality response. This publication covers water supply technologies suitable from the acute response to the more longer-term stabilisation and recovery phases. This is seen crucial as the humanitarian community has been increasingly confronted with longer-term and protracted crisis, with an increased need to further reinforce synergies and linkages between lifesaving humanitarian efforts and sustainable development.

Together with Global WASH Cluster partners and under the leadership of the German WASH Network, the elaboration of this technical guidance demonstrates an impressive level of collective commitments and collaborative efforts from an extensive range of international sector experts and organisations – resulting in an all-inclusive reference that encompasses the broad spectrum of appropriate water supply technologies in the sector.

The Global WASH Cluster is pleased to host the online version of this compendium together with the Sustainable Sanitation Alliance. We have great appreciation for the partners and donors, who have made this possible through their past and continuous support efforts.

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Introduction

Background and Target Audience

The Compendium of Water Supply Technologies in Emergencies offers a comprehensive and structured planning guide on new and existing technologies for water supply operations in humanitarian settings.

The target audience includes humanitarian staff, local first responders, engineers, planners, government representatives, capacity building agencies and other WASH professionals involved in humanitarian response. Although humanitarian WASH interventions primarily focus on immediate life-saving measures and protecting public health, the humanitarian community has been increasingly confronted with longer-term protracted crises that stretch beyond an emergency response. Humanitarian WASH professionals often work in both urban settings and displacement camp contexts to address the WASH needs of refugees, internally displaced people (IDPs), and host communities. The compendium addresses this reality by covering suitable technologies ranging from the initial acute response to the stabilisation and recovery phases (including rehabilitating existing infrastructure). It addresses a broad spectrum of scenarios that humanitarian WASH practitioners may encounter when planning and selecting appropriate water supply services or upgrading existing infrastructure.

The Compendium of Water Supply Technologies in Emergencies is the humanitarian response counterpart to the "Compendium of Drinking Water Systems and Technologies from Source to Consumer" developed by the University of Applied Sciences and Arts Northwest Switzerland (FHNW) in collaboration with the Swiss Federal Institute of Aquatic Science and Technology (Eawag) and the World Health Organization (WHO). Like the development compendium, it disaggregates water supply technologies into their functional components, defines key terminology and provides guidance on identifying the most appropriate water supply technology solutions in a given context. It also provides links to further reading for more information.

The Compendium of Water Supply Technologies in Emergencies is primarily a capacity building tool and reference book. It supports decision making and technological choices when designing a water supply system. This document offers concise information on key decision criteria for each technology and facilitates combining these technologies to develop full technical water supply system solutions as well as linking the technologies to relevant cross-cutting issues.

This compendium is a starting point for accessing relevant information for designing suitable water supply systems and is meant to be used in conjunction with other available publications and tools.

Structure and Use of the Compendium

The compendium consists of three major sections:

Introduction

The introductory chapter describes the structure of the compendium, defines key terminology, and provides a useful framework for configuring emergency water supply systems. It provides background information on different emergency scenarios and phases of the response, the implications for water supply infrastructure and on relevant principles and standards related to water supply. Compendium users are encouraged to review the sections "Compendium Terminology" **(page 9)** and "Technology Selection" **(page 10)** to ensure familiarity with key terms and the systematic approach for determining full water supply schemes. This section also introduces the key selection criteria that users should keep in mind when selecting water supply technologies and designing context-appropriate water supply systems.

Part 1: Technology Compilation

This core section of the publication is a comprehensive compilation of relevant water supply technologies that can be implemented in a wide range of contexts from acute emergencies to long-term stabilisation and recovery settings. The technologies are categorised and ordered according to their functional group: S Source, I Intake, A Abstraction, T Treatment, D Distribution/Transport, and H Household Water Treatment and Safe Storage (HWTS).

The section starts with a general overview of all the technologies presented in the compendium and a more specific overview of the technologies according to their appropriateness for different response phases. This is followed by a compilation of 68 "Technology Information Sheets", which are two-page summaries for each technology outlining the basic working principles and design considerations as well as key information regarding applicability, cost implications, space and materials needed, operation and maintenance (O & M) requirements and social and environmental aspects.

Part 2: Cross-Cutting Issues

This section presents cross-cutting issues and background information that should be considered when making technology and design decisions. It includes requirements for (1) an assessment of the initial situation including the existing institutional and regulatory environment and the rehabilitation and upgrade of existing infrastructure, (2) monitoring and quality control ranging from data flows and information/communication technology to working with sub-contractors, water quality monitoring and water safety and risk management, (3) conceptual aspects such as resilience and preparedness, the exit strategy and handover of infrastructure and specific features of urban settings and (4) design and social considerations such as inclusive and equitable design, hygiene promotion and market-based programming.

Compendium Terminology

Water Supply System

A water supply system is a multi-step process with an end goal of providing safe water for drinking, personal hygiene, cleaning and other domestic purposes. It comprises functional groups of technologies and services: from source exploitation, intake, abstraction and treatment to distribution methods and user safety at the point of use. With this, a logical, modular water supply system can be designed by selecting technologies from each applicable functional group and considering the suitability of the technologies in a particular context. A water supply system also includes the management and O&M required to ensure that the system functions safely and sustainably.

Water Supply Technology

Water supply technologies are defined as the specific infrastructure, methods or services needed from source exploitation through distribution to the final user safety at the point of use. Each of the 68 technologies included in this compendium are described in a two-page technology information sheet. Only water supply technologies that have been sufficiently proven and tested in emergency settings are included. Additionally, technologies that are commonly used in urban, peri-urban and rural settings and that might require rehabilitation in an emergency context are described. The compendium is primarily concerned with water supply systems and technologies directly related to the provision of safe water for drinking and other domestic purposes. It does not specifically address the provision of water for productive purposes, such as irrigation or industrial use.

Functional Groups

The functional groups cluster the technologies that have similar functions. The compendium proposes six different functional groups from which technologies can be chosen to build a water supply system (of which some may already be in place in a specific context that can potentially be rehabilitated):

- S Source (Technologies **S.1–S.12**)
- I Intake (Technologies **I.1–I.9**)
- A Abstraction (Technologies **A.1–A.10**)
- T Treatment (Technologies **T.1–T.15**)
- D Distribution/Transport (Technologies **D.1–D.8**)
- H Household Water Treatment and Safe Storage (Technologies **H.1–H.14**)

Each functional group is identified by a distinctive colour; technologies within a given functional group share the same colour code for easy identification. Also, each technology within a functional group is assigned a reference code with a single letter and number.

Source S refers to the original raw water source and considers whether it provides enough water as well as the energy sources needed to power abstraction, treatment and transportation of the water. Typically, groundwater or surface water resources are exploited, though in areas with sufficient rainfall, rainwater may also be an appropriate complimentary water source. The quantity, quality and location of the source determine the subsequent water treatment and water supply system design. A variety of energy sources is available ranging from gravity (if the water source is elevated) and human power (for abstraction of comparably small water volumes) to traditional (e.g. electricity or diesel) or renewable (e.g. wind and solar) energy sources.

Intake I refers to the withdrawal system that collects water from the source. For each water source, there may be one or more intake systems available. Some intake systems may act as a reservoir for storing water or provide a certain degree of treatment. Intakes can be classified according to the water source: rainwater, surface water or groundwater intakes. The choice of intake systems depends on a number of factors, including the volume of water needed for the target population, availability of appropriate surfaces, characteristics of the water body, flow and flow characteristics, hydrogeological conditions, water accessibility, availability and the risk of contamination. Properly constructed intake systems should provide convenient and efficient access to water sources as well as protect those sources from contamination and prevent harm to ecosystems.

Abstraction A refers to the various ways of extracting/abstracting water through a pump. Pumps can be divided into three broad categories, depending on how water moves through the pump: (1) impulse pumps, (2) positive displacement pumps or (3) velocity pumps. A wide variety of pump types are commercially available, each with specific operational advantages. Choosing the most appropriate water abstraction technology depends on a range factors, such as the water source, intake structure, available energy source, elevation, required capacity, O & M requirements, local availability of components and service, socio-cultural and environmental considerations and other infrastructure already in place.

Treatment T refers to technologies for water treatment, which are generally appropriate for a larger group of users, such as communities, semi-centralised applications in neighbourhoods, and more centralised applications in urban areas. Water treatment technologies can be divided into three groups: (1) pre-treatment with the main objective of reducing raw water turbidity, (2) targeting primarily microbial contaminants and (3) targeting chemical contaminants of various origins, including high salinity. Some technologies can function as a single-step treatment, while others may need to be applied as part of a multi-stage treatment system.

Distribution/Transport D refers to technologies for delivering water from the source, pumping station or water treatment plant to the user. These are either communal distribution systems with varying complexity, scale and types of connections or privately adopted solutions. Distribution/Transport also includes water storage technologies that can play a significant role within the distribution system as well as at the Intake (I) and during Treatment (T).

Household Water Treatment and Safe Storage H refers to household water treatment and safe storage technologies used as single-stage water treatment alternatives when centralised or community scale treatment is not available or the quality of produced water does not meet the applicable standards. Should contamination occur during transport between the point of abstraction/collection and the point of use, household water treatment is a viable option to remedy this and includes the safe storage of water within the household.

Technology Selection

Drinking water supply systems can be graphically presented as a sequence of functional groups **(see technology overview on page 24)** that can be linked together in various combinations. All components of the system, from the source to consumption, form a part of this sequence and are considered and displayed. The six functional groups are represented by colour-coded columns as follows: S Source, I Intake, A Abstraction, T Treatment, D Distribution/Transport, H Household Water Treatment and Safe Storage.

Before exploitation can begin, the water source must be identified. In the acute phase of an emergency, the chosen water source may not be ideal (such as in terms of water quality) but may still be chosen due to other advantages (such as proximity and/or accessibility). As the emergency stabilises, more time may become available for developing sustainable alternative sources (e.g. a Groundwater source **(S.5)** requiring less ongoing treatment or a Spring **(S.6)** amenable to gravity flow rather than pumping).

The intake chosen depends, for example, on the time available to build it, and thus in the acute response phase, the choice of intake is often limited to those that can be developed quickly, such as a River or Lake Intake **(I.3)**, or where existing Wells **(I.7)** or Boreholes **(I.8)** can be commandeered. Again, as the emergency progresses, additional time availability may allow the construction of other intakes more suited to the ongoing situation.

The water will need to be abstracted from the intake via an energy source. During the acute phase of a response, this often means some kind of pump **(see A.1–A.9)** that is powered by Electricity **(S.11)** or Diesel **(S.12)**, although these may be replaced with more sustainable alternatives over time, such as Gravity **(S.7)** or Solar Energy **(S.10)**.

Following abstraction, the water will usually need treatment prior to distribution. The level and complexity of the required treatment largely depends on the water quality and the standards and indicators to be reached, though this is also dependent on the stage of the emergency response. For example, in the acute phase, the priority is always to reduce microbiological contamination immediately, as this has the highest short-term health impact. Over time, other treatment methods can be added to address additional sources of contamination that have long-term health impacts (e.g. fluoride). In the acute response, prefabricated, packaged water treatment plants are very useful, as they are designed to treat turbid or contaminated surface water in large volumes. They also tend to use treatment methods such as (Assisted) Sedimentation with or without Filtration **(T.4, T.5)** that are effective reducing significant amounts of chemicals that may have long-term health impacts. Over time, more sustainable treatment options that take longer to set up can be designed. For example, Slow Sand Filters **(T.9)** dramatically reduce the chemical requirements in water treatment, thus reducing running costs.

Subsequently, treated water will need to be both transported from the source to the vicinity of the users (such as using trucks or pipes to transport water to storage tanks) and from the storage tanks to the users (such as using pipes and jerrycans). In the acute response, it is common to rely more on short-term solutions such as Water Trucking **(D.3)** to transport water to Flexible Bladder Tanks **(D.5)**, which in turn are connected to Tap Stands **(see D.7)**. However, solutions like water trucking are very expensive and bladder tanks are not robust in the longer term. Hence other transport/distribution systems that are less expensive, more sustainable, and more convenient should be deployed as soon as possible. These include pipelines using gravity or solar pumping, tanks with larger volumes made from more robust materials **(see D.6)** and distribution systems that bring water closer to, or even into, the household **(see D.7, D.8)**.

Drinking water must be stored safely in the household, and users can perform additional treatments within the household if necessary. Historically, certain household-level water technologies have been useful in the acute response before centralised treatment is set up or where it is not possible, e.g. the use of Coagulant-Flocculant Sachets **(H.8)**. In some acute situations where the population is already familiar with a particular household water treatment product, these can be included as part of the first non-food item distributions in the acute phase to help address water quality, especially in dispersed populations. Overall, many of these household-level water treatment systems are also good long-term solutions where centralised water treatment is not reliable and where pilot interventions can be done prior to scaling up, potentially using local markets to do so.

Some humanitarian WASH organisations also use package systems consisting of several technologies from the functional groups presented above that are usually flown in, are immediately deployable and allow for a safe provision of water from the source to the user in a variety of contexts. These systems are usually only used in the acute response before context-specific, long-term solutions can be identified and set up or existing systems can be rehabilitated.

It is important to note that it is not always necessary for water to pass through all functional groups to reach a consumer. In some systems, treatment is excluded due to the high quality of the source water. Water can also be supplied by gravity to avoid the need for pumping.

There are multiple factors that influence an initial decision about which technologies to choose in an emergency. In reality, some experience is required to choose the most suitable technologies for the respective response phase, and it is not possible to be too prescriptive about this. The following steps provide some guidance to determine appropriate water supply technology options for specific contexts:

Assessment of the initial situation **(see X.1– X.4)**, including the identification and accessibility of available water sources with sufficient yields, the practices, preferences and water demand of the user groups to be served, the geographical conditions, the existing infrastructure and services in the area and the institutional and regulatory environment.

Identification of technologies that may be appropriate for each of the functional groups based on the technology overview **(page 24)** and the more detailed descriptions from the Technology Information Sheets **(page 26–175)**. In the Treatment (T) functional group, multiple technologies may be applicable depending on potential contamination of the available water resource(s). Parts of a water supply system may already exist that can be integrated.

Combine technologies logically to build several appropriate water supply systems.

Compare the systems and iteratively change individual technologies based on considerations such as user/community priorities, time pressure, scale, operation and maintenance requirements, economic constraints and technical feasibility.

Emergency and Crisis Scenarios

Emergencies can arise from a range of scenarios and can be either acute and time-limited or chronic and protracted in nature. The scenarios leading to emergencies can be broadly categorised as follows:

Emergencies Triggered by Natural or Technological Hazards: Earthquakes, volcanic eruptions, landslides, floods, storms, droughts, temperature extremes and disease epidemics/pandemics (e.g. Cholera, Ebola or Covid-19) are natural hazards that can cause humanitarian disasters claiming many lives and causing economic losses and environmental and infrastructure damage. However, humanitarian disasters only occur if a hazard strikes where populations are vulnerable to the specific hazard. The growing world population, continuing global urbanisation and changes in land use can further increase vulnerability to natural and technological hazards, such as dam failures and chemical or nuclear accidents. Such emergencies often result in a deterioration of environmental health conditions, particularly regarding access to basic WASH services. Infrastructure such as schools, roads, hospitals and water and sanitation facilities are often directly affected, reducing access to clean water, sanitation and relevant hygiene practices like handwashing, which increases the risk of water- and sanitation-related diseases.

Conflicts: This refers to societally caused emergency situations such as political conflicts, armed confrontations, and civil wars. Many displaced people (internally displaced and/or refugees) have to be housed in camps, temporary shelters, or host communities, where access to clean water, sanitation, and hygiene items needs to be guaranteed at very short notice and often must be maintained over long periods. Most displaced persons are usually absorbed by host communities. This can overburden the existing water supply (and sanitation) infrastructure, making it difficult to identify and quantify actual needs and potentially requiring upgrades to existing infrastructure.
Due to conflict dynamics and because population displacement can occur (and dynamically change) over a longer period of time, it is often difficult to plan how long shelters and corresponding water supply infrastructure must remain in place. This required operational time can vary from a few weeks or months to several years or even decades. The majority of refugee camps are becoming increasingly longer term (10 years or more) that often develop into continuous urban settlements. Hence, all technologies implemented in such settings should be viewed through the lens of long-term sustainability.
An adequate water supply source is generally the main criteria for siting a camp or displaced population. However, refugee camps are often constructed in water scarce environments, so it is important to make the decision to move people to water or bring water to people early on in the response. In many situations, settlement solutions are considered a short -term intervention, as it is politically undesirable to consider more permanent settlement options. Local authorities might oppose activities that are seen to make the water or sanitation infrastructure in a temporary settlement more permanent or better developed for fear of having long-term responsibility for the displaced population. This is further complicated if the conditions in the camp might become better than those in local settlements, which can create tension between the local and refugee populations. Such cases should be seen as opportunities to improve water supply services for both host and refugee communities.

Fragile States and Protracted Crises: Fragile states and countries in protracted crises are becoming increasingly more common. States can be considered fragile when they are unwilling or unable to meet their basic functions. For the affected population, safety may be at risk if basic social services are not provided or are only poorly functioning. Weak government structures or lack of government responsibility for ensuring basic services can increase poverty, inequality and social distrust and can potentially develop into a humanitarian emergency.
Protracted crisis situations are characterised by recurrent disasters and/or conflicts, prolonged food crises, deterioration of the health status of people, breakdown of livelihoods and insufficient institutional capacity to react to crises. In these environments, a significant proportion of the population is acutely vulnerable to premature death or illness. The provision of basic water supply services is often neglected, and external support using conventional government channels can lead to highly unsatisfactory experiences. Under these conditions, it may be necessary to explore complementary and alternative means of service provision, basing it mainly on non- and sub-state actors at a relatively decentralised level. Water supply technologies should be selected that can withstand theft (as far as possible) and have the fewest external inputs as possible (e.g. fuel or chemicals).

(High-) Risk Countries Continuously Affected by Disasters and Climate Change: Climate change and the increased likelihood of associated natural hazards is an enormous challenge for many countries. The risk that natural events become a disaster is largely determined by the vulnerability of the society, the susceptibility of its ecological or socio-economic systems and the impact of climate change both on occasional extreme events (e.g. heavy rains causing floods or landslides) and on gradual climatic changes (e.g. temporal shift of the rainy seasons). Climate change also exacerbates problematic situations in countries that are already suffering from disasters. In addition to the immediate emergency response that may be required, it also needs a stronger focus from development actors to consider adequate preventative and disaster risk reduction **(see X.10)** measures. Existing water supply infrastructure may need adaptations or more appropriate and robust water supply systems may need to be introduced to increase resilience and help communities cope with climate-induced recurrent extreme weather events (e.g. raised water points for flood-prone areas or bigger storage tanks to withstand longer dry seasons). It may also include preparedness measures such as capacity development, equipment stockpiling and surge roster development. In addition, water supply systems may need to be prepared to serve climate change refugees.

Disasters can often be a mix of several categories (e.g. fragile or conflict-affected states hit by a natural disaster), which makes response targeting more difficult (e.g. targeting only those affected by the natural disaster vs. those affected by more chronic conditions). In addition, disaster and crisis scenarios can be further differentiated into sudden onset disasters (e.g. earthquakes or conflicts) and slow-onset disasters (e.g. droughts that may lead to a prolonged food crisis or fragile contexts that lead to the deterioration of services over time). Depending on the type of crisis, population and infrastructure may also be affected very differently. While some disasters may lead to massive population movements with implications for strong public health measures, others may only affect the infrastructure, which would shift the response focus to repairs and respective improvements.

Response Phases

Common categories used to distinguish between the different response phases are: (1) acute response, (2) stabilisation and (3) recovery. The identification of these broad phases is helpful when planning assistance, though the division should be viewed as theoretical and simplified, as it is modelled after singular disaster events.

Acute Response: This refers to humanitarian relief interventions that are implemented immediately following natural disasters, conflicts, epidemics/pandemics, or a further degradation of a protracted crisis situation. It usually covers the first hours and days up to the first few weeks or months, where effective short-term measures are applied to quickly alleviate the emergency situation until more permanent or durable solutions can be found. An initial (rapid) assessment **(see X.1–X.4)** is needed to identify priority needs and to get a better understanding of the contextual and technical aspects as well as the institutional and actor landscape.
The purpose of interventions in the acute response phase is to secure and ensure the survival of the affected population, guided by the principles of humanity, neutrality, impartiality and independence. It must also be considered that in certain emergencies, the affected people are often much more vulnerable to disease due to non-existing or inadequate WASH facilities and an inability to maintain good hygiene. Therefore, essential water-supply related services needed at this stage include the provision of sufficient supplies of clean water for drinking, personal hygiene and cooking, primarily on a communal level, and ensuring a safe environment while preventing contamination of water sources. Where applicable, the preferred intervention is the quick rehabilitation or reinforcement of existing water supply infrastructure (alongside short-term rapid emergency water supplies, if needed) and the provision of tools and equipment to ensure basic O&M services.
To ensure that the entire affected population has safe and adequate access to water supply services and that services are appropriate, relevant water authorities and local first responders need to be involved from the onset, and it must be ensured that there is an equitable participation of men, women, children and marginalised and vulnerable groups in planning, decision-making and local management **(see X.15, X.16)**. Intervention at this stage in an emergency is largely provided by local resources, as it takes time for external support agencies to mobilise. However, local resources are often unprepared for such events, meaning those affected have to largely deal with the emergency themselves.

Stabilisation: The stabilisation or transition phase usually starts after the first weeks/months of an emergency and can last to around half a year or longer. The main focus, apart from increasing service coverage, is the incremental upgrade and improvement of temporary emergency structures that would have been installed during the acute phase or the replacement of temporary technologies with more robust long-term solutions. This phase includes the establishment of community-supported structures with a strong focus on the entire WASH system, the gradual involvement of water utility structures where applicable, and the consideration of water safety and risk management measures **(see X.7, X.8)**.
In this phase, water and energy sources should be reconsidered after accounting for environmental factors and long-term sustainability, particularly where groundwater is used as the major water source or where the water supply relies on water trucking. Water supply hardware solutions should be based on appropriate technologies and designs, ideally using locally available materials. A detailed assessment is required to respond adequately within a given local context and to increase the long-term acceptance of the planned interventions **(see X.1–X.4)**. Emphasis should be given to aspects such as taste, odour and colour of the supplied water, as these will affect acceptance, as well as to hygiene-related issues that imply certain levels of behaviour change **(see X.16)**. The scope of using market-based approaches **(see X.17)** should also be examined.
As in the acute phase, the equitable participation of men, women, children and marginalised and vulnerable groups in planning, decision-making and local management is

key to ensuring the entire affected population has safe and adequate access to water supply services and that services are appropriate. During the stabilisation phase, relevant resilience and disaster risk reduction measures should be pre-emptively considered, particularly if another disaster is likely to happen **(see X.10)**.

Recovery: The recovery phase, sometimes referred to as the rehabilitation phase, aims to recreate or improve on the pre-emergency situation of the affected population by gradually incorporating development principles. This phase usually starts after or even during relief interventions (usually >6 months) and can be seen as a continuation of already executed relief efforts. Overall, it can prepare the ground for subsequent development interventions and gradual handing over to medium- to long-term partners. Depending on local needs, the general timeframe for recovery and rehabilitation interventions is usually between six months to three years, though difficult situations may need up to five years or more, such as in conflict-affected areas.

Recovery and rehabilitation interventions are characterised by the active participation of local partners and authorities in the planning and decision making to build local capacities and contribute to the sustainability of the interventions. The scope of using market-based approaches **(see. X.17)** or introducing tariff systems for water use in the long-term should be further examined here.

Water supply recovery interventions can take diverse forms and depend on local conditions as well as the actual needs of the affected population. Beyond the technical implementation of a water supply system, these interventions include significant efforts to strengthen WASH service structures and systems and promote markets for water services. In long-lasting camp situations that may develop into permanent settlements, interventions might include upgrading the existing emergency water supply infrastructure.

Recovery interventions also include long-term capacity development and training, including working with relevant local authorities and development partners. Stronger collaboration with local governments, utilities, civil society, private sector and the handing over of responsibilities are also paramount. This necessitates the increased participation of involved stakeholders in planning and decision-making early on. Where possible, recovery interventions should consider that the investments made may provide a foundation for further expansion of WASH facilities and services. In addition, recovery interventions may include relevant resilience and disaster risk reduction measures **(see X.10)**. Recovery interventions should include a clear transition or exit strategy **(see X.11)**, including hand-over to local governments, communities or service providers to ensure that the service levels created can be maintained.

Principles and Standards Related to Water Supply

Access to water is fundamental to the health and well-being of people and is considered a basic human right. This right entitles everyone to have access to sufficient, safe, acceptable, physically accessible and affordable water for both personal and domestic use. This right applies to all contexts of an emergency, regardless of where or when it occurs or its scale. For access to water in emergencies, there are specific standards and guidelines addressing both water quantity and quality that serve to orient efforts for meeting this right of access. These include the Sphere project's minimum standards for all emergency types and phases as well as specific standards for internally and internationally displaced people by UNHCR, the WHO guidelines for drinking water, and existing national standards and guidelines **(see X.3)**.

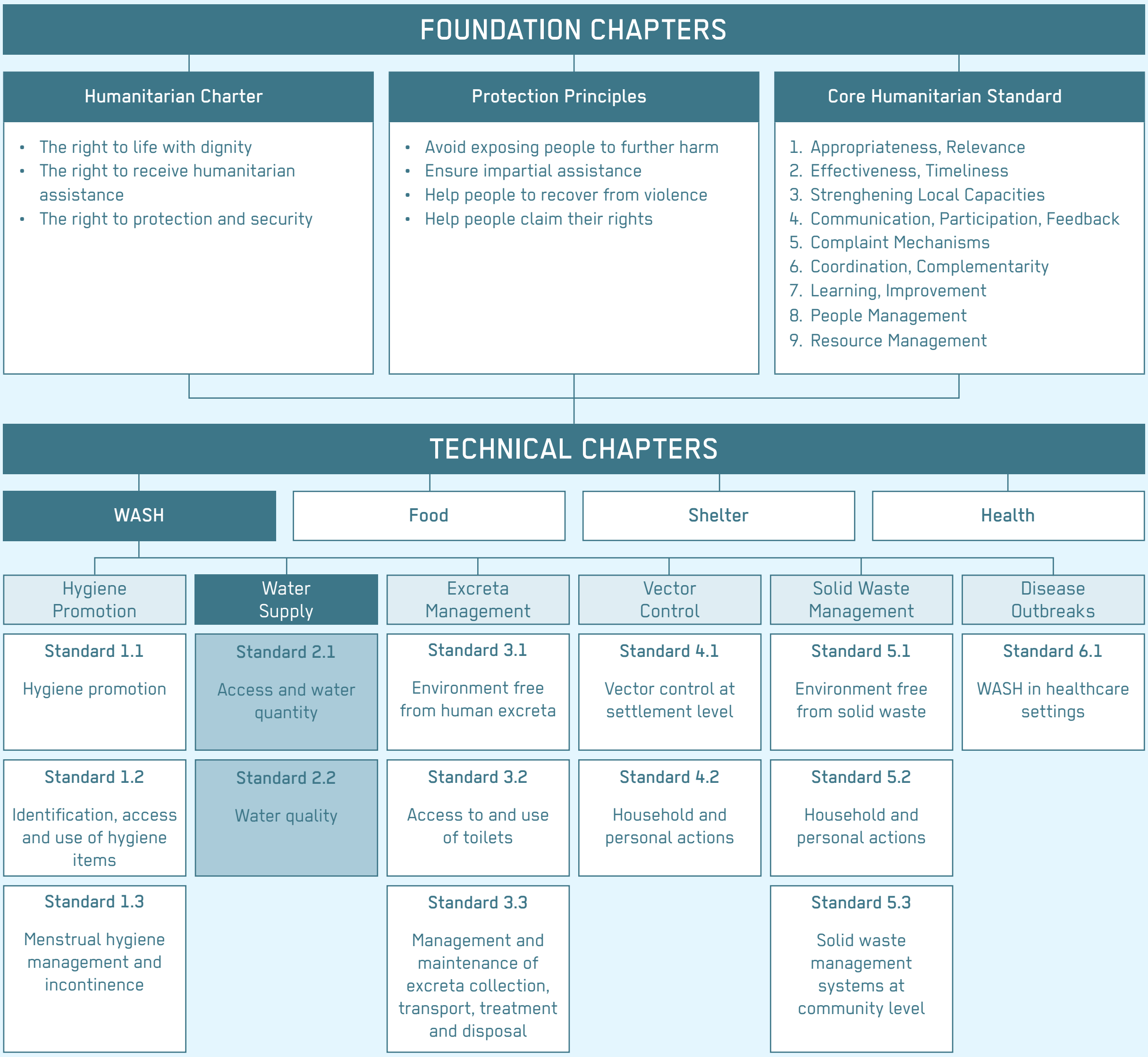
Whatever the balance between national capacity, resources and the international support mobilised in response to a crisis, all parties must respect and observe the national regulatory environment, including relevant national policies, laws and standards. Local regulations at the municipal level are likely to be unfamiliar to external actors but need to be understood and adhered to **(see X.3)**. This is of particular importance when transitioning to long-term solutions during the stabilisation and recovery phases.

However, national water standards are not always adaptable for crisis situations, so it may not be appropriate or feasible to follow existing standards. If national emergency guidelines are not specific or existent, the Sphere Humanitarian Charter and Minimum Standards in Humanitarian Response should be referred to for guidance (or UNHCR indicators and targets in refugee settings), which need to be further adapted based on context, response phase and existing national targets. Wherever possible, government stakeholders should be engaged in the discussion about the application of these emergency standards and indicators.

The Sphere Project

The Sphere Project was launched in 1997 to develop a set of globally agreed and universal principles and standards in core areas of humanitarian assistance. With its rights-based and people-centred framework it aims to improve the quality of assistance provided to people affected by disasters and to enhance the accountability of the humanitarian system in disaster response.

The Humanitarian Charter and Minimum Standards in Disaster Response (also known as the Sphere handbook) that was subsequently developed by the project is the product of the collective experience of many people and agencies. They do not therefore reflect the views of any one agency. It is a practical translation of Sphere's core belief that all people affected by disaster have the right to life with dignity and the right to receive humanitarian assistance. It consists of both foundation and technical chapters **(see Figure 1)**. The **Foundation Chapters** include the Humanitarian Charter as its backbone with common legal principles and shared beliefs, the Protection Principles and the Core Humanitarian Standard that defines nine commitments applicable to all humanitarian actions. The **Technical Chapters** outline response priorities in four key life-saving sectors: water, sanitation and hygiene promotion (WASH), food security and nutrition, shelter and settlement, and health.



Structure of all Technical Standards

Standard:	Universal, general and qualitative, state to be reached
Key Actions:	Practical steps to attain the standard
Key Indicators:	Signals to measure progress and whether a standard is being attained
Guidance Notes:	Additional information on how to consider context and operational requirements

Figure 1:
Sphere Overview and the WASH Technical Chapter (adapted from Sphere 2018).

In the technical chapters, standards define the status that must be reached and describe the humanitarian response that is required for people to survive and re-establish their lives and livelihoods in ways that respect their voice and ensure their dignity. These standards are universal, general, and qualitative. Key actions outline practical steps for attaining the standard, though these are considered suggestions that may not be applicable in all contexts. Provided indicators signal whether the standards are being met and provide a way to compare programme results over the life of the response. Minimum quantitative requirements are the lowest acceptable level of achievement and are only included where there is sectoral consensus. Guidance notes provide additional information on how to link the standards with the principles and how to consider context and operational requirements.

The WASH Chapter in the 2018 edition of the Sphere Handbook consists of six key areas (or sub-chapters) with a total of 14 minimum standards **(see Figure 1)**. The water supply sub-chapter includes two standards:

The Sphere Water Supply Standard 2.1: Access and Water Quantity

Minimum Standard: People have equitable and affordable access to a sufficient quantity of safe water to meet their drinking and domestic needs.

Key Actions:

- Identify the most appropriate groundwater or surface water sources, considering seasonal variations in water supply and demand and mechanisms for accessing water for drinking, domestic and livelihood purposes.
- Determine how much water is required and the systems needed to deliver it, including information on the operation of water access points to allow safe and equitable access for all community members and to establish maintenance systems that assign clear responsibilities. The systems are to be established in consultations with the community and stakeholders while considering previous and current water governance structures.
- Ensure appropriate water point drainage at household and communal washing, bathing and cooking areas as well as handwashing facilities. This should already be considered in the design phase and monitored throughout the water distribution. The potential environmental impacts of the selected water sources should also be considered here along with opportunities for water reuse (e.g. vegetable gardens, brick making or irrigation).

Key Indicators:

- Average volume of water used for drinking and domestic hygiene per household
  - Minimum of 15 litres per person per day
  - Determine quantity based on context and phase of response
- Maximum number of people using water-based facility
  - 250 people per tap (based on a flow rate of 7.5 litres/minute)
  - 500 people per hand pump (based on a flow rate of 17 litres/minute)
  - 400 people per open hand well (based on a flow rate of 12.5 litres/minute)
  - 100 people per laundry facility
  - 50 people per bathing facility
- Percentage of household income used to buy water for drinking and domestic hygiene
  - Target is 5 % or less
- Percentage of targeted households who know where and when they will next get their water
- Distance from any household to the nearest waterpoint
  - <500 metres
- Queuing time at water sources
  - <30 minutes
- Percentage of communal water distribution points that are free of standing water
- Percentage of water systems/facilities that have a functional and accountable management system in place

The Sphere Water Supply Standard 2.2: Water Quality

Minimum Standard: Water is palatable and of sufficient quality for drinking and cooking, and for personal and domestic hygiene, without causing a risk to health.

Key Actions:

- Identify public health risks associated with the available water as well as the most appropriate way to reduce them, including protecting water sources and regularly renewing sanitary surveys at source and water points.
- Determine the most appropriate method for ensuring safe drinking water at point of consumption or use, including bulk water treatment and distribution with safe collection and storage at the household level or household-level water treatment and safe storage.

- Minimise post-delivery water contamination at the point of consumption or use, including equipping households with safe containers to collect and store drinking water as well as the means to safely draw drinking water. This step also includes measuring water quality parameters, particularly focusing on free residual chlorine (FRC), coliform forming units (CFU) and turbidity at the point of delivery and point of consumption or use.

Key Indicators:

- Percentage of affected people who collect drinking water from protected water sources
- Percentage of households observed to store water safely in clean and covered containers at all times
- Percentage of water quality tests meeting minimum water quality standards
  - <10 CFU/ 100 ml at point of delivery (unchlorinated water)
  - ≥0.2–0.5 mg/l FRC at point of delivery (chlorinated water)
  - Turbidity of <5 NTU

→ **Further resources related to the Principles and Standards chapter can be found on page 212**

Water Cycle and Water Resources

Water is essential for all living organisms on Earth. To ensure that people have equitable access to water in sufficient quantity, of safe quality and that is physically acceptable according to national or other applicable standards, such as Sphere, a prior basic understanding of the water cycle is necessary. Knowing the different processes, sources and sinks in the water cycle or hydrosphere facilitates the assessment, design, planning, implementation and monitoring of water supply interventions that remain within the boundaries set by the available natural resources and their respective risk exposure.
The water cycle as shown in **Figure 2** describes the continuous movement of water above, on and below the Earth's surface between the different reservoirs of water in its different states, which are water vapour in clouds; precipitation as rainfall or snow; runoff to streams, rivers, lakes and the ocean; and groundwater flow within aquifers supporting the existence of springs, streams, rivers and lakes. The process driving these include evaporation, transpiration, precipitation, infiltration, baseflow, overland flow and runoff.
Global water availability is finite, with the overall balance generally defined by 'inflow - outflow = change in storage', with only 2.5 % of global water reserves consisting of fresh water while the rest is saline, predominately occurring as seawater. Two thirds (68.7 %) of the available fresh water is locked up in glaciers and ice caps, while the rest consists of groundwater (30.1 %) and surface water (1.2 %).

Figure 2:
Water Cycle Overview

Prior to exploiting any water source, a rapid assessment **(see X.1–4)** is required, especially for the rapid on-set of an emergency. This assessment involves: structured field observations to determine access to affected populations; field mapping of water sources in relation to the quantity and quality of water available; and interviews with key stakeholders including relevant authorities, affected and non-affected people. Rapidly assessing the hydrological and hydrogeological environment (surface and groundwater) early on will assist in planning and designing safe infrastructure, especially if flooding has been identified as a hazard. During the acute stage, surface water could be the first choice, as rapid access to fresh water is key. This is sufficient even if the water is of a poorer quality, because the default approach is to chlorinate regardless of the water source to mitigate any potential outbreaks.

Knowledge of seasonal weather patterns and the resulting water flow and distribution patterns is very important. An affected population relocating to a floodplain for example, could potentially access both river water and shallow aquifers but will be at risk from flooding if emergency pit latrines are used due to possible shallow groundwater tables. For larger more complex emergencies, particularly during the acute stage, the use of drone surveys and/or crowd-sourced crisis mapping can be very helpful, especially with access to remote sensing data. This type of data can be easily used on cloud-based platforms such as Google Earth Engine but is most commonly used in subsequent emergency phases during detailed interagency assessments with specialist support. Over the mid- to long-term stages of a humanitarian crisis, water source availability inclusive of quality should be re-assessed.

The three main water source types accessed during emergencies are rainfall, surface water (streams, rivers, reservoirs and lakes) and groundwater. It requires technical expertise from hydrologists, water and public health engineers, and hydrogeologists together with policy makers and regulators to ensure safe, equitable and sustainable water sources are developed, especially for the longer term. If cost effective sustainable surface water treatment options are not available, then it is usually possible to use groundwater through springs, hand dug shallow wells or drilled and cased boreholes. To provide the safest accessible sites for affected communities to best site boreholes where motorised pumps are required, approaches such as Rapid Groundwater Potential Mapping (RGWPM) already exist. These methods rely on open-source data (digital elevation models, geomorphology, local and regional geology, rainfall and evapotranspiration) coupled with available local knowledge and capacity. In cases of long-term emergencies or protracted crises, it will be important to have knowledge of the institutional landscape (national policies, regulators, standards and water service providers) of the host large water basins. The overarching objective here is to foster a transformative change from water vulnerability to water resilience.

→ **Further resources related to the Water Cycle and Water Resources chapter can be found on page 212**

Key Decision Criteria

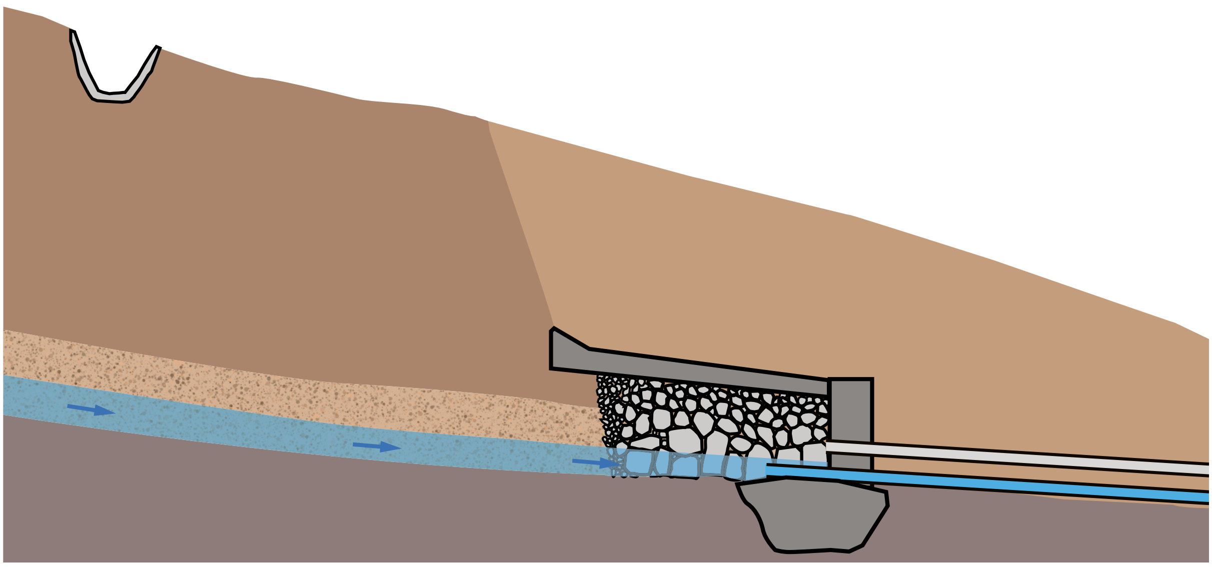
Selecting the most appropriate water supply technology(ies) for a specific context is a complex task requiring technical and analytical skills. The selection must be based on an assessment that includes a wide range of data gathered from field-level surveys **(see X.1–X.4)**.

The key decision criteria **(see Figure 3 below and detailed description on the following pages)** aim to give the compendium user general guidance in the technology selection process and in the overall design of a water supply system. The decision criteria are featured in each of the subsequent technology information sheets.

Figure 3:
Generic Structure of the Technology Information Sheet

Name of the Technology

Response Phase ❶	Application Level ❷	Management Level ❸	Objectives / Key Features ❹
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared * Public	Natural flowing groundwater, no pumps needed, generally good quality water
Local Availability ❺	**Technical Complexity ❻**	**Maturity Level ❼**	
*** High	** Medium	*** High	



Technology Description	⓬ Health and Safety
❽ Design Considerations	⓭ Costs
❾ Materials	⓮ Social and Environmental Considerations
❿ Applicability	⓯ Strengths and Weaknesses
⓫ Operation and Maintenance	⓰ References and Further Readings

❶ Response Phase

This section indicates for which phase of the response the technologies are appropriate (provided they are to be newly built). Their suitability is characterised for the three response phases (described in detail on **page 13**):

- **Acute Response**
- **Stabilisation**
- **Recovery**

An indication of whether a technology is suitable for a specific response phase is given using asterisks (**two asterisks**: suitable, **one asterisk**: less suitable, **no asterisk**: unsuitable). The level of appropriateness is decided on a comparative basis between the different technologies, mainly based on applicability, speed of implementation and material requirements. It is up to the compendium user to decide on the response phase for their specific situation.

❷ Application Level

The application level describes the different spatial levels and scale for which the technology is most appropriate. It is subdivided into the following levels:

- **Household** (one unit serving one up to several individual households)
- **Neighbourhood** (one unit serving a few to several hundred households)
- **City** (one unit serving an entire settlement, camp or district)

An indication of whether a technology is suitable at a specific spatial level is given using asterisks (**two asterisks**: suitable, **one asterisk**: less suitable, **no asterisk**: unsuitable). It is up to the compendium user to decide on the appropriate level for their specific situation.

❸ Management Level

The management level describes where the main responsibility for operation and maintenance (O & M) for a specific technology lies:

- **Household:** all O & M related tasks can be managed by the individual household
- **Shared:** group of users places a person or a committee in charge of O & M on behalf of all users
- **Public:** government, institutional or privately-run facilities where all O & M is assumed by the entity operating the facility

An indication regarding the appropriateness of each management level is given using asterisks (**two asterisks**: well-handled at that level, **one asterisk**: less suitable, **no asterisk**: unsuitable).

❹ Objectives/Key Features

This section gives a concise indication of the main features and functions of the specific technologies. It also provides general guidance for the immediate evaluation and classification of technologies and their suitability for an envisioned application or context.

❺ Local Availability of Technology and Components

This section indicates to what extent the technology and its components/materials are likely to be accessed locally and whether they need to be brought in from outside. Asterisks are used to indicate the local availability for the given technology (**three asterisks**: high availability, **two asterisks**: medium availability, and **one asterisk**: low or no availability). High local availability means that the technology or its components can be easily obtained in-country. Medium local availability means that some materials or components can be obtained easily, though some components maybe more challenging. Low local availability means that most or all technology components must be sourced from outside and are likely not to be available in-country.

❻ Technical Complexity

This section provides an overview of the technical complexity of each technology, meaning the level of technical expertise needed to implement, operate and maintain the given technology. This can help planning in cases where skills and capacities are limited or temporarily unavailable. Asterisks are used to indicate the technical complexity for the given technology (**three asterisks**: high complexity, **two asterisks**: medium complexity, and **one asterisk**: low complexity). Low technical complexity means that only minimal technical skills and simple tools are required to implement, operate and maintain or repair a technology, which can be done by non-professionals and artisans. Medium technical complexity means that certain skills and tools are required for either implementation, O & M or repair. Here, skilled artisans or engineers are required for the design and O & M. High technical complexity means that an experienced expert, such as a trained engineer, is required to implement, operate and maintain the technology in a sustainable manner. The categorisation is based on a comparative approach between the different technologies and is not to be considered in absolute terms.

❼ Maturity Level

This section gives an overview of the maturity level of each technology, indicating whether or not the technology has been proven and tested in different response phases and if the technology has been established for a sufficient time for the required experience in set up, use and O & M to exist. Asterisks are used to indicate the maturity level for the given technology (**three asterisks**: high maturity, **two asterisks**: medium maturity, and **one asterisk**: low maturity).

❽ Design Considerations

In this section, general and key design considerations are described, including general size and space requirements. This section does not describe the detailed design parameters for complete construction of a technology, but instead provides an idea of the features to consider as well as the main potential pitfalls to be aware of when designing the technology. This section helps the compendium user understand the technical design and complexity of a given technology.

❾ Materials

This section lists the different materials and equipment required for the construction, operation and maintenance of a given technology. It indicates whether materials are likely to be locally available or producible (e.g. wood and bricks) or whether materials will need to be imported or require special manufacturing, which will considerably delay implementation during an emergency. The materials section also indicates whether a technology can be prefabricated as a unit to speed up implementation.

❿ Applicability

Applicability describes the contexts in which a technology is most appropriate. This section indicates the applicability of a technology in terms of type of setting, distinguishing between rural or urban and short-term or long-term settlements. It describes the response phases in which a technology can be implemented and the potential for replicability, scalability and speed of implementation. Other physical considerations of applicability are listed here, including required soil conditions, necessary water availability and groundwater table considerations (including aquifer types and properties). This section also provides information on the robustness (ability to withstand future disasters) of the technology and its susceptibility to climate change as well as the potential for the rehabilitation and/or expansion of already existing facilities.

⓫ Operation and Maintenance (O & M)

Every technology requires O & M, more so if it is used over a prolonged period of time. Therefore, the O & M implications of each technology must be considered during initial planning, especially because many technologies fail due to the lack of appropriate O & M. In this section, the main operation tasks that need to be considered and the maintenance that is required to guarantee long-term operation are listed. This section differentiates between different O & M skills and provides an indication of the frequency of O & M tasks and the time required to operate and maintain a technology. A list of potential misuses and pitfalls to be aware of is also provided.

⓬ Health and Safety

Most water supply technologies have health and safety implications. The health implications or risks described in this section should be considered during planning to reduce health risks in the local community and among personnel and staff. This section also describes overall risk management procedures, which could exclude a technology from potential use if safety cannot be guaranteed. Where relevant, the personal protective equipment needed to guarantee personal safety is listed. This section also provides information on the potential of a technology to reduce the pathogen load in the water (log removal values).

⓭ Costs

Each technology has costs associated with the construction, O & M and management, including resulting cost implications for other technologies along the water supply chain. Because costs are geographically dependent and cannot be described in absolute numbers, this section presents the main cost elements associated with a technology and a price range where possible, allowing for an initial approximation. While money is often available at the start of an emergency for capital expenditures (CAPEX), this availability usually decreases radically over time. Therefore, the selection of technologies needs to consider how to achieve the lowest possible operational expenditures (OPEX) for long-term solutions (>6 months) and/or establish services that will continue after the acute response phase, such as through the introduction of cost-recovery measures or strengthening of local management capacity.

⓮ Social and Environmental Considerations

Social considerations are important when deciding on specific water supply technologies, especially at the user level. There are potential cultural taboos, user preferences and habits as well as local capacities that may be challenging, impossible or inappropriate to change. A water supply technology (as well as the water it provides) needs to be accepted/acceptable by the users as well as the personnel operating and maintaining it. Environmental considerations include the impact of the proposed technology choice on the local environment, the broader carbon footprint and its potential to exacerbate or mitigate the impact of climate change.

⓯ Strengths and Weaknesses

This section concisely summarises main strengths and weaknesses and thereby supports the decision-making process. The weaknesses of a technology might indicate that an existing exclusion criterion renders a technology unsuitable for a specific context. Both strengths and weaknesses can effectively inform decisions of users and all involved in the planning and implementation of the water supply system.

⓰ References and Further Readings

This section refers users to specific pages of a detailed bibliography included in the annex to the publication. The bibliography is a compilation of the most relevant water supply publications sorted by chapter along with a short description for each listed publication. Users can use the publication list to find additional relevant information (e.g. design guidelines, research papers, case studies) on specific technologies.

Technology Overviews

General Technology Overview

This overview **(page 24)** provides a summary of all water supply technologies covered in this compendium. The technologies are disaggregated according to their assigned functional group. In addition, this overview page summarises all cross-cutting issues that are included in the second part of the publication.

Water Supply Technologies in Different Response Phases

This overview **(page 25)** indicates which technologies are suitable for the acute response phase (first days and weeks) and which technologies are more suited for long-term stabilisation and recovery interventions. There may be additional technologies applicable in acute scenarios depending on already existing infrastructures that can be quickly rehabilitated.

PART 1:
Technology Overview

General Technology Overview (including Cross-Cutting Issues)

Source

Water Source

- S.1 Rainwater
- S.2 Rivers and Streams
- S.3 Ponds, Lakes and Reservoirs
- S.4 Brackish Water, Seawater
- S.5 Groundwater
- S.6 Spring Water

Energy Source

- S.7 Gravity
- S.8 Human-Powered Energy System
- S.9 Wind-Powered Energy System
- S.10 Solar-Powered Energy System
- S.11 Electric-Powered Energy System
- S.12 Diesel- and Gasoline-Powered Energy System

Intake

- I.1 Rainwater Harvesting: Raised Surface Collection
- I.2 Rainwater Harvesting: Ground Surface Collection
- I.3 River and Lake Water Intake
- I.4 Protected Spring Intake
- I.5 Groundwater Dam
- I.6 Riverbank Filtration
- I.7 Protected Dug Well
- I.8 Protected Borehole
- I.9 Seawater Intake

Abstraction

- A.1 Hydraulic Ram (Impulse) Pump
- A.2 Piston-Plunger Suction Pump
- A.3 Direct Action Pump
- A.4 Deep Well Piston Pump
- A.5 Deep Well Progressive Cavity Pump
- A.6 Diaphragm Pump
- A.7 Rope Pump
- A.8 Radial Flow Pump
- A.9 Axial Flow Pump
- A.10 Pumping Station

Treatment

Pre-Treatment

- T.1 Roughing Filtration
- T.2 Rapid Sand Filtration
- T.3 Microfiltration (MF)
- T.4 (Assisted) Sedimentation
- T.5 Assisted Sedimentation with Filtration

Treatment (Microbiological Contaminants)

- T.6 Chlorination
- T.7 Onsite Electro-Chlorination
- T.8 Ultraviolet (UV) Light
- T.9 Slow Sand Filtration
- T.10 Ultrafiltration (UF)

Treatment (Chemical Contaminants)

- T.11 Fluoride Removal Technologies
- T.12 Arsenic Removal Technologies
- T.13 Granular Activated Carbon (GAC)
- T.14 Ozonation
- T.15 Nanofiltration (NF) / Reverse Osmosis (RO)

Distribution/Transport

- D.1 Household Water Container
- D.2 Water Vendor Cart
- D.3 Water Trucking
- D.4 Water Kiosk
- D.5 Water Storage Tank (Transportable)
- D.6 Water Storage Tank (Long-Term Locally Built)
- D.7 Community Distribution System
- D.8 Large-Scale Distribution System

HWTS

- H.1 Safe Water Storage
- H.2 Handwashing Facility

Household Water Treatment

- H.3 Ceramic Filtration
- H.4 Membrane Filtration
- H.5 Biosand Filtration
- H.6 Point-of-Use Chlorination
- H.7 Point-of-Supply Chlorination
- H.8 Coagulation, Sedimentation and Chlorination
- H.9 Boiling
- H.10 Pasteurisation
- H.11 Ultraviolet (UV) Lamp
- H.12 Solar Disinfection (SODIS)
- H.13 Fluoride Removal Filter
- H.14 Arsenic Removal Filter

Cross-Cutting Issues

Initial Situation

- X.1 Assessment
- X.2 Area- and Situation-Specific Conditions
- X.3 Institutional/Regulatory Environment and Coordination
- X.4 Community Engagement and Accountability

Monitoring and Quality Control

- X.5 Monitoring
- X.6 Groundwater Monitoring
- X.7 Water Quality Monitoring
- X.8 Water Safety and Risk Management
- X.9 Data Flows, Information and Communication Technology

Conceptual Aspects

- X.10 Resilience, Preparedness and Disaster Risk Reduction
- X.11 Exit Strategy and Hand-Over
- X.12 Water for Multiple Use and Water Reuse
- X.13 Urban Water Supply in Protracted Crises
- X.14 Cholera Prevention and Epidemic Management

Design and Social Considerations

- X.15 Inclusive and Equitable Design
- X.16 Hygiene Promotion and Working with Affected Communities
- X.17 Market-Based Programming

Water Supply Technologies in Different Response Phases

Suitable already in acute response phase (and potentially other response phases)

Source

Water Source
- S.1 Rainwater
- S.2 Rivers and Streams
- S.3 Ponds, Lakes and Reservoirs
- S.4 Brackish Water, Seawater
- S.5 Groundwater
- S.6 Spring Water

Energy Source
- S.7 Gravity
- S.8 Human-Powered Energy System
- S.10 Solar-Powered Energy System
- S.11 Electric-Powered Energy System
- S.12 Diesel- and Gasoline-Powered Energy System

Intake
- I.1 Rainwater Harvesting: Raised Surface Collection
- I.2 Rainwater Harvesting: Ground Surface Collection
- I.3 River and Lake Water Intake
- I.4 Protected Spring Intake
- I.6 Riverbank Filtration
- I.7 Protected Dug Well
- I.8 Protected Borehole

Abstraction
- A.1 Hydraulic Ram (Impulse) Pump
- A.5 Deep Well Progressive Cavity Pump
- A.8 Radial Flow Pump
- A.10 Pumping Station

Treatment

Pre-Treatment
- T.1 Roughing Filtration
- T.2 Rapid Sand Filtration
- T.3 Microfiltration (MF)
- T.4 (Assisted) Sedimentation
- T.5 Assisted Sedimentation with Filtration

Treatment (Microbiological Contaminants)
- T.6 Chlorination
- T.7 Onsite Electro-Chlorination
- T.8 Ultraviolet (UV) Light
- T.10 Ultrafiltration (UF)

Treatment (Chemical Contaminants)
- T.13 Granular Activated Carbon (GAC)
- T.15 Nanofiltration (NF) / Reverse Osmosis (RO)

Distribution/Transport
- D.1 Household Water Container
- D.2 Water Vendor Cart
- D.3 Water Trucking
- D.4 Water Kiosk
- D.5 Water Storage Tank (Transportable)
- D.6 Water Storage Tank (Long-Term Locally Built)
- D.7 Community Distribution System

HWTS
- H.1 Safe Water Storage
- H.2 Handwashing Facility

Household Water Treatment
- H.3 Ceramic Filtration
- H.4 Membrane Filtration
- H.6 Point-of-Use Chlorination
- H.7 Point-of-Supply Chlorination
- H.8 Coagulation, Sedimentation and Chlorination
- H.9 Boiling
- H.12 Solar Disinfection (SODIS)

Suitable in stabilisation and recovery phase

Source

Energy Source
- S.9 Wind-Powered Energy System

Intake
- I.5 Groundwater Dam
- I.9 Seawater Intake

Abstraction
- A.2 Piston-Plunger Suction Pump
- A.3 Direct Action Pump
- A.4 Deep Well Piston Pump
- A.6 Diaphragm Pump
- A.7 Rope Pump
- A.9 Axial Flow Pump

Treatment

Treatment (Microbiological Contaminants)
- T.9 Slow Sand Filtration

Treatment (Chemical Contaminants)
- T.11 Fluoride Removal Technologies
- T.12 Arsenic Removal Technologies
- T.14 Ozonation

Distribution/Transport
- D.8 Large-Scale Distribution System

HWTS
- H.5 Biosand Filtration
- H.10 Pasteurisation
- H.11 Ultraviolet (UV) Lamp
- H.13 Fluoride Removal Filter
- H.14 Arsenic Removal Filter

Depending on context technologies may also be applicable in other response phases

Water Sources

To establish a water supply system, a resource (or resources) providing sufficient water to meet the needs of the target population must be available. Water supply systems draw on Groundwater (S.5) resources, Surface Water (S.2, S.3, S.4) resources, or both (S.6). If there is adequate rainfall, Rainwater (S.1) can also be considered as a complementary water resource. The subsequent required water treatment and water supply system design is determined by the quantity and quality of the source water. Depending on its origin, water resources can contain dissolved or particulate matter and gases stemming from interactions with the atmosphere, minerals in rocks, natural organic matter and macro- and microorganisms. Human activities further impact the quality of water resources.

A rule of thumb for selecting a water source from a water quality perspective is that where there is a choice, groundwater or uncontaminated rainwater are preferred over surface water, as less treatment is generally needed; however, there may be context-specific issues, such as groundwater that is saline or contains dissolved salts of arsenic, fluoride or high levels of nitrate from agriculture. Additionally, in the acute phase of an emergency, it is better to provide a large amount of lower-quality water than a small amount of high-quality water.

S.1 Rainwater
S.2 Rivers and Streams
S.3 Ponds, Lakes and Reservoirs
S.4 Brackish Water, Seawater
S.5 Groundwater
S.6 Spring Water

When selecting a water source, an initial assessment of the available sources and their exploitability should be conducted that considers the following factors:

- Quality of the water at source and possible variations due to local activities and geology
- Quantity and variable availability of water throughout the year (wet season, dry season), as well as future availability for use beyond the initial emergency (predicted demand versus forecasted availability, accounting for climate change)
- Accessibility and proximity to the users
- Time required to tap the source for exploitation
- Availability of skills and technology for abstraction, ongoing treatment and maintenance
- Financial resources for capital investment and recurring costs (possibly distributed across different groups)
- Energy required for pumping (including gravity and available, reliable energy sources **(see S.7–S.12)**
- National and local applicable laws and regulations
- Management and legal constraints (such as land ownership)
- Safety and security
- Social acceptability
- Environmental and social impacts of development

S

Source

Rainwater

Rain is liquid water in the form of droplets that have condensed from atmospheric water vapour and then fall to earth under gravity. It is one kind of 'precipitation', which also includes other forms of condensed atmospheric water (e.g. snow, sleet, hail and drizzle).

Rainwater is collected as runoff from larger surfaces. Any impermeable surface can be used for collection as long as it is sloped (e.g. from roofs, courtyards, hill slopes, roads or temporary surfaces created using cloth or plastic sheets), and the collected Rainwater can be stored using a variety of methods (e.g. ponds, Rainwater catchment dams, or water storage tanks). Rainwater is most often used as a complementary source to existing water resources when they become scarce, are polluted or, in emergency cases, are destroyed. If the runoff area is well maintained, Rainwater can provide very high-quality drinking water requiring minimal treatment. In an emergency, it will mostly be used to supplement drinking water, but if there is enough, it may also be used for gardening, irrigation or to water animals. Sometimes it may be the only source of drinking water when alternative sources are not (yet) available or accessible or have considerable quality issues.

Applicability: Rainwater can be used in all response phases to supplement existing water resources, particularly if they have become scarce (e.g. when supply systems fail) or are of low quality (e.g. if they are contaminated or saline). Rainwater is often a first-phase solution to water supply whilst water supply systems from other sources are being established, especially in rural areas where the collection is often small in scale for individual households or small community groups. Larger scale ground-based Rainwater collection systems are generally more suited to later phases of an emergency and to areas with lower annual rainfall (e.g. water-stressed arid and semi-arid areas), where intense rainfall events produce large volumes of runoff. The major advantage of Rainwater collection systems is that they are relatively quick, simple and inexpensive to install using local materials and skills.

For Rainwater collection to be viable, annual rainfall should be at least 300 mm, although in extremely arid conditions it may be considered as a measure of last resort if the rainy season is approaching. Where annual rainfall surpasses 1000 mm, other water sources are generally readily available, and Rainwater catchment systems may not be the most economical. It should be noted that rainfall patterns vary throughout the year and must be carefully analysed before designing and implementing Rainwater Harvesting **(I.1, I.2)** systems.

Operation and Maintenance: Depending on the area from which the rain is harvested and the volume of water collected, a Rainwater harvesting system can be built, operated and maintained by communities or individual households (external expertise may be required to set up the system). Community approaches require a high level of organisation to limit water usage to match availability and prevent waste, ensuring that the water supply lasts for the appropriate amount of time. Regular maintenance is essential, and the system should be regularly inspected, cleaned and repaired when needed with responsibilities clearly assigned. The Rainwater collection areas should be kept clean. If ground-based, they should at least be fenced off to prevent damage or contamination by animals or people. Properly collected and stored rainwater can be of very high quality and require minimal treatment. The amount of treatment required will depend on the collection method and level of pollution.

Health and Safety: Rainwater is usually of high quality, but may become contaminated during harvesting and storage. Air pollution in urban areas may reduce the water quality to such an extent that rainwater collection might not be recommended. The state of the catchment surface also can have an impact on water quality. For example, unprotected ground catchments can be contaminated by animal droppings or other surface pollutants. Roof catchments can be contaminated by bird droppings, leaves and dust. Certain roofing materials (e.g. paint coatings, metals) can introduce chemical contamination (e.g. heavy metals), and the subsequent danger these pose will depend on the toxicity of the material, the health of the users and the time over which Rainwater will be used for drinking.

Once in storage, water can become polluted through poor collection and storage designs, such as through exposure to light leading to algal growth and the ensuing risk of toxin formation as well as taste and odour problems. Additionally, storage tanks accessible to mosquitoes may turn into a breeding ground. This can be avoided with a well-constructed system that is maintained regularly, i.e. protected openings with lids or screened inflow and overflow pipes.

Social and Environmental Considerations: Rainwater collection is well accepted in most cultures, though its lack of minerals such as calcium and magnesium means it lacks taste, which may hamper its acceptance as drinking water. Taste and odour issues may also develop during storage or from small dead animals, sediments or algal growth in the storage tank, which may also affect its acceptance as drinking water. The use of Rainwater is a key aspect of climate change adaptation techniques and drought-mitigation activities, such as through increased water storage or control of groundwater table levels using managed aquifer recharge methods.

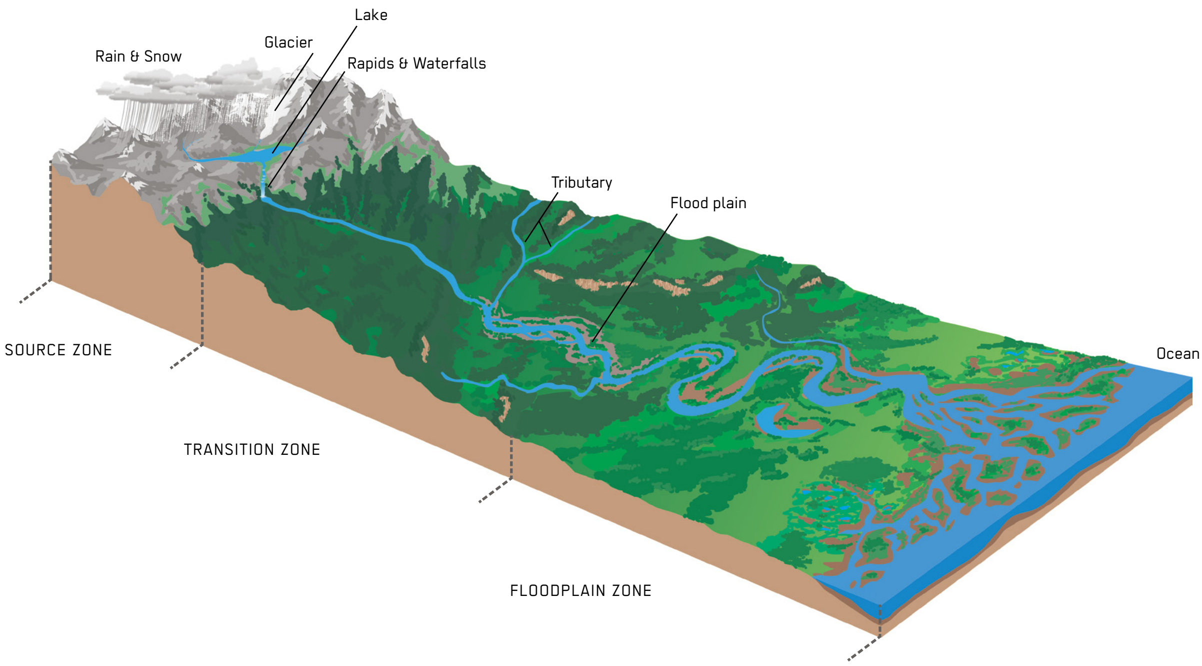
Strengths and Weaknesses:

- (+) Generally high quality when properly collected, stored and supplied
- (+) Rapidly deployed
- (+) Requires no electrical energy
- (+) Easily available, accessible and applicable in almost any climate

- (−) Limited by quantity of rainfall, size of Rainwater capturing area and storage capacity
- (−) Requires proper management for successful community operation
- (−) Potentially contaminated by air pollution, animal or bird droppings, insects, dust, or poor maintenance
- (−) Often lacks taste, leading to difficulties in acceptance
- (−) Serves as potential breeding area for mosquitoes

→ **References and further reading material for this technology can be found on page 212**

Rivers and Streams



A River or Stream is a naturally flowing, usually fresh, watercourse that moves towards an ocean, sea, lake or another River, though a River can flow into the ground and dry out at the end of its course without reaching another body of water. Rivers generally collect water from precipitation through a catchment basin from surface runoff and other sources, such as groundwater recharge, springs and the release of water stored in natural ice and snowpacks (e.g. from glaciers). They follow drainage channels that tend to be smaller and faster nearer the source and can be seasonal depending on the climate. Rivers are useful in acute stages of an emergency where large quantities of water are needed quickly, though they can be used in any phase.

The upstream section of a River near the source tends to be narrower and shallower, with faster flowing water often carrying a gravelly bed load. Further downstream, Rivers widen and deepen and the water velocity slows down, reducing the gravelly bed load, yet at the same time organic load and anthropogenic pollution is likely to increase. Many Rivers and Streams gain water from and/or lose water to groundwater during along their course, as the surface water in the River regularly interacts with groundwater in shallow aquifers, which causes variations in the total volume of River water. The main suitability issues for Rivers and Streams used as a water supply relate to water quantity and the seasonality of flow, as well as water quality and River velocity.

To ensure the River can meet the demand without causing major environmental or social disruptions, the total quantity of water available at any given time as well as existing water demands (e.g. of downstream wetlands or settlements) must be considered. When available, existing Stream flow data may be used when estimating water volumes; otherwise, an estimation of the water flow is needed. Rivers may be seasonal, with high flows in wet seasons that dry up completely in dry seasons when the flow is confined to the underground sedimentary material. For such Rivers, it may prove more productive to directly

exploit this groundwater, which will be both a more reliable source and will provide higher-quality water due to the filtering effect of the subsurface strata **(see I.5, I.6)**.
Water quality may be an issue with River sources, which depends largely on any contaminants entering the River from the upstream catchment. This contamination may be physical, microbiological or chemical. During the wet/high-flow season, both the silt load (turbidity) and microbiological contamination will generally be higher, particularly at the start. During the dry season, the silt load will reduce, but the total dissolved solids will increase. Some form of water treatment will therefore always be needed for surface water, which may be further complicated by industrial effluent or agricultural runoff entering the River. In addition to the danger of water-borne diseases caused by consuming poorly treated water from Rivers and Streams, other diseases can be spread through these sources. In slow-moving water (below 0.3 m/s), water-based diseases such as schistosomiasis may be an issue, as can other water-related diseases such as malaria or onchocerciasis.
An extensive overview of potential chemical and microbial hazards in surface water catchments is available from the WHO. In many cases, there are steps that can be taken to improve the quality of water withdrawn from Rivers to minimise treatment requirements. These include abstracting higher-quality water from near or underneath the riverbed after it has travelled through the subsurface zone, e.g. using infiltration galleries and collector wells **(see I.6)**, jetted wells **(see I.8)** and riverbed wells **(see I.7)**, minimising turbidity by choosing a floating intake **(see I.3)** or constructing the intake upstream of any obvious contamination sources. Rivers with large variations in seasonal flow can affect intakes due to an unstable riverbed, water-level variability and the speed of water flow **(see I.3)**. Seasonal flooding occurs in many River systems when surface runoff increases following rains, though flooding can also occur because of failures in man-made infrastructures (e.g. weir, dyke or levee).

Applicability: In the acute response phase, Rivers and Streams can often provide large volumes of water quickly through extractive pumping and bulk treatment in combination with water trucking (depending on the location of the users). They can also be useful in the stabilisation and recovery phases where large volumes of water are needed. The overall amount of water available depends on the stream flow in the River, its seasonality and the needs of other downstream users. In general, surface water taken from the upper reaches of a system will be safer to extract as it will be less contaminated and its use will have less effect on others. For smaller volume requirements, groundwater may serve as a more sustainable water supply (less treatment and equipment needed). Certain types of dams/embankments in seasonal Rivers (gully plugs, leaky dams) can be used to manage aquifer recharge of local groundwater for longer-term drought-mitigation projects.

Operation and Maintenance: The tributaries and catchment of a River can be managed in the longer term with a view to slow down and infiltrate runoff to minimise the flood risk and improve groundwater recharge. Measures related to this can include contour trenches, gully plugs, check dams and leaky dams, which slow down and infiltrate runoff, as well as a variety of farming techniques used to slow down water for crops (such as bunds, pitting systems, terraces, trash lines and planting vetiver grass along contours). O & M also involves establishing and respecting the limits of what can be considered safe withdrawal from the River to protect the needs of other users and to establish and maintain protection zones around the point of extraction.

Health and Safety: Microbiological water quality can generally be assumed to be poor in open water sources, and treatment will always be required. Runoff from urban or agricultural areas can also introduce problematic chemicals (e.g. pesticides). If these contaminants pose significant problems to treatment processes or public health, alternative sources of drinking water should be considered. Surface water may also have other associated health concerns, such as vector-borne diseases and schistosomiasis. Access to reliable water quality data, especially in the initial phase of a response, is often minimal. Sanitary surveys and historical data may be available from national bodies.

Social and Environmental Considerations: Generally, Rivers and Streams can be acceptable drinking water sources following appropriate treatment. However, if water is used for a certain purpose in one location, it might affect users in another downstream location, causing conflicts or affecting the broader ecosystem. When proportionally large volumes of water are planned to be withdrawn from a River, integrated water resource management principles including consultation with key stakeholders should be applied locally.

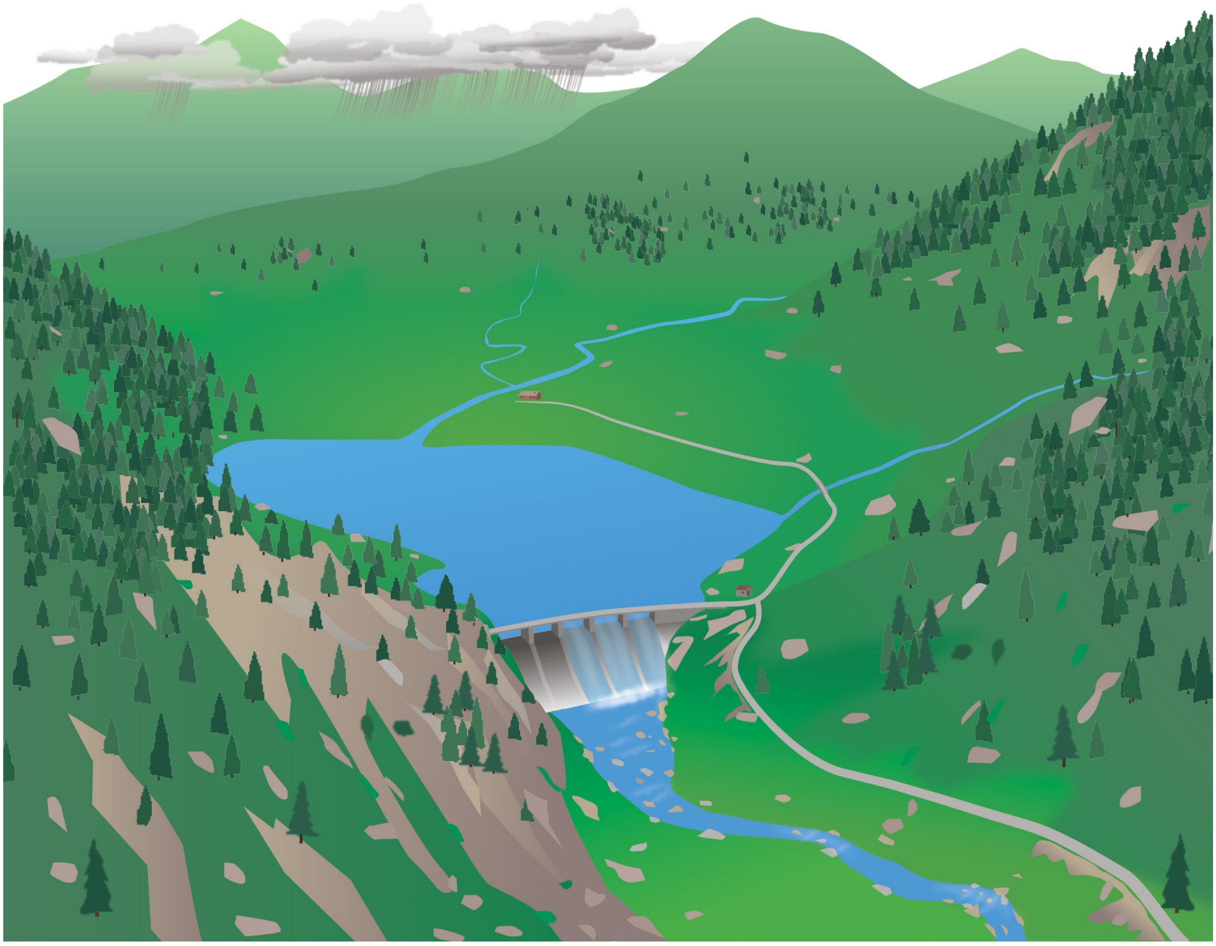
Strengths and Weaknesses:

(+) Often easily available and accessible
(+) Can facilitate recharge for local groundwater

(−) Often has low water quality, which will require treatment
(−) Can pose health risks from water-related diseases
(−) Can be seasonal and prone to flooding
(−) Structures can be damaged in unstable riverbeds

→ **References and further reading material for this technology can be found on page 212**

Ponds, Lakes and Reservoirs



A Pond or Lake is a still or slow-moving surface water body formed by surface runoff, river water collecting in a depression or groundwater collecting in an excavated area. They can thus be natural or man-made (e.g. by damming flowing water to form a Lake). Naturally occurring Lakes, Ponds or existing Reservoirs can be useful in acute stages of an emergency where large quantities of water are needed quickly, while planned new Reservoirs may be an option for long-term interventions such as drought mitigation.

Ponds or Lakes may occur naturally in places where ground or bare rock surfaces slope towards a depression that collects rainwater or when groundwater fills a depression or excavation. Reservoirs are depressions that have been enhanced in some way that prevent the water from escaping (e.g. with a retaining wall/embankment or by lining the base of the Reservoir). Naturally occurring Ponds or Lakes are usually open for general public use, whereas access to Reservoirs tends to be controlled or managed (e.g. Reservoirs for town water supplies). The quantity and quality of water that can be obtained from Ponds and Lakes are the main issues to have in mind when considering these as water sources, and in addition for reservoirs there are some important design issues to consider.

Water quantity can be an issue particularly in arid and semi-arid areas due to water losses through evaporation and seepage. Especially in places with low rainfall and long dry seasons, more water may be lost from a Lake than can be replenished, resulting in it drying up within several months. While many larger Reservoirs are not lined or covered due to their size, there are some design considerations that can reduce both evaporation and seepage. For instance, evaporation can be reduced by increasing the volume to surface area ratio via deeper Reservoirs or by planting trees around the Reservoir as a windbreak. Infiltration rates can be reduced by compacting clayey soil in situ to form a lining, or by using an artificial liner (usually expensive and prone to damage by cattle and sunlight). These measures are only suited for long-term planned interventions when a new Reservoir is to be installed. Smaller Reservoirs are more suited to being lined and covered/shaded.

Water quality is an issue with open surface-water sources, which are open to physical, microbiological or chemical contamination that must be addressed with the proper treatment. Open water can also be problematic for other diseases not directly related to drinking water (e.g. schistosomiasis or insect vector-related diseases). Water quality can be improved using simple measures to reduce treatment requirements, including structures to prevent people from entering the Pond (such as a fence) combined with alternative methods for collecting water (e.g. platforms, bank-mounted extraction devices), abstracting water through Riverbank Filtration **(I.6)** methods or through minimising turbidity by choosing a certain type of intake (e.g. floating intake, **see I.3**). Compared to Rivers and Streams **(S.2)**, though, Ponds and Lakes tend to be calmer, so sediment can settle more before abstraction or treatment.

Technical design is needed for artificial Reservoirs, and earth-filled dams over two metres high need to be specially designed. Issues to consider include the choice of dam material, design of an erosion-resistant spillway, a suitable slope angle for the dam wall, and a rock toe drain to collect seepage water. The structural failure of dams or embankments is often caused by 'piping', which is where seeping water finds a path through a dam wall or foundation and creates channels. Piping is exacerbated by poor compaction, poor choice of materials, tree roots or animal burrows. Siltation, which refers to the deposition of fine sediment in the bottom of a Lake or Reservoir, is another major problem that can be reduced by keeping a good cover of grasses in the runoff area or by using silt traps.

Applicability: In acute emergencies, Ponds and Lakes can quickly provide large volumes of water. They are generally more suited to areas with intense rainfall where there are water availability issues throughout the year. Constructing artificial Reservoirs can take some time, so they are generally not suitable as a new technology for the acute response phase, though where they already exist, they can be rehabilitated quickly for an approaching rainy season.

Operation and Maintenance: O&M-related activities to improve water quality include limiting access and restricting activities in the Pond or Lake, having separate Ponds for drinking water and other activities, having a buffer zone of vegetation between the land and Lake to reduce silt load, and reducing and monitoring industrial effluent or runoff from agricultural areas. For artificial Reservoirs, regular inspection is needed to check for erosion damage to banks/spillway and for evidence of piping through the walls. De-silting will be occasionally needed and can be done manually (e.g. cash-for-work activities that can work well in emergencies) or using oxen or large machinery.

Health and Safety: Microbiological water quality will always be poor in open water, so treatment will be needed. Where runoff from urban or agricultural areas might introduce unwanted chemicals (e.g. pesticides), alternatives for drinking water should be considered. Open water may also be prone to cyanobacterial blooms; here, reducing the nutrient load in the water will help, and Biosand Filtration **(T.9 or H.5)** is a good treatment option for removing cyanobacterial toxins. Open water can also serve as a breeding ground for other water-related diseases. For large Reservoirs with a dam, catastrophic dam failure can result in injury and death, so rigorous design is required.

Social and Environmental Considerations: Generally, Ponds and Lakes are well accepted by users as a water source, despite the poor water quality. They can support the livelihood of pastoralists that move from one grazing area to another, as these areas can all be fed by rainwater dams if well managed. However, impacts on people, aquatic organisms and the ecosystems should always be assessed during the planning phase. The construction of a dam and Reservoir within a river system can greatly impact the people living downstream of the river as well as aquatic organisms, plants and animals, and biodiversity might be irreversibly affected by their construction. Therefore, even for small dams, construction and planning requires coordination with respective authorities **(see X.3)**.

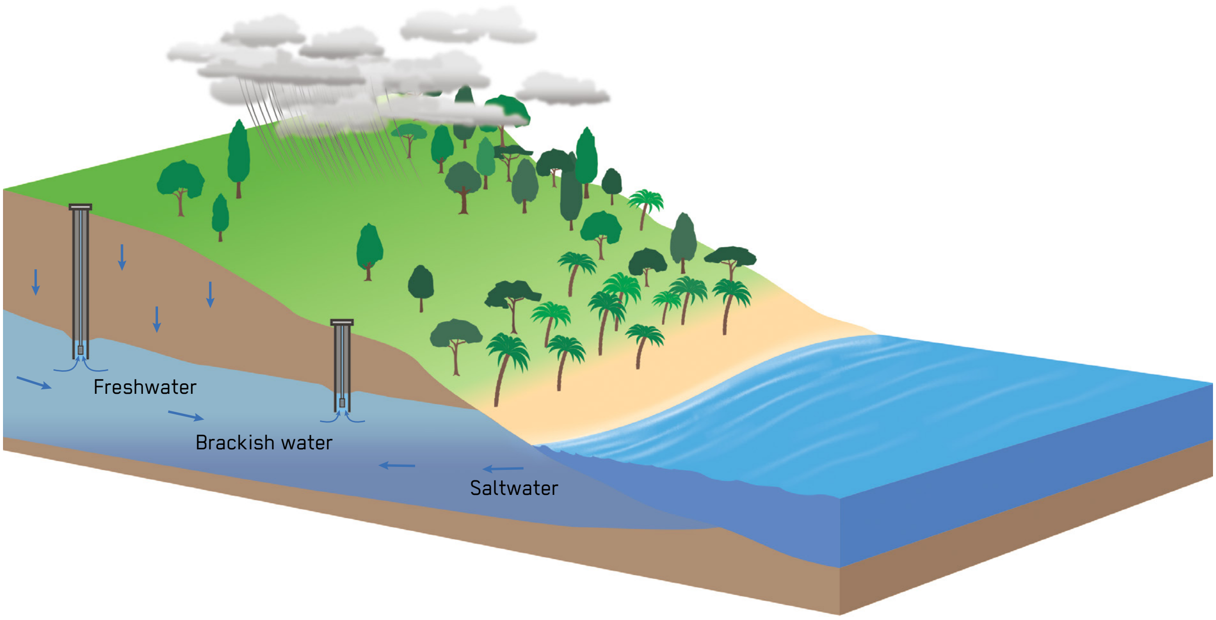
Strengths and Weaknesses:

(+) Provides large amounts of water in water-stressed areas
(+) Can facilitate recharge of local groundwater

(−) Requires treatment for low water quality
(−) Associated with health risks from water-related diseases
(−) Can dry up quickly in areas with long dry season
(−) Regular de-silting may be needed
(−) Competing uses by other communities (or sharing with wild animals or cattle)

→ **References and further reading material for this technology can be found on page 212**

Brackish Water, Seawater



Brackish Water has a higher salinity than freshwater, but it is not as saline as Seawater. It occurs naturally where Seawater (salt water) and fresh water mix, as in estuaries or in brackish fossil aquifers. In an emergency, Brackish Water might be the only available source, and it is possible that it is already in use, or in the case of Seawater, it might already be used as part of a pre-existing desalination plant.

Brackish Water can be found in surface water bodies near the sea (where Seawater mixes with fresh water found in estuaries) or inland (where a high evaporation rate concentrates minerals in the water). It can also be found in coastal aquifers (resulting from saline intrusion) or fossil groundwater (where rocks in the aquifer have a high mineral content that leaches into the water). Seawater has a total dissolved solids (TDS) content of >35,000 mg/L, while Brackish Water has TDS values between 1,000–10,000 mg/L (compared to <1,000 mg/L for fresh water).

The decision to desalinate Brackish Water depends on local acceptability levels. If it is being used and is accepted in general and poses no health risk, it can be considered an acceptable water source for an emergency. Where it is not accepted, such as when moving internally displaced people into a new area, the first option would be to look for alternative, less saline, water sources before considering treatment. Where treatment is the only option, then different desalination technologies are available (e.g. Reverse Osmosis, **T.15**) that can produce fresh water with a very low concentration of salts and other minerals from saline water. The specific water quality characteristics of the proposed water source and the volume and quality characteristics for the treated water are required for a cost-effective and reliable water production plan, as a range of conditions may cause large changes in water quality (e.g. water temperature ranges, rain seasonality months and algae bloom events). The pre-treatment processes and capacities will then be selected based on the range of source water quality.

Applicability: In coastal areas where other fresh water sources are scarce or not (readily) available, Seawater or Brackish Water may already be used. For Seawater, there would need to be a pre-existing desalination treatment plant. Brackish Water, by comparison, is sometimes used by communities that have no other alternative.

Operation and Maintenance: Fresh water is less dense than Brackish Water and floats on the surface (which is quite common close to the sea). To protect water quality in coastal aquifers, it is essential to control abstraction rates from shallow groundwater to limit saltwater intrusion into the groundwater. All other O & M requirements tend to be related to the type of desalination technology used. These tend to be complex and require high level technology, so ideally should be avoided if possible (i.e. look for alternative water sources first).

Health and Safety: Seawater and Brackish Water contain high levels of dissolved minerals. While Seawater will not be drinkable without treatment, Brackish Water may be the only water source available to some communities. While the water can have a salty taste, it may not have any negative health impacts – meaning that if the water is generally accepted, then there is no need for action. However, specific chemicals known to directly affect human health (e.g. fluoride, arsenic, nitrate), may be cause for concern. Here, alternative sources should be found, or when there is absolutely no option, the water needs to be treated.

Social and Environmental Considerations: There are communities that consume water with high levels of TDS because there are few other options available, meaning that acceptability is context specific. In contrast, desalinated water with a low TDS can taste "flat" due to the absence of minerals, which can result in low consumer acceptance. Where desalination technologies are used, the removed salts and minerals concentrated in the brine need to be disposed of carefully.

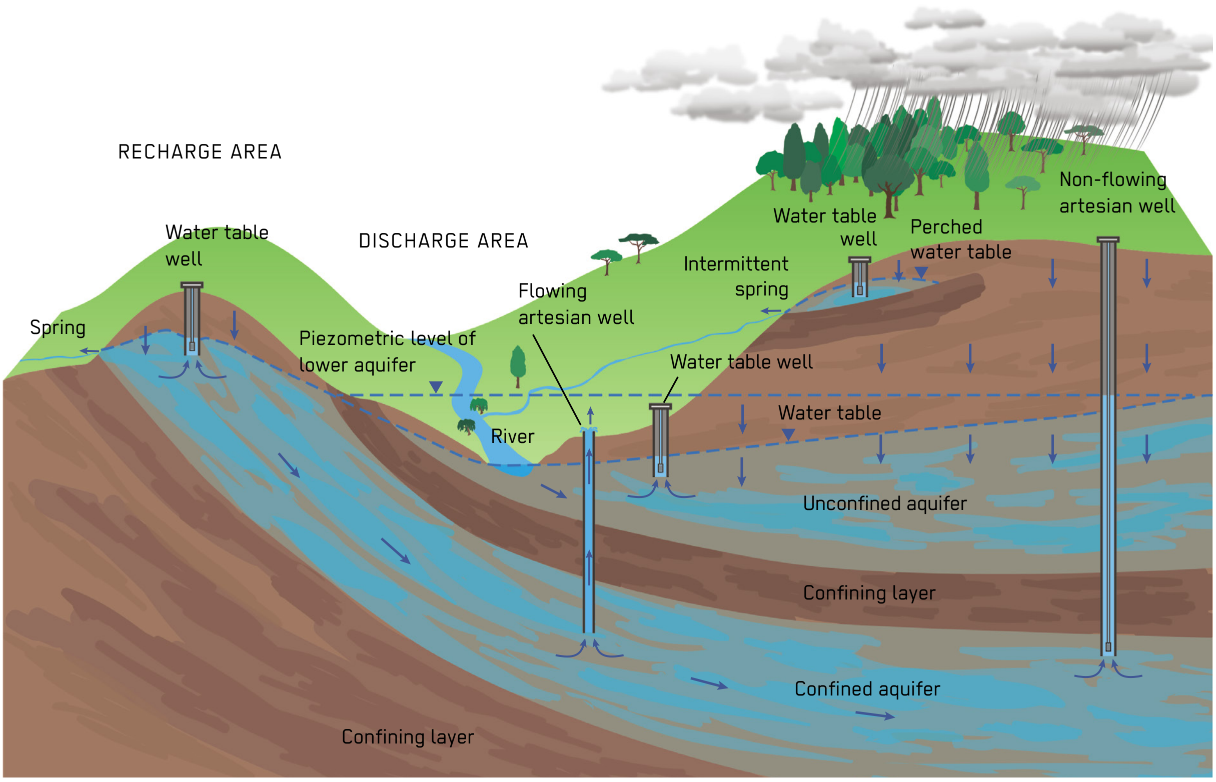
Strengths and Weaknesses:

(+) Serves as abundant water source (in the case of Seawater)
(+) Can be easy to access

(−) Has high treatment costs for freshwater production and brine management
(−) Might require re-mineralisation of produced fresh water
(−) Expensive and complex treatment might be needed if users do not like the Brackish Water and there are no alternative sources

→ **References and further reading material for this technology can be found on page 212**

Groundwater



Groundwater originates from both surface water, such as rivers or lakes, and via precipitation that infiltrates the surface. This infiltration is mostly natural, though can be enhanced through managed aquifer recharge techniques. Once in the ground, water collects in the spaces between particles and can flow slowly. This saturated area that allows water movement is called an aquifer, which can be either unconfined (open to atmospheric pressure) or confined (under greater pressure than atmospheric pressure). Groundwater is useful in all phases of an emergency.

Groundwater can flow at different speeds depending on the permeability of the aquifer, although the flow is overall much slower than surface water. The volume of Groundwater within an aquifer depends on the porosity of the rock or soil, though the presence of a lot of water does not necessarily mean it can all be abstracted (as in clay aquifers). In an unconfined aquifer, the water table is equal to the top of the saturated layer since it is open to atmospheric pressure, and the water will remain at this level when accessed by a well. In confined aquifers, which are effectively pressurised between two layers of lower permeability rock or sediment, the water is not open to atmospheric pressure and will rise up in the well to where it is equal with atmospheric pressure. This is known as the piezometric level, and can be below or above ground level. When the piezometric level is above ground level, the well will continue to flow without the need of a pump and is known as an artesian well.

Due to the protection and filtration provided by the overlying soil and rock, Groundwater is often of a much higher quality and requires less treatment than surface water. However, Groundwater quality can vary according to location, depending on the local and regional geology and the proximity of contamination sources. Groundwater quality may also deteriorate depending on how the water is withdrawn and any protection measures that are in place. Whilst nearby wells or trial borings can give an indication of Groundwater quality, the final quality of the accessed Groundwater can only be determined once drilling reaches the Groundwater at the well site.

Microbiological contamination of Groundwater is generally more of a concern in shallow aquifers near either point or diffuse pollution sources (e.g. on-site sanitation systems). Here, the risk of contamination depends largely on various factors that impact the time it takes the water to travel between the pollution source and the abstraction point, where longer times generally produce a better microbiological quality. Although 30 metres is often taken as a rule of thumb for safe lateral distance from a pollution source, it can vary considerably depending on site conditions (particularly the soil type). Outside of emergency conditions, Groundwater withdrawn using simple methods (e.g. a handpump) is often used without treatment. In emergencies, however, Groundwater is generally chlorinated as a standard practice **(T.6)**, regardless of the extraction method. This is to protect against any microbiological contamination in the aquifer itself, and from recontamination of water during transport and storage in the household **(H.1)**, which becomes increasingly important in densely populated settings (e.g. an existing handpump within a refugee camp).

Chemical contamination can occur in different regions and conditions, and the source can be natural or artificial. Groundwater will contain chemicals naturally present in the aquifer or in other contact points, such as the sea. These dissolved solids can affect taste and odour, which can result in some people seeking alternative, and possibly unsafe, sources. Natural contaminants, such as arsenic, nitrate and fluoride, as well as those from artificial sources, such as agricultural or industrial pollution or metal corrosion in acidic Groundwater, can also directly impact human health.

The quantity of Groundwater can vary significantly and depends on the actual aquifer yield and seasonal fluctuations, although this often less pronounced than for surface water. Regardless, good well design can help maximise the potential and efficiency of abstraction **(see I.8)**. In the long term, the total water abstracted from an aquifer for all the different needs it satisfies (including existing withdrawals as well as springs, rivers and wetlands) should not exceed the total water entering the aquifer. This can be calculated through a water balance estimation that considers the climate and catchment area, both of which affect the water that recharges the aquifer, as well as the total demand on the aquifer. This is of particular importance if large volumes of water are to be abstracted. Where this is not considered, over-abstraction can draw down water levels in other wells, which in turn leads to higher pumping costs and reduced yields, as well as the drying out of springs and wetlands, water quality deterioration, conflicts, and in coastal areas, the irreversible salinisation of water.

Applicability: Groundwater is a reliable water source in all phases of an emergency. In the acute response phase, deeper Groundwater is most likely going to be accessed through existing boreholes or wells that, if needed, can be quickly fitted with submersible pumps to pump large quantities of water to a tank. It is possible to construct new wells accessing Groundwater in the acute phase, but these are most likely to be jetted wells or a similar technology, which can access shallower aquifers to reach water quickly **(see I.8)**.

Operation and Maintenance: The over-abstraction of Groundwater can cause environmental damage (e.g. Groundwater 'mining', where ground subsides or the draining of wetlands). Especially for large abstraction requirements, systematic Groundwater level monitoring should be conducted, and provisions for this must be made at the time of borehole construction.

Health and Safety: Groundwater is generally of a better quality than surface water, especially in terms of the microbiological risk. Regardless, it should still be checked regularly, as variations can have health impacts..

Social and Environmental Considerations: Groundwater is generally well accepted as a water source, though this does depend on the taste, odour and physical characteristics. Even though Groundwater tends to be free from microbiological and chemical contaminants, it can still be rejected on aesthetic grounds, which can cause people to revert to unsafe water sources. It is therefore important to follow maximum guideline limits set for all water quality parameters, even if they are not a direct risk to human health.

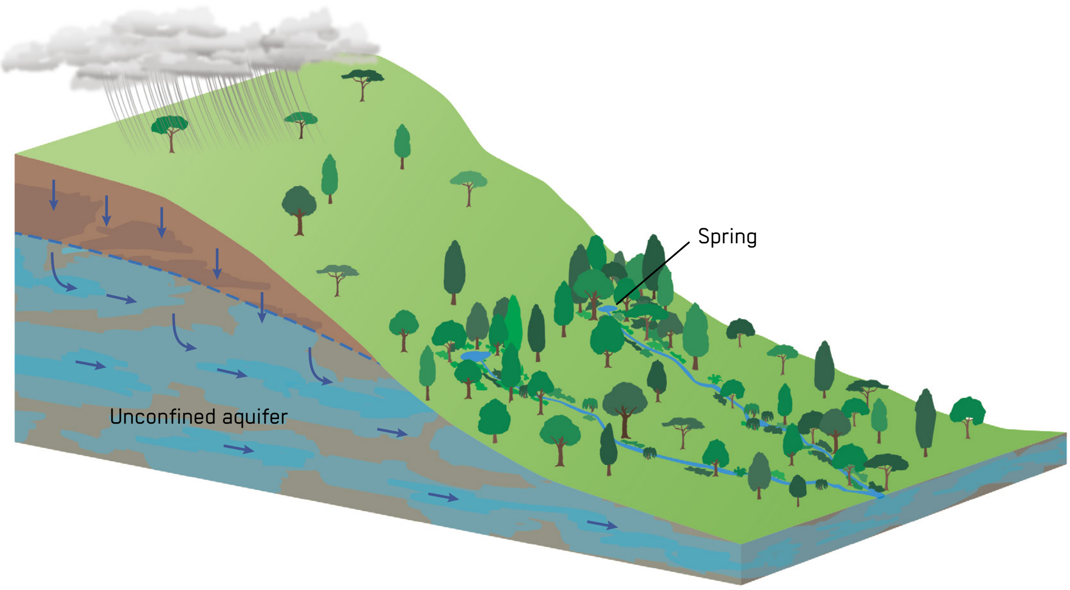
Strengths and Weaknesses:

(+) Is more likely to be free of pathogens (disease-causing organisms) compared to surface water
(+) Maintains a constant temperature
(+) Not immediately affected by drought

(−) Chemical or physical qualities (e.g. dissolved solids, odour) may be off-putting to users, causing them to resort to unsafe sources
(−) Total water available is limited by the aquifer yield, recharge capacity and borehole design
(−) Challenging to assess water quality or quantity without existing boreholes
(−) Accessing most types of Groundwater requires constructing wells and pumping systems, which requires specialist knowledge and can be expensive
(−) Over-abstraction can cause environmental problems that impact other users and potentially the water quality

→ **References and further reading material for this technology can be found on page 212**

Spring Water



A Spring is formed where groundwater exits the surface at a particular point. When the water comes from unconfined aquifers where the water surface is open to atmospheric pressure, gravity springs are formed, and when the water comes from a confined aquifer that is under pressure, artesian springs are formed. Springs are useful in all phases of an emergency.

Springs result as a coincidence of hydrogeology and topography. For gravity Springs from an unconfined aquifer, an impermeable layer restricts downward groundwater flow, which causes water to flow out where the water level intersects with the ground surface. Artesian Springs are less common and occur in confined aquifers where the water pressure causes water to flow vertically upwards through weak points in the impermeable layer. For both Spring types, flow can be an identifiable point (a Spring eye) or a more diffuse seepage area and can be seasonal or permanent.

Spring Water has two main advantages that can be exploited: the water quality is usually good and gravity flow reduces the need for pumping, which in turn reduces maintenance and other associated costs. Even though Spring Water quality is generally good, it can be contaminated from microbiological pollution in the immediate catchment (e.g. open defecation or on-site sanitation systems) or from sources in the aquifer further away from the Spring (e.g. in fissured rock or limestone, pollution can rapidly affect water quality as water can reach the Spring quickly). Chemical pollution is also possible from the use of chemicals in the catchment (e.g. fertilisers) or from the aquifer itself (e.g. fluoride or arsenic sources). Various types of Spring protection constructions are designed to reduce the risk of contamination **(see I.4)**, but this may not always be possible and disinfection might be necessary. This will most likely involve chlorination, which is often standard in emergency settings **(see T.6)**, which could be done on a communal scale (e.g. when water is distributed via a piped system) or at a household scale using household water treatment (e.g. in remote areas, see section H). As indicators of the quality of Spring Water, the water temperature can be monitored throughout the day and the turbidity can be measured after rainfall. Good quality Spring Water tends to have a constant temperature and does not change in turbidity after rainfall, while a Spring with water that has a varying temperature and turbidity indicates that the water has not spent much time in the ground.

Because the available quantity of water from a Spring can vary according to the season, Spring yields need to be determined as part of the design process, which is normally done by timing how long it takes to fill a container of known volume. The ideal time when this flow should be measured is usually several weeks to months after the rains have started as opposed to the actual end of the dry season. An acute emergency, however, might not coincide with this period, so in this case it is recommended to measure the present flow rate and also to enquire with the community about the variations in Spring flow throughout the year. Even a small yield will still flow 24 hours a day and can significantly contribute to meeting demand if there is adequate storage. Spring yield can improve slightly with Spring protection works that uncover and clear flow paths, but the flow will return to normal after the water table stabilises. The flow that is possible at a Spring will generally be fixed according to the hydrogeological conditions, though joining water collected from several Springs can be an alternative way to increase flow.

Applicability: Spring Water is suited to all phases of an emergency. Unprotected or protected Springs may already be in use as a main water source, and these structures can be quickly improved in the acute response phase. Even an unprotected Spring will still yield water that has lower turbidity, which means it is easier to treat and could be trucked elsewhere before Spring protection structures are in place. However, the construction of additional storage (if needed) and distribution pipelines (where the collection point is further away) may require some time **(see I.4)**.

Operation and Maintenance: Springs require little O&M other than monitoring water quality, which can indicate a problem within the catchment. For example, an increase in turbidity after storm events could indicate contamination from surface runoff. In this case, the protected area around the Spring should be checked. ion trenches there should be an attendant at all times.

Health and Safety: Spring Water quality is usually good, but it should be verified as there can be microbiological contamination where the catchment is polluted or where the water has spent only a short time in the ground. Access paths to Springs located near the bottom of slopes can be slippery and cause people to fall.

Social and Environmental Considerations: Springs are usually very well accepted by the population.

Strengths and Weaknesses:

(+) Usually have good water quality
(+) Easier to maintain than wells or boreholes
(+) Reduced need for pumps and associated costs

(−) Variability in water flow depending on the site and season
(−) Water quality might be affected by the aquifer type and immediate catchment area
(−) Location of the Spring may not be easily accessible
(−) Total water available is generally fixed and limited to the actual Spring yield

→ **References and further reading material for this technology can be found on page 213**

Energy Sources

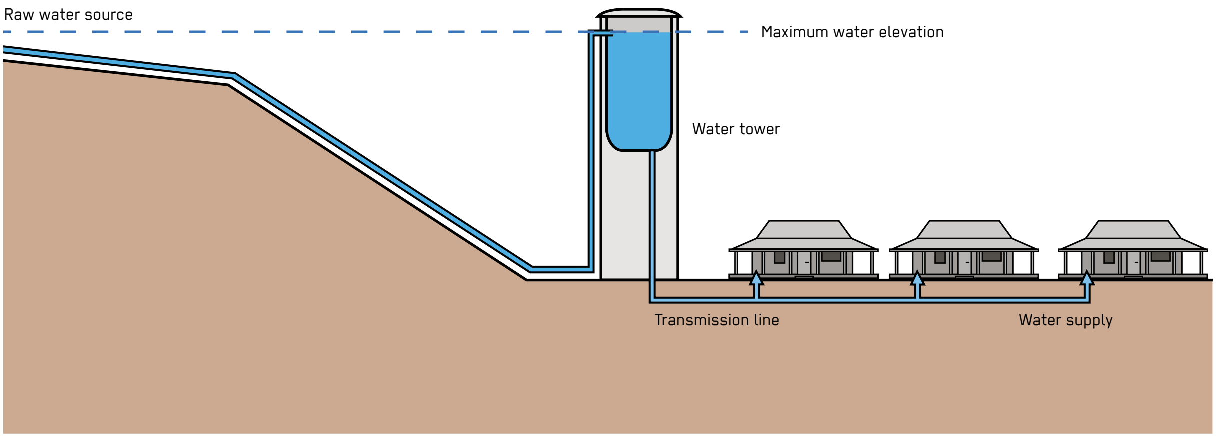
Different energy sources can be used to transfer water from a source to a distribution network, treatment works or storage facility. When the water source is elevated above the area of use, Gravity (S.7) is a cost-efficient and comparably simple transfer technology. Electricity (S.11) and Diesel (S.12) are traditional energy sources used for pumping and to abstract and convey water over long distances; here, the investment and recurrent costs as well as the reliability of an existing grid or diesel supply must be considered. Wind and Solar Energy (S.9, S.10) are becoming increasingly popular alternative energy sources that generally have higher investment costs and lower operating costs. Human Power (S.8) can be used to abstract comparably small water volumes from an easily accessible source.

The choice of energy source should be addressed in the initial assessment, using the following criteria:

- Required water source and quantity
- Geographical considerations
- Speed of implementation in an emergency
- Availability of grid power, fuel, sun and wind
- Financial resources
- Local availability of materials and devices (e.g. solar cells, generators)
- Local skills for installation and operation and maintenance

Gravity

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Abstraction and transport of water without external energy sources
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	



Gravity can be used as an energy source for transporting water by taking advantage of differences in elevation to move water (usually via pipelines). This can occur either from elevated water sources to storage tanks and treatment facilities or directly from elevated storage facilities to supply points. It can be used in many different stages in a water system and in all phases of an emergency.

Water sources from where water can be suitably transported through Gravity include springs, streams, lakes, reservoirs or simply an elevated tank. As an energy source, the major advantage of using Gravity is that it is free, so pumps are rarely needed within a Gravity-based system. Where pumps are used, the principles of water flow in pipes, which are described below, also apply to those systems (only the energy source changes).

Design Considerations: The total energy of water at any specific point in a Gravity system is the sum of its energy due to elevation, pressure and velocity. When water is not flowing (e.g. in a full tank with closed taps), the pressure head, indicating the energy per unit weight of water measured in metres, is determined by the difference in height between the tap and the surface level of water in the tank. When a tap is opened, water flows, and the pressure head at the tap reduces due to the energy lost through heat dissipation to the environment that occurs when water molecules collide with each other and the pipe wall. This reduction of pressure energy is known as 'friction loss' or 'head loss' and is a known quantity for any particular pipe that is fully filled with water and open at the other end (usually given in metres friction loss per 100 metres). Friction loss varies according to the type of pipe and its diameter. For example, rougher or smaller pipes have more turbulence, which creates more energy loss, so the pressure at the end of the pipe will be less. Also, the longer the pipe, the greater the friction loss.

With the known friction loss, the hydraulic gradient line can be calculated. Since some energy is lost when water is moving, the pressure head will be less than when the taps are closed, so this line always slopes downhill from the source. Importantly though, this line should always be above ground (ideally 10 metres or more to keep air in solution, or if not, then air release valves should be used), as going underground causes negative pressure and a siphoning effect that can bring in air or soil contamination via poor pipe joints and could block the flow. The hydraulic gradient line should also terminate above the last tap in the system so that there is an excess ('residual') pressure at the furthest point. This ensures that water will flow at a sufficient speed through the tap (which will add some energy loss that varies according to the type of tap) while accounting for any discrepancies in actual pipe runs. The usual rule of thumb is to plan for at least five metres of residual pressure above the taps in larger Gravity systems; however, in acute emergencies for short distances, less residual pressure is required (e.g. usually one metre vertical distance between bladder base and tapstands is sufficient to meet recommended Sphere flow rate indicators). It is also possible to have too much pressure at a tap. Where residual pressure would be over 56 metres, measures have to be installed in the pipeline to reduce this pressure.

Materials: Materials needed depend on the particular Gravity system, which usually require pipes, valves, tanks and taps **(see D.7 and D.8)**.

Applicability: During the acute response phase, short pipe lengths to tapstands are often used, so a detailed design is less important initially. For larger systems, a thorough topographical survey and design are essential, so they require a longer time for implementation. Here a quick topographical estimate using elevation data from GPS or satellite will not be accurate. This means that for these larger systems, they tend to be more applicable to the stabilisation and recovery phases. Gravity flow systems are particularly suitable in areas with topographical variation (e.g. hills, mountains).

Operation and Maintenance: O & M needs will vary according to the type of Gravity system, though will generally involve pipe repair and tap replacement **(see D.7 and D.8)**.

Health and Safety: Health and safety concerns will be linked to the type of Gravity system installed, and will typically involve tank construction or pipe trench work **(see D.7 and D.8)**.

Costs: Gravity is a free energy source. Depending on the size of the system, the capital costs of Gravity-fed schemes are usually higher than the costs for those that obtain water from underground sources. This is due mainly to the cost of long pipelines from the upland sources down to the villages and partly due to the cost of providing storage tanks. In contrast, running costs over time are usually low.

Social and Environmental Considerations: Gravity is well accepted as it is a free energy source, which can reduce ongoing expenses. It is environmentally favourable, since it reduces the need for pumping using energy derived from fossil fuels, which have a greater impact on a system's carbon footprint as well as overall air quality.

Strengths and Weaknesses:

(+) Have lower O & M and running costs
(+) Provides more reliable supply due to not depending on fuel supplies or pump repairs

(−) Needs a natural difference in elevation to operate, so not applicable everywhere
(−) May need alternative energy sources for support

→ **References and further reading material for this technology can be found on page 213**

Human-Powered Energy System

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household * Neighbourhood City	** Household ** Shared ** Public	Abstraction and transport of water using human power
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	

Human-Powered Energy Systems are based on the use of human force. In the acute response phase, Human Power is often limited to transporting water, while supply and treatment are managed centrally to ensure adequate water quantity of the desired quality can be delivered. Human-Powered abstraction, transport and treatment can be used in all response phases and is common during acute emergencies, especially in natural disasters where it might be the only energy source available for a period of time.

Human Power, estimated at around 70 Watts (for an adult male) over a longer duration (e.g. 8 hours), is a free power source that can reduce ongoing financial costs of a water system. Women and children are most often the ones powering these systems (e.g. for water collection and transport), and technologies should be designed with these two groups in mind. The cost of Human-Powered Energy Systems is principally measured in the time and the physical cost, particularly for women and children. For water supply, human energy is most commonly used for pumping water for drinking and irrigation purposes, as well as for transporting water and treating it at household level **(see chapter H)**.

Design Considerations: The design of any Human-Powered System is limited by the fact that it will use only human energy, and design considerations tend to focus on water abstraction technologies **(see chapter A)**. Protected Wells **(I.7)** and Protected Boreholes **(I.8)** are by definition capped with a pump, reducing the potential for contamination. Where this pump is manually operated, the design must ensure that the water can be lifted using human energy alone. The key criteria is whether it is possible to operate the pump with only one person or sometimes two (e.g. in the case of a rope pump).
There are design parameters that can facilitate Human-Powered pumping from different depths (e.g. having smaller pipe diameter, or levers for mechanical advantage) and for giving different flow rates (e.g. hand pumps versus foot pumps). Where higher volumes of water are required, foot pumps may be preferred as they are usually less tiring to use since they make use of larger body parts (legs). Suction pumps are suited to shallow groundwater up to six or seven metres in depth, and include both foot and hand-operated types **(see A.2)**. Beyond suction depth and up to a depth of around 15 metres, the water column in the pipe can be lifted directly by the user using Direct Action Pumps **(A.3)**. For depths of more than 15 and up

to 45 metres, mechanical levers must be added to make the work easier, while gearing mechanisms can enable pumping from depths greater than 45 metres and up to 90 metres **(see A.4)**. This is considered the limit for Human-Powered abstraction. Design considerations can also be applied to water transport and treatment, but here it can be that the users themselves modify the design. For example, round jerrycans are modified to be rolled along the ground, or water is transported in wheelbarrows or carts or by Water Vendors **(D.1, D.2)**.

Materials: The needed materials depend on what Human-Powered method is to be used (e.g. what type of pump or water container).

Applicability: Human Power can be appropriate for water abstraction, transport and treatment. It is often more viable at the household level and in the context of rural communities, where there is limited access to other energy sources, limited financial resources, and where water demands tend to be lower. In contrast, in acute emergencies and/or urban settings, populations are often much denser. Here, human energy is mainly used for transporting water from a source (e.g. water at tapstands), while the water supply and treatment is handled at a central location where water quantity and quality can be assured. This centralised treatment and supply is necessary because in these situations there is often a limited number of actual water points (such as wells or handpumps) that are available compared to the population density, and also the flow from Human-Powered sources is extremely limited. To avoid queues and conflict, a single handpump should serve no more than 500 people during the acute response, and given that one handpump might typically extract only 1 m^3/hour. Additionally, high density populations can pose a significant contamination risk, particularly for shallow groundwater sources. However, context is important, and there are situations where handpumps do form a part of the emergency water supply strategy in acute phases.

Operation and Maintenance: Use of human energy ultimately depends on the nutrition and health status of the population, so a lot of the inherent O & M will revolve around the health of those operating the system. In terms of Human-Powered equipment, the level of O & M will vary according to the type of system in use, which most often involves manually operated pumps. Although the energy source in this case is finance-free, over one-fifth of manually operated pumps do not remain functional over time. There is a broad range of reasons for this, including technical issues regarding the groundwater or borehole (e.g. corrosive groundwater or poor borehole design) or with the pump itself (e.g. quality of pump materials or pump age) or various other reasons (e.g. issues to do with management, monitoring, finances, corruption, access to hardware or having the skills needed for repair). This is a similar level of functionality as other types of water systems but illustrates that a free energy source does not necessarily equate with better functionality.

Health and Safety: Health and safety concerns of using Human Power as an energy source can include over-exertion (especially for women and children) due to the excessive energy needed to lift water from deeper wells, which is a greater risk in hotter and/or more humid environments. Transporting water can also be physically hazardous, especially near open water or on paths that are steep or slippery, and there may be safety risks for women if the source is remote and insecure. In these cases, it is important to consider whether all members of a society are able to use the water systems, irrespective of their power capacities **(see X.15)**. Transporting water by hand requires filling and emptying small Household Water Containers **(see D.1)**, and this process may contaminate the water.

Costs: The use of human energy can positively impact recurring financial costs. This does not mean that these systems are without recurring energy costs, as labour has an intrinsic cost to the one providing it, which also ends up providing value to both households and the wider community.

Social and Environmental Considerations: Human Power as an energy source is well understood and accepted by users. However, there is a non-financial cost to using human energy that must be accounted for, as much of the water abstraction and transport is carried out by women. While there may be social benefits to the women-only interactions at water points, this unequal gender role also leads to possible physical risks as well as economic and educational effects, where less time is spent on more productive uses (e.g. school, work). Due attention is needed to assure protection measures are in place so that women can safely use water supply facilities.

Strengths and Weaknesses:

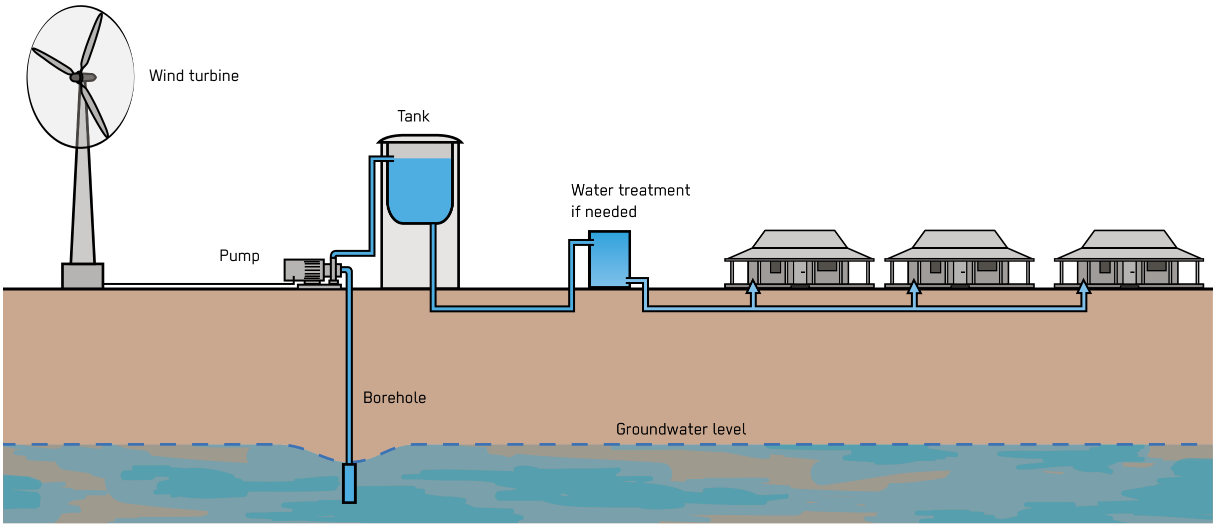
(+) Has lower recurring financial costs
(+) Tends to be used with lower-technology infrastructure, which has a lower investment cost
(+) Low carbon footprint

(−) Energy produced is limited, which in turn limits the amount of water that can be abstracted or transported
(−) Has inherent health risks, such as over-exertion, physical and protection hazards
(−) Can contribute to gender inequality

→ **References and further reading material for this technology can be found on page 213**

Wind-Powered Energy System

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood City	* Household ** Shared ** Public	Abstraction of water using wind power
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	*** High	*** High	



Wind-Powered Energy Systems use wind energy either directly (e.g. to mechanically move a pumping mechanism) or indirectly (e.g. to create electricity that can be used or stored). If it is not already present, this system is not well suited to the acute response phase, though may be a suitable option for more sustainable power in the longer term.

Wind energy can reduce the running costs of a water system. In a typical simple system, wind turns a turbine, often mounted on a tower, to lift water. This can consist of only a simple system to lift surface water short distances for irrigation, though it more commonly involves bringing groundwater to the surface via a pumping mechanism.

Design Considerations: Mechanical (direct) windpump systems work by physically connecting a bladed wind turbine directly with a mechanical pumping system (usually a positive displacement pump with pistons, **see A.2, A.4**). However, with this system, the borehole must be in an ideal location to capitalise on the wind speed and it can be difficult to match the power characteristics of the turbine with the type of pump, meaning power is not transferred efficiently at all wind speeds.

Wind-electric (indirect) pump systems that create energy to be stored are more efficient, using either direct current (DC) pumps or standard three-phase electric alternating current (AC) centrifugal pumps. AC pumps can be operated directly using power generated through a permanent magnet generator connected directly to the pump motor. Operation is possible as standard pumps can operate at variable speeds if the powering voltage and frequency also vary, which is the case here. With this system, the more efficient match in power requirements is advantageous (where the turbine and impellers in the pump have similar rates of increase in rotational speed), as is the ability to offset the pump from the turbine. However, an offset pump can suffer from voltage drops along longer lengths of electric cabling, though if the turbine receives higher wind speeds at the offset position, the extra power can compensate for cable losses for an overall favourable energy balance.

Some design considerations apply to both mechanical and electrical systems. Water is used as an energy store where more water is pumped on windier days, which can then be released into the system by gravity on days when the wind drops and pumping is less productive. For this to work, a storage tank should have the capacity to hold at least three days demand. As a standby option for low wind days, wells can also be fitted with a handpump **(see S.8)**. The maximum flow during peak wind conditions should be compatible with borehole design, where velocity across the screens should not exceed 0.03 m/s and where groundwater drawdown is still sustainable **(see I.8)**. As wind speeds increase with height above the ground surface, turbines are installed on towers. The exact height and site of the tower should ensure that the turbine is not obstructed, which means placing it so that the rotor is at least ten metres above and 100 metres from any surrounding trees and buildings. To prevent damage from over-rotation in winds over 13 m/s, turbines should be equipped with an automatic mechanism that furls the blades (turns them away from the wind) through various active or passive design measures. A manual override should also be included.
In addition to pumping water, wind energy can be used to generate electricity for other processes (e.g. certain water treatment systems) or that is fed to the grid. Energy can be stored using batteries (e.g. in hybrid systems that also use solar energy), though due to the cost, short lifespan and inherent energy losses that occur during battery storage, it is generally better to avoid batteries through a well-designed pumping system together with adequate storage.

Materials: Materials needed include the turbine, a supporting tower, pumping mechanism (which can vary), sufficient water storage to cope with wind fluctuations and, where they cannot be avoided, batteries.

Applicability: For wind to be a viable energy source, the location needs to have enough wind. A wind assessment is therefore needed, but care should be taken with interpreting local data, which can often be underestimated, particularly if meteorological stations are poorly maintained, as is often the case. Pumping type and wind conditions should be carefully matched. For mechanical pumps that are optimised for low wind speeds and that provide water on most days, the minimum average wind speed required is 2.5 m/s, while electric centrifugal pumps **(see A.8)** require an average of at least 4 m/s. Given this variability and the need for careful design, wind energy is not well suited to the acute response phase unless existing windpumps are functional. Wind energy is generally more suited to the medium- to long-term stabilisation and recovery phases.

Operation and Maintenance: Wind turbines can operate for long periods with little maintenance if the initial set-up ensures good lubrication of the gears and driving mechanisms and if the vanes and blades are protected against corrosion. Turbine blades and bearings should be checked and replaced at the latest every 10 years, which should outlast most emergencies. The pump usually requires more intensive O & M; the mechanical linkage between the turbine and pump, in particular, is responsible for around 40 % of all maintenance requirements. In addition, piston seals in the pump should be replaced every one or two years.

Health and Safety: Health and safety issues concern the safe design and construction of the tower structure. If battery systems are used, they should be in a place with restricted access to avoid electrocution risks.

Costs: On one hand, the capital costs of mechanical Wind-Powered pump systems are high, usually varying between 35,000 and 60,000 USD and up to 120,000 USD for a larger, community-level wind electric system (including storage and distribution). On the other hand, maintenance costs for mechanical wind systems are moderate (around 0.8–1.5 USD per person per year), which are comparable to other electric-powered systems. With this offset, wind electric systems can be a least-cost approach, such as where "m^4" (daily volume required in m^3 multiplied by pumping head in meters) ranges from 200–10,000, where the average annual wind speed at 10 meters is above 4 m/s, where other fuel-based pumping systems have proved problematic and where the electricity grid is more than 2 km away. Apart from financial costs, choosing a renewable source of energy has a much lower ongoing environmental cost, and like solar power, it should be a key (if not over-riding) design consideration.

Social and Environmental Considerations: Wind is a relatively untested resource, but ought to be uncontroversial – particularly as environmental awareness increases. In environmental terms, wind is a renewable energy source that reduces the need for energy derived from fossil fuels, thus reducing the system's carbon footprint and improving air quality. However, turbines may have an impact on migratory birds, depending on the size of the rotors, the height of the tower and the location of the windmill. In terms of social acceptance, turbines might be viewed as unsightly, and the noise from whirling turbines can be viewed as a nuisance for those living too close by, which however, may be less relevant in emergency settings.

Strengths and Weaknesses:

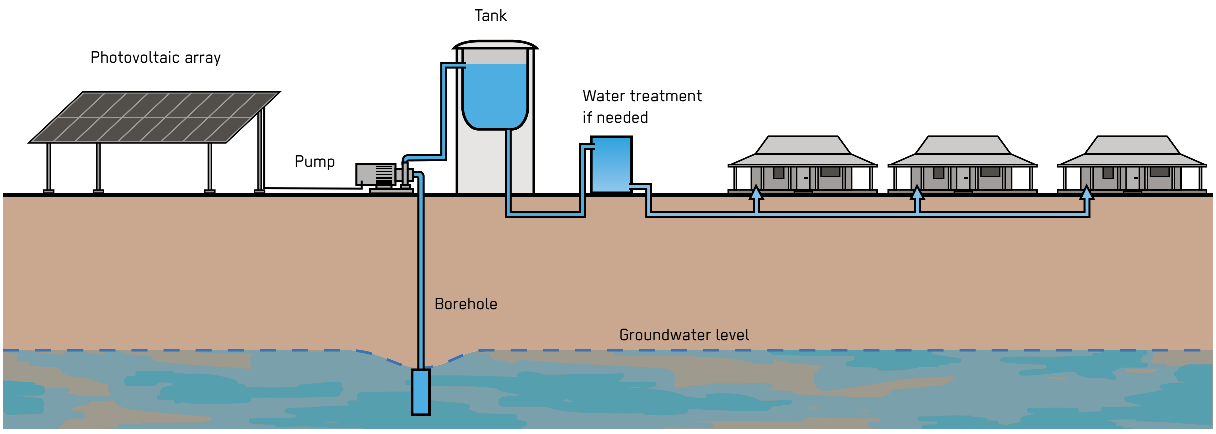
(+) Uses renewable energy, a low-carbon energy option
(+) Is relatively low maintenance

(−) Requires larger storage requirements to compensate for intermittent power supply
(−) Has relatively expensive initial hardware costs

→ **References and further reading material for this technology can be found on page 213**

Solar-Powered Energy System

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Abstraction, transport and treatment of water using solar power
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



Solar electrical energy is produced when photovoltaic (PV) cells convert solar energy to electricity, which usually then powers a submersible or surface pump to abstract raw water. Solar-Powered pumping systems (SPPS) should be combined with an elevated water storage tank (or if unavoidable, with batteries) to store energy, ensuring a continued water supply on cloudy days and at night.

PV cells are commonly made from silicon and arranged together under a protective glass plate to form a PV module. Commonly, several of these modules are arranged in a PV array, with the total number depending on the amount of water to be supplied per day, the total dynamic head of the water scheme and the available solar energy. The average amount of solar energy typically available in an area during a day is referred to as 'peak sun hours', which differs from 'hours of daylight', as solar intensity changes during the day. For example, in areas in locations with an average of eight hours of daylight, the average peak sun hours can be much lower. Identifying the yearly and seasonal average peak sun hours is important for deciding whether solar panels are a feasible energy source in an area. The fewer peak sun hours available, the higher the investment costs, as a higher number of PV modules is needed. Generally, SPPS need peak sun hours of at least 3–4 kW/m^2 to be a viable option for community water supplies.

Design Considerations: Apart from the geographical location, peak sun hours and available space on site, the other considerations for SPPS design are the same as for any of the water schemes powered by a generator or the grid (e.g. safe yield of water point, drawdown and total dynamic head). Solar panels need to be completely exposed to sunlight to produce the maximum solar electricity. The electricity generated by solar energy on cloudy days is significantly reduced (usually by between 25–40 % compared to sunny days). To maximise direct radiation, solar arrays should be securely mounted on a tilted rack, facing the equator at a tilt angle equal to the latitude of the location and in an area without trees or nearby buildings to prevent shadows on the panels. The solar panels should also be protected from strong winds, lightning storms, falling objects (e.g. tree branches) and theft.
There are numerous software packages available to aid the design of Solar Powered systems. This software computes all factors and geographical locations and proposes designs, including solar panel layout and power, cable sizes, inverter or control box models, pumps and balance of systems components. These software-based solutions also ensure that the performance and electrical characteristics of the components are matched so that the expected electrical and water outputs are ensured. The electricity generated from PV systems is in the form

of direct current (DC). For alternating current (AC) motors, inverters must be installed to change the supply from DC to AC. Standard inverters should be avoided in favour of a variable frequency drive (VFD), which will vary the required voltage and frequency (suited to smaller single-phase pumps without start capacitors or any three-phase pump).

Materials: Good quality solar panels, inverters, control boxes, water pumps, pipes and balance of systems components (cables, switches, etc.) can be found in most countries. Due to the proliferation of fake and low performance solar materials (especially solar panels), it is of upmost importance to ensure that purchased components are manufactured according to the relevant specifications and international standards to ensure long and correct functionality.

Applicability: In an emergency context, it is possible to effectively accelerate the SPPS installation process by equipping existing handpump-operated boreholes, which is feasible when the borehole yield is sufficient to serve the targeted number of beneficiaries and the technical specifications of the borehole are known. The scope for the application of SPPS during the acute response significantly improves with the use of emergency solar pumping kits that contain all necessary components. SPPS are applicable for a wide range of water needs. A single SPPS scheme can supply communities from 50 households up to entire towns or camps with over 100,000 people. Since SPPS are able to pump groundwater from 5 metres to up to 500 metres in depth ('pumping head') and with inverters made for solar pumping applications to match pumps of over 210 kW, almost any water scheme in a humanitarian context can be solarised. Water Storage Tanks **(D.5, D.6)** should be included in the water system for periods when the pump is not running (e.g. during cloudy days and night) as well as to balance daily fluctuations in demand. In SPPS design, the storage tank volume usually covers at least two days of community water supply, wherein the tank acts like a battery to deliver water via gravity when it is needed. If sufficient water storage at elevation is not available, different back-up power options exist. However, batteries reduce SPPS efficiency and increase costs as well as O & M and replacement requirements. Alternatively, a SPPS can be made hybrid by combining different energy sources (e.g. electric grid or diesel generator with solar). Piston **(A.4)**, Progressive Cavity **(A.5)**, Diaphragm **(A.6)**, and Radial Flow **(A.8)** pumps are all available as submersible Solar-Powered pumps from different manufacturers.

Operation and Maintenance: While a good quality solar panel has a warranty of 25 years and requires only simple maintenance, batteries (if used), inverters and pumps need more frequent servicing from skilled operators. The system should be occasionally inspected to check pumping rate, condition of the panels, storage tanks and pipes. Maintenance involves regularly cleaning the dirt and dust from the panels and protecting the panels from animal and human damage. A secure fence should be built around solar panels to prevent theft or vandalism. To ensure regular preventative maintenance and speedy repairs, the establishment of post-sale service agreements with knowledgeable contractors is recommended. A well designed and maintained SPPS can work for over 10 years without any major problems.

Health and Safety: Electrical shocks are possible in schemes with solar arrays of more than a few panels, so only trained technicians with adequate protective equipment should be allowed access when repairs are made. DC switches should be installed at critical points in the scheme to isolate different components and ensure electrical safety.

Costs: Capital costs of SPPS vary greatly depending on the size of the system, ranging from several thousand USD to over 100,000 USD, with the solar array typically being the most expensive component. The high potential for cost reduction compared with other pumping technologies (especially those based on diesel) is realised if the analysis is based on costs over the life cycle of the scheme rather than the capital costs of installation only. While capital costs will normally be higher than those of equivalent diesel generator schemes, studies show that SPPS offer a high potential for cost reduction over time, with the return on investment ranging generally from between 1–4 years.

Social and Environmental Considerations: SPPS are a well-accepted technology. As a renewable energy source, they reduce the need for energy derived from fossil fuels, thus reducing the system's carbon footprint and improving air quality. SPPS also have a low running cost, and the operation and use are simple and reliable.

Strengths and Weaknesses:

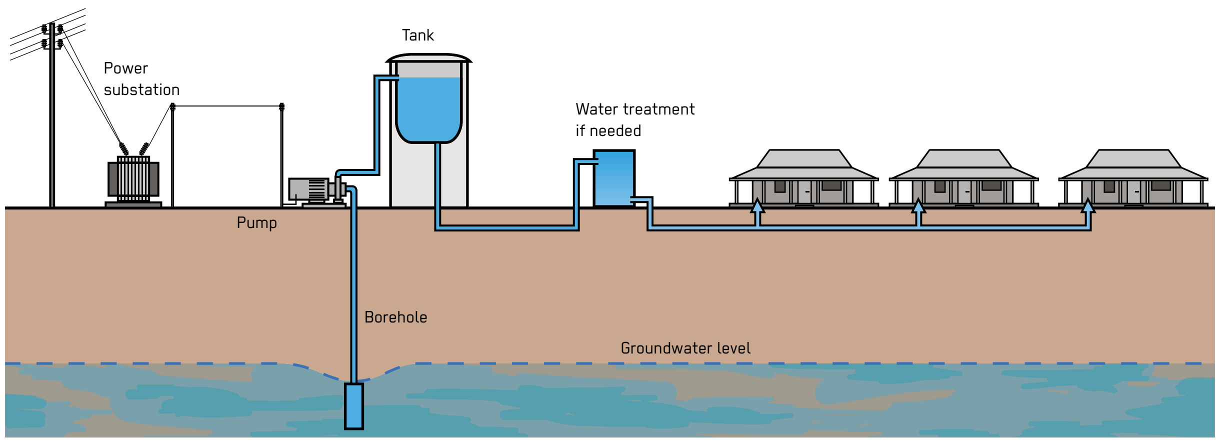
(+) Reliable, lasting and robust systems with easy O & M, and free, renewable energy source
(+) Modular system can be closely matched to required water supply
(+) No dependency on erratic or expensive fuel chain supply, and no pollution or noise produced

(−) Has high capital investment, including risk of theft of panels, which are a valuable commodity in some areas
(−) Generally requires a larger water storage capacity than for equivalent diesel systems
(−) Is dependent on solar radiation levels
(−) Spare parts and knowledgeable technicians often only available at level of the capital city

→ **References and further reading material for this technology can be found on page 213**

Electric-Powered Energy System

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	Household * Neighbourhood ** City	Household Shared ** Public	Abstraction, transport and treatment of water using grid electricity
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	



Electric-Powered Energy Systems use electricity from a grid to power water pumping, transport or treatment. It is an energy source suited for all phases of an emergency, but it may not always be available (e.g. in the acute phase after a natural disaster).

On a small local scale, electricity produced by a set of solar panels **(see S.10)** or one diesel generator **(see S.12)** can power a simple water system, such as a pump in a borehole. Electricity at a larger scale is generally centrally produced and fed into transmission lines. Whilst this electricity may still be produced by a set of diesel generators or other means (e.g. solar, wind or hydropower), the O & M is centralised, and the power is fed into a grid to be used over a wide area.

Design Considerations: For water supply, electrical energy is mostly used for pumping, though it can also be used for other processes, such as water treatment **(see chapter T)**. Key considerations for the design of Electric-Powered Energy Systems relate to whether the required supply is direct current (DC) or alternating current (AC), and for the latter whether it is single-phase or three-phase. All supply types can be used for water systems, and the choice depends on the context and power requirements. For example, DC power provides electric charge (current) in only one direction, and is the type of power produced by a solar panel to efficiently run a DC pump. However, DC supplies are limited by the distances the energy can be conveyed without prohibitive energy losses, so cable sizing is important.
With AC power, the current and voltage change direction periodically, and is the type of energy from the grid that operates the more commonly available AC pumps. This change in direction creates a wave which can have differing heights (called amplitude, a measure of how much voltage occurs at the top or bottom of each wave) and frequency (number of waves per second). In addition, the number of waves at any moment in time is termed the phase. Single phase is produced using one

live wire to create one wave (230 volts), whereas three phase is produced using three live wires to create three waves simultaneously that are offset in time (415 volts). Three-phase current is used when more power is needed, such as supplying power for transmission lines, as well as for large motors and heavy loads. AC is the mode used for transporting electricity across long distances, as at high voltages (over 110,000 volts) less energy is lost in transmission. Higher voltages mean lower currents, and lower currents generate less heat in the power line due to decreased resistance. AC is converted from these high voltages using transformers at the destination before the power is used. Energy can be stored using batteries, but it is generally better to avoid this due to the cost, short lifespan and inherent energy losses that occur during battery storage through a well-designed pumping system together with adequate storage.

Materials: The type of power supplied should be matched to the operating requirements of the equipment at a location. For example, a large pump motor with a voltage of 415 volts will require a three-phase supply.

Applicability: Grid electricity is suitable for all response phases, though may not always be available in the acute phase if power lines or power stations are affected or in areas with frequent and prolonged power cuts. For emergency response and in certain non-emergency contexts, alternative sources of power could prove a better choice.

Operation and Maintenance: Electric pumps can operate with little maintenance, but regular checks of current, voltage and frequency are needed to warn of potential problems. If readings are higher or lower than normal, appropriate steps need to be taken with the power supply or the pump. Where electricity is produced by a local generator, maintenance burden and cost will increase significantly **(see S.12)**. A voltage regulator needs to be installed to protect the system against variable voltages and blackouts, and access to alternative power sources will also be useful at the time of such blackouts.

Health and Safety: Electricity can be dangerous. Only trained personnel should work with mains supply, and all health and safety rules regarding electricity must be followed. If work is remote from a distribution board, then supply should be disconnected at the isolator, the fuses should be removed, wires should always be assumed to be live until tested, hands should be kept dry, everyone must verify that they have finished working and are aware before switching back on, cables should be properly insulated and earthed, and fuses and circuit breakers should not be overridden. If battery systems are used, access should be restricted to avoid electrocution risks.

Costs: In addition to the costs per kWh, the actual maintenance costs for grid electric systems are moderate (0.8–1.5 USD/person/year) and comparable to Wind-Powered Energy Systems **(S.9)**. However, if using Diesel **(S.12)** directly to produce power, the ongoing costs are significant. Apart from financial costs, the high environmental costs from energy produced using non-renewable sources should be considered at the design stage when choosing a power supply.

Social and Environmental Considerations: Grid electricity as an energy source is very common and is well accepted by people.

Strengths and Weaknesses:

(+) Can be produced using renewable energy, a low-carbon energy option

(+) Relatively low maintenance and therefore low overall cost to users when electricity is supplied through the grid (maintenance is done further away in centralised location)

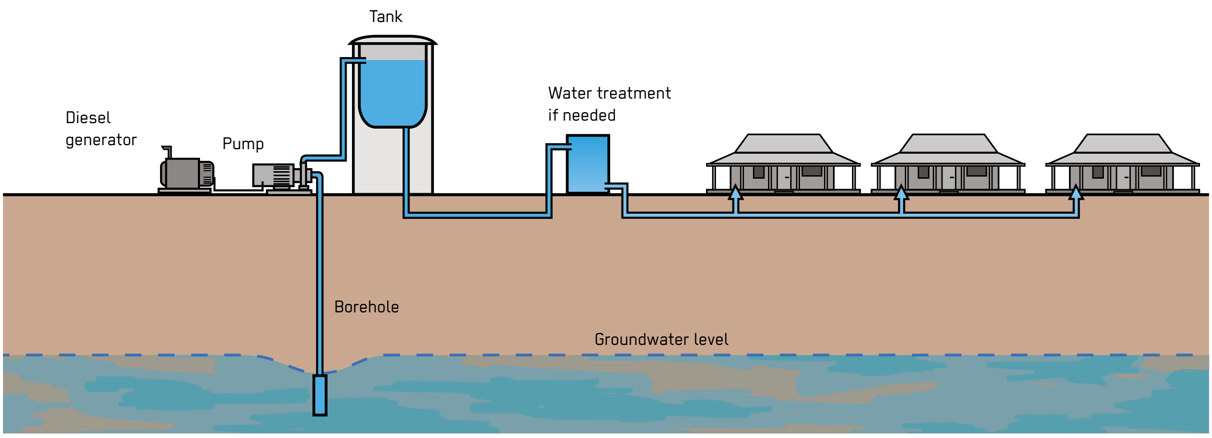
(−) May not be useful in certain contexts where power is unreliable

(−) Requires specialised technical O & M at centralised level

→ **References and further reading material for this technology can be found on page 213**

Diesel- and Gasoline-Powered Energy System

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation * Recovery	* Household ** Neighbourhood * City	* Household ** Shared ** Public	Abstraction, transport and treatment of water using energy from fossil fuels
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Diesel-Powered Energy Systems use diesel engines directly on site to generate the energy needed to power water pumping, transport or treatment. This energy source is more suited to acute emergencies when grid power might not be immediately available, but it is less suitable in the long term due to the mounting environmental and financial costs.

Diesel engines can be used to either directly drive a pump through mechanical connections (e.g. through a V-belt attached to a spindle or by turning an impeller of a suction pump) or to produce electricity to power pumps. This differs from diesel-produced electricity that is sent to the grid in that the energy production here remains local with no long-distance transmission, though this comes with higher O & M requirements.

Design Considerations: In water supply, diesel is a common energy source for both pumping and supplying energy for other treatment processes (e.g. dosing pumps). A key consideration when designing Diesel-Powered Systems is whether the required supply should be direct current (DC) or alternating current (AC). For the former, a converter will be needed, and for the latter, it should be clear whether single-phase or three-phase is needed. All of these options can be used for water systems, and the choice depends on the context and power requirements **(see S.11 for details)**.
Another important design consideration at the outset is how long the Diesel-Powered supply will be needed. On-site Diesel Power can address the more acute phases of an emergency but should be phased out for the medium- to long-term water supply where possible. A diesel generator for water pumping should be sized correctly, so that enough energy can be supplied to run the pump as well as to start it (when more power is needed). This involves understanding what total equipment will be drawing power

from the generator now and in future, and then sizing it based on the required kW. For pumps, a rule of thumb for required KVA is to multiply the kW of the motor by two. In addition, the power output from diesel engines decreases with an increase in both temperature and altitude. To account for this, 1.3 % is deducted for every 100 metres over the standard altitude (taken as 100 metres), and 2 % is deducted for every 5° C above standard temperature (taken as 25° C). Whilst a generator should be large enough to cope with the starting requirement, over-sizing should be avoided to prevent excessive fuel and oil consumption. A load should be designed to be at least 40 % of the rated generator capacity, as running continuously on a light load risks clogging the injectors over time with carbon deposits from unburnt fuel, which will require a major service to decarbonise. To increase the life of the fuel filters and to protect the fuel injectors when diesel fuel is used directly from drums, the drums should stand for twelve hours before use so that the sediment can settle and then be tilted such that the extraction pipe is away from the sediments.

Materials: In addition to the diesel generator, necessary materials will depend on what type of equipment requiring Diesel-Powered supply is to be used (e.g. pumps) and how water will be stored and distributed.

Applicability: Diesel generators are suited to acute emergencies when power is needed immediately, and grid power might be intermittent or unavailable. In the longer term, other sources of power should be used due to the cumulative environmental and financial costs of using diesel.

Operation and Maintenance: Diesel generators require significant O & M, including oil and oil filter changes every 250 hours (or half that if the air temperature is more than 35° C), an air and fuel filter change every 500 hours (or more frequently depending on local dust conditions and if the fuel is dirty), a major service every 1,000 hours, an overhaul every 10,000 hours, and replacement after 35,000 hours. Trained personnel are needed for these services, yet there is often no focus on this, especially in an emergency. Good practice is to employ one specialist to carry out this service for all generators in a location. The availability of trained personnel also means that problems can be troubleshooted as they arise. Generators can have a host of problems with either the ignition system or engine, and finding remedies based on symptoms requires experience. Otherwise, instead of analysing and then repairing a malfunction, the tendency of untrained electricians or mechanics is to do a 'fix' to get the generator working in the short term (e.g. bypassing safety controls or switches), which can then lead to accidents.

Health and Safety: Only trained personnel should be allowed to work on generators and diesel-engine-driven pumps. The area where the equipment is operating should be off limits to the general public, and there should be shields for fast-moving V-belts in engine-driven pumps. If fuel is not stored and decanted correctly, it may pose a hazard by contaminating groundwater. This can be minimised by storage on bunded concrete platforms and requires suitable drainage to collect any leaks or spills. Generators also emit significant noise and particulate pollution, which can be a health hazard to people living nearby.

Costs: Maintenance costs for diesel systems are at least 25 % higher than for solar or electric (up to 2.8 USD/person/year) due to fuel consumption and the required maintenance, and they do not make economic sense for systems running for more than a few years. For example, a solar-powered system will usually pay back the initial investment in under five years compared to a Diesel-Powered System that will continue to consume financial resources. Environmental costs in terms of carbon emissions are also high with diesel. For example, experience from a refugee camp in South Sudan showed that pumping around 1,000 m^3 per day via 10 boreholes with a 40-metre deep water table consumed over 58,000 litres of diesel per year, equivalent to driving 26 times around the world in a diesel car.

Social and Environmental Considerations: Diesel as an energy source is very common and is well accepted by people. However, if users pay for operation, then higher fuel prices might lead to a preference for renewable options, especially in the longer term. Diesel generators can also be a nuisance due to noise levels.

Strengths and Weaknesses:

- (+) Useful where electrical power is unreliable
- (+) High performance

- (−) High environmental cost
- (−) High ongoing financial cost
- (−) Significant O & M needed, requiring trained personnel
- (−) Noise and particulate pollution, plus pollution risk to soil and water

→ **References and further reading material for this technology can be found on page 214**

Water is collected from the source through an intake or withdrawal system. Each water source has its own range of suitable intake systems. Some intake systems can also act as a reservoir to store water and provide a certain level of treatment. Intakes can be classified according to the water source: rainwater intakes (I.1, I.2), surface water intakes (I.3), groundwater intakes (I.4, I.7, I.8), and those that might be possible as (or combine elements of) both surface and shallow groundwater intakes (I.5, I.6, I.9).

Properly constructed intake systems should provide both a convenient access to water sources and protection from contamination or harm to the ecosystem. The choice of the intake structure depends on:

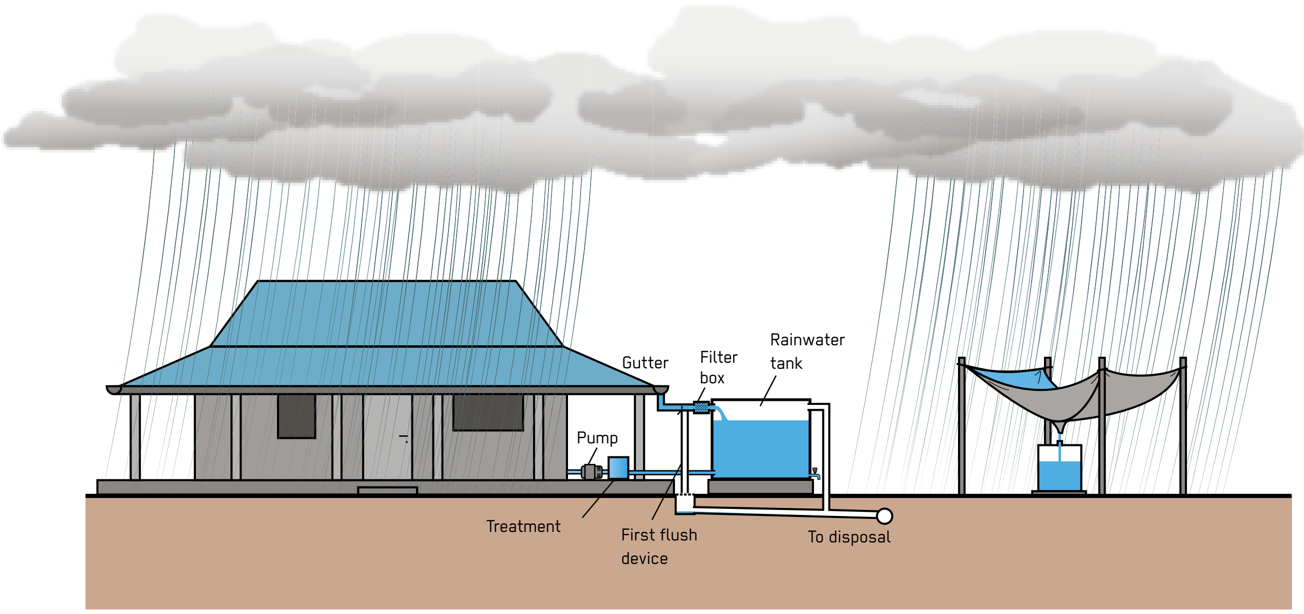
- Ease and ability to obtain acceptable water quality
- Capacity to withdraw sufficient volumes of water to satisfy current needs while accounting for seasonal variation (wet season, dry season) and to remain operational under future needs scenarios (based on predicted demands and changes in resource variability due to climate change)
- Accessibility and proximity to population
- Maintenance and ease of repair
- Speed of setup
- Local availability of skills and technology for the construction of the intake (at speed required) and for ongoing maintenance
- Financing and management of initial capital investment
- Ongoing operational financing and management
- Energy required for pumping, opportunities for using gravity and availability of reliable energy sources
- Local laws and regulations (e.g. groundwater use in an urban area)
- Management and legal constraints (such as land tenure/ownership; access rights)
- Safety and security
- Social acceptability
- Impacts of development on the environment, existing users and other stakeholders

I

Intake

Rainwater Harvesting: Raised Surface Collection

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household ** Shared ** Public	Complementary water collection at the point of use, generally good quality water
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



ROOF WATER COLLECTION SYSTEM

TARPAULIN COLLECTION SYSTEM

A Rainwater Raised Surface Collection system uses a raised surface to channel runoff water to a storage tank that is either under or above ground. It can provide convenient access to water in an emergency when alternative sources are scarce, emergency water supply systems are not yet in place, populations are scattered and/or to mitigate seasonal water shortages.

Raised surfaces are usually man-made. The most common example is a roof on a residential or communal building, though any raised surface can be used to construct simpler rainwater catchments (e.g. tarpaulin collection systems in emergencies). The key advantage of raised surfaces is that they tend to be less easily polluted than the ground surface, so the water quality is usually better. Artificial raised surfaces tend to be inorganic (such as galvanised iron roofing sheets), which prevent changes in taste and colour. Once collected, water should be stored in a covered tank.

Design Considerations: The system consists of a raised surface (e.g. roof) and a gutter to convey water to a downpipe connected to a storage tank. A first-flush device should be incorporated in the downpipe to divert the first flush of water away from the tank, preventing dust and debris from the surface from entering. The size of the gutter should correspond to the anticipated water flow (a rule of thumb is 1 cm^2 of gutter cross section for every 1 m^2 of roof area). Splashguard devices help steer any runoff into the gutter. Poorly installed or broken gutters are the main weakness in many roof rainwater collection systems, resulting in greatly reduced efficiency. For example, gutters are often poorly attached, warped or broken and are often positioned incorrectly such that rainwater overshoots the gutter. An uneven slope may also send water away from the tank to overflow elsewhere while also making puddles and stagnant pools that may lead to mosquito breeding. Underground or above-ground tanks can be used to store rainwater and should be covered to keep out insects, dirt and sunlight, the latter of which can lead to algal growth in the tanks.

The main design parameters are the rainfall quantity and pattern, the collection surface area, the runoff coefficient and the storage volume in relation to the water demand. The runoff coefficient is the ratio of the volume of rainwater that runs off the roof surface to the volume of rainwater that falls on that surface (varies between 0.5–0.9). The coefficient shows water losses (i.e. a coefficient of 0.8 means that 80 % runs off while 20 % is lost) due to splashing, evaporation, wind, overflowing gutters, and leaky collection pipes and first-flush devices. The volume of water supplied by the system can be estimated by multiplying the rainfall, roof area and runoff coefficient parameters each month. Where annual rainfall collection is greater than annual demand, there is sufficient water to meet needs, though sufficient storage will be needed to account for variations between supply and demand. This depends on how much rainfall can be collected per month (which varies) compared with the monthly drinking water demand (which is more constant and a function of the number of people and litres/month/person). By comparing monthly supply and demand over a year, a balance graph can show the storage requirements, where the maximum storage is indicated by the greatest difference between peaks or troughs in the graph. The longer the dry season, the larger the storage needed. In contrast, where annual rainfall is less than demand, the demand/expectation must be adjusted (if the existing collection area cannot be changed), or the collection area must be increased. In this scenario, community rainwater harvesting operations can be difficult to manage; in the absence of proper management, people may take more than the demand amount used in the design calculations and the tank will empty faster than intended.

Materials: These systems can be made with local materials. For the roof surface, any hard materials that do not absorb rain can be used (e.g. tiles, metal sheets, plastics). For the gutter and pipes, suitable materials include UV-resistant polyvinyl chloride (PVC), metal (e.g. aluminium), bamboo or wood. The storage reservoir can be made of different materials, such as polyethylene (PE), ferrocement, clay or concrete. During an emergency, temporary above-ground Water Storage Tanks **(D.5)** can also be made of tarpaulins with a bamboo support structure or underground with a dug hole and tarpaulin lining.

Applicability: In emergencies, rainwater collection tends to be either a short-term response to supplement existing water sources, or for scattered populations where centralised water supplies are expensive. It can also be used specifically for drinking water where other sources are low quality, such as Brackish Water **(S.4)**. Annual rainfall should be at least 300 mm. Where rainfall is over 1000 mm, there tend to be more economical medium- to long-term water source options.

Operation and Maintenance: O & M is minimal and can be carried out by the user. Water quality in roof water collection systems should be controlled by diverting first flushes and the occasional cleaning of the roof and gutters. It also includes regular inspection, tank cleaning and occasional repairs.

Health and Safety: With no screens to the tank inlet/outlet, mosquito can breed in the storage tanks. If water is used for drinking, as with many water sources, it is recommended to disinfect the water to inactivate any microorganisms.

Costs: For individual small-scale systems that can be built with local material and labour, investment costs are relatively low. For large-scale systems, capital costs can become relatively high compared with alternative water supply options, though ongoing costs tend to be lower. Quoted costs tend to be in the range of around 50–1,000 USD and often only consider the cost of the tank and pipes but not the catchment itself, which often takes advantage of the availability of an existing structure such as a rooftop. The cost per cubic metre of storage alone can range between 25–100 USD. Operational costs for inspection, cleaning, disinfection and maintenance are also low but need to be considered when calculating long-term costs.

Social and Environmental Considerations: Rainwater harvesting systems are generally well accepted in most cultures. However, if not properly planned or operated, rainwater can develop a noticeable taste and odour during storage **(see D.5, D.6)**, which may affect acceptance as drinking water source. Rainwater harvesting systems require individual household ownership and responsibility, which should be kept in mind and clearly communicated in the decision-making process. The use of rainwater is also a key aspect of climate change adaptation techniques and drought mitigation activities.

Strengths and Weaknesses:

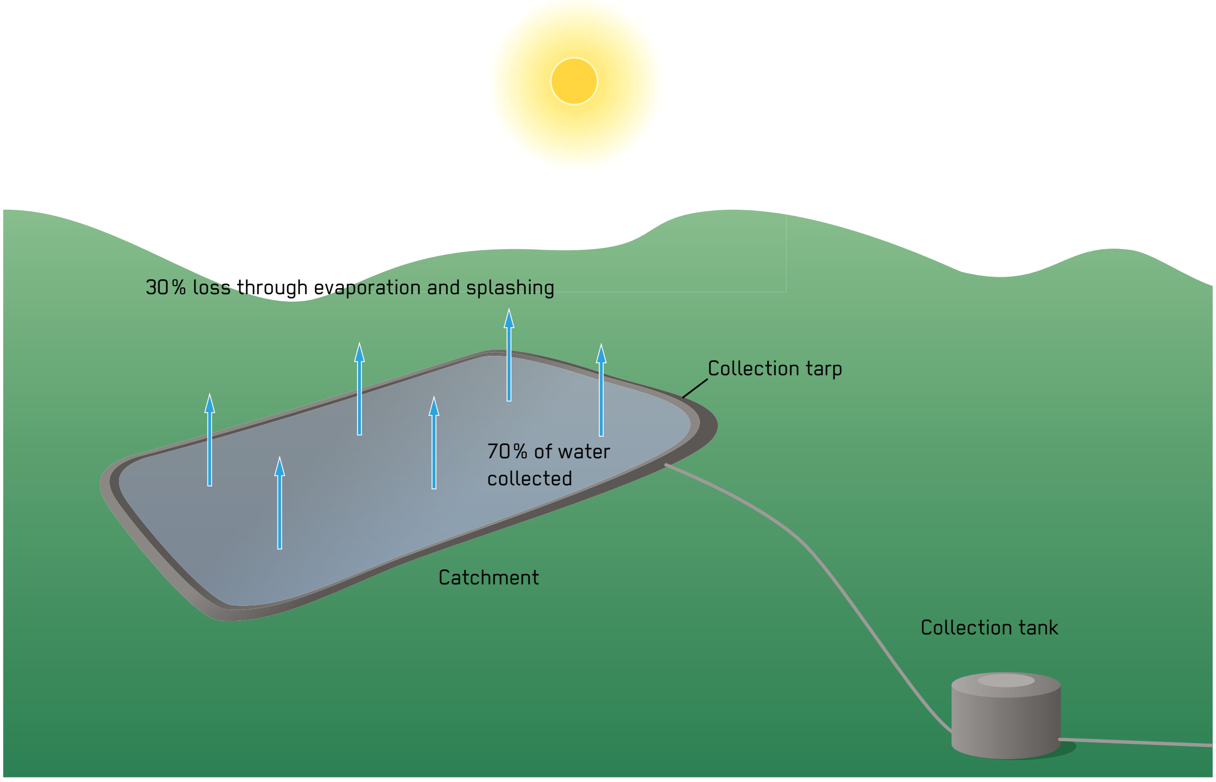
(+) Good quality water
(+) Easily available and accessible
(+) Low operating costs with long service life

(−) Supply limited by rainfall quantity, size of the rainwater capturing area and storage capacity
(−) Possibly contaminated by air pollution, animal or bird droppings, insects, dust, algae or poor O & M
(−) Storage becomes expensive where there is a long dry season
(−) Higher capital cost compared to alternative water supply options for providing water at scale

→ **References and further reading material for this technology can be found on page 214**

Rainwater Harvesting: Ground Surface Collection

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response * Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Large water volume collection, low water quality, drought mitigation
Local Availability *** High	**Technical Complexity** ** Medium	**Maturity Level** *** High	



A Rainwater Ground Surface Collection system uses the ground to channel runoff water to a storage area. Although rarely done in practice during the acute response phase, any natural or artificial ground surfaces that already exist (and certain types of rapidly installed artificial surfaces such as plastic sheeting) could be useful during the rainy season. Overall, this type of rainwater catchment tends to be more suited to long-term drought mitigation or groundwater recharge.

Ground catchments are either naturally occurring (ground or bare rock surfaces sloping towards a depression that collects rainwater) or modified/improved to minimise infiltration, increase runoff and reduce contamination. In either case, a dam wall or embankment might be added to retain water. Alternatively, the water can be channelled into storage tanks.

Design Considerations: Ground Surface Collection catchments are generally sited to minimise excavation for the drainage and water storage structures by making use of the existing topography. While some catchments will drain to an open water reservoir behind a dam **(see S.3)**, others will channel to a storage tank. In these cases, considerations include how water will reach the tank from the catchment, the tank's location in relation to the catchment and how water will be withdrawn later. Tanks can be constructed on site and are commonly subsurface **(see D.6)**, though in emergencies, they are more commonly prefabricated **(see D.5)**.
A good assessment of the ground conditions is needed, since these affect the volume of water that can be collected. In general, catchments work well in areas with intense rainfall that causes high runoff. The volume of water that can be collected depends on the runoff coefficient, which is the ratio of the volume of rainwater that runs off the ground surface to the volume of rainwater that falls on that surface. For natural, unsealed ground

surfaces, the runoff is reduced due to increased infiltration, the extent of which depends on the permeability of the ground, as well as the amount of vegetation cover which can also intercept rainfall, slow down runoff and increase evaporation. Consequently, runoff coefficients for natural surfaces tend to be much lower than for artificial surfaces (typically around 0.1 for forested sandy soil, meaning only 10 % runs off the land while 90 % is infiltrated or intercepted), though they can still vary dramatically depending on conditions (up to 0.8 for non-forested bare clay soil, or even higher for bare rock catchments). Runoff can be increased by adjusting the ground surface to reduce infiltration, for example through covering (e.g. using concrete, butyl rubber, plastic sheeting or mud/dung plaster) or compaction (e.g. puddled clay). However, these artificial catchments tend to fail over time due to poor construction techniques and lack of maintenance.
Animal and human contamination of the catchment area must be prevented to preserve or improve water quality. This can be done through fencing off the catchment, which will require maintenance over time.

Materials: Naturally occurring Ground Surface Collection catchments consist simply of the existing surface in an area (e.g. natural rock or soil). Where this surface is enhanced, commonly used materials include concrete, butyl rubber, plastic sheeting or mud/dung/clays.

Applicability: Although possibly a suitable approach for the acute response phase (where natural or artificial surfaces already exist or where certain types of rapidly installed artificial surfaces might be used), these catchments are more suited to the stabilisation/recovery phases or later, as construction can take time. They are generally suited to areas where annual rainfall is low (e.g. water-stressed arid and semi-arid areas) and where rainfall is intense and the runoff is high, making it possible to collect significant volumes of water to serve as an additional non-drinking source for part of the year (e.g. washing, bathing), leaving a limited supply of potable water for drinking and cooking during times of water stress. The speed of deployment in an acute response depends on the planned type of runoff diversion system and storage tank, and the time needed for construction.

Operation and Maintenance: Any modified/enhanced catchment surface needs regular damage inspection (checking for tears in the lining, or cracks in concrete), and any fencing needs to be maintained (which may be a challenge with communal systems). The storage tank will also need to be checked, as leaks from underground tanks can be difficult to spot.

Health and Safety: Rainwater from ground catchments is more likely to be of poorer microbiological quality than from roof catchments, so more treatment may be needed. Contamination can be minimised using fencing around the catchment as well as using an appropriate surface (e.g. concrete/rocks will be less contaminating than soil).

Costs: Capital costs for a whole system can be higher than alternative water supply options, such as Protected Dug Wells **(I.7)** or Protected Boreholes **(I.8)**, whilst running costs tend to be lower. Per area, Ground Surface Collection systems are less expensive than Raised Surface Collection **(I.1)** catchments, as they use an existing surface (so no supporting structure is needed) and because the subsurface tanks commonly used with ground catchments are generally more economical (around 1 USD per m^3). Artificial or enhanced catchments are more costly due to the work needed to modify the catchment, which depends on the type of catchment, tank size and total area. As an example, a 1,000 m^2 concrete catchment draining to a 100 m^3 subsurface tank can cost around 20 USD per m^3 of storage, which is on the low end of what a Raised Surface Collection would cost where only the tank (and not the catchment) cost is considered.

Social and Environmental Considerations: Generally, Rainwater Ground Surface Collection systems are well accepted by users, despite the poorer water quality. Preventing access and maintaining a fence around the catchment may be challenging. The use of rainwater is also a key aspect of climate change adaptation techniques and drought mitigation activities, such as through increased water storage or control of groundwater table levels using managed aquifer recharge methods.

Strengths and Weaknesses:
- (+) Collects from a larger area, which can accumulate large amounts of water in water-stressed areas
- (+) Costs less per cubic metre of water stored when compared to Raised Surface Collection **(I.1)** systems

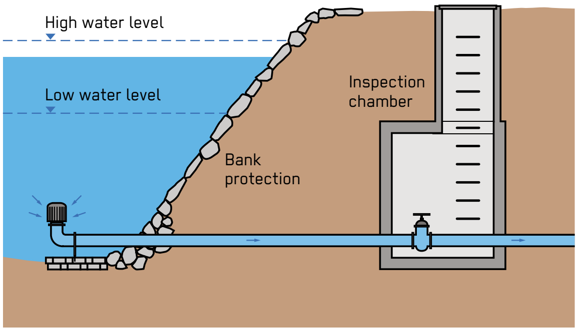
- (−) Low water quality depending on catchment surface type and access by animals/people
- (−) Higher capital cost compared with alternative water supply options
- (−) Community operation may be difficult (reduced motivation for maintenance due to being communal)

→ **References and further reading material for this technology can be found on page 214**

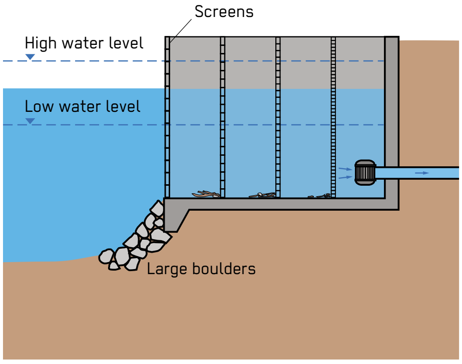
River and Lake Water Intake

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Abstraction of better-quality water, mitigates seasonal variations
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	

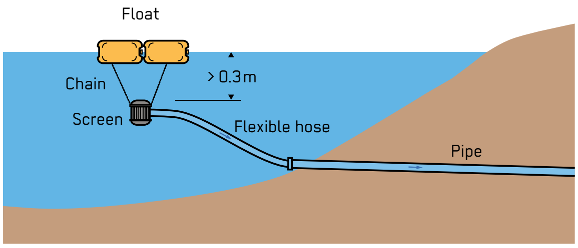
UNPROTECTED INTAKE



PROTECTED INTAKE



FLOATING INTAKE



River and Lake Water Intakes are used in surface water bodies to abstract raw water that is pumped to a water treatment facility. In acute emergencies, unless these structures are already permanently installed, they tend to be simple temporary floating intakes. For longer-term use, more permanent structures might be considered.

River and Lake Water Intakes should be designed to abstract the required volume without damage, clogging or silting of the intake whilst minimising turbidity to facilitate subsequent water treatment. To ensure this, the design must be based on the characteristics of the source, such as riverbed stability, water depth, variability of water level, and speed of flow.

Design Considerations: An intake and treatment plant are often sited together, partly to reduce pumping costs (as more raw water needs to be pumped than treated water due to water losses during treatment). To minimise silting, pollution and structural damage, particularly when withdrawing water from rivers, the intake site should be located upstream of silt/pollution sources (e.g. wastewater outfalls, urban and agricultural areas), upstream of obstructions that cause turbulent flow (e.g. bridges) and on the outside of river bends where there is less riverbed load and deposition.
Where water velocity and gravel loads are low (e.g. slow-moving rivers or lakes) and where water levels do not change much during the year, an unprotected intake might be possible. However, this type of intake is often unsuitable, particularly in areas with intermittent, high-intensity rainfall, which is likely to become more common with climate change. Here, river velocity can surge periodically (e.g. flash floods), and water levels can fluctuate greatly throughout the year, increasing the risk of damage to the intake from rolling boulders or floating debris, with the added problem of abstracting water at low flow periods. In these cases, water velocities can be slowed with a submerged weir or partial/full dam that protects the structure, decreases the sediment load and stabilises

the water levels. To reduce the length and expense of the structure, it is ideally located at a stretch of river that is not too wide or shallow. Weirs/dams are combined with a protected side intake (which can also be used without a weir) that is built into the riverbank with reinforced walls, with a wing wall on the upstream side, large stones at the entrance and an angled steel bar screen to block large debris. A sand trap and spillway can also be added. If the intake is installed on a straight section of river, material transported in the river can accumulate on the intake side. This can be reduced by placing groins (angled walls) on the opposite riverbank to deflect water flow. The water level within the intake after the screen will normally be 0.2 metre lower, but it is better to design a water level drop of up to 1 metre in case maintenance is infrequently carried out. An alternative approach for handling variable water levels is a floating intake (which can also be combined with suction or sump intakes) consisting of a flexible pipe connected to a float that is held in position through mooring cables. For small intakes, the float can simply be an empty jerrycan with the pipe inlet and weight attached underneath. For larger intakes, the inlet can be located under a pontoon (a steel or wooden frame) attached to empty drums. In all cases, the inlet should be a minimum of 0.3 metre below the water surface to prevent air entering the pump. The advantages of a floating intake are that water taken from near the surface has a lower turbidity, making water treatment more consistent, and the intake can be readily retrieved for cleaning. Floating intakes are, however, vulnerable to damage from floating debris.
Depending on the volume of water required, the turbidity can be further reduced by having either an infiltration intake within the riverbed or riverbanks **(see I.6)** or using other measures to protect the source **(see S.3)**. For all intakes, silt and suspended matter can be reduced by a slower flow at the intake (less than 0.1 m/s before any screens). The type of pump chosen needs to be designed to be resistant to pumping solids.

Materials: Generally, local materials and skills can be used to construct intakes, including weirs or dams when needed. These do not necessarily have to be built from concrete or masonry, and can be made from wooden poles, cement-filled jute sacks, sandbags or stone mounds covered with plastic sheeting.

Applicability: River and Lake Water Intakes are suited to all stages of an emergency, with the design depending on the characteristics of the source and the volume to be abstracted. In the acute response phase, even temporary weirs can be made quickly in low-flowing rivers using whatever material is locally available, including sandbags, felled trees and rocks.

Operation and Maintenance: Strainers, screens and approach channels to intakes need regular checks to prevent or remove clogging and/or silting, and the structural integrity of the intake should be checked at the same time. For protected side intakes with angled screens, lowering the angle of the screen (e.g. to 30–45 degrees from horizontal, rather than 60 degrees) can make it easier to rake the screen clean where large amounts of coarse solid material is expected. Silt also needs to be flushed from larger dams or weirs several times per year, depending on the silt load of the water source. Any metal parts, such as screen bars, will need to be either made from corrosion-resistant material or treated regularly. A double intake structure at a site allows for maintenance while the intake remains functional.

Health and Safety: When a weir is built, the downstream risk of flooding, loss of property and loss of life resulting from a possible failure of the structure must be considered, as even small weirs can accommodate large volumes of water that can cause considerable damage. Water stored behind a weir or small dam may encourage the breeding of mosquitoes or other parasites upstream, which can negatively impact the health of families near to or using the water. The quality of surface water collected at intakes is generally poor and requires further treatment.

Costs: Cost will depend on the type of intake. Simple intakes can be very cheap, but cost will increase according to the size and complexity.

Social and Environmental Considerations: With a dam, there is a risk of flooding in upstream areas or, where it is included as part of the intake, an impact on downstream users, both of which may be problematic for local people. There can also be a risk of damage to the intake from people using the river or lake (e.g. children playing can damage floating intakes), as well as a drowning risk. Certain intakes might be more prone to failure or poor performance as a result of climate change.

Strengths and Weaknesses:

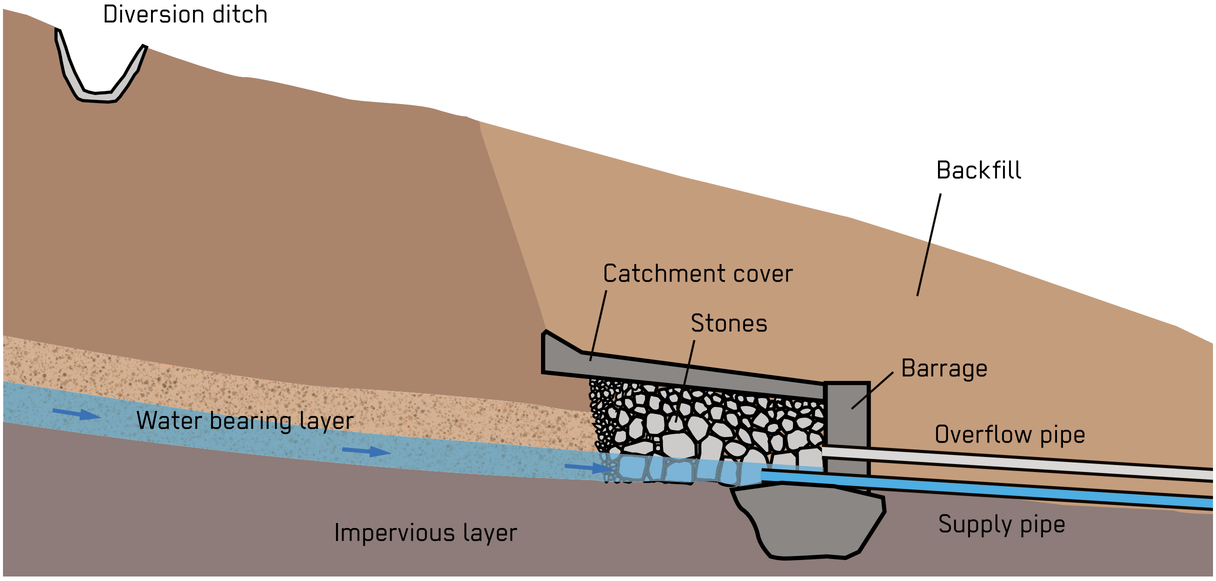
- (+) Can have low material costs
- (+) Certain types are fairly easy to implement (e.g. floating intakes)

- (−) Can be easily damaged in unstable riverbeds
- (−) Requires significant maintenance to clean frequently clogged screens and strainers
- (−) Difficult to position intake to avoid silting up where there is a large variation in water levels throughout the year, and intakes in such areas require constant monitoring of water levels
- (−) Surface water will always require further treatment

→ **References and further reading material for this technology can be found on page 214**

Protected Spring Intake

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared * Public	Natural flowing groundwater, no pumps needed, generally good quality water
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



A Protected Spring Intake is designed to collect, store and transport spring water while preventing source contamination. If springs are available, the technology is suitable for all response phases.

Springs result as a coincidence of hydrogeology and topography and can be gravity flow or artesian in nature, can emanate from a defined point (a spring eye) or from a diffuse seepage area, and can be seasonal or permanent **(see S.6)**. Spring protection works include protecting the area around the spring from contamination, finding means for transporting the water to where it is needed, storing the water (not always needed), and delivering the water conveniently. Protected Springs can be both developed as the source of a distribution network and/or used directly for water collection.

Design Considerations: Spring constructions vary significantly, with the exact works depending on the type of spring, yield, level of spring eyes in relation to other topographical features, proximity to the population and the time and materials available for the work. The area where water exits the ground surface must be protected from contamination, which at its simplest is an enclosure of stones that is either topped with flat stones/tiles and covered with 100 mm of puddled clay and backfilled (simple, cheap, quick, replicable and can be built on a clay base), or topped with a concrete slab with a masonry wall on one side as shown above (requires more expense, skills and time, and there must be a solid foundation for building the wall onto). In some designs, this structure doubles as a storage box, but this must be carefully considered, as some spring eyes can disappear if overly disturbed (e.g. where the impermeable layer is dug out too far). It is therefore generally recommended to channel/protect the source and then transport the water away from the spring to a larger storage structure where damage to the spring eye is avoided. A screened overflow at the spring ensures that water will always flow, and that no back pressure will develop that could cause the spring to divert elsewhere. The spring should also be protected from contamination by having a fence and drainage channel at least 10 metres uphill from the spring eye to divert surface runoff. To ensure this less glamorous task is done, scheduling it at the start of works can help since community enthusiasm wanes towards the end of construction. Water then needs to be transported to where it is going to be further treated (if needed), stored or used.

Water can be transported over short distances using plastic pipes (avoid metal pipes if water pH < 5) or a stone-filled trench (stones covered with clay and backfilled). Over longer distances, proper pipe design will be needed with adequate numbers of washout valves at low points and air release valves at high points **(see also S.7, D.6)**.

Storage may be needed depending on the waiting times, which in turn depends on dry season flow rates and the water demand of the population. Sphere suggests that the flow rate should be at least 0.125 L/s per outlet, with no more than 250 people per outlet. If the measured flow is less than this or there are more people per outlet, water storage is needed for an efficient supply. In these cases, outflow from the system at peak times will be greater than inflow, so the required reservoir volume must be designed accordingly **(see D.5, D.6)**. Storage tanks require a washout valve for desilting and a screened overflow. Water is normally distributed at a headwall, which should be higher and stronger the closer it is to the spring eye. Access to the apron should be safe, and steps and handrails should be considered for slippery paths.

Materials: For Protected Spring Intakes, local materials can be used, including stones, clay, stone masonry or concrete, along with plastic pipes and tanks.

Applicability: Protected Spring Intakes are suited to all response phases when springs are available. In the acute response phase, improving an existing spring protection structure can be achieved quickly, and water from an unprotected spring can be easily treated and trucked elsewhere in the short term. The additional construction of storage and transport pipes (to a collection point at a distance) can take more time. In this case several weeks may be needed to install Spring Intakes, in addition to the time required to locate the source and carry out topographical surveys and spring yield analyses (which should be carried out at the start of the rainy season).

Operation and Maintenance: Little O & M is needed, as water flows from springs by gravity (i.e. little need for pumping). Increased water turbidity after heavy rains could indicate contamination from surface runoff. When this occurs, the fence and channel uphill of the spring should be checked. Annual microbiological water quality checks are also recommended. If the flow rate decreases, the intake may be clogged, and a re-excavation of the spring eye may be necessary. In such a case, markers placed during construction can help indicate the position of the spring eye at a later date. Siltation may occur in the pipeline that transports water from the spring to storage or in the storage tank itself, and both should be de-silted annually via washouts in pipes and cleaning/draining tanks. Where baseline turbidity is high, a sedimentation tank installed before the water enters the pipes can reduce silting.

Health and Safety: Spring water is usually of good quality, though should be checked for microbiological or chemical contamination where the catchment is polluted, where the water is not truly groundwater (predominantly subsurface runoff) or where there are rapid transit times for water through the ground (e.g. in karstic terrain). Access paths to springs located near the bottom of slopes can be slippery, and steps and handrails are sometimes needed.

Costs: Springs can be comparatively cheap to improve. Costs usually vary between 200–3,500 USD, depending on the extent of the works.

Social and Environmental Considerations: Springs are usually well accepted by the population as a water source and can be easier to manage, as the community can see where the water is coming from. However, springs can often have existing users who may not want it used for other purposes, and a clear understanding of access, ownership and responsibility is needed. Springs can dry up or move position seasonally, and this might become more pronounced with climate change.

Strengths and Weaknesses:

(+) Low material costs
(+) Low cost/effort O & M due to gravity flow
(+) Usually good quality water

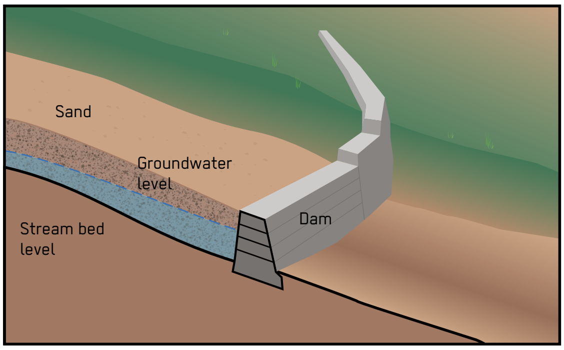
(−) Variability of water flow between seasons
(−) Total water available is limited to spring yield (which cannot be increased much by design), regardless of demand
(−) Spring Intakes are susceptible to temporary or permanent modified water flow following earthquakes
(−) Risk of impacting groundwater-dependent ecosystems downstream, especially if no overflow

→ **References and further reading material for this technology can be found on page 214**

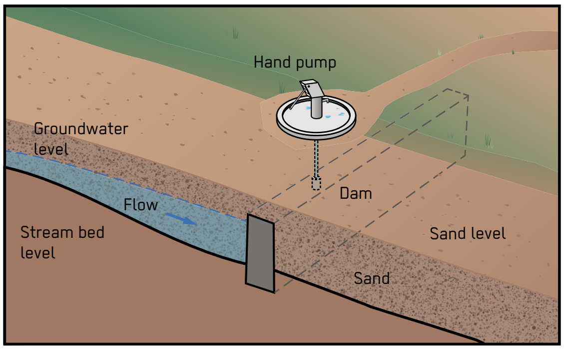
Groundwater Dam

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response Stabilisation ** Recovery	Household ** Neighbourhood * City	Household ** Shared * Public	Large water volumes stored in arid areas, drought mitigation
Local Availability *** High	**Technical Complexity** *** High	**Maturity Level** *** High	

SAND STORAGE DAM



SUBSURFACE STORAGE DAM



A Groundwater Dam is a structure that slows or stops the flow of shallow groundwater, most often in seasonal riverbeds, increasing the availability of shallow groundwater upstream of the structure. The technology is not suitable for the acute or stabilisation phases of emergencies, and is more suited to long-term drought mitigation.

There are two main types of Groundwater Dam, each suited to different initial site conditions. Sand storage dams (in the above figure on the left) are built in riverbeds where the volume of sand or other permeable material in an existing riverbed is not yet deep enough to store significant amounts of water. Most of the structure is therefore built (in stages) above the original riverbed. Each time a stage is constructed, sand that is washed downstream during flash floods then deposits behind the wall, which creates a new higher riverbed level upstream that holds water. These dams are usually built onto a rock layer, though can also be established with care onto an impermeable clay layer. Subsurface dams (in the above figure on the right) are built within riverbeds where the sand volume is already sufficient to store water. After a flooding event, the water behind the dam infiltrates, increasing storage. They can be built onto a rock or impermeable clay layer.

Design Considerations: A Groundwater Dam is a technology that is not suitable everywhere, and requires careful siting. Dams should be sited where the river has sufficient velocity to carry medium/coarse sand grains while minimising silt deposits. In practice, this means a site with a gradient between 0.13 % and 4 %, which will also likely keep the dam width to under 25 metres, reducing materials and labour. The exact location should not be close to a river bend or where old riverbeds might exist laterally through which groundwater can escape. A detailed site investigation is needed to ensure water losses do not occur through fractures when building on rock or through deeper sediments below the impermeable layer. Riverbanks should be high enough to prevent water bypassing the structure (i.e. height of dam + flood + 10 %). Siting the dam where the riverbed is narrower and where the basement rock or clay is shallower will ensure cheaper and quicker construction.
Careful design and construction are also important, especially for sand storage dams. For both dam types, erosion must be prevented around the edges of the dam. For subsurface dams, this means keying in the dam to the riverbank, whereas for sand storage dams, it entails the construction of wing walls. A good construction technique is

to start with the wing walls and work towards the centre, because if the wing walls are constructed last, community enthusiasm may lag considerably. The length of the wing walls varies according to the characteristics of the bank. For sand storage dams, there are further critical design issues to be aware of. For instance, the height of the dam wall to be built before each flood should not exceed the accumulation rate of coarse/medium sand during that flood event. The height will vary according to location and should be adjusted after the first flood event, though it is rarely more than 50 cm. If this is not done, ponding and siltation will occur, resulting in lower specific yield and higher capillarity, which in turn will reduce the extraction rate of wells and increase the evaporation loss. The spillway must also be designed to accommodate peak river flow and will therefore vary according to the site. Incorrect design will lead to erosion around the wing walls. Thirdly, where there is no rock bar immediately downstream of the dam, erosion can be prevented by placing large stones at the point below the spillway where floodwater will fall. These should be large enough to resist river flow. Water can be abstracted by scoop holes in the riverbed (which are prone to contamination), through riverbed wells **(see I.7)**, or by wells in the riverbanks. Certain designs for sand storage dams show a pipe taking water by gravity through the dam wall, but these can be problematic due to blocked intakes, broken taps and the possibility of a weakened dam wall.

Materials: Subsurface dams can be made of stone masonry or even clay, whereas sand storage dams are generally built of stone masonry. Subsurface dams made with clay are susceptible to damage, but can be functional if the top of the dam is 0.3 metres below the original sand bed and if concrete is used at critical points (foundation, upstream plaster, top of dam).

Applicability: Groundwater Dams are generally suited to arid areas with high evaporation rates and intense rainfall events. These areas tend to coincide with pastoralist areas prone to drought, where water availability does not always correlate well with pasture availability. Sand storage dams are suitable for riverbeds with insufficient sand as a storage medium, while subsurface dams are suitable where there is enough sand, but the subsurface water does not remain long enough (if water does remain, Riverbank Filtration **(I.6)** should suffice). The construction of Groundwater Dams can take a long time, especially for sand storage dams, so they should not be considered for the acute or stabilisation phases of an emergency.

Operation and Maintenance: If dams are properly constructed, then very little continuous O&M is required. Sand dams should be inspected for potential damage after floods and repaired. Building dams in stages over a period of years can also be more beneficial for the functioning of dam committees since communities are continually involved. Subsurface dams made from clay should be checked after the first flood events to ensure no damage has occurred. If a pump is used for abstraction, then appropriate pump maintenance is needed.

Health and Safety: Where excavation exceeds two metres for subsurface dams, trench shuttering should be used along with appropriate construction safety measures. Water quality should be controlled. If many herds of animals access the upstream river, nitrates from urine could become an issue, as may contamination from animal faeces. In volcanic sands, fluoride may build up in deeper parts of a sand reservoir.

Costs: The initial dam structure can be expensive and varies between projects according to site conditions, volume of excavation, type of structure, and labour. Sand storage dams can be more expensive than subsurface dams. Costs range from 3,500 up to 30,000 USD. The cost per cubic metre of water stored, however, is low.

Social and Environmental Considerations: The principle of Groundwater Dams is generally easily understood by users, as it builds on what they know already about water held within sand. Where dams are planned to aid pastoralists, full discussions on locations in relation to pasture and grazing rights of different groups will be required during the planning phase. The available water in Groundwater Dams is very much linked with seasonal rainfall, and they can play a key role in climate change adaptation and drought mitigation activities, as they provide increased storage and/or can help control groundwater table levels through managed aquifer recharge.

Strengths and Weaknesses:

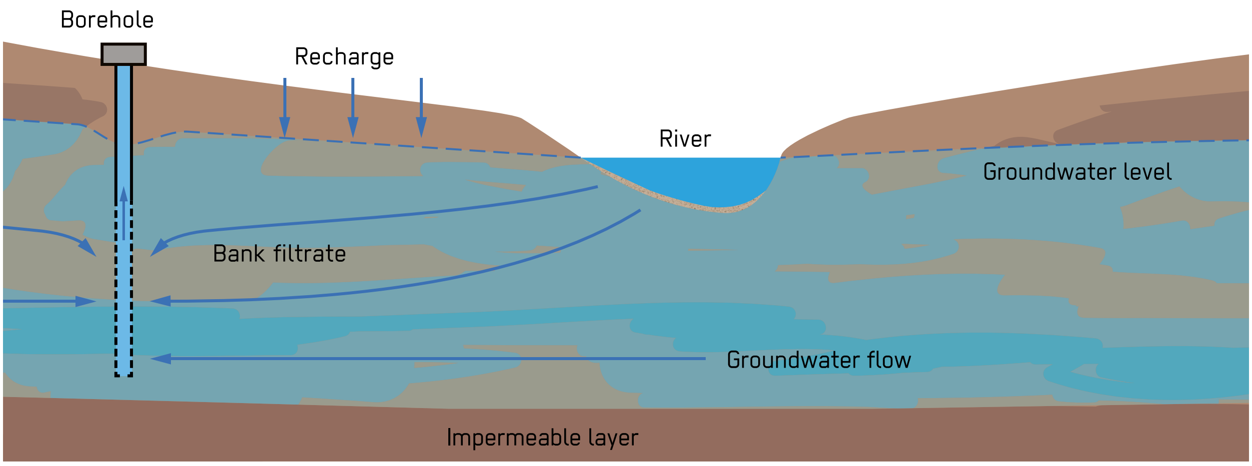
(+) Low evaporation and better water quality than open water
(+) Produces large water quantities
(+) Low O&M requirements

(−) Requires expertise for good design
(−) Is a site-specific technology
(−) Can take years to properly build a sand storage dam, which clashes with short-term funding
(−) Possible water quality issues (e.g. from cattle)

→ **References and further reading material for this technology can be found on page 214**

Riverbank Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Groundwater intake, water quality improvement
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Riverbank Filtration is a water withdrawal method in which water is pumped from the ground via the banks of a river (or other surface water body). The water abstracted is thus surface water that has received a preliminary treatment by passing a short distance through sediments and soil to where it is abstracted. Riverbank Filtration can be very useful both in the acute response phase where certain types of wells (e.g. jetted wells) can be installed quickly, as well as in the recovery and stabilisation phases.

Riverbank Filtration describes a process in which an intake is located a short distance away from a surface water source (typically less than 50 meters). The short distance and time the surface water spends as groundwater means that not much filtration is likely to occur, such that the water may have a lower quality compared to other groundwater sources. Riverbank Filtration can be therefore viewed more as a pre-treatment clarification process prior to final treatment. The intake can be a Protected Dug Well **(I.7)** or Protected Borehole **(I.8)**, or might require more complex ways to improve water flow through the banks (e.g. infiltration gallery).

Design Considerations: The main design considerations when using Riverbank Filtration are water quantity and quality, and any system will require a balance of the two. The intake needs to produce sufficient quantity for the intended purpose at an acceptable quality. Both will be determined by the type of sediments between the surface water source and the intake as well as the distance between the water source and abstraction point.
In most long-term set-ups, the abstraction rate will decrease due to clogging of the interface between the surface and groundwater. Where bank sediments are not permeable enough to allow the required volume to be abstracted from the intake, various improvements can be made. These include creating an artificial channel of permeable sediments between the water source and intake, which is then backfilled above the channel, or using an

infiltration gallery, which consists of a horizontal 75–300 mm jointed or slotted pipe laid beneath the riverbed or in the banks. Infiltration galleries should have a graded gravel filter installed around the pipe, which should be at least 1 metre below the dry-season saturated zone and deep enough to not be affected by river scour (at least 1.5 metres). For infiltration galleries, clogging can still occur with time, so they are best suited to river sections where there is no deposition (i.e. choosing riverbeds with medium to coarse sand and avoiding the inside of river bends where deposition occurs). It is also best to avoid having any gravel bed in direct contact with the river water, as clogging may increase compared with a sand surface (as fine particles tend to penetrate the bed deeper, preventing their subsequent resuspension through scour).
The construction of both of these systems is usually more difficult than for other intakes and requires a significant amount of excavation and de-watering. Various other intakes can be used in conjunction with Riverbank Filtration, such as Protected Boreholes or jetted wells **(see I.8)**, and Protected Dug Wells or riverbed wells **(I.7)**. These can be constructed within/under the riverbed itself (e.g. jetted or riverbed wells with off-set suction pump) or in the riverbanks. Water quantity for all types of Riverbank Filtration intakes can also be increased through managed aquifer recharge methods, such as gully plugs, check dams, leaky dams and groundwater dams in seasonal rivers **(I.5)**.
The microbiological, chemical and physical water quality of surface water will be much improved through Riverbank Filtration due to the combination of natural treatment processes, though a final treatment may still be needed. Alternatives to Riverbank Filtration include treating surface water through Roughing Filtration **(T.1)**, Rapid Sand Filtration **(T.2)** and Slow Sand Filtration **(T.9)** on the riverbanks or in the home.

Materials: Riverbank Filtration can be a good option for using local materials and skills, depending on the type of intake (e.g. PVC pipes, locally available gravel, concrete).

Applicability: Riverbank Filtration is a good option for the acute response phase, as long as the intake can be created quickly (e.g. jetted well). Other intakes will probably be more suited to the recovery and stabilisation phases due to the time taken for excavation and construction (e.g. infiltration gallery or Protected Dug Well, **I.7**). Its main use is to improve water quality to reduce subsequent treatment needs (e.g. to allow for chlorination only).

Operation and Maintenance: The volume of water entering the intake should be monitored for signs of the permeable zone becoming clogged, which is a common issue with Riverbank Filtration systems. This is best mitigated through good design and siting, but it is possible that major rehabilitation works will be needed if the intake becomes too clogged. Apart from that, Riverbank Filtration actually reduces the O & M required for water clarification (e.g. demand for chemicals in coagulation process) and can completely replace clarification in some cases.

Health and Safety: Water may still need treatment or may be a risk to health, particularly from the microbiological contamination that is more likely to be an issue in populated areas or where there are a lot of animals. Other health risks are associated with excavation and will vary according to the type of intake. For infiltration galleries or where channels of permeable material are installed between the source and intake, a risk of collapse in the saturated zone combined with the required deep trench excavation pose a health risk where construction/shuttering procedures are not adequate.

Costs: Cost will vary depending on the type of intake constructed. Jetted wells can be cheap, as they are completed quickly and with little material (around 150 USD per metre) compared to infiltration galleries, which can be more expensive, take longer to install and require significant excavation work (around 11,000 USD or more for a gallery 20 meters long x 3 metres wide x 5 metres deep).

Social and Environmental Considerations: Riverbank Filtration tends to be well accepted by people, as the process of water being filtered through sediments in the riverbank is easily understood. However, over-extraction of water can cause a surface water body to dry out or river flows to reduce, which may cause significant problems to other users.

Strengths and Weaknesses:

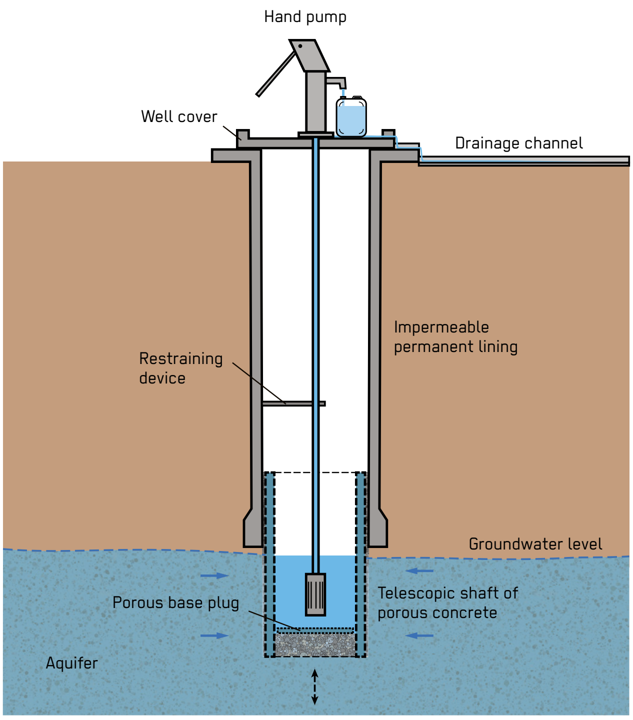
(+) Reduces turbidity in cost-efficient manner
(+) Improved microbiological, physical and chemical water quality compared to surface water
(+) Some types of intakes (e.g. boreholes or wells) can be cheaper using Riverbank Filtration compared with deeper aquifers, since the required depth is less and various cheaper forms are possible (e.g. jetted wells)

(−) Likely to clog over time, reducing long-term water quantity
(−) Difficult to construct infiltration galleries deep enough to have water at all times
(−) Requires large excavation works for some intakes (infiltration galleries) with associated cost and health risk

→ **References and further reading material for this technology can be found on page 215**

Protected Dug Well

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household ** Shared * Public	Extracting shallow groundwater, dug by hand
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



A Protected Dug Well is a large-diameter structure dug by hand that is lined and covered and allows for water abstraction using a pump. New wells are not normally considered in the acute response phase, but any existing wells can be rehabilitated quickly to provide water.

Protected Dug Wells are normally around 20 metres deep, although some traditional hand-dug wells are much deeper. Variations of dug wells include riverbed wells (capped well lining below a riverbed surface; water accessed with offset suction pump) and infiltration wells (capped well lining in the water table and backfilled above).

Design Considerations: The well shaft below the water table (the intake) must allow water to enter the well. The easiest way this can be achieved is by using porous concrete blocks or rings for the lining, and leaving the base open or lined with gravel layers and/or a porous concrete plug to prevent sand/silt build up and bottom heave (which can happen when water is withdrawn, reducing pressure on the bottom material and causing it to flow upwards). Normally, this porous intake extends between 1–4 metres below the water table, where the depth achieved is dependent on the permeability of the aquifer compared to the rate of de-watering. The well shaft above the water table is normally lined to just above ground level (typically with concrete, though other materials can be used). This lining is not porous, and should also be continuous, so that any water infiltrating from the surface cannot short-circuit back into the well (this can be an issue where gaps between concrete rings are not sealed).
Protected Dug Wells in shallow aquifers tend to be affected by infiltration from rainfall more quickly compared to deeper aquifers, and water table fluctuations of up to several metres between seasons is possible. Shallow well construction should therefore be planned for the end of the dry season. However, this is not always possible in practice, and it is thus recommended to use a design that easily allows for subsequent deepening. For this, the best practice is to include a permanent non-moveable lining for

the well shaft above the water table, with a smaller-diameter telescopic lining that can then be 'caissoned' (sunk while digging) into the water table. This allows the well to be easily deepened at a later date. An additional strategy for wells that seasonally run dry is to use managed aquifer recharge techniques to increase water.

At ground level the well is protected using a slab over the well, a pump, an apron (concrete drainage pan around the well) and a drainage channel (takes spillage water away from the well shaft). In flood-prone areas, the well shaft can also be extended above ground as a headwall to prevent floodwater from entering. Even if shallow wells are protected, there is always the risk of contamination in shallow groundwater, and risk analysis should normally be made. In an emergency however, this will not be a problem when water is chlorinated and is really only an issue when the well is converted to handpump use.

Materials: A Protected Dug Well can be built using local materials. Concrete is often used for most parts of the structure, although the lining can be built using other materials. In addition, some organisations have emergency well digging kits that include a prefabricated lining. A pump is also needed. In the acute response phase, a handpump can be converted to a submersible pump which would also require a power supply, and the water will need to be chlorinated.

Applicability: Protected Dug Wells can be made in most types of ground (except solid rock). However, they can take quite a long time to construct since a wide excavation must first be dug and then lined by hand, meaning that new dug wells are not normally an option for water supplies in the acute response phase. However, existing wells can often be upgraded or rehabilitated in the acute response phase to provide water quickly, typically using a submersible pump and water distribution systems. In these cases, a pump test will be needed to determine the safe yield before upgrading the extraction method. In cases where the well is low yielding and yet in a sandy aquifer, it can be possible to increase the yield quickly by jetting a screen into the bottom of the well to increase water flow into the main well compartment.

Operation and Maintenance: O&M involves ensuring that spillage and other water from the surface cannot short-circuit into the well (e.g. preventing ponding of wastewater, checking the slab and apron for cracks) and using a fence to keep out grazing animals). Occasionally the well might have to be deepened or may require the sand and silt to be removed, which can accumulate over time. Wells may also require disinfection following a contamination event (such as flooding). On occasions where wells have been flooded by seawater, additional pumping will not help, and more time is required (up to two years) for any saline water that has contaminated the aquifer to infiltrate deeper. Overall, though, most of the maintenance burden will likely be related to the pump itself.

Health and Safety: The main risks occur during excavation: collapsing walls, things falling into the excavation during digging, people falling in, worker fatigue, non-robust equipment, lack of ventilation, electrocution, crushed limbs from heavy rings and geared winches. Risks can be mitigated by: avoiding the need to lift heavy things through choice of construction method (using in-situ permanent lining and concrete blocks for the telescopic lining), fencing the well site, having a rescue plan in case a worker collapses, ensuring all diggers wear a construction harness for quick extraction, having a ventilation system during excavation (e.g. temporary 100–150 mm PVC pipe from base of hole to above ground level, attached to the crossbar), ensuring all pumps/generators are downwind and never lowered into the excavation, and fitting submersible pumps with circuit breakers.

Costs: Comparing a hand-dug well and a drilled well where labour is reimbursed, the projected cost per metre for a dug well can be more than for a drilled well, but the overall cost will most likely be less since the dug well will be shallower.

Social and Environmental Considerations: Protected Dug Wells are usually accepted in many areas, as they are the traditional way of abstracting water. However, some aquifers can have significant mineral levels, which can affect taste and acceptability. Shallow wells can also dry up and be more prone to drought, especially those within perched aquifers with limited recharge, but they can also be very responsive to climate change adaptation activities, such as check dams to slow down runoff.

Strengths and Weaknesses:

(+) Works well for low-yielding aquifers (due to storage ability)
(+) Can be deepened later, access still possible if pump breaks down
(+) Lower overall cost for construction compared with mechanical drilling
(+) Provides good option for certain soil types where manual drilling is not possible
(+) Greater probability of hitting a useable aquifer (compared to deep wells)

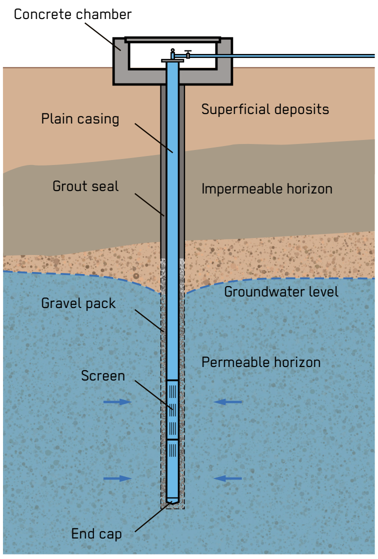
(−) Takes more time to construct a dug well
(−) Limits maximum water possible because there is a limited depth to which one can sink the shaft
(−) Has significant health and safety risks – not good for inexperienced workers
(−) More susceptible to microbiological contamination compared to drilled wells

→ **References and further reading material for this technology can be found on page 215**

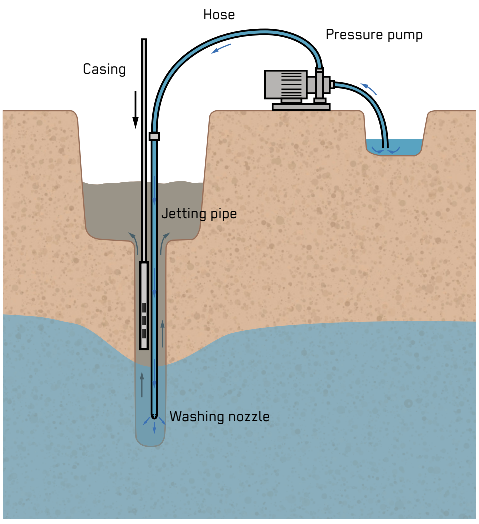
Protected Borehole

Response Phase	Application Level	Management Level	Objectives / Key Features
★ Acute Response ★★ Stabilisation ★★ Recovery	★ Household ★★ Neighbourhood ★★ City	★ Household ★★ Shared ★★ Public	Extracting shallow/deep groundwater, drilled wells
Local Availability	**Technical Complexity**	**Maturity Level**	
★★ Medium	★★★ High	★★★ High	

PROTECTED BOREHOLE



JETTED WELL METHOD



A Protected Borehole is a small diameter drilled hole that is lined and covered, with water withdrawn using a pump. Existing boreholes can be equipped quickly to provide water in the acute response phase, but new boreholes, with the exception of jetted wells, are normally reserved for the stabilisation phase, as they can take several months to organise and complete.

Protected Boreholes can be drilled using various methods, both manually (e.g. augering, percussion, sludging, jetting) and mechanically (e.g. with a rotary mud flush drill rig or using compressed air to drive a down-the-hole hammer). The drill depth ranges widely from several metres up to 500 metres. The drilling diameter is usually between 100–250 mm. Borehole drilling is a specialist activity requiring proper siting, design, construction and testing for proper functioning.

Design Considerations: Well jetting is suited to shallow, weakly cohesive sandy/silty aquifers and can be done rapidly and with high success rates. For most boreholes, finding water in deeper aquifers can be more challenging. Even when drillers have experience in a particular area, the exact amount of water and its quality cannot be known in advance. Hydrogeological surveys (including geophysics) can help reduce failure rates in certain areas but do not guarantee success. Even if a borehole can deliver a certain yield in the short term and the aquifer is able to yield the water, if the groundwater is not replenished, then that yield will not be sustainable. It is therefore important (more so where high-production submersible pumps are installed) to evaluate this through a water balance calculation. In coastal areas, saltwater intrusion can also become a problem depending on withdrawal rates **(see I.9)**.
Boreholes should last for 20 to 50 years, and to achieve this proper design is essential, which considers thickness/depth/productivity of the aquifer, target yield, efficiency when in use and water quality. All these elements

should be considered at the outset and then checked during and after the drilling process, yet often this is not the case. Casing stabilises the well walls and prevents contamination from the surrounding soil, though is not always needed in stable rock with clean fractures. The screen serves a similar function, though is placed within the aquifer and contains holes/slots to allow water through. Screens come with slots of different widths (e.g. 0.5–1.5 mm), which are chosen based on the size of the material surrounding the screen to prevent finer material from entering in the long term. The required length of the screens depends on aquifer type/thickness, the demand, expected well productivity and the velocity of water entering the screen. The velocity should never exceed 0.03 m/s due to turbulence and resulting energy losses, as well as incrustation and sand particles being continually drawn in over time. Pumps should never be installed within the screens, and drawdown (the level of the water table during pumping) should never reach the screens. Pumps can be installed below a screen, but a shroud should be fitted in this case to ensure motor cooling. A sand trap with a plug is installed at the bottom of the screens to collect sand entering during borehole development and later use. In most aquifers, a gravel pack will be needed between the screen and the borehole walls, as the aquifer material is often smaller than the available screen slot size. The gravel pack is a mix of sieved coarse sand (usually between 1–6 mm) determined by a sieve analysis and is sized so that only 10 % of the grains in the aquifer pass through the slots. Its additional function is to increase the velocity of water entering the well.
After screens are in place, borehole development is essential to clean out any drilling mud or foam and to pull in finer material from the gravel pack to thereby increase water flow, a lengthy process that will vary according to the drilling technique (i.e. done until water is clear and free of any particles in suspension). A pumping test is also critical to investigate the well efficiency, safe yield and pump placement and may take several hours. Finished boreholes are protected by backfilling around the casing with clay, sealing the top five metres with a sanitary seal (e.g. cement grout) and installing a well head (usually metal and visible above ground) to prevent contamination of the well and protect against floods.

Materials: Materials include the casing/screen/sand trap (usually PVC or steel), gravel pack and a pump for abstracting the water.

Applicability: In the acute response phase, jetted wells can be made rapidly in sandy/silty alluvial aquifers, and existing boreholes can often be upgraded to provide water quickly, typically using a submersible pump and water distribution system. Deeper boreholes can be made in all types of ground and aquifers. While sometimes quick to drill, in practice it tends to take a few months to contract a driller to complete a well, so new boreholes are generally only considered for the stabilisation and recovery phases.

Operation and Maintenance: Includes ensuring that water from the surface cannot short-circuit into the well (e.g. preventing ponding of wastewater, checking the slab and apron for cracks) and using a fence to keep out grazing animals). Screens must be cleaned every few years. Most O & M will be related to pump function.

Health and Safety: Heavy drilling machinery with moving parts are always a risk, so good site management is needed, especially managing spectators. Overhead power lines are a risk factor when setting up drilling rigs. Care is needed to prevent collapse when installing jetted wells which are often started near the water table at the bottom of an excavated hole. In certain regions, there can also be health risks associated with levels of natural chemicals (e.g. arsenic, fluoride and nitrate). Where the pH is <5, the corrosion of metal pipes is a concern.

Costs: The cost for a typical drilled well varies from 125–300 USD per metre. Jetted wells tend to be cheaper (up to 150 USD per metre).

Social and Environmental Considerations: Boreholes are usually accepted if the water quality and taste are acceptable to users. Some aquifers though have significant levels of minerals that can affect taste and acceptability and cause users to search for alternative sources. For high abstraction requirements, the water taken from an aquifer should not exceed the water entering the aquifer **(see S.5)**.

Strengths and Weaknesses:

(+) Safer and quicker to construct than dug wells
(+) Good option for all soil types
(+) Less susceptible to microbiological contamination compared to dug wells

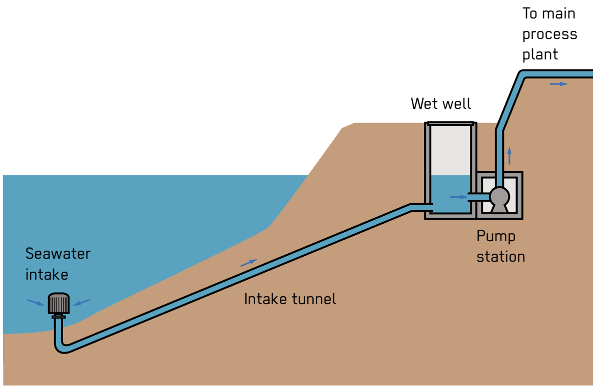
(−) High-technology option using specialised equipment and needing expertise
(−) Water access not possible if pump breaks down
(−) Higher overall cost for construction compared with dug wells, yet at times with more uncertain results
(−) Chemical water quality can be variable
(−) Difficult to assess water quality or quantity without existing boreholes as evidence

→ **References and further reading material for this technology can be found on page 215**

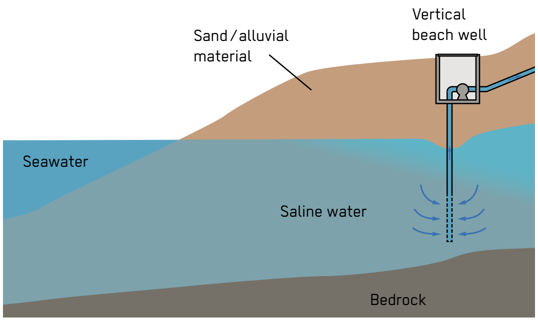
Seawater Intake

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response Stabilisation * Recovery	Household ** Neighbourhood ** City	Household * Shared ** Public	Surface or bank filtration intakes for seawater
Local Availability *** High	**Technical Complexity** *** High	**Maturity Level** *** High	

SURFACE INTAKE



SUBSURFACE INTAKE



Seawater Intakes are used for desalination plants and non-drinking purposes, such as swimming pools or cooling. They are therefore usually not considered for emergencies unless the work is to restore damaged existing intakes for desalination plants to restore drinking water supplies.

Seawater Intakes can be categorised as surface or subsurface structures, and the choice of one or the other depends on different factors. They are usually designed for large volumes of water and must be done in such a way as to prevent damage and avoid environmental problems while producing water of sufficient quality and consistency for any subsequent treatment process.

Design Considerations: The main design concerns for desalination plants are abstracting sufficient water to meet the demand, minimising the environmental impact, and achieving good water quality as consistently as possible. Seawater Intakes are site specific, tend to be the most challenging aspect of desalination plant construction and can account for up to one-fifth of the total capital cost. Various factors influence the choice of site and the intake type, including the topography and geology of the coastline, raw water quality data, marine biology, pollution sources and navigation requirements. Overall, an intake and treatment plant are often sited close together to reduce pumping costs. This is especially important with Reverse Osmosis **(T.15)**, which produces significant amounts of high-salinity wastewater.
Surface intakes are usually used where large volumes are required (over 38,000 m^3/day), where the force of the sea is not likely to cause damage to the structure or where geology does not allow a subsurface intake. Surface intakes have an open pipe on the seabed that commonly connects to a sump built onshore, where water is first screened before being pumped onward. Issues with this arrangement include impingement, where organisms get trapped on the screen by the force of the water flow, and entrainment, where smaller organisms pass through and reach the treatment plant. Solutions for this include measures at both the ends of the intake pipe and screens to scare fish away (e.g. a velocity cap over the pipe end), to prevent larger organisms from entering (e.g. filter net

barriers around the pipe end or fine mesh screens) and to reduce velocity (e.g. passive screens). Water quality can also vary with surface intakes (e.g. after storms), which can prevent desalination plants from operating. Water from an open intake will still always require significant pre-treatment to remove anything that can foul membranes in the treatment process.

Where environmental or water quality concerns cannot be met, a subsurface intake may be considered, which has several advantages over surface intakes. While they tend to abstract smaller volumes, they produce better quality water with greater consistency, therefore reducing pre-treatment requirements. They can be constructed using techniques similar to Riverbank Filtration **(I.6)**, as well as through a Ranney collector well (large diameter concrete well with radial horizontal well screens driven in horizontally), angled drilled wells or horizontal drilled wells. However, the most common technique used is vertical drilling close to the sea to tap the deeper wedge of seawater that sits underneath the fresh water in this zone. The exact type of subsurface intake can also depend on the total water quantity needed. Jetted seawater wells have also been used effectively for lower abstraction requirements, the advantage being that they are quick and easy to install. One problem with subsurface intakes, however, is the risk of destabilising the equilibrium between sea and fresh water, which could cause local wells that tap into the freshwater zone to be affected by saline intrusion.

Materials: Materials depend on the intake design that is used, which could be PVC pipes, locally available gravel or concrete. These materials must be corrosion resistant due to the highly corrosive nature of seawater. Pumps used, particularly for surface intakes, should also be resistant to pumping solids.

Applicability: Seawater Intakes are an option for the stabilisation and recovery phases of an emergency where the goal is to restore damaged existing desalination plants. A new desalination plant construction however is clearly work that is done outside of the emergency context.

Operation and Maintenance: Depending on the type of intake infrastructure, different O&M measures will be needed. A duplicate intake structure will allow maintenance to be carried out while the intake continues to function. Surface intakes will need regular underwater checks of screens (every two to three months) to deal with any impingement and biofouling. This typically involves checking for the presence of sea grass, oil and grease from shipping, wastewater discharges, mussels/barnacles and algal blooms, all of which can foul screens and membranes. Subsurface intakes require less maintenance. The quantity of water entering the intake should be monitored for signs of screen clogging, which will clog completely over time if left unchecked. Maintenance work will involve periodic well screen cleaning, and redevelopment will be required to maintain production efficiency. Well screen maintenance in slant and horizontal drilled wells may require specialised maintenance techniques. All intakes pump seawater, which is corrosive, so any metal parts will likely need repair or replacement at some point.

Health and Safety: Health implications are the same as those for the construction method chosen. For wells, health risks are associated with excavation, which varies according to the type of intake **(see I.7)**, while for borehole drilling, risks include the use of heavy drilling machinery with moving parts and overhead power lines when setting up the rig **(see I.8)**. In addition, working close to the open sea is potentially hazardous and requires adequate protective gear and a thorough risk analysis.

Costs: Capital and ongoing costs vary depending on the type of intake and how many wells are needed given the water quantity required. In general, costs will be higher than equivalent freshwater intakes due to the need for corrosion-resistant materials in the system. As a rough guide, capital costs of surface intakes range from tens of thousands to tens of millions of dollars, which is significantly higher on average than for subsurface intakes, varying based on the site and design. In addition, they need to have environmental assessment and pre-treatment costs included. By comparison to subsurface intakes where pre-treatment is not necessary, costs can still be high (up to 5,000,000 USD).

Social and Environmental Considerations: Seawater Intakes might result in the loss of recreational uses in the intake area, and there may be a visual impact of some intake structures. Surface intakes that are not designed correctly can also impact marine organisms, and subsurface intakes can cause saline intrusion into local wells.

Strengths and Weaknesses:

(+) Can abstract large volumes of seawater
(+) Subsurface intakes provide better quality water, and pre-treatment is then not needed
(+) Subsurface intakes have less environmental impact

(−) Surface intakes have impingement and entrainment risks, and additional pre-treatment is required after abstraction
(−) Finding a suitable protected site might be challenging
(−) The success of subsurface intakes depends on the local geology
(−) Subsurface intakes can have a negative effect on nearby fresh water sources, and may disturb sensitive coastal ecosystems

→ **References and further reading material for this technology can be found on page 215**

Water abstraction is the process of extracting water from natural sources, such as rivers, lakes and aquifers, for a range of uses including drinking, irrigation, recreation and industrial production. This section describes the variety of different pumps that can be employed for water abstraction, which can be categorised as follows: Impulse Pumps (A.1), Positive Displacement Pumps (A.2–A.7), Velocity Pumps (A.8–A.9) and Pumping Stations (A.10). This categorisation is based on the method by which energy is added and the way in which the fluid moves through the pump.

The decision on the type of pump to use should be made during the initial assessment and is influenced by the following factors:

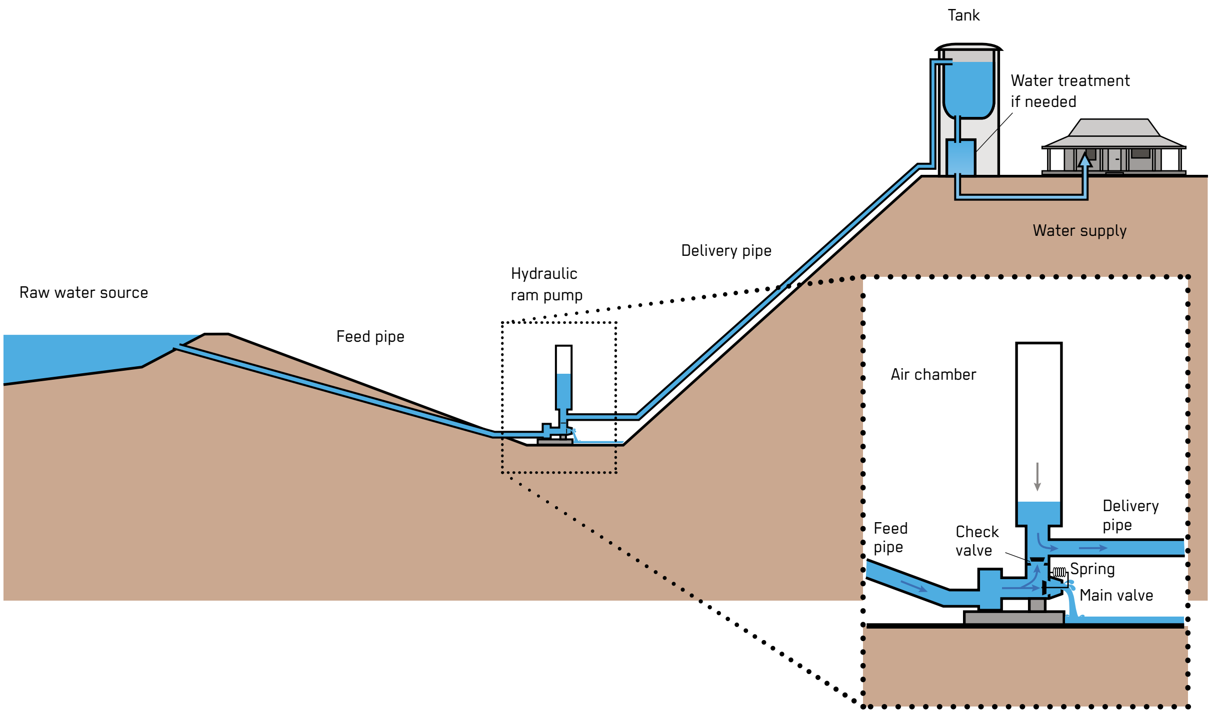
- Water source specifications, including water quality, location and intake design
- Required water quantity
- Geographic considerations
- Availability power sources, such as fuel, renewable energy and human energy
- Financial resources
- Local availability of technology and skills for installation, operation, speed of implementation and maintenance

A

Abstraction

Hydraulic Ram (Impulse) Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household * Neighbourhood City	** Household * Shared Public	Impulse pump, pumping and transport of water, use of energy from the water
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	



Hydraulic Ram or Impulse Pumps convert the difference in elevation between the feed pipe intake (e.g. from a nearby river or flow from an elevated reservoir) and the pump itself into kinetic energy that moves water through the delivery pipe. Impulse Pumps require little to no energy input other than a flowing water source and can reliably provide pressurised water from that existing source (including spring water). This technology is mainly applicable during the stabilisation and recovery phases of an emergency.

A Hydraulic Ram Pump uses a series of one-way valves and a compressible pocket of air to harness the energy (or impulse) from a flowing stream, river or reservoir discharge located at a higher elevation than the pump itself. The flowing water compresses the air pocket, which in turn forces a small amount of water through the pump discharge at a higher pressure. Most of the energy from the inlet flow velocity is transferred to the compressed air pocket, with only a small fraction of the inlet flow being pumped onwards, which results in it being propelled at a higher pressure.

Design Considerations: A Hydraulic Ram Pump does not need electricity or fuel for operation, instead relying on a natural flow and elevation difference. Water can be pumped from 20–40 times higher than the available height difference driving the pump, meaning that a height difference of 1 metre in the feeding pipe can pump water over 30 metres upwards in the delivery pipe. However, less than 10 % of the water volume flowing through the feeder pipe can be delivered to the outlet, as the energy for lifting the water to the outlet including losses is taken from water escaping the pump through the main valve. The minimum water flow rate required is 7–10 litres per minute for small pumps, and the minimum working fall is 1 metre.

Materials: The availability of ready-made Hydraulic Ram Pumps is regionally dependent (lighter pumps are available in Asia with a reasonable working life). While the design is simple enough to allow for homemade assembly using locally available valves, thermoplastic pipes and fittings, homemade versions tend to be unreliable. Ram pumps may be fabricated from HDPE or other thermoplastic components and commodity fittings (PVC and other brittle materials should be avoided).

Applicability: A Hydraulic Ram Pump is most suitable for hilly or mountainous areas where water sources are situated lower than the point of use. Generally, streams, rivers or springs can be used as a source to operate these pumps, but a sufficient flow/capacity is needed to operate them, as a large portion of the water serves as an energy source that then exits below the pump and returns to the water source. Commercial pumps are reliable but are only available in sizes capable of producing water at low flow rates. There are no widely available, commercial products for neighbourhood scale or larger. The best application of Hydraulic Ram Pumps may be for agricultural or livestock needs near a river. The major drawback is the low efficiency and wastage of these pumps, along with their relatively low flow. The pump may provide a simple alternative to pump water for agricultural purposes from a nearby stream or river with no additional power requirements.

Operation and Maintenance: A Hydraulic Ram Pump will operate 24 hours a day, 7 days a week for many years with no external power requirement. Regular maintenance of the main valve and the check valve is required to ensure longevity, and the air in the air vessel must be regularly checked and refilled. Apart from that, minimal maintenance is needed. Although it requires no external power source, it does need a continuous inflow of water from the source. It is recommended to check the performance of the ram pump once a month. Inlet filters on the feed pipe may require daily or weekly checks and cleaning, depending on the available water quality.

Health and Safety: There are relatively few risks associated with Hydraulic Ram Pumps. PVC and other brittle materials should be avoided when used with compressible fluids. As the system runs on renewable energy, environmental impacts are considered negligible. Where the Hydraulic Ram Pump uses surface water (e.g. from a river), care must be taken for proper water treatment.

Costs: Homemade Hydraulic Ram Pumps are relatively cheap and comparable to the available HDPE piping and fittings required to install them. Commercial pumps, especially with metal components, will be more expensive, although they will be more robust and offer a longer life cycle than locally fabricated options. Actual costs differ due to factors such as size and geography. An indicative price is in the range of 150–400 USD.

Social and Environmental Considerations: Some technical capacity is needed to fabricate and troubleshoot a Hydraulic Ram Pump. As the periodical closing of the main valve creates a clicking sound, Hydraulic Ram Pumps may be heard over some distance. It is therefore recommended that they be located away from houses and public buildings such as schools and health centres. The Hydraulic Ram Pump is a renewable energy water-pumping technology, which harnesses the energy contained within flowing water to pump a portion of that water to a higher elevation. No other energy is required as long as there is a continuous flow of water, which makes it an environmentally friendly pumping application.

Strengths and Weaknesses:

(+) Simple technology
(+) Fabricated using readily available materials from the local market
(+) Requires no power input

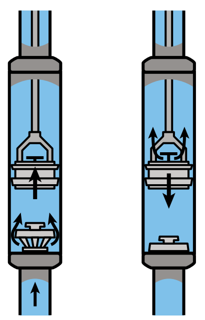
(−) Produces low flow rates
(−) Often not readily available in commercial sizes

→ **References and further reading material for this technology can be found on page 215**

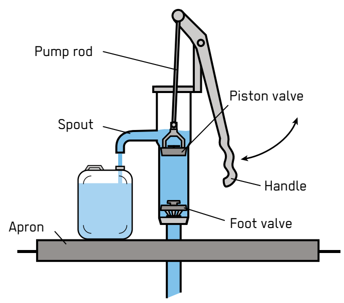
Piston-Plunger Suction Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation * Recovery	** Household * Neighbourhood City	** Household ** Shared Public	Positive displacement pump, all working parts above ground
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	

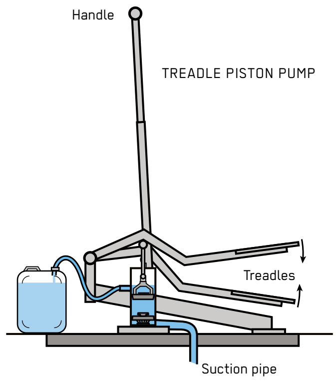
PISTON PUMP OPERATION



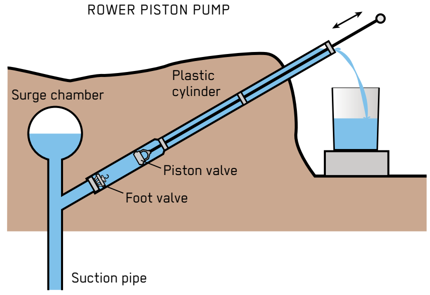
PISTON PUMP



TREADLE PISTON PUMP



ROWER PISTON PUMP



A Piston-Plunger Suction Pump is a positive displacement pump that displaces a fixed amount of water per cycle. All working parts are usually above ground. This type of pump can be quite common in some areas, and can be rehabilitated in emergencies to bring them back into use, though it tends to not be suitable in acute emergencies where infrastructure must be built. It is instead more suitable for long-term water supply in rural areas (or for irrigation purposes). Non-suction Deep Well Piston Pumps are described in A.4.

Piston-Plunger Suction Pumps can be both manually (by hand or foot) or mechanically operated. They function through a sliding seal within a cylinder, which moves up and down (reciprocating action) to force water through one of two non-return valves, usually located within the pump head itself. This action creates a vacuum in the suction pipe that pushes water up the pipe through atmospheric pressure.

Design Considerations: The maximum height to which water in the suction pipe can rise is limited and determined by atmospheric pressure. Theoretically, this is the point at which the atmospheric pressure pushing water up the pipe is equal to the weight of the water column in the pipe (i.e. 10.34 metres). In reality, however, imperfect suction conditions and friction losses in the pipe mean that at sea level, this maximum is more likely to be around 7 metres. At higher altitudes, this will be even lower (e.g. around 4.5 metres at an altitude of 2,400 metres) as there is less atmospheric pressure that can push the water. An advantage of this pump type is that a higher flow rate is possible (between 3,000–4,500 L/hour from 5 metres depth) compared to non-suction types (2,500–3,000 L/hour at the same depth), making it well suited for small-scale irrigation requiring larger volumes of water.
There are different varieties of the pump available both for irrigation or drinking water supply. Pumps used for irrigation generally serve a larger demand and are subsequently designed to be operated using stronger body parts

(such as the legs or back). For example, rower pumps can be operated sitting or standing using a rowing action performed by the arms and back, whereas treadle pumps are operated using a stepping action performed by the legs to activate pistons under each foot. Suction pumps usually need priming to create a vacuum, which involves pouring some water into the cylinder to create an airtight seal between the piston seals and cylinder. Additionally, it is essential that the intake pipe is airtight to facilitate efficient pump priming and operation. Having a non-return foot valve at the other end of the suction pipe helps to hold water in the pipe once it has entered. In this case, even though it may leak back into the well over time, less effort is required to bring water back between pumping intervals.

Materials: Materials needed include the pump mechanism, a suction pipe to the water source, potentially a non-return valve at the end of the pipe, and for some pumps, a discharge pipe to deliver water to a higher elevation than the pump. In many cases, this type of pump is produced locally. Availability will depend on country context.

Applicability: Manually operated Piston-Plunger Suction Pumps are most viable in emergencies when used at a household level. If they already exist in communities requiring an emergency response, they can be overhauled to be fully operative rather than being newly installed. Depending on the design, they can be used either for drinking water supply (e.g. cast-iron suction pump) or for small-scale irrigation (e.g. treadle or rower pump). As these pumps operate using suction lift, they are only suitable for shallow aquifers. However, within this context, they can be useful in situations where an offset pump is needed (e.g. withdrawing water from a riverbed well with the pump offset on the riverbank), or where higher volumes of water are needed (e.g. irrigation for small gardens).

Operation and Maintenance: The maintenance requirement for Piston-Plunger Suction Pumps is less onerous than for most other handpumps, as there are fewer working parts, and all the working parts are above ground which means that maintenance is more easily carried out. The parts that do need to be replaced are the piston seals and valves. These pumps can use plastic or metal for both the cylinder and suction pipe. From experience, if metal components are used in conjunction with groundwater with a pH of less than 6.5, corrosion is more likely to require a frequent replacement of the affected parts, particularly pump rods and pipes. Pumps used for irrigation tend to have a different ownership structure, and are often owned by individuals or groups for productive use (i.e. irrigation of crops), and because of this vested interest they may be better maintained compared to pumps used for non-productive use (i.e. drinking water) that may have been donated rather than purchased.

Health and Safety: The main health and safety issue is that microbiological water quality can be compromised if contaminated water is used to prime the pump. Additionally, these pumps withdraw water from shallow aquifers, which are by nature more prone to contamination, particularly in urban areas or where there is a source of pollution nearby. Chemical water quality can be an issue in some metal pumps if the groundwater has a pH of 6.5 or less, as solubility of iron from pipes is increasingly likely. If lead is used for the weighted non-return valve as part of soldering or if it is integrated into brass fittings, it may leach into water at pH values of 7 and below. Lead contamination poses a direct health risk, whilst iron leaching from pipes is a more indirect risk where it can cause or worsen the effect of iron-related bacteria, affecting taste and colour to the point where people may choose an alternative, unsafe source.

Costs: Costs are usually within a range of 100–200 USD. Ongoing costs are low, as there are fewer moving parts. For some pumps, parts can be fabricated locally.

Social and Environmental Considerations: Generally, these pumps are well accepted. As this pump is mainly operated manually it represents an environmentally friendly way of extracting water, with limited risk for over-exploiting the water source used for pumping.

Strengths and Weaknesses:

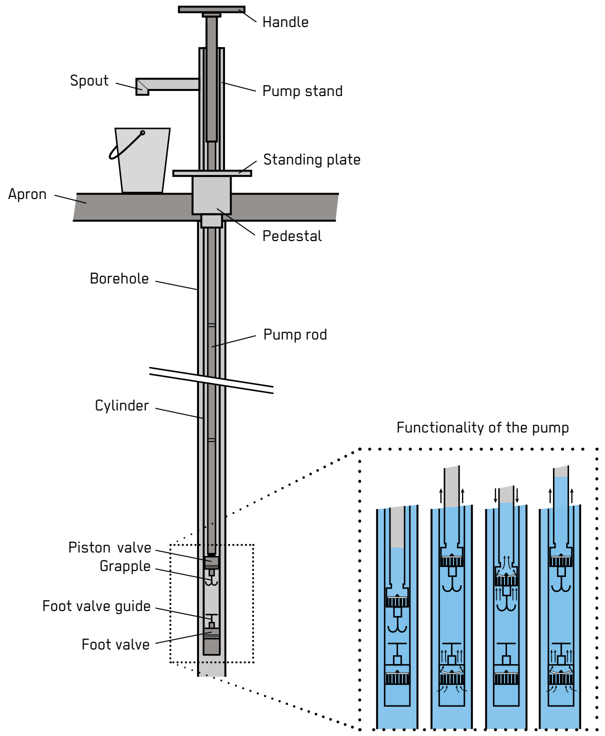
(+) Requires low O & M due to fewer working parts
(+) Easier O & M because working parts are accessible above ground
(+) Good for offset pumping situations

(−) Lifts only limited amounts of water
(−) Can be contaminated during priming

→ **References and further reading material for this technology can be found on page 216**

Direct Action Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation * Recovery	** Household * Neighbourhood City	** Household ** Shared * Public	Positive displacement pump, medium lift pump, water column lifted directly
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	



A Direct Action Pump is a positive displacement pump that displaces a fixed amount of water per cycle. Water is lifted or displaced directly by the user without additional levers or bearings. The pump is mostly unsuitable for emergencies and should be reserved for long-term water supply in rural areas.

Direct Action Pumps are manually operated. They work through directly lifting and displacing the water column in a reciprocating manner, causing the water to move into the pump head on both the up and down stroke due to two non-return valves, one at the bottom of the outer pipe and the other at the bottom of the inner pipe. Maintenance requirements are low, and underground components are made mostly from plastic, so they are corrosion resistant and easier to handle.

Design Considerations: Direct Action Pumps can generally lift water to around 15 metres. As the water column is lifted directly, pumping water from greater depth is usually not feasible. The only way this can be achieved is by reducing the weight of water in the pipes through a modified pipe design (e.g. with the Canzee pump, this would require a 40 mm outer and 32 mm inner pipe, rather than the usual 50 mm/40 mm configuration). Flow rates are generally between 2,500–3,000 L/hour at 5 metres in depth, which is slightly less than suction pumps but still better than deeper well pumps.
There are two main types of Direct Action Pump in use, the Tara and Canzee pump, which differ slightly from each other. Both of them use two non-return valves, and both require the water column to be lifted directly on the upstroke (during which water is held in place by the non-return valve of the inner pipe). However, they differ in two ways. The Tara pump has an inner pipe that is hollow and sealed which makes it buoyant, whereas the inner pipe of the Canzee fills with water that is lifted. Also, the hollow

inner pipe of the Tara pump has a piston at the base (with integrated non-return valve) that seals against an outer pipe, above which water is lifted within the outer pipe on the upstroke. In this way, the outer pipe in the Tara acts like a cylinder, in contrast to the Canzee pump which allows water to enter both the inner and outer pipes on alternate strokes, and there is no piston or cylinder.

Materials: The materials needed include the pump head, outer pipe with valve, inner pipe with valve, the connection from the inner pipe to the handle (usually made from metal) and the handle (made from metal, plastic or wood). In many cases, this type of pump is produced locally. Availability will depend on country context.

Applicability: Direct Action Pumps are used mainly for drinking water supply. As the pump works by directly lifting or displacing a water column, the depth to which users can easily operate it is limited to water tables at up to around 15 metres in depth, and the pump must be set directly over the well or borehole. These pumps are more often viable at household level and in the context of rural communities with fewer users per pump, rather than in emergencies and/or urban settings where there are dense populations and where manual water extraction from a single shared source may not meet the volume demand **(see S.8)**. This type of pump is suited to lower numbers of users (e.g. up to 150), as the plastic materials are not as robust as deep well pumps, though more intensive use is possible but will require more maintenance.

Operation and Maintenance: O & M is easier for Direct Action Pumps than deeper well pumps, as they lift water directly using no levers or bearings, resulting in fewer maintenance issues in comparison. Plastic pipes and fittings are lighter, which makes extracting the pipes easier and more straightforward than for metal pipes. In addition, for the Tara pump the foot valve can be removed without actually removing the outer pipe. Some of the parts can also be locally manufactured (e.g. valve washers can be made from inner tubes for the Canzee pump), which can theoretically contribute to sustainability. Another factor reducing maintenance is that the pump rods and rising mains are made from plastic, making them resistant to corrosion by groundwater with a low pH such that less repair and replacement is needed. However, certain parts will eventually need replacement, either more frequently (e.g. valve washers) or less frequently (e.g. pump handle and rod connecting to rising main). While the design lends itself to easy maintenance, the reality is that even such simple pumps are often not maintained as required. There are various reasons for this that are separate from the pump technical design **(see S.8)**.

Health and Safety: Since most of the below-ground components are made of plastic, there are no concerns with the solubility of metals in lower pH water, meaning also less exacerbation of the effect of iron-related bacteria on water quality. One issue with Direct Action Pumps is physical over-exertion, as the water must be lifted directly. This could cause back issues for adults, and long pumping times are not suitable.

Costs: Costs for Direct Action Pumps are usually within a range of 150–500 USD. Ongoing costs are low since there are fewer moving parts, and for some pumps, the parts can be fabricated locally.

Social and Environmental Considerations: Generally, these types of pumps are well accepted. As they are manually operated, they represent an environmentally friendly way of extracting water, with limited risk for over-exploiting the water source used for pumping.

Strengths and Weaknesses:

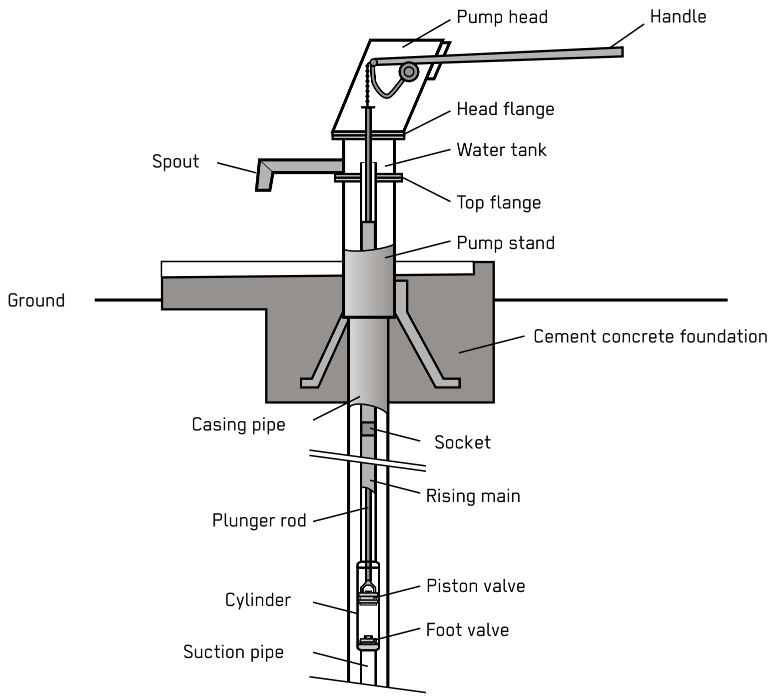
(+) Requires less O & M than deep well pumps due to fewer working parts and plastic components
(+) Relatively easy access to pipes and valves below ground
(+) Relatively cheap and easy to manufacture

(−) Relatively limited water lift
(−) Not suitable for too many users
(−) Can be physically hard work to operate, especially for children or the elderly

→ **References and further reading material for this technology can be found on page 216**

Deep Well Piston Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	* Household ** Neighbourhood City	Household ** Shared ** Public	Positive displacement pump, medium to deep lift pump, water column lifted with mechanical assistance
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



A Deep Well Piston Pump is a positive displacement pump that displaces a fixed amount of water per cycle. Water is lifted from depths of up to 90 metres with the aid of additional levers or gears. The pump is rarely suitable in the acute phase of an emergency and is instead better for long-term water supply in rural areas with low population densities.

Most Deep Well Piston Pumps are manually operated lever-action handpumps, although flywheel action designs also exist. These pumps function using reciprocating action through a connection from the lever or gear via pump rods to a piston in a cylinder situated underwater. Here the presence of non-return valves ensures water is lifted in the rising main.

Design Considerations: When pumping from over 15 metres in depth, the weight of the pump rods and water column become too much to lift directly, so an additional form of mechanical advantage is needed to make it easier to lift the water column. This is the main feature of deep well handpumps. For depths of up to 45 metres, mechanical levers are generally included in the design (e.g. India Mark pumps, or Afridev design), while for depths of up to 90 metres, either gearing mechanisms (e.g. Duba Tropic pump) or heavy-duty counterbalanced lever systems (e.g. India Mark Deepwell) are used, both in conjunction with cylinders designed for higher pressures. Deep Well Piston Pumps can be used for shallower groundwater, but some designs rely on the weight of the pump rods for the downstroke (e.g. India Mark pumps) so may not perform as well. Flow rates tend to vary between 600–900 L/hour at 40 metres depth for conventional lever pumps depending on the design, which is reduced somewhat for depths of up to 95 metres.

These pumps work using a reciprocating piston within a cylinder. The cylinders can be larger than the rising main (so removing a piston or foot valve requires removing the entire rising main pipe, for example with the India Mark 2) or can have an open top design (where piston/valve removal is possible while keeping the rising main in place, for example with the India Mark 3, Afridev, or Blue Pump). In the latter case, the rising main must have a large enough diameter for the piston and foot valve to pass, which can increase the pipe weight. This has been solved using plastic pipe for the rising main (e.g. India Mark 3 pump or Afridev) and by doubling up the casing to act as rising main (e.g. Blue Pump for a new borehole).

Materials: Materials needed include the pump head, lever or gearing mechanism, rising main (can be plastic), pumping rods (sometimes made with stainless steel) connected to a piston with a non-return valve within a cylinder with foot valve. This type of pump tends to be produced at a few production sites in a few countries and exported, though there have been some attempts at local production.

Applicability: Even though Deep Well Piston Pumps service higher numbers of users than other handpumps, they are still more suited to providing drinking water to rural communities with fewer users per pump rather than for emergencies and/or urban settings with dense populations where manual water extraction from a single shared source may not meet the volume demand **(see S.8)**. It is also essential wherever possible to introduce pump models that are already in use and for which a spare parts market exists.

Operation and Maintenance: O & M can be demanding for Deep Well Piston Pumps as they are designed for greater depths, requiring a more robust pump construction that adds more weight, which in turn requires the use of heavy lifting equipment. Greater depth also means that more equipment must be removed during maintenance, which requires more time and skill. The moving parts, such as levers or gears, also require more regular maintenance and replacement. In certain settings where pumps are heavily used, breakdowns can be expected every three to four months (e.g. for India Mark and Duba pumps) or even monthly (e.g. for Afridev). Some pumps, though, aim to prolong the functionality between breakdowns (12–36 months for the Blue Pump).
Since maintenance will be needed at some point in time for every pump type, certain aspects of a pump can facilitate that maintenance. A design that requires fewer tools for maintenance procedures can help (e.g. Afridev), and if the rising main does not have to be taken out to reach the piston, foot valve or cylinder, the process is easier (e.g. Afridev, India Mark 3 and Blue Pumps). Plastic or metal can be used for the rising main, while metal is used for pumping rods, pistons and cylinder assemblies. Where metal components are used in conjunction with groundwater that has a pH of 6.5 or less, corrosion is likely. This means more frequent replacement of affected parts, especially pump rods and pipes, though the damage can be mitigated by using stainless steel for the pumping rods or cylinder (e.g. Blue Pump) and plastic rising pipes where possible (e.g. Afridev, Blue Pump, India Mark 3), although this may also increase the cost. The frequency of O & M also depends on the quality of local spare parts, which may be poor even where a pump design has been standardised. Added to this is the reality that pumps are not maintained as they should be, usually for various reasons separate from the pump technical design **(see S.8)**. One approach to address this that has been tried for Blue Pumps has been to employ professional regional repair mechanics carry out the repairs rather than the communities.

Health and Safety: One health issue can be over-exertion, even where the pumps have a mechanical advantage. Chemical water quality can become an issue with some metal pumps. Where groundwater has a pH of 6.5 or less, the solubility of iron from pipes is increasingly likely and can cause an indirect health risk, and lead can leach out from certain welds and fittings, regardless of pH **(see A.2)**.

Costs: Deep Well Piston Pump capital costs can vary significantly. For depths of 50 metres, costs range from less than 1,000 USD up to 5,000 USD. Ongoing repair and maintenance costs tend to be between 60–150 USD per year per water point, which is higher than for shallower well pumps. Costs per pump can be much higher (300–600 USD) where maintenance is done centrally and pumps are remote.

Social and Environmental Considerations: Generally, these types of pumps are well accepted and meet the needs of users. As most of these pumps are operated manually, they represent an environmentally friendly water extraction option with limited risk for over-exploiting the water source used for pumping.

Strengths and Weaknesses:

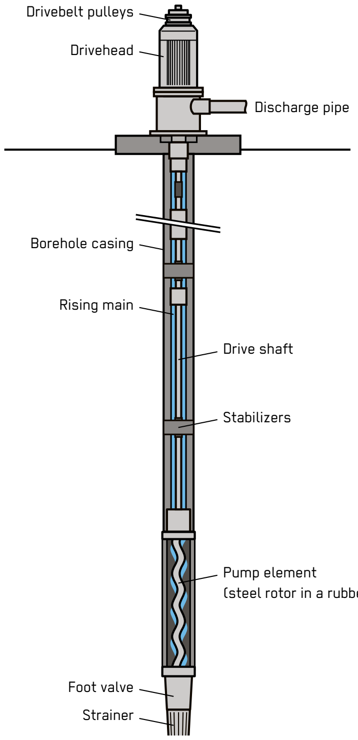
(+) Design is well proven and robust, suited to many users
(+) Can manually lift from deeper depths

(−) Has lower flow rate at deeper depths
(−) More difficult to access the piston/valves on some designs
(−) Greater O & M requirement than other handpump types
(−) Manual versions can be heavy to operate

→ **References and further reading material for this technology can be found on page 216**

Deep Well Progressive Cavity Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood City	* Household ** Shared ** Public	Positive displacement pump, shallow to deep lift pump, water column lifted with mechanical assistance
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	*** High	*** High	



A Deep Well Progressive Cavity Pump is a positive displacement pump that displaces a fixed amount of water per cycle. Water is lifted from depths of up to 300 metres using a helical rotor rather than a reciprocating piston. These pumps are useful for all phases of an emergency.

Most Deep Well Progressive Cavity Pumps are mechanised, though handpump versions also exist. They function using rotary rather than reciprocating action. Different drive mechanisms exist that can be powered by hand, electricity (grid or solar) or diesel/petrol engines. In the past, the drive mechanism was situated at ground level and connected to a drive shaft (either through a V-belt or a geared drive head), but nowadays an electric motor is close-coupled to a short section of flexible drive shaft within the borehole. In both, the drive shaft connects to a single helix metal rotor that is in constant contact with and rotates within a double helix rubber stator.

Design Considerations: Deep Well Progressive Cavity Pumps can operate over a range of depths up to 300 metres, with flow rates up to 50,000 L/hour at low heads. In general, they are the pump of choice for higher head and lower flow requirements. They operate through the rotation of a helical rotor, which is shaped as a single helix that sits within a stationary double-helix rubber stator. Water occupies the cavity between the two, and when the rotor turns, this cavity moves ('progresses') upwards together with the water (hence the name of the pump), causing the water to be lifted in the rising main. This rotary design does not need a system of non-return valves, as is the case with reciprocating pumps, but a foot valve is still usually installed under the rotor to prevent backflow. The advantage of mechanised positive displacement pumps (of which progressive cavity is the main type) is that water flow does not vary significantly with differences in head.
There are a few different considerations for operating this type of pump. These pumps can be set up in parallel, with both pumping into a pipe **(see A.8)**. Where the drive

mechanism is at ground level with a vertical drive shaft in a borehole, the borehole also needs to be vertical to allow the drive shaft to hang vertically. Also the pumps should never be operated against a closed valve, as this can damage the pump and fittings. Progressive Cavity Pumps also exist as suction pumps (rather than only deep well), and in this case there is a maximum height to which water can rise in a pipe depending on atmospheric pressure, which itself varies with altitude **(see A.2)**. Another design consideration for motorised suction pumps is to ensure that enough pressure is maintained at the suction port to prevent cavitation. This is where air bubbles form in the water under low pressure, which then collapse, triggering shockwaves that can cause significant damage to the pump. To prevent this, the Net Positive Suction Head (NPSH) needs to be calculated using atmospheric pressure at the pump site, NPSH data from the pump manufacturer, friction loss in the inlet pipe and vapour pressure.

Materials: Materials needed include the rising main, drive shaft (stainless steel), motor, a helical rotor (usually chromium plated steel), a stator (rubber) and foot valve. This type of pump is produced at a few production sites in a few countries and exported.

Applicability: Deep Well Progressive Cavity Pumps can be a good choice for emergencies, when detailed pumping design is not usually possible in advance (compared to velocity pumps where good design is usually required). This means one choice of pump will serve different heads without too much variation in flow rate. These pumps are also more suitable for pumping water with solids or abrasive particles compared to other common types of borehole pump (e.g. velocity pumps) and are used for both drinking and non-drinking water applications. Even so, borehole pumps still need to be sized and positioned correctly to prevent excessive velocity across a screen (which pulls in more particles, **see I.8**).

Operation and Maintenance: Deep Well Progressive Cavity Pumps have a simple mechanical design, which makes them generally more reliable and easier to maintain than other mechanised pumps. When the drive mechanism was at ground level in older designs, everything was easily accessible so maintenance was more straightforward, but issues with constant pump vibration commonly resulted in shaft seal failures. Submersible pumps are now designed with close-coupled motors and flexible shafts lacking joints, meaning the life of the parts is now five times greater than before, but here motor maintenance requires removing it from below ground, which involves removing the riser pipes as well. Stators will wear out first however, and for every two changes of stator, a rotor should also be changed. Stators in storage can degrade quicker with increased heat, humidity, sunlight or ozone, so they must be stored correctly. If stators are older than five years, there will already be some degradation before they are even installed, and the operational lifetime will be decreased. Metal is used for part of this type of pump; where these components contact groundwater with a pH of 6.5 or less, corrosion is likely to occur, which means more frequent replacement of affected parts. For this pump, the galvanised iron riser main is more at risk than the other metal parts, which are made from stainless steel (e.g. drive shaft, helical rotor).

Health and Safety: Only trained personnel should work on mechanised pumps. The equipment should be off limits to the general public, and any fast-moving V-belts should be shielded. Chemical water quality can be an issue with some metal pumps. Where groundwater has a pH of 6.5 or less, iron from the pipes may begin to dissolve, causing an indirect health risk, and lead can leach out from certain welds and fittings regardless of pH **(see A.2)**. If engine-driven pumps are employed, potential health risks with engine emissions should be evaluated.

Costs: Progressive Cavity Pumps cost around 1,250 USD for depths of 50 metres. Typically, stators (170 USD) last around 12,000 operating hours, though should be replaced every three years no matter what, due to the shelf life of the rubber. Rotors (140 USD) last around 30,000 hrs.

Social and Environmental Considerations: The end user of the water supply system typically does not interact with these pumps. The complexity of O & M of the system should be considered, as trained and capable staff are required. There is a risk of over-exploiting (ground)water resources that should be considered when using this type of pump. For motor driven pumps, major environmental considerations relate to use of consumables (lubrication, oil, chemicals) and power sources. A plan for the appropriate containment and disposal of consumables should be in place. The pump may also be driven with solar power **(see S.10)** to limit the environmental impact of its operation.

Strengths and Weaknesses:

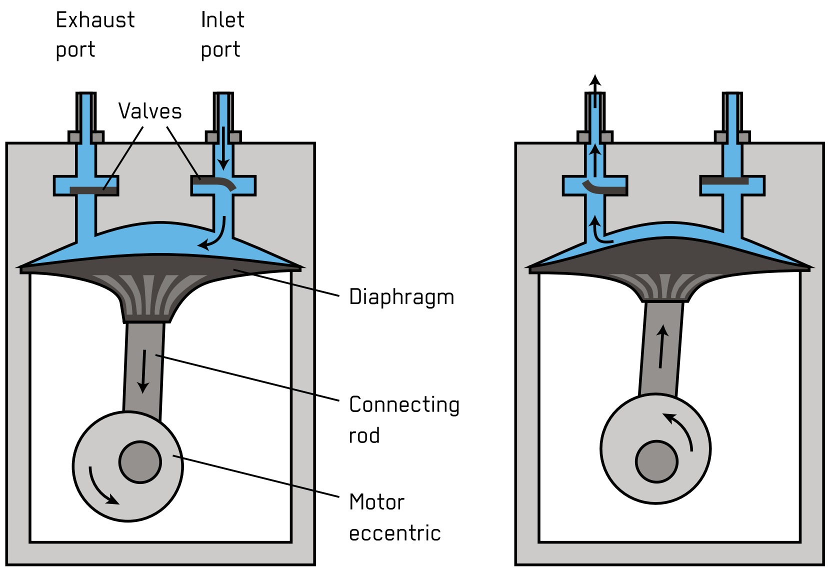
(+) More resistant to aggressive groundwater (through having more stainless steel)
(+) Can cope with pumping solid particles
(+) Flow rate does not vary too much with increasing head, so less design needed

(−) Not as readily available in the marketplace
(−) Running dry for even a minute will destroy the stator
(−) Running against a closed valve can damage pump and fittings

→ **References and further reading material for this technology can be found on page 216**

Diaphragm Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response Stabilisation ** Recovery	** Household ** Neighbourhood City	Household ** Shared ** Public	Positive displacement pump, high pressure pumping of water and for dosing of chemicals
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



INLET STROKE EXHAUST STROKE

A Diaphragm Pump is a positive displacement pump that displaces a fixed amount of water per cycle. Diaphragm Pumps use a flexible diaphragm to force fluid through the pump and are mainly applicable in the recovery phase.

Diaphragm Pumps are available in mechanical/electrical, pneumatic and hydraulically actuated forms. Commercial Diaphragm Pumps are available in a wide range of sizes, capacities and materials. The variety of materials, various actuator types and Diaphragm Pump geometries allow Diaphragm Pumps, in general, to pump a wide range of liquids apart from drinking water, including slurries of various viscosities, degrees of corrosiveness, solid content and other characteristics. Diaphragm-type pumps are also available in arrangements designed specifically for below-ground deep-well fluid abstraction.

Design Considerations: Diaphragm Pumps operate via the expansion and contraction of a diaphragm that is used to move a liquid, such as for delivering water to the surface. These pumps are a robust option for thick or viscous fluids but are not often feasible if high flow rates are needed. Material compatibility with the pumped liquid must be carefully considered. Manufacturers generally offer several options for pump body and diaphragm material to suit most types of pumped liquids and should be closely consulted for compatibility.
All positive displacement pumps are capable of generating large pressures on the discharge side, so care must be taken to ensure these pumps do not operate against closed valves or blockages without a method of protecting the downstream valves and fittings; otherwise, the pressure will continue to build in the system until the motor overloads or the weakest downstream pipe fails.
Diaphragm Pumps can also be manually operated, motor driven, or pneumatically or hydraulically powered. The Vergnet Hydro pump is one example of a deep-well Diaphragm Pump operated by foot with a pedal, and it has

a maximum recommended lift of 60 metres. The piston movement is hydraulically transmitted via a flexible hose to a rubber diaphragm down in the pumping element, and the expansion and contraction of the diaphragm is used to deliver water to the surface.
The suction head is limited by atmospheric pressure, pump design and suction pipe material and arrangement. The individual pump selected should be evaluated against suction lift requirements.

Materials: Diaphragm Pumps are available in a wide range of metallic and non-metallic materials. The manufacturer or a specialist should be consulted to determine material compatibility with the pumped fluid and environment. Options for powering Diaphragm Pumps include electric motors, compressed air or hydraulic fluid.

Applicability: Diaphragm Pumps are not appropriate for the large-scale pumping of water for community use. They are instead more useful for small, controlled flow rates, for dosing chemicals and corrosive liquids (e.g. chlorine) or for pumping water with solid particles (e.g. for pumping water containing a high percentage of suspended solids, such as when dewatering, or for slurry recirculation while drilling boreholes). As there are options that do not rely on electrical power, dewatering with Diaphragm Pumps can be achieved with compressed air if available.

Operation and Maintenance: The operating principle for Diaphragm Pumps is simple, and pumps are easily maintained. Diaphragm Pumps generally have fewer parts that wear than other pumps with rotating assemblies and bearings. Motor-operated Diaphragm Pumps will have some mechanical wearing parts, but Diaphragm Pumps operated pneumatically or hydraulically do not have wearing parts apart from the flexible membrane that is moved via a pressure differential between the pumped and the actuating fluid. Many Diaphragm Pumps are designed with the inlet and outlet valves as integral parts of the pump. The manufacturer should be consulted to determine the expected life of the membrane and wearing parts based on service conditions, duty-cycle and fluids pumped.

Health and Safety: Best safety practices should always be followed around mechanical equipment. Compressed air and hydraulic power may reduce electrical hazards but can still be hazardous or deadly if handled improperly. When pumping chemicals, proper personal protective equipment should be worn, and the manufacturer's recommendations should be followed. If engine-driven pumps are employed, potential health risks with engine emissions should be evaluated.

Costs: The cost of small Diaphragm Pumps is dependent on the material selected. For small flow rates (< 5 L/sec), prices are usually between several hundred to several thousand US dollars. Standard thermoplastic and aluminium options are typically less expensive, while specialised thermoplastic components or stainless-steel alloy components are typically the most expensive. Thermoplastic or aluminium pumps may be relatively affordable and resilient compared to other commercial pumping options. Pump power options should be considered in the cost. Compressed air supplied by a gas-powered compressor provides flexibility for pumping without electric power but may add operating costs compared to electric motor-driven options.

Social and Environmental Considerations: The end users of a water supply system typically do not interact with these pumps. The complexity of O&M of the system should be considered, but trained and capable staff are always required. For smaller, simple Diaphragm Pumps, like the Vergnet handpump, minimal training and O&M will be required. For motor driven pumps, major environmental considerations relate to use of consumables (lubrication, oil, chemicals) and power sources. A plan for the appropriate containment and disposal of consumables should be in place. For smaller pumping systems, solar power or hybrid power systems with solar panels are feasible and often have a lower environmental impact and a short payback period.

Strengths and Weaknesses:

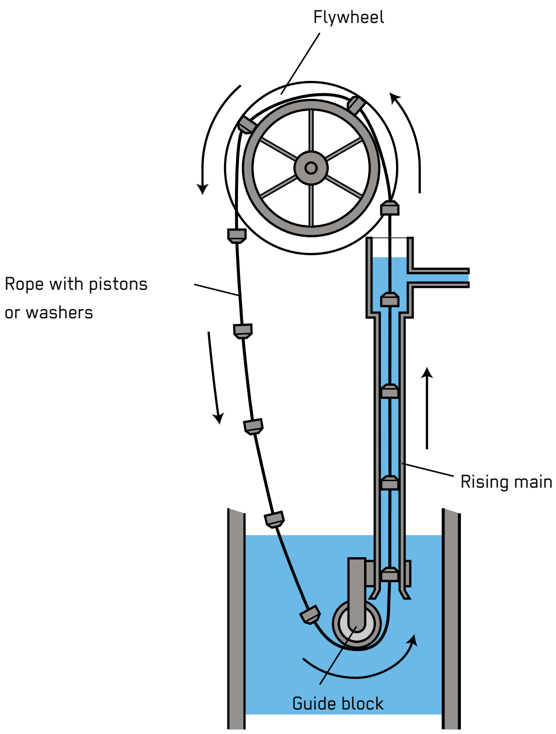
(+) Available in many sizes and material options
(+) Variable flow rate
(+) Available in various power options (manual, motorised, hydraulic power, pneumatic)
(+) Can pump corrosive liquids and solids if properly designed
(+) Capable of providing suction lift

(−) Generally low flow rates only
(−) Somewhat expensive, therefore only viable for municipal or larger installations

→ **References and further reading material for this technology can be found on page 216**

Rope Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household ** Shared * Public	Positive displacement pump, simple shallow lift handpump
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



A Rope Pump (also known as a rope and washer pump) is a positive displacement pump that displaces a fixed amount of water per cycle. Water is lifted directly using the continuous movement of a flywheel moving in one direction (rather than in a reciprocating manner). Components below ground are mostly made from plastic, making them corrosion resistant and easier to maintain. These pumps are usually not suited to the acute response phase, and are more for long-term water supply in rural areas, where they are good for upgrading open wells and disused boreholes to improve access and water quality.

Rope Pumps are usually manually operated, but may also be motorised. They function using a loop of rope with washers attached, which connects the flywheel at the top to a flared entry point to the rising pipe at the bottom. The washers fit only loosely within the rising pipe, but this is enough to ensure that at a certain rotational speed, more water is lifted than falls by gravity around the washers, with the net result that water is transported into the pump head.

Design Considerations: There are several key features of a Rope Pump. The flywheel has two handles, one on each side, meaning it can be operated by either one or two people. A loop of rope connects the flywheel above ground to a guide below the water surface. A metal flywheel is often joined with two sides of old tyres, which help grip the rope and washers within its central groove. Nylon rope may be used, although it tends to slip and stretch more than polypropylene (PP). Washers are spaced on the rope at a minimum of 1 metre intervals (to avoid slippage on the flywheel) and are supported and restricted by two knots around each washer. Washers tend to be made from either moulded high-density polyethylene (HDPE) pieces or rubber discs cut from car tyres.
For Protected Dug Wells **(I.7)**, the rope enters via a point on the slab and makes its way to a guide situated under the rising main pipe, though there is also a borehole version where the rope is funnelled after it leaves the flywheel by an above-ground guide that brings it closer so it will enter a narrow borehole (even down to 75 mm diameter is possible). The rope descends into the well without

a pipe and is then caught by a flared catcher pipe that is part of the guide structure at the base of a rising pipe. Its function is to guide the rope back into the bottom of the rising main pipe, which is also flared. Having flared ends helps prevent the rope or washers from catching on the end of the pipe and damaging it while making the pumping motion smoother. Finally, the rising main, which can have a diameter of between 18 to 40 mm depending on the lift, is connected with the pump head and spout.
Manually operated rope pumps can be used for water depths up to 50 metres, while they have also been motorised for depths up to 100 metres. Flow varies on the lift and pumping method. Manual pumps at 5 metres depth can give around 5,000 L/hour, which is reduced to 500 L/hour at 50 metres depth, while motorised pumps at 100 metres depth can give 1,100 L/hour.

Materials: The Rope Pump can be produced with locally available materials and skills using small workshops or can be purchased from specialist manufacturers. Materials needed include the pump head (metal), rising pipe (plastic), rope with washers, a flywheel, handles, and rope guides. In many cases, this type of pump is produced locally, but this is not true in all countries. Availability will depend on country context.

Applicability: Rope Pumps are mainly suited for household use or in the context of rural community water supplies, rather than in emergencies and/or urban settings where there are dense populations and where manual water extraction from a single shared source may not meet the volume demand **(see S.8)**. The pump is more suited to a low number of users (e.g. up to 50) due to the plastic materials that are not very robust. It is used mainly for drinking water or for irrigation and watering livestock and can be useful for increasing the yield from hand-dug wells or providing a hygienic collection system for a surface water source in an emergency.

Operation and Maintenance: Although all hand-powered pumps require a comprehensive strategy for maintenance due to the high level of usage and wear and tear, O&M is easier for Rope Pumps than other handpumps due to the simple design. There are fewer parts with no levers or bearings (apart from models that have bearings on the flywheel axle), which results in fewer pump maintenance issues. Also, the use of plastic pipes and fittings means that extracting pipes is easier and more straightforward than for metal pipes (total weight of around 15 kg, 5–10 times lighter than other piston pumps). Also, all parts can be manufactured locally, contributing to sustainability. Maintenance of the underwater components is also reduced, as they are made from plastic and are therefore resistant to corrosion by groundwater with a low pH. Certain parts will, however, require replacement at some point (e.g. washers or ropes), though these are easily replaced and can be manufactured on site most of the time. While the design lends itself to easy maintenance, the reality is that even these pumps are not maintained as needed, for reasons usually separate from the pump design **(see S.8)**.

Health and Safety: Since most of the below-ground components are made from plastic, there are fewer concerns about the solubility of metals in lower pH water and any related direct and indirect health consequences. There is a small risk of microbiological contamination at the point where the rope is exposed within the pump head, and some designs mitigate this through a pump head cover.

Costs: Manually operated Rope Pumps tend to cost between 50–170 USD depending on context. Ongoing costs are very low (around 20 USD or less per year per pump) since parts can be made locally — this is a lot less than many other handpump types. Any repair to metalwork is easily done if there is a local workshop with welding capabilities.

Social and Environmental Considerations: These types of pumps are very well accepted by people where they have been installed. As this type of pump is mostly applied in its manual version, it represents an environmentally friendly way of water extraction, with limited risk for over-exploiting the water source used for pumping.

Strengths and Weaknesses:

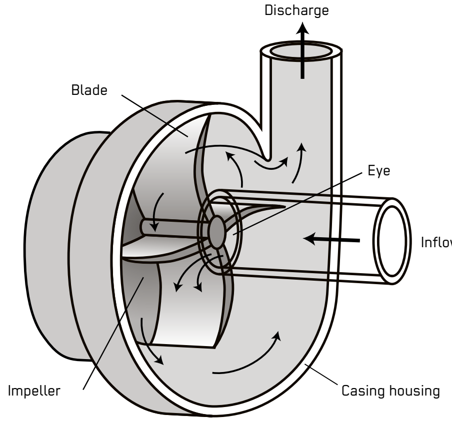
(+) Lower O&M requirements than deep well pumps due to fewer working parts and plastic components
(+) Relatively easy access to pipes and valves below ground
(+) Low cost for purchase and maintenance
(+) Can be manufactured locally

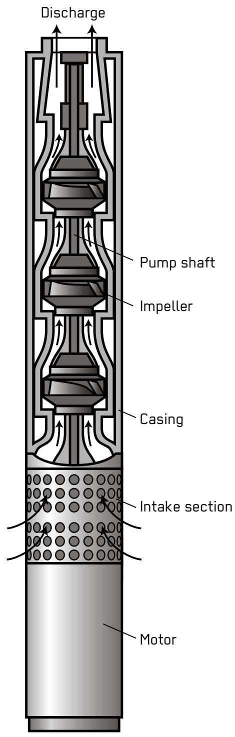
(−) Pump design not suited to too many users
(−) Possible risk of contamination through touching the rope
(−) No foot valve, meaning the raising main needs to be filled with water each time pumping starts

→ **References and further reading material for this technology can be found on page 216**

Radial Flow Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood * City	* Household ** Shared ** Public	Velocity pump, shallow to deep lift pump, water column lifted with mechanical assistance
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	





A Radial Flow Pump (also known as a centrifugal pump) is a velocity pump where a rotating impeller displaces varying amounts of water per rotation depending on the speed of rotation, which throws water outwards at right angles to the shaft. The pump is useful for all phases of an emergency.

Radial Flow Pumps function by forcing water towards the outer edge of a rotating impeller, where the discharge is captured by the pump casing and the kinetic energy is converted to pressure energy before leaving the pump. When this happens, a negative pressure zone is created at the inlet of the pump chamber, which in turn draws water into the pump. These pumps can be driven by electricity (grid or solar) or directly by diesel/petrol engines, and they can be situated at ground level (suction pumps) or submersible.

Design Considerations: Radial Flow Pumps can operate over a range of depths up to around 400 metres, with flow rates up to 280,000 L/hour at lower heads. In general, they are good for higher flow requirements, as their mechanical efficiency increases with higher flows. For borehole pumps, a non-return valve is generally installed after the impellers. An important design consideration of velocity pumps is that the water flow can vary significantly with differences in head, meaning that careful design is needed to meet flow requirements. This entails creating a system curve based on the total elevation to which water must be transported plus any additional energy (frictional) losses in the pipe at different pumping velocities **(see S.7)**. Based on this, a pump is chosen where the pump curve intersects the system curve at the desired flow rate. Pump operating points then also need to be efficient. A pump that operates at an inefficient flow rate can develop multiple issues that decrease pump life (e.g. wear and tear on seals and bearings, or cavitation). Pump choice should also match the electricity supply on site (single or three-phase). If this type of pump is driven using

solar power, a Variable Frequency Drive (VFD) is needed **(see S.10)**. Seeking the correct pump expertise is therefore essential to ensuring an efficient pump choice.
Single impeller (single stage) pumps are available, where the operational head of the pump is determined by the impeller type and speed. Where pumping to higher heads is required, (e.g. in boreholes), several impellers can be built in series within one pump (called multi-stage), or single-stage pumps can also be linked in series to double the head of the pump curve. Pumps can also be set up in parallel, with two or more pumping into one pipe. Here, the flow of the pump curve is doubled, which increases the volume that will flow depending on where it intersects the system curve. Borehole pumps have the motor situated below the water intake, and the motor is cooled by a portion of the flow that is diverted past the motor. Where this does not occur (e.g. below screens in a borehole or in a large diameter well), a shroud should be used to first direct water past the motor.
Radial Flow Suction Pumps that are directly coupled on a skid with a combustion engine are often used as a general-purpose pump in emergencies. For such pumps, there is a maximum height to which water can rise in a pipe depending on atmospheric pressure, which itself varies with altitude **(see A.2)**. Another design consideration for motorised suction pumps is to ensure that sufficient pressure is maintained at the suction port to prevent premature pump wear due to cavitation **(see A.5)**.

Materials: Materials needed include the pump stages, a pump motor or engine, and the rising main (can be various materials, but galvanised iron is often used).

Applicability: Radial Flow Pumps are often used in emergencies mainly because they are widely available, although they do require a more detailed pumping design especially for boreholes **(see I.8)**. They are suitable for different water types depending on the pump design. Some single-stage pumps are designed to pump solids, whilst multi-stage borehole pumps tend to have less space between the impeller and casing, so solids can damage the pump. They are used for both drinking and non-drinking water applications.

Operation and Maintenance: Radial Flow Pumps installed at ground level are easier to maintain, as everything is easily accessible. However, many pumps are submersible, meaning that all pipes must be removed to repair or to replace the pump itself. Repair and maintenance will be increasingly likely where pumps have not been sized correctly for the piped system (e.g. operating inefficiently) or are not sized or positioned correctly for a borehole (e.g. excessive velocity across a screen pulls in particles that degrade the pump, **see I.8**). Pump repair should be carried out in a specialist workshop, so the O&M strategy is to have spare pumps on hand in case of a problem. Metal is used for part of this type of pump; where these components contact groundwater with a pH of 6.5 or less, corrosion is likely to occur, which means more frequent replacement of affected parts. For this pump type, the galvanised iron riser main is more at risk than other metal parts, which are made from stainless steel.
In emergencies, the main operational issues with Radial Flow Suction Pumps come from problems with the suction main. These pumps cannot pump air, so any leaks or airlocks in the suction main may prevent the pump working. When starting pumping, the pumps should be primed, ensuring that the suction pipe is connected to the pump with the rubber washer (if not, air leaks into the system) and that there are no holes in the suction pipe.

Health and Safety: Electrical connections from the pump to cable should be correctly spliced with waterproof resin to prevent electric shock or electrocution. This is particularly important where pumps are used to dewater a structure when a person is present (e.g. a protected dug well during construction). Chemical water quality can also become an issue with some metal pumps. Where groundwater has a pH of 6.5 or less, iron leaching from the pipes can cause an indirect health risk, and lead can leach out from certain welds and fittings regardless of pH, causing a direct health risk **(see A.2)**.

Costs: Radial Flow Pumps are relatively inexpensive, with costs starting at 100 USD, and there is a broad range of competing brands and models. Cost increases with increasing flow or head requirements.

Social and Environmental Considerations: Generally, these types of pumps are well accepted by people. A risk of overexploitation of (ground)water resources should be taken in consideration when using this type of pump. For motor driven pumps, major environmental considerations relate to use of consumables (lubrication, oil, chemicals) and power sources. A plan for the appropriate containment and disposal of consumables should be in place. The pump may also be driven with solar power **(see S.10)** to limit the environmental impact of its operation.

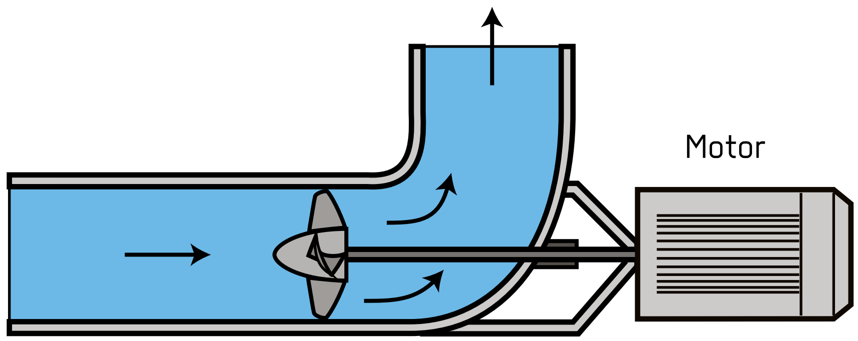
Strengths and Weaknesses:
- (+) More resistant to aggressive groundwater (through having more stainless steel)
- (+) Some pump types can cope with pumping solid particles
- (+) Readily available in most countries
- (+) Can be safely run against a closed valve for short periods of time

- (−) Flow rate changes significantly with increase in head, so a good pumping system design is needed to ensure efficient pumping and lower O&M, yet it is something few people have been trained to do

→ **References and further reading material for this technology can be found on page 216**

Axial Flow Pump

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	Household * Neighbourhood ** City	Household * Shared ** Public	Velocity pump, moves high volumes of water at low pressure
Local Availability ** Medium	**Technical Complexity** *** High	**Maturity Level** *** High	



An Axial Flow Pump is a large diesel or electric motor-driven pump capable of moving large volumes of water at relatively low heads. The most common uses for Axial Flow Pumps are for clearing water from flooded areas, lifting large amounts of flow within a treatment plant or water system, or for agricultural purposes, but they tend not to be used in the acute phase of an emergency.

An Axial Flow Pump is a velocity pump that increases flow velocity or pressure at the pump impeller to impart energy to the pumped fluid. The volume of liquid pumped is relative to the impeller size and rotational speed. Within this category, Axial Flow Pumps are distinguishable in that they push water in the same direction as the axis/shaft and not radially at right angles to the shaft, as with radial flow pumps **(see A.8)**. Axial Flow Pump impellers are shaped similarly to a boat propeller and are designed to push water along instead of creating high pressures. Vertically oriented Axial Flow Pumps are used to move very large volumes of water with minimal vertical lift (e.g. over a river berm). Pumps may also be oriented horizontally and generally offer ease of access to the rotating parts during dry periods.

Design Considerations: Centrifugal pumps can produce flow over a wide range of pressures and flow rates. Where high flow rates and very low head (less than 5–10 metres of head) is needed, Axial Flow Pumps should be considered. Generally, these pumps are installed in a single-stage arrangement. Where additional flow is needed, pumps are installed in parallel rather than in series. Axial Flow pumps do not produce significant pressure to push fluid to a height, and the maximum head is generally 5 metres or less. Axial Flow Pumps are an established and well-tested technology available from many commercial and industrial manufacturers. They should not be used in applications where a valve would be closed during pump operation. When siphons are used, Axial Flow Pumps should be designed carefully for priming considerations. As they are normally used to pump large volumes at high flow rates, these pumps are physically large with special spatial requirements. Engine-driven vertical pumping units require right angle gear drives and additional space for the maintenance of engines, drives and pumps. Axial Flow Pumps are typically a low-speed application requiring special motor designs. Synchronous motors should be considered, where applicable, to reduce the impact on the electrical system.

Materials: Most normal sizes of Axial Flow Pumps are shipped assembled. For very large applications, these pumps may need to be assembled on site. Depending on the size, additional equipment and materials may be needed (locally and/or brought in). This could be skids, valves, buildings or weather covers, construction materials and equipment. Consumables include general lubricants for bearings, such as oil and grease.

Applicability: Axial Flow Pumps are not capable of providing high pressures at discharge and are therefore not useful for supplying water to large distribution systems or elevated storage tanks. However, where high flow rates and very low pressures are needed, Axial Flow Pumps can be considered. Large Axial Flow Pumps are generally permanent installations, though tractor-driven Axial Flow Pumps do exist that are smaller and easy to use. They are useful for flood control but are most effective when designed and installed prior to a flood event. Geotechnical and structural design should be carefully evaluated, as these pumps are usually very large and heavy. Where water depths are shallow on the suction side, these pumps do not perform well, as they need several metres of submergence to prevent the impact of damaging vortices. In an emergency, Axial Flow Pumps are mainly used during the stabilisation and recovery phases.

Operation and Maintenance: Typical preventative maintenance includes the periodic inspection of gaskets, seals and lubricant levels. Replacement of worn parts is required at regular intervals as determined by the manufacturer.

Health and Safety: Safety precautions should be exercised around any electro-mechanical equipment. Hazards associated with pump stations include risk of electric shock, rotating equipment, open water, and pressurised flow. If engine-driven pumps are employed, potential health risks with engine emissions should be evaluated.

Costs: Costs for complete pump stations are high and are closely tied to capacity and construction materials. Costs also depend on elements such as the prime mover (motor/engine driver), and capital costs include fuel storage tanks for fuel and any large, dedicated power lines needed for special motors.

Social and Environmental Considerations: The end users of a water supply system typically do not interact with these pumps. The complexity of O & M of the system should be considered, and trained and capable staff are a requirement. For motor-driven pumps, environmental considerations concern the use of consumables (lubrication, oil, chemicals) and power sources. A plan for appropriate containment and disposal related to consumables should be in place. For smaller pumping systems, solar power **(see S.10)** or hybrid power systems with solar panels are feasible and often have a lower environmental impact and short payback period.

Strengths and Weaknesses:

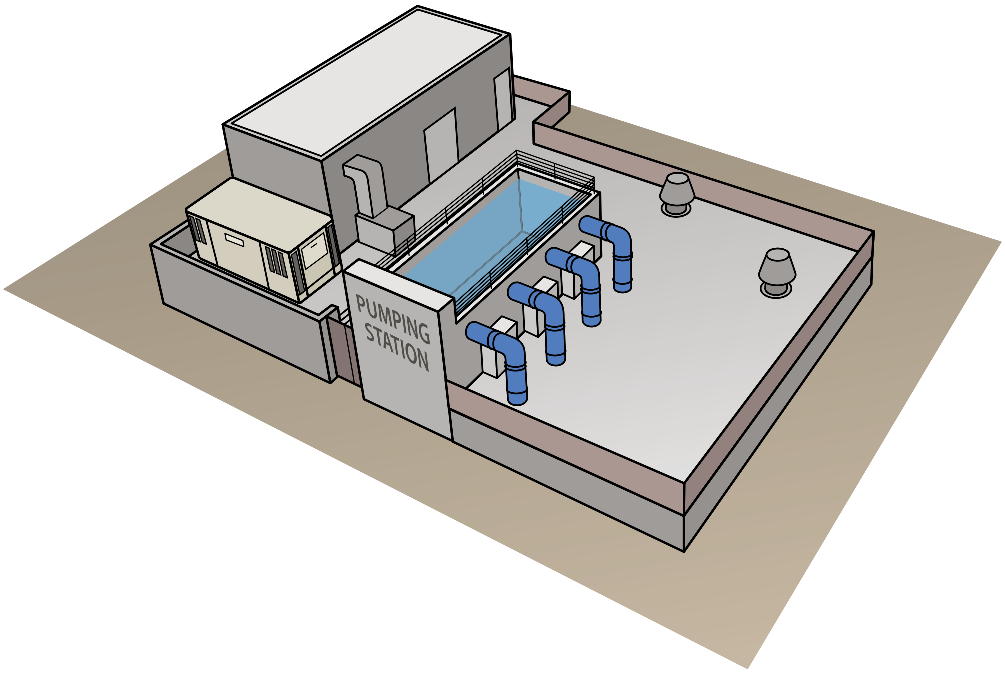
(+) Can pump large flow rates
(+) Typically run at low speed, so less wear

(−) Not possible to pump to high pressures
(−) Better performance with individual discharge headers than combined discharge headers
(−) Should not be used with a closed discharge valve
(−) Need large depths of water in the suction pit to meet submergence requirements

→ **References and further reading material for this technology can be found on page 217**

Pumping Station

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household * Shared ** Public	Complete pumping systems to provide pressurised water
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



A Pumping Station is an entire system dedicated to pumping water and a wide range of other liquids. Clean water Pumping Stations range in size from small, prefabricated or skid-mounted systems capable of providing water to a few households to large, municipal- or industrial-scale permanent installations that are up to several hundred kilowatt in size and that require detailed design by engineers followed by complex construction. Smaller systems exist that can be quickly deployed in all phases of an emergency, whereas large Pumping Stations tend to be part of a well-functioning municipal water supply system, and as such, will not be used in an emergency unless in the case of the rehabilitation of an existing plant.

A Pumping Station includes all components and subsystems necessary to provide pressurised flow, including pumps, valves, in-station piping, controls, standby/backup power (if desired) and instrumentation. Pumping Stations do not necessarily include the power-generating source for pumping. Clean water Pumping Stations are available in several different scales and levels of complexity, and may form part of a water treatment element, such as disinfection and intermediate storage.

Design Considerations: The most important design considerations for Pumping Stations are the required flow rate and the required discharge pressure. These are determined by a detailed analysis of the population and geography being served, treatment plant capacity, storage capacity, pumping times, and systems hydraulics. For small Pumping Stations, flow rates may be quickly estimated using Sphere guidelines and discharge pressures which are dictated by water elevation in a storage tank along with energy losses in the discharge piping **(see A.8)**. For larger, more complicated systems, a detailed engineering analysis is required. Other design considerations include characteristics of the pumped liquid, pressure, conditions upstream of the Pumping Station, environmental exposure, inter-operability of components and maintenance capabilities. With the exception of small, temporary systems, detailed engineering design is essential, particularly for permanent and semi-permanent systems that must be designed in conjunction with the rest of the system network.

Materials: Small Pumping Stations (skid-mounted systems) can be prefabricated and shipped to a site ready for pumping. In acute emergency settings, simple systems are either made up of readily locally available elements or standard pre-packaged elements held in store by major emergency WASH providers. Larger systems must be analysed on a per-component basis to determine appropriate materials and component types. As capacities and pressures increase, different pump types should be considered, as the effects of scaling are more prominent on component design. For example, forces and reactions on pump bearings become more critical as the pump scales to larger flows and pressures.

Applicability: Pumping Stations are part of many well-managed water systems for neighbourhoods or municipalities. Large Pumping Stations take considerable time to design and construct and are therefore most applicable in recovery or post-disaster contexts. Small skid-mounted pumping systems can help to provide clean water in acute responses to disasters and all subsequent stages of the response. Where access to electrical power is limited, Pumping Stations can be configured with supplemental power, such as from small engine generators. Some Pumping Stations can also be packaged to be driven by engines, directly enabling quick system deployment in a natural disaster where restoration of electricity may take several weeks to months. Depending on the water source characteristics (the location above or below the elevation of the Pumping Station, the turbidity or chemical make-up) the type of pumps used may vary. For example, if the available water source is an aquifer, then a submersible pump may be required to bring the water to ground level. Here, factors such as the depth of water, amount of flow and size of the well will require a customised pump design, which will be a limiting factor for being able to use standard, skid-mounted designs. Each Pumping Station should therefore be designed for its individual needs. For clean water systems, the type of pump and installation can be scaled to a specific level. Depending on capacity and pressure requirements, entire Pumping Stations can be rented based on local availability. Custom designs typically need 20–24 weeks for equipment procurement and assembly.

Operation and Maintenance: Large Pumping Stations require more intensive and skilled O & M. Regular maintenance is required for all mechanical and wearing components. Operations of large Pumping Stations may be complex and require dedicated control systems. Sufficient time for installation and O & M should be allowed for, based on the complexity of the system installed. If the installed pumps are not designed to be used with fluids other than clean water, Pumping Stations may experience excessive wear and tear of components, electrical overload and clogging.

Health and Safety: Safety precautions should be exercised around any electro-mechanical equipment. Hazards associated with Pumping Stations may include the risk of electric shock, rotating equipment, open water, and pressurised flow.

Costs: Costs for complete Pumping Stations are high and are closely tied to capacity and construction materials.

Social and Environmental Considerations: The end users of a water supply system typically do not interact with a Pumping Station. The complexity of O & M of the system should be considered, though trained and capable staff are always required. Electric, gasoline or diesel engines are commonly used as power sources in Pumping Stations. From an environmental point of view, the electric motor is the most favoured power source because of its cleanliness, relatively low noise, and lower pollutant emissions. An electrical pump may also be driven with solar power.

Strengths and Weaknesses:

(+) Mature and scalable technology
(+) Many technical options to fit a given situation

(−) Can be very expensive
(−) Requires highly trained staff

→ **References and further reading material for this technology can be found on page 217**

This section describes a range of water treatment technologies suited to various larger settings, such as groups of up to and around 50 people (several households or a small community), semi-centralised treatment works for neighbourhoods, and centralised applications for urban areas. Household water treatment methods are described in section H.

Water treatment technologies can be divided into three main groups: technologies applied for pre-treatment with the primary objective of reducing raw water turbidity (T.1–T.5), treatment technologies targeting primarily microbial contaminants (T.6–T.10) and treatments targeting chemical contaminants of various origins, including salinity (T.11–T.15). Some of these technologies can function as a single-step treatment (e.g. T.6, T.7, T.8, T.9, T.10) in specific contexts. Others need to be applied as part of a multi-stage treatment system (T.1–T.5, T.13–T.15). Some treatment technologies can be applied to treat multiple contaminants from different groups (T.9, T.10, T.14, T.15). The technology information sheets T.11 and T.12 focus on the multiple technologies required to remove the priority chemical contaminants of fluoride and arsenic. Basic pre-treatment technologies, such as screens, weirs, or sedimentation in storage tanks, are not part of the Treatment section and are instead included in the Intake (I) or Distribution (D) sections.

Pre-Treatment

T.1 Roughing Filtration
T.2 Rapid Sand Filtration
T.3 Microfiltration (MF)
T.4 (Assisted) Sedimentation
T.5 Assisted Sedimentation with Filtration

Treatment (Microbial Contaminants)

T.6 Chlorination
T.7 Onsite Electro-Chlorination
T.8 Ultraviolet (UV) Light
T.9 Slow Sand Filtration
T.10 Ultrafiltration (UF)

Treatment (Chemical Contaminants)

T.11 Fluoride Removal Technologies
T.12 Arsenic Removal Technologies
T.13 Granular Activated Carbon (GAC)
T.14 Ozonation
T.15 Nanofiltration (NF)/ Reverse Osmosis (RO)

Generally, a logical series of treatment steps is required to achieve safe drinking water, with the treatment technology steps defined by the following factors:

- Available water resources and their seasonal quantity
- Water contaminants and seasonal variations in contamination
- National drinking water standards for water quality and quantity
- Multiple barriers to prevent pollution so that a failure of one barrier may be compensated by the effective operation of the remaining barriers
- Scale and speed of establishment
- Financial resources
- Availability of materials and space
- Availability of skills for design, management, operation and safety
- Sources of energy

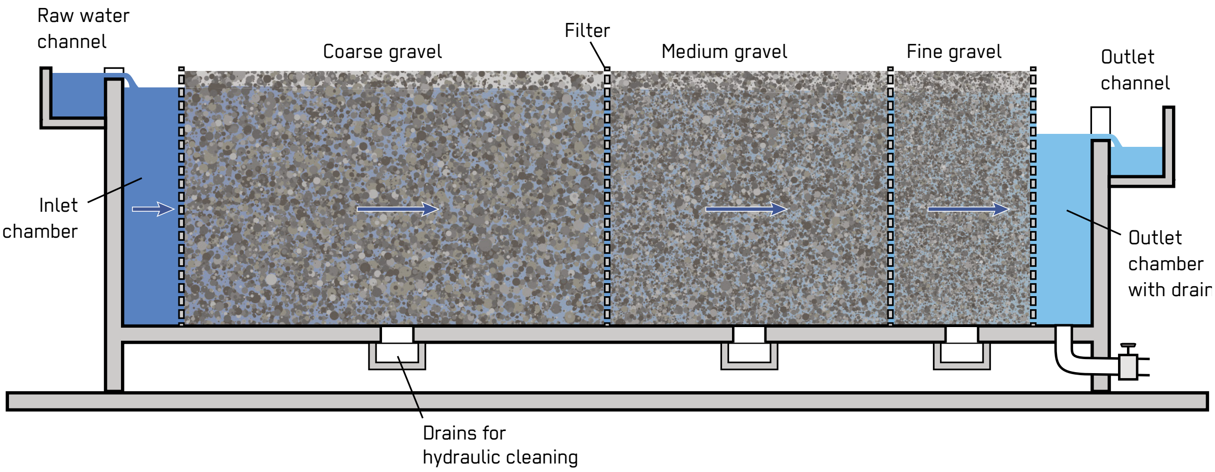
T

Treatment

T.1

Roughing Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household * Shared ** Public	Turbidity removal, pre-treatment, and sedimentation
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



A Roughing Filter is used to remove suspended solids from very turbid (or muddy) water using differently sized filtration media ranging from coarse to fine gravel. It is a pre-treatment step prior to a final disinfection process, such as Chlorination (T.6), Slow Sand Filtration (T.9) or Ultrafiltration (T.10). It can be used in the stabilisation and recovery phases of an emergency.

Roughing Filters act less as 'filters' and more like sedimentation tanks with an extended surface area. A sedimentation tank is generally designed based on the time it takes for particles to settle out given the tank depth. With a Roughing Filter, the required distance for the settling process is much shorter since the tanks are filled with gravel. This feature, together with an increased available surface area for processes such as sedimentation and adsorption, helps trap particles to make it a more efficient form of sedimentation.

Design Considerations: Roughing Filtration uses filtration media that decreases in size, either in the same tank in three separated layers or more commonly/efficiently as three separate chambers in a horizontal tank. Media sizes range from 4–25 mm, with larger sizes towards the inflow (typically 12–25 mm and 8–12 mm) and smaller sizes at the outflow (typically 4–8 mm). For horizontal filters, the total length generally reaches up to 7 metres that is divided into three chambers of decreasing length at a ratio of 3:2:1 moving from coarser to finer media. For filters made from horizontal compartments, the flow can be both horizontal as well as up or down through each compartment. For filters with three layers in one compartment, water flows only in the upflow direction, as it is more efficient for hydraulic cleaning, which uses the force of gravity to drain sediments. Various types of filtration media can be used, though it should be relatively uniform in each chamber/layer and have a good porosity. Roughing Filters can effectively treat turbid water of up to 500 NTU (where NTU is a measurement of turbidity), reducing this turbidity by up to 90 % and bringing it to a level suitable for subsequent treatment processes. For example, when the next step is Slow Sand Filtration (T.9), a turbidity of about 10 NTU is desired. Additionally, Roughing Filters improve microbial water quality by reducing bacterial levels by between 60–99 %.

A key design consideration is a low water velocity throughout the filter, as sedimentation works most efficiently with a non-turbulent flow. To achieve this, the velocity needs to be within 0.3–1.5 m/hour (compaction of m^3/m^2/hour), though this should preferably be kept close to the most efficient rate of up to 0.6 m/hour. Water coming into or leaving the filter should also not be turbulent to avoid scour and short circuiting. At the intake, this requires inlet weirs covering the width of the filter or baffles to distribute water energy, and at the outflow, a full-width wall over which the water flows or a false filter bed below. A Roughing Filter must remain saturated, as cleaning becomes difficult if it dries out. The outlet control should thus be designed such that the water leaves the filter only at a certain height (e.g. a weir or raised effluent pipe). Hydraulic cleaning via gravity performs best when the drainage components are sized for a high flow of 60–90 m/hour over the filter bed.

Materials: Materials include the filter compartment(s), water inflow and outflow system with control mechanism, drainage system and filter media (gravel, burnt clay bricks, plastics, burnt charcoal or coconut fibres).

Applicability: Roughing Filters are suitable where the local capacities and finances are limited (e.g. rural or small- to medium-scale systems in urban and peri-urban contexts). They are more applicable to the stabilisation and recovery phases of an emergency, as they require set-up time. They can be a good replacement for Assisted Sedimentation **(T.4)** and Rapid Sand Filtration **(T.2)**, both of which are more common in the acute response but require higher ongoing inputs. The performance of Roughing Filters depends on the amount of colloidal matter in the water. Before scaling up, part of the design work will be to test the separation characteristics of solids in the water followed by a small pilot plant.

Operation and Maintenance: The main O & M task is to remove the accumulated solids that penetrate deep into the filter medium, usually through hydraulic cleaning that involves rapidly draining the filter. Shorter intervals between hydraulic cleanings are preferable (e.g. every few weeks) to minimise solid build-up, but manual cleaning will usually be required once every one to five years, depending on the raw water quality. This entails manually excavating the filter material, washing it separately and replacing it. Having two or more filters keeps water flowing during the time-consuming maintenance process. Other O & M tasks include applying anti-corrosive agents to metal parts (valves, rods and pipes) and lubricating the different valves.

Health and Safety: Roughing Filtration is a pre-treatment and should not be used as a single-step treatment process for drinking water. In emergencies, Chlorination **(T.6)** is always advised as a minimum post-treatment step. The sludge produced during filtration is easily disposable and does not cause health concerns.

Costs: Roughing Filters cost at least 150–200 USD per m^3 of installed filter volume. Ongoing costs are low because of the lack of required chemicals and the simplicity of the design. As an indication of required maintenance costs based on a filter treating 240 m^3/day, only 30 work hours would be required per year (including hydraulic cleaning every one or two months depending on the season and manual cleaning every 5 years). In comparison, a Slow Sand Filter **(T.9)** requires 300 % more time.

Social and Environmental Considerations: Roughing Filters tend to be well accepted by users and institutions where this is a known technology. Establishing it as a new technology requires training, O & M capacity development and willingness of local staff.

Strengths and Weaknesses:

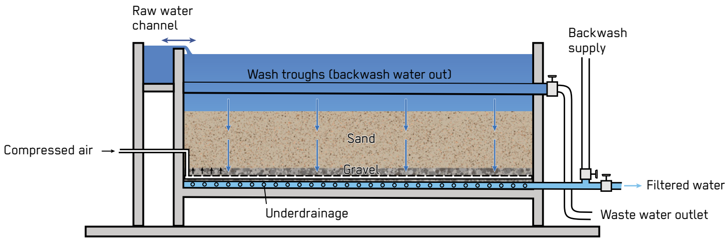
- (+) Does not require chemicals or mechanical equipment
- (+) Can be constructed with local resources
- (+) Has low maintenance requirements and low operational costs

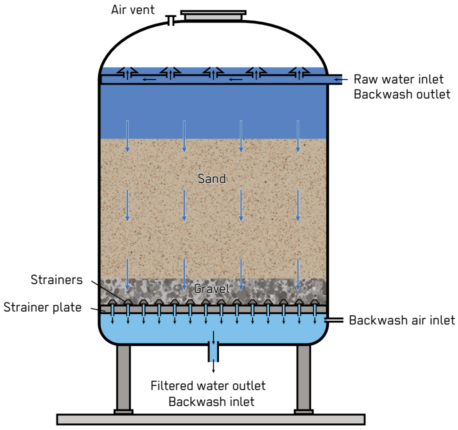
- (−) Varies in performance depending on the filter design, O & M and raw water characteristics
- (−) Not suitable for treating stable suspensions with high concentrations of colloidal matter
- (−) Comparably poor efficiency in colour removal compared to other pre-treatment methods
- (−) Requires more time and resources for installation than coagulation and sedimentation

→ **References and further reading material for this technology can be found on page 217**

Rapid Sand Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household * Shared ** Public	Turbidity removal, pre-treatment and coarse sand filtration
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	





Rapid Sand Filters use coarse sand as a filtration medium to remove fine suspended solids from water with varying levels of turbidity (or 'muddiness'). It is a pre-treatment step prior to a final disinfection process, such as Chlorination (T.6), and can be used in all phases of an emergency.

Rapid Sand Filters consist of a tank or basin containing the filter media with a gravel support at the base, an underdrain system to collect filtered water and inject backwash water, and troughs along the top of the filter (0.5 metres above the unexpanded filter bed) to collect the backwash water. Rapid Sand Filters mainly remove particles from the water using physical processes, the most important of which is adsorption, though sedimentation and straining also play a role. Rapid Sand Filters require backwashing. Pressurised Rapid Sand Filters are often part of compact water treatment units designed for emergencies.

Design Considerations: Rapid Sand Filters can be used directly or in combination with other pre-treatment processes, depending on raw water turbidity. It works well where raw water quality is around 25 NTU (where NTU is a measurement of turbidity). For higher turbidity (up to 100 NTU), Rapid Sand Filtration can be combined with a hybrid form of an upflow Roughing Filter **(T.1)** using higher-than-normal flow rates. For water over 100 NTU, a standard Roughing Filter **(T.1)** or conventional (Assisted) Sedimentation **(T.4)** can be used. Rapid Sand Filters reduce turbidity by at least 90 %, aiming to reach a suitable turbidity for the subsequent treatment process (i.e. less than 5 NTU for Chlorination **(T.6)** or about 10 NTU for Slow Sand Filtration **(T.9)**). They may also reduce bacteria by 60–90 %, depending on conditions, and can slightly reduce colour, taste and heavy metals. For groundwater with high iron and manganese content, they are often used after aeration to filter out precipitates.

Sand is the most used filtration medium, and it should be fairly uniform in size with an effective range from 0.4–1.2 mm. Sometimes a coarser layer is added on top of the sand (e.g. anthracite or coconut husks) to reduce the rate of blockage. Flow direction can be either down or up, and water is driven either by pumping or gravity. For decentralised applications, gravity downflow filters are mainly installed for ease of inspection and maintenance. Pressure filters (or closed filters) make longer filter runs possible and are used in industrialised settings and emergency water treatment kits. They can be operated at a flow of between 15–30 m/hour (a compaction of m^3/m^2/hour). Gravity filters (or open filters) are open to atmospheric pressure and operate between 5–15 m/hour. Even with adjustment (controlling flow with valves), the flow will reduce after some days, at which point backwashing is carried out in the upflow mode using either pumps or gravity. If done by gravity, it requires a clean water tank installed high enough above the backwash troughs of the filter to provide the desired backwash flow rate (a height difference of 4–6 metres tends to be sufficient). For pressure filters, a pressure drop (around 0.5 bar with a stable flowrate) is an indication of clogging. When designing, it is important to consider that a pure sand filter expands by up to 30 % during backwashing.

Materials: Materials include the filter compartment(s), water inflow and outflow system with control mechanism, underdrain system, filter media, pumps (or raised water tank) and (optional) compressed air system for backwashing.

Applicability: Rapid Sand Filters require sufficient local capacity and financial resources (e.g. larger urban or industrialised contexts). As pressure filters, they can be used in the acute and stabilisation phases of an emergency. Larger-scale units are possible in the recovery phase (test characteristics of the water, followed by a small pilot plant).

Operation and Maintenance: O&M requirements are significant, with the main tasks related to flow control and backwashing. Backwashing is frequent, at every 0.5–2 days for up to 30 minutes; where the raw water is turbid and the runs between backwashing are shorter than 6 hours, design changes must be considered. The operator must ensure that the backwash flow rate is high enough to expand the filter bed, yet low enough that filter material is not washed out of the wash troughs (at least 0.5 metres above the unexpanded filter bed). Backwash rates vary from 12–90 m/hour depending on sand size and ambient temperature (slower rate possible at lower temperature). Compressed air may also be used in some filters for backwashing. Gravel layers below the coarse sand support the medium and prevent the drain from clogging with sand. The gravel should not be displaced by the backwashing procedure. General plant maintenance will also be needed (e.g. application of anti-corrosive agents to metal parts, lubricating valves).

Health and Safety: Rapid Sand Filtration is a pre-treatment method and should not be used as a single-step treatment process for drinking water. Sludge dislodged during backwashing should be disposed of safely where coagulation has been used as part of the system to avoid metals such as aluminium entering the water supply.

Costs: Capital costs for the filter can vary in the range of 100 USD/m^3/day capacity. Ongoing costs for O&M are around 13 USD/m^3/day capacity, which is higher than for Slow Sand Filters **(T.9)** due to more frequent supervision plus pumping for backwashing. For backwashing alone, up to 180 work hours are required per year. Costs can be reduced by designing smaller pumps for pumping to a raised water tank rather than larger pumps for backwashing.

Social and Environmental Considerations: Rapid Sand Filters are well accepted by users/institutions, as they visibly improve turbidity. Establishing it as a new technology requires training, O&M capacity development and willingness of local staff. Sludge produced during filter backwashing should be treated (dewatered) and safely disposed of. Disposal of untreated sludge into the environment may lead to health and environmental risks.

Strengths and Weaknesses:

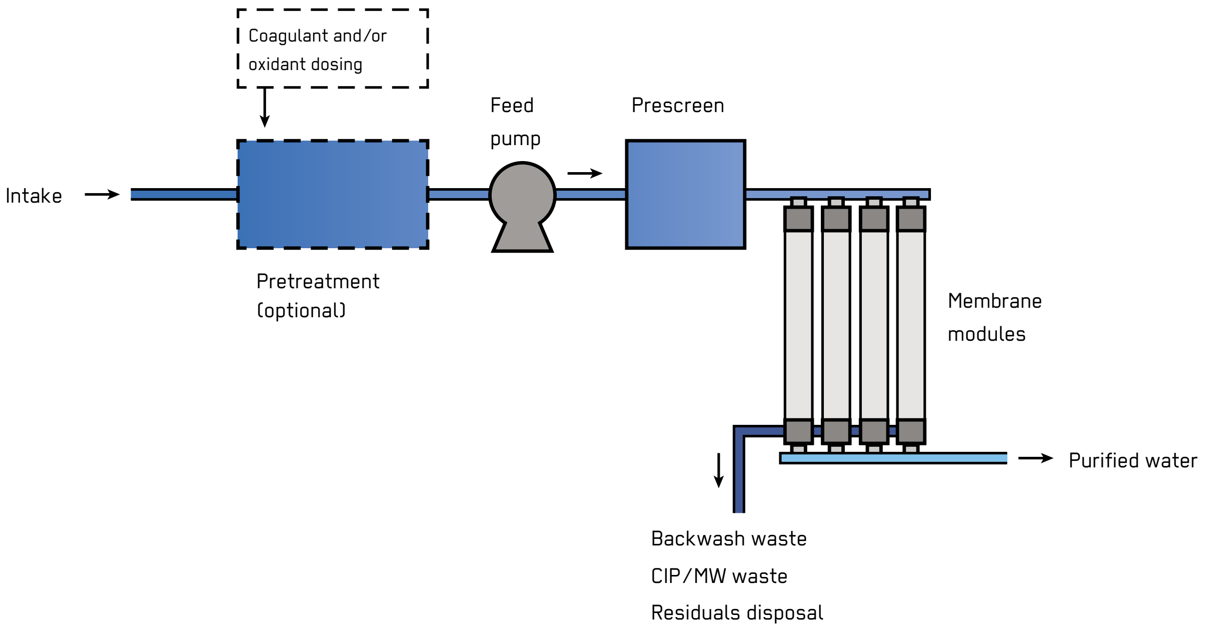
(+) Can be constructed with local resources
(+) Treats stable suspensions with high concentrations of colloidal matter when combined with coagulation

(−) Uses filtered water for backwashing
(−) Has high maintenance requirements
(−) Has high operational costs
(−) Requires more time and resources for installation than coagulation and sedimentation

→ **References and further reading material for this technology can be found on page 217**

Microfiltration (MF)

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Turbidity removal, pre-treatment and partial pathogen removal
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	** Medium	*** High	



Microfiltration (MF) membranes provide excellent filtration with low final water turbidity (typically less than 0.1 NTU) and high removal levels for pathogenic protozoan cysts/oocysts, Giardia and Cryptosporidium and bacteria. As a final treatment step, Chlorination (T.6) or Ultrafiltration (T.10) as well as Nanofiltration/Reverse Osmosis (T.15) can be used. MF is applicable in all emergency phases and at different scales (see H.4 for household scale).

MF uses membranes to filter water. Raw water is forced through the membrane by a pressure difference, and components of the water are retained based on the size of the pores in the membrane. The smaller the pores, the greater pressure that must be exerted. MF membranes used for water treatment have pore sizes of 0.1–0.5 µm. These membranes remove particles and protozoa and can remove a 4-log (99.99 %) or higher amounts of Giardia/Cryptosporidium and bacteria, though usually remove under 1-log of viruses. Post-treatment usually includes disinfection, such as Chlorination **(T.6)**. MF-based plants are usually factory prefabricated and skid-mounted, although there are also single-membrane modules available. Most of the MF membrane modules in skid-mounted systems are made of small, string-like hollow fibres that are mounted in cylindrical (pipe-like) vessels or tanks due to the extremely high packing density (2,000–15,000 m^2/m^3), depending on the system type.

Design Considerations: Membrane-based filters have two fundamental design differences over non-membrane filtration: dead-end-filtration (feed is pushed completely through the membrane) and cross-flow filtration (feed flows over the membrane, not all of the feed is filtered). Typical MF membranes run as dead-end-filters. Pre-treatment always includes a protective pre-screen (typically auto-backwashing type rated at about 300 micron). Additional pre-treatment (e.g. Assisted Sedimentation, **T.4**) can augment the removal of dissolved materials or reduce the fouling potential of water with a high organic matter content. Automatic in-line coagulation followed by direct

MF is used for waters with a high fouling potential to reduce membrane plugging. Usually membrane-friendly coagulants like poly-aluminium-chloride and/or aluminium-chlorohydrate are preferred. Prefabricated and skid-mounted MF systems mostly include a control system to regulate operating conditions during cycles, including pump-driven filtration, backwash frequency, chemical cleaning (typically once a month) and integrity tests (to ensure the membranes are not damaged).
Typically, systems auto-backwash with filtered water every 20–30 minutes depending on the raw-water quality. An MF unit does not produce filtrate during the roughly 3-minute auto-backwashing period, so a break tank is required for filtrate storage. About 85–95 % of the feed water becomes usable filtrate, and the rest is discharged as spent backwash or chemical cleaning waste. A major design parameter is flux, indicating the filtrate flow per membrane area. If the flux is set too high for an application, it can result in membrane fouling. Reversible fouling can increase the operating pressure, though can be managed by regular backflushing and chemical cleaning (typically 1 day/month). Irreversible fouling will require advanced chemical cleaning and can permanently damage the membrane. Running some MF membranes dry can also lead to permanent damage. There are MF systems that operate at constant flux and/or constant pressure. Most projects conduct onsite piloting before design, though if this is not possible, trial-and-error experimentation is advised.

Materials: Typically, the entire MF system is purchased together because the ancillary equipment, including support racks, pumps, valves, pre-screen(s), air compressor(s) and computer system (for backwash and water quality monitoring), are just as important as the membranes. Consumables include membrane elements (5–10-year service life if operated correctly), membrane repair kits, electricity and chemicals (e.g. citric acid and sodium hypochlorite for cleaning and disinfection; caustic (sodium hydroxide and sodium bisulfide) for neutralisation).

Applicability: Compared to Ultrafiltration **(T.10)**, MF is more often used as pre-treatment for Nanofiltration/ Reverse Osmosis **(T.15)** or to reduce turbidity for subsequent disinfection by other methods. In such cases, MF is typically applied where efficient and cost-effective automation is required. These systems can be set up very quickly (automated skid-mounted-systems). MF can be applied in remote locations and urban areas, since it is easily scalable, and can be used in all phases of an emergency, including the acute response.

Operation and Maintenance: Well-trained operators are advised for a long, reliable service life. Although the systems are usually automated or semi-automated, operating mistakes can cause major damage to membrane elements (broken fibres, fouling). Regular tasks include the daily verification of instrument accuracy and integrity testing, a daily check of chemical levels, a weekly calibration of chemical feed pumps and instrument cleaning, and a weekly review of the data, which includes considering revisions of any operating parameters, such as flux, chemical cleaning frequency and a volt-amp check on electric motors.

Health and Safety: MF membranes retain high levels of bacteria and protozoa (also cysts) of up to 99.9–99.9999 % (3-log to 6-log reduction values, LRV), while the removal of viruses is usually under 1-log. Retentate disposal must be carefully considered, since it contains the contaminants found in the feed water. Depending on the constituents and local regulations, retentate can be directed back to the source water, such as a river, disposed in the municipal sewer, diluted and used for irrigation or treated on-site before disposal. Treatment before disposal and reuse is recommended when disposal in municipal sewers is not possible. Chemical cleaning agents can be corrosive and require trained operators and personal protective equipment.

Costs: The initial acquisition costs are comparatively high due to the high costs of membrane modules and need for advanced axillary equipment. While the MF membrane alone is relatively cheap (10–20 USD/m^2 of the membrane), the costs of the entire modules vary between 70–120 USD/m^2. By caring for the system by means of frequent and appropriate cleanings, the filter will have a service life (depending on the manufacturer) of up to 10 years, resulting in relatively low costs per user over time.

Social and Environmental Considerations: MF filters are well accepted by users and institutions, as the turbidity of water is visibly improved. Establishing it as a new technology requires training, O & M capacity development and willingness of local staff. The energy requirements for operating MF systems are comparable to conventional water treatment systems.

Strengths and Weaknesses:

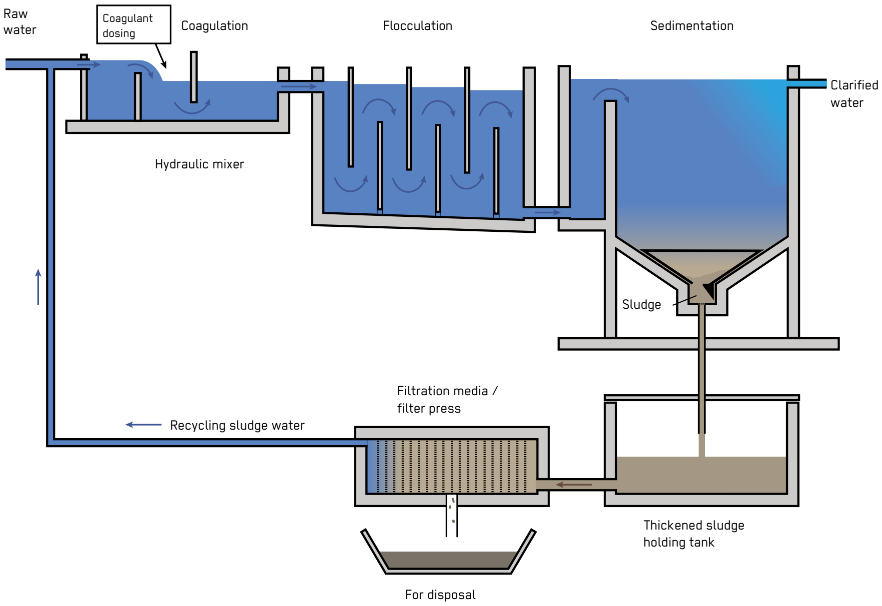
- (+) Produces excellent filtrate quality in terms of turbidity and pathogen removal
- (+) Is usually fully automated and can be operated unattended or manually
- (+) Requires little space for these very compact systems

- (−) Limited flow based on the optimal flux of the membrane
- (−) Uses special components, e.g. the membranes themselves are likely only available in specific areas
- (−) Rarely inter-changeable, so one manufacturer's membranes cannot be installed in another's system
- (−) Requires trained operator

→ **References and further reading material for this technology can be found on page 217**

(Assisted) Sedimentation

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Turbidity removal, pre-treatment, coagulation and sedimentation
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Sedimentation is a pre-treatment step used to remove suspended solids from water with varying levels of turbidity (or 'muddiness') and may involve the addition of chemicals to accelerate the process. It can be used prior to a final treatment step, such as Microfiltration (T.3), Chlorination (T.6) or Nanofiltration/Reverse Osmosis (T.15). Sedimentation can be used in all phases of an emergency.

Sedimentation is a process in which physical particles in water settle out over time. Gravity alone may be sufficient for this process, though for raw water containing fine colloidal matter that only slowly settles or does not settle at all, the addition of chemicals is required to speed up the process. This is known as both 'Assisted Sedimentation' (since the natural Sedimentation process is accelerated) or as 'coagulation and flocculation'. Here, the chemical coagulant added to the water destabilises the electrostatic charges of colloids so they come together to form larger particles (flocculation) through mechanical mixing. These heavier particles then settle out faster (sedimentation). (Assisted) Sedimentation can be done at all scales, from large treatment plants to the household level.

Design Considerations: Sedimentation as a pre-treatment aims at reducing turbidity to a level suitable for subsequent treatment processes. In most cases, this is Chlorination **(T.6)**, so a turbidity of less than 5 NTU is required. During Sedimentation, pathogen concentrations are somewhat reduced (as they tend to be associated with solid particles in the water), and there is considerable improvement in colour, taste, odour and levels of metals such as iron, manganese, fluoride and arsenic. The first stage is to decide whether a coagulant is required, which can be determined using a settling test in a bottle. A rule of thumb is to settle water for one hour (or whatever the proposed detention time would be in the Sedimentation tank) and check if the particles have settled. If the top 80 % of the bottle has water that is clarified enough for the next treatment process, then natural Sedimentation will be sufficient.
Where natural Sedimentation is too slow, the process can be accelerated by the addition of a chemical coagulant. Aluminium-based coagulants (such as aluminium sulphate) are effective over a fairly narrow pH range of around 6 to 8. Outside of this range, more coagulant must

be added, which increases the cost as well as the aluminium concentration in treated water, creating a health hazard. Therefore, initially adjusting the pH of the raw water may be needed to reduce the required coagulant amount. Alternatively, iron-based coagulants are effective over a wider pH range, but are less frequently available and may cause staining. Both of these coagulants reduce the pH of treated water, and where this drops to < 6.5, post-treatment pH adjustment might be needed to reduce the risk of corrosion if metal pipes and tanks are subsequently used. Organic coagulants also exist (e.g. Moringa seeds) that have a wide effective pH range and have been used both at the household level **(see H.8)** and on a larger scale. The actual optimal dose for any raw water cannot be calculated in theory so is instead determined experimentally by a 'jar test' using a series of beakers containing an increasing dose of coagulant. Jar tests need to be redone when turbidity changes seasonally.
The abstraction method can help to ensure a relatively stable turbidity by pumping water from the same place and from near the surface (e.g. using a floating intake, **see I.3**). Coagulants should be dosed at a point of turbulent flow due to the rapid chemical reaction and at a rate proportional to the water flow rate. In emergencies, dosing is often performed using a variable-area flow meter, valve and tee on the suction side of a pump, though other methods also exist (e.g. electric-driven dosing pump). Flocculation requires slow stirring (< 1 m/s to prevent floc break up), although in emergencies, this is often done by discharging pumped water into a tank at an angle to stimulate a slow circular flow.
Larger Sedimentation basins are sized based on design guidelines for detention time and surface loading rate. When little land area is available, inclined plates or tubes can be installed within the Sedimentation basin to reduce the area needed by over 75 %. In emergencies, Assisted Sedimentation often occurs in the same tank as the flocculation. Here it can be difficult to achieve perfect results, so a good option is to pump water through rapid sand pressure filters to trap the remaining flocs **(see T.5)** prior to final treatment. Another option that saves space and equipment in an emergency is an upflow clarifier that requires only one tank. In this design, flocs accumulate as a floating blanket near the top of the tank.

Materials: Materials will vary depending on whether chemicals are required. In addition to the Sedimentation tank, materials may include a pump, a coagulant dosing mechanism, flocculation tank, sludge disposal mechanism, as well as chemicals for coagulation and possibly pH adjustment (acids or alkalis).

Applicability: This treatment process is suitable for all phases of an emergency. In the acute response, it can be started quickly for bulk water treatment. At a household level in emergencies, flocculant-disinfectant sachets **(see H.8)** may prove a good option for immediate distribution to dispersed populations where bulk water treatment might not be possible. In the longer term, communities can be educated about the benefits of the household 3-pot system for maximising natural Sedimentation. Larger-scale Sedimentation units are possible in the recovery phase once there is time for adequate design and piloting. However, consideration should also be given to possible alternative pre-treatment options such as Roughing Filtration **(T.1)** to reduce cost, ongoing reliance on chemicals and sludge removal issues.

Operation and Maintenance: O & M requirements are significant and require well-trained operators. Tasks include monitoring turbidity before and after treatment, regular jar testing, modifying dosing, draining and cleaning tanks, disposing of sludge, and storing and mixing chemicals. General plant maintenance will also be needed (e.g. pumps, mixers, valves).

Health and Safety: As a pre-treatment process, further disinfection is always required. Sludge should be disposed of safely (e.g. in landfills, sewers or with wastewater plant sludge), although this can be a challenge in an emergency. Where aluminium sulphate is used as coagulant, the aluminium concentration in clarified water cannot exceed 0.2 mg/L for health reasons. If problematic, this can be reduced by adjusting the pH of the raw water or by filtering through a Rapid Sand Filter **(T.2)**. Chemicals must be treated with care since they are corrosive.

Costs: Capital and ongoing costs vary widely according to the exact treatment set-up, required flow rate and country location, though in general, increasing the plant size decreases the cost per m^3 of water produced.

Social and Environmental Considerations: (Assisted) Sedimentation is generally well accepted by consumers and institutions, as water turbidity is visibly improved. Sludge produced during coagulation can cause environmental risks if disposed of near groundwater sources.

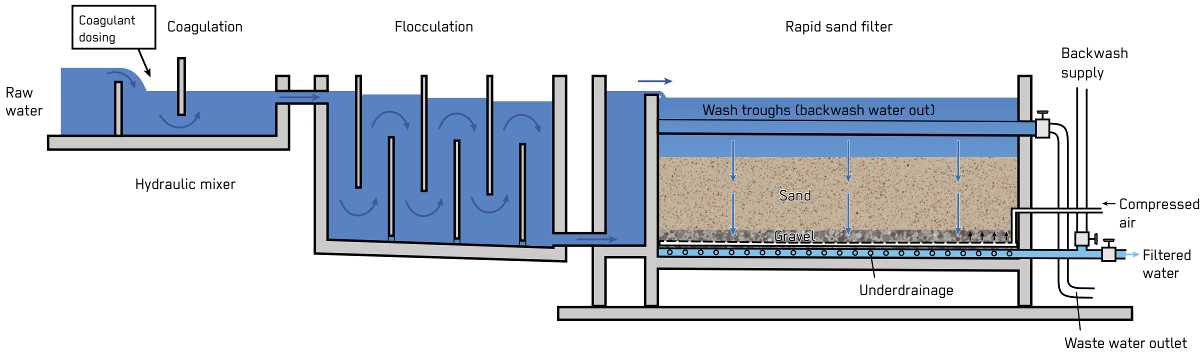
Strengths and Weaknesses:
- (+) Good method for treating highly turbid water with high concentrations of colloidal matter
- (+) Can be used to start bulk treatment quickly in an emergency
- (+) Required materials are widely available

- (−) Requires a lot of land space
- (−) Requires skilled operators for dosage/chemical handling
- (−) Requires a continuous supply of coagulant and power

→ **References and further reading material for this technology can be found on page 217**

Assisted Sedimentation with Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Turbidity removal, pre-treatment, coagulation and direct filtration
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	



Assisted Sedimentation with Filtration is a pre-treatment step used to remove suspended solids from water with varying levels of turbidity (or 'muddiness') to prepare it for a final disinfection step, such as Chlorination (T.6). It can be used in all phases of an emergency.

For raw water containing fine colloidal matter that only slowly settles or does not settle at all, the addition of chemicals is required to speed up the process. This is known as both 'Assisted Sedimentation' (since the natural Sedimentation process is accelerated) or as 'coagulation and flocculation'. In this process, the chemical coagulant added to the water destabilises the electrostatic charges of colloids so they come together to form larger particles (flocculation) through mechanical mixing. In a standard treatment process, these particles would be settled out using Sedimentation (T.4), though this can be omitted by directly filtering the flocs using Rapid Sand Filters **(T.2)** in a process also known as 'direct Filtration'. When compared to a conventional plant with the same flow rate and raw water quality, Assisted Sedimentation with Filtration can provide better turbidity removal at a lower cost. This is a process that is usually done at larger scale, though packaged plants used in acute emergencies often include coagulation using a hydraulic mixer followed by a pressurised rapid sand filter. Coagulation and flocculation followed by Microfiltration **(T.3)** or Ultrafiltration **(T.10)** can also be used, though this is referred to as membrane Filtration with in-line coagulation.

Design Considerations: The aim of direct Filtration is to reduce turbidity to a level suitable for subsequent treatment steps. This is usually Chlorination **(T.6)**, so a turbidity of less than 5 NTU is required. During this pre-treatment, bacterial concentrations are also reduced and there is a considerable improvement in colour, taste, odour and levels of metals such as iron, manganese, fluoride and arsenic. Direct Filtration works well where raw water quality is relatively constant and with an average turbidity of around 25 NTU (with peaks up to 100 NTU). Where turbidity

is higher or more variable, more coagulant may be needed, which will form more flocs that can clog the filter faster. An alternative for water with a higher turbidity of around 100 NTU (with peaks up to 200 NTU) is to combine Rapid Sand Filtration **(T.2)** with a hybrid form of an upflow Roughing Filter **(T.1)** with higher flow rates than usual. For water with an even higher turbidity, standard Roughing Filters **(T.1)** or conventional (Assisted) Sedimentation **(T.4)** can be used.
The Assisted Sedimentation and Rapid Sand Filtration processes are similar to conventional treatment processes **(see T.2 and T.4)** with some differences. For the coagulation stage, smaller quantities of coagulant are required, which reduces cost, and sometimes a polymer is also added. The flocculation stage is similar, though can be omitted. The main difference with Rapid Sand Filtration is that since there is no Sedimentation basin, and flocs are stored within the filter bed instead, which requires a larger storage capacity. This is achieved by deepening the filter bed and including another larger-sized filter medium as the top layer (e.g. anthracite) which makes the filter more efficient compared with standard Rapid Sand Filters at the same loading because the flocs penetrate deeper into the bed, thereby making use of the entire depth (instead of trapping them only in the upper layers). The larger-sized top layer is made up of something with a lower specific gravity (the ratio of a material's density to that of water) so that the two layers retain their relative positions after backwashing.
The Filtration rates of dual-media filters tend to be higher than conventional Rapid Sand Filters, meaning less filter area is needed, though faster flow rates result in shorter filter runs, requiring more frequent backwashing that uses slightly more water (around 6 % of filtered water). The lower layer of sand in dual-media filters has an effective sand size (meaning 90 % of the sand used is larger) ranging from 0.45–0.8 mm (a bit smaller than for conventional Rapid Sand Filters), while the upper layer typically has an effective size of 1.0–1.6 mm. Both layers are relatively uniform.

Materials: Materials may include a pump, coagulant dosing mechanism, flocculation tank (optional), sludge disposal mechanism, chemicals for coagulation and possible pH adjustment, and for Rapid Sand Filtration **(T.2)**, a water inflow and outflow system with control mechanism, underdrain system, pumps (or raised water tank), filter media (sand plus a coarser medium) and (sometimes) a compressed air system for backwashing.

Applicability: This treatment process is suitable for all phases of an emergency. It can be very useful during the acute response, as it can be quickly started for bulk water treatment and where equipment and processes are not yet perfect (e.g. where the same tank is used for flocculation and Sedimentation). Having direct Filtration early in an emergency gives some leeway in producing clear water quickly despite small errors. Larger-scale units are possible in the recovery phase once there is time for adequate design and piloting, but consideration should also be given to possible alternative pre-treatment options, such as Roughing Filtration **(T.1)**, to reduce cost, ongoing reliance on chemicals and sludge removal issues.

Operation and Maintenance: O & M requirements are significant and similar to those for conventional treatment processes. These include checking the turbidity and pH before and after treatment, regular jar testing, modifying dosing, draining and cleaning tanks, disposing of sludge, storing and mixing chemicals, controlling flow, and backwashing solids. General plant maintenance will also be needed (e.g. pumps, mixers, valves, application of anti-corrosive agents to metal parts, lubricating valves).

Health and Safety: Health and safety concerns are similar to those for standard treatment processes, including the need for further disinfection and the safe removal of sludge (e.g. landfill, disposal to sewers or coordination with wastewater plant sludge). Where aluminium sulphate is used as a coagulant, the aluminium in clarified water cannot exceed 0.2 mg/L for health reasons. When high, the required dose can be reduced by adjusting the pH of the raw water or by filtering through a Rapid Sand Filter **(T.2)**. Chemicals must be treated with care since they can be corrosive.

Costs: Comparatively, direct Filtration is cheaper than standard treatment processes, as fewer chemicals are used and there is less plant to construct. This can save up to 30 %.

Social and Environmental Considerations: Generally, this treatment process is well accepted by consumers and institutions, as the turbidity of water is visibly improved. Sludge produced during coagulation can cause environmental risks if disposed of near groundwater sources.

Strengths and Weaknesses:

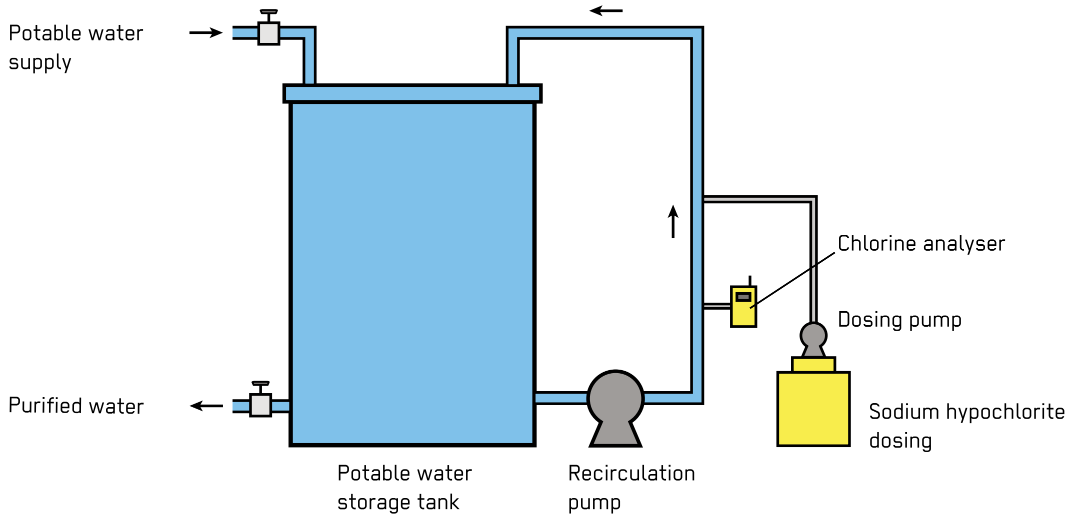
- (+) Costs less than similar processes that include Sedimentation
- (+) Provides a quick start to bulk water treatment in emergencies where perfect conditions for flocculation and Sedimentation are hard to achieve
- (+) Has higher Filtration rates with dual-media filters over conventional Rapid Sand Filters

- (−) Limited to treating lower turbidity water
- (−) Requires skilled operator for dosage and chemical handling (highly depending on the raw water)
- (−) Requires continuous supply of power and coagulant, which might not be locally available

→ **References and further reading material for this technology can be found on page 217**

Chlorination

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Disinfection with residual protection
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Chlorination is a final drinking water treatment step, as it inactivates pathogens such as bacteria and viruses. It is also used for other purposes such as disinfecting infrastructure (e.g. wells, pipes or boreholes) and equipment (e.g. in cholera treatment centres, X.14). It is used in all phases of an emergency.

Chlorination is applied at all treatment scales from a household level to centralised treatment. Chlorine provides ongoing protection from recontamination, which makes it unique over other disinfection processes such as Ultraviolet Light **(T.8)** or Ozonation **(T.14)**. It is strongly recommended for drinking water in emergencies, where hygienic conditions are often compromised and people are more prone to disease.

Design Considerations: For Chlorination to be effective, the water turbidity should be less than 5 NTU, although in emergencies, up to 20 NTU can be accepted for short periods while pre-treatment is established. Chlorinating turbid water (over 5 NTU) wastes chlorine, results in poorer disinfection (suspended solids can protect pathogens), increases the chlorine smell and taste (causing users to reject the water), and can generate potentially harmful by-products (e.g. trihalomethanes that are carcinogenic in the long term). For chlorine to disinfect properly, factors such as temperature and pH (should be < 8) have a major impact.
Chlorine exists in different forms with differing percentages of active chlorine. In emergencies, the most commonly used product for bulk treatment is calcium hypochlorite (also known as High Test Hypochlorite or HTH, 65–70 %). Other products are sodium hypochlorite (liquid bleach, 2–15 %), chlorinated lime powder (30 %) and chlorine gas (100 % elemental chlorine). Chlorine can be dosed at the source (e.g. borehole), as the final step of water

treatment in the treatment plant, at the Point of Supply **(H.7)** or at the Point of Use **(H.6)**. Types of dosing include batch dosing where chlorine is added to a fixed volume (e.g. a water truck), constant rate dosing where chlorine is added at a fixed rate (e.g. water flowing at a steady rate) and proportional dosing where chlorine is added at a variable rate (e.g. for solar pumping where water flow varies). In cholera outbreaks **(see X.14)**, batch dosing individual water containers at the point of supply/collection (known as 'bucket Chlorination', **H.7**) is useful as a temporary measure in areas identified as high risk (based on patient origins).
For drinking water, chlorine dosages range from 1–6 mg/L (0.5–2 mg/L for non-turbid water) for a standard 30-minute contact period. The amount that has then been used up is referred to as the 'chlorine demand', and the amount remaining is known as 'free residual chlorine' (FRC), which should be between 0.2–0.5 mg/L. The actual optimal dose for any water cannot be calculated in theory and is determined experimentally by a 'jar test' using a series of buckets containing an increasing dose of 1 % chlorine. Residual chlorine degrades over time, though will disappear faster when there is more contamination from pipes and containers, where temperature is higher and where there is more turbulence and mixing with air (e.g. pumping in long pipelines). Residual chlorine should still be present at 0.2 mg/L or more when the last cup is consumed at the household, so a higher FRC level might be required at tanks and tapstands depending on local conditions.

Materials: Materials include the chlorine product, a place for storing it safely, a mixing mechanism, a dosing mechanism (electric or mechanical) and equipment for monitoring residual chlorine.

Applicability: Chlorination should be carried out at all scales and in all phases of an emergency, especially in the acute response, because its residual presence can keep water safe for some time in storage tanks and distribution networks and during transport and storage in households. It is the method of disinfection that is often mandated for emergency response.

Operation and Maintenance: The main O & M tasks include the daily operation of chlorine mixing and dosing and monitoring the residual chlorine in the network. Monitoring in non-epidemic conditions should be carried out daily at tanks and treatment plants. A certain number of samples from the distribution network is recommended per month according to population, and chlorine should be continuously monitored at the household level via random checks. Chlorine should never be stored in or near metal containers and should not be stored in the sun, hot and humid warehouses or enclosed and unventilated buildings.

Health and Safety: Chlorine is a gas that is denser than air, is highly corrosive, can burn skin, cause blindness and damage internal organs, leading to death. Chlorine should always be kept in well-ventilated storage facilities and not near fuel, fertiliser or dry powder fire extinguishers. Different chlorine types should never be mixed (risk of explosion). Adequate training and safety equipment (protective glasses, gloves, mask) should be provided for all staff in contact with chlorine. Potentially carcinogenic trihalomethanes (THMs) can be produced when chlorinating turbid water or water with a high organic content. While chlorine can reduce bacteria and viruses by 3 to 6-log, it is not an efficient method of disinfection against Cryptosporidium, Giardia and some bacterial spores under normal dosing conditions.

Costs: Chlorination is generally not expensive, as not much is required to dose chlorine to water (e.g. typically under 35 kg of HTH will be sufficient to treat water for 20,000 people for a month). Most costs are related to the ongoing monitoring that requires employed staff.

Social and Environmental Considerations: Acceptance varies depending on the context and whether people have had previous exposure to it. There are mistaken perceptions linked to chlorine (e.g. chlorine confused with cholera), so community engagement is a key element for effective implementation. As chlorine changes the taste of water, this can also lead to rejection. Leakage of concentrated chlorine into the environment from poor storage, transport or treatment facilities is a severe environmental and health hazard. The release of chlorinated water into water bodies can harm the environment.

Strengths and Weaknesses:

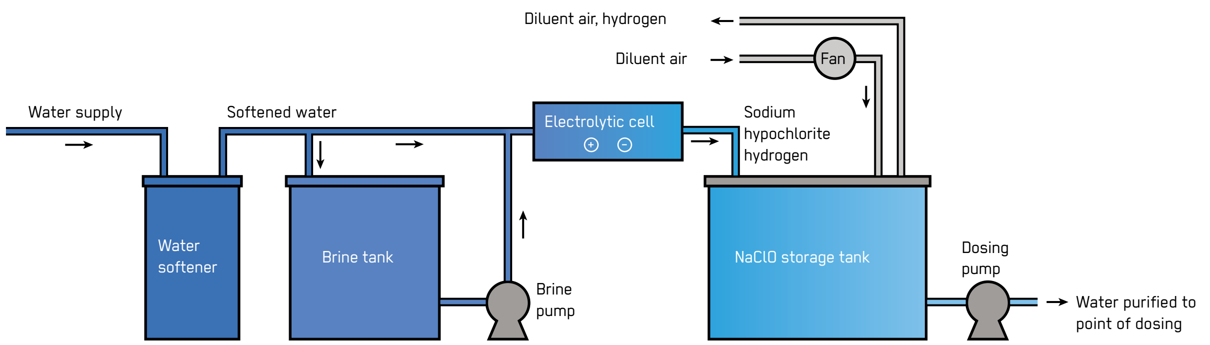
(+) Provides residual disinfection
(+) Is cheap to operate
(+) Usually locally available
(+) Reliable method if water is not turbid

(−) Requires proper storage/transport
(−) May have limited availability in conflict areas
(−) Can limit acceptance due to high impact on taste
(−) Effectiveness depends on various factors like temperature, sanitary conditions, pH and turbulence
(−) Ineffective in turbid water or against certain organisms (e.g. Cryptosporidium)

→ **References and further reading material for this technology can be found on page 218**

Onsite Electro-Chlorination

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Disinfection with residual protection
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	* Low	



Onsite Electro-Chlorination (electrolytic generation of sodium hypochlorite) produces chlorine for disinfection through the electrolysis of aqueous sodium chloride (common salt, or NaCl). It can be produced in batch mode, converting a salt solution into sodium hypochlorite with a concentration of 6–12 g/L either in one buffer tank or in a flow-through system that continuously produces hypochlorite.

Electrolysis uses a direct electric current to drive otherwise non-spontaneous chemical reactions. The reactions occur at two electrodes: the anode and cathode. At the anode, the chloride ion is converted into molecular chlorine (chlorine gas), while the reaction at the cathode produces hydrogen gas and increases the pH. The chlorine gas reacts immediately with hydroxide ions and forms hypochlorite ions. The sodium hypochlorite solution can be used directly for disinfection and/or pre-treatment when operated in a continuous mode or can be stored in a buffer tank for later use when operated in batch mode.

Design Considerations: The quality of the raw water is an important parameter for continuous systems. Generally, the hardness, or the concentrations of manganese, iron, fluoride, free chlorine and cyanides, should be low, or an extensive pre-treatment is needed to protect the electrodes. To account for hard-water, continuous systems are usually designed to have 20–30 % greater capacity to extend the life of equipment. Alternatively, solar salt (i.e. salt produced by the evaporation of brine as opposed to salt that is mined) with a minimum of 99.8 % NaCl is more suitable, as it has lower concentrations of calcium and magnesium (< 0.14 %) as well as other contaminants that foul the electrodes. Batch systems have a greater flexibility in raw water quality, as the electrodes are usually more accessible for cleaning and any salt type can be used. The production cycles can take between 3–12 hours, depending on the scale and manufacturer. The concentration of sodium hypochlorite may vary and must be monitored after every cycle. The produced solution is not stable and needs to be used directly or stabilised by adding caustic soda.

Materials: Small electrolytic cells are available from a few manufacturers as part of a set that includes the testing equipment and solar panel or power adapter. Large continuous systems are available from international companies and occasionally through local distributors as a fully designed system adapted to the local requirements and context.

Applicability: Small batch systems are compact enough to be carried in luggage to produce hypochlorite very quickly in acute emergency contexts when a power supply (or a solar panel) is available. For example, a typical small system on the market can produce 2 L of chlorine with a concentration of 6 g/L in 2.5 hours, enough to treat around 8,000 L of water. Larger systems can produce 30–60 L of chlorine in 4–5 hours and are suited for camps or at drinking water treatment plants when a supply of liquid hypochlorite cannot otherwise be ensured. The systems can be set up using available tanks, and the produced hypochlorite can be dosed through existing dosing systems. When batch systems are set up from scratch, local operators must be trained, which is more realistic during the recovery phase of an emergency or later. Large-scale continuous systems can be considered in protracted urban crises to replace those relying on chlorine gas or liquid hypochlorite, especially when the supply cannot be assured in the long term due to security concerns, embargoes or a limited production capacity in the country.

Operation and Maintenance: Batch systems are relatively simple to operate. They require a power supply as well as equipment to measure salt (brine) concentration, water hardness and final hypochlorite concentration. Most suppliers provide testing equipment as part of the system. Production should be done in well ventilated rooms. Large-scale continuous systems require the support of a trained engineer during the installation and start-up phase, after which the equipment is fully automated. Brine tanks are required to maintain capacity to cover a 15–30-day demand, and the level should be maintained close to the recommended storage capacity to avoid automatic shut-down. Leakage control is essential, as is the careful monitoring of operating voltage, current and the relationship between salt usage versus operating time. Regular inspections should look for signs of electrode fouling and float switches, which may require electrode cleaning. Most systems are supplied with an integrated acid cleaning system, which may be either fully automated or manually operated.

Health and Safety: Onsite Electro-Chlorination reduces the need for the handling, transport, and storage of hazardous materials, thus increasing general site safety. Small batch production should be carried out in well ventilated rooms. For large systems, there is a need for a good ventilation system to remove hydrogen, and hydrogen trapping in pipes should be avoided.

Costs: Small batch systems (producing 0.5–2 L of hypochlorite in up to 3 hours) without solar panels are available starting from 150–300 USD, while large batch systems (producing 30 L of chlorine in 4–5 hours) start from around 1,000 USD. Semi-batch systems require a higher degree of automation and are more expensive. The cost of large-scale continuous systems varies with the context, though they generally have higher initial costs but lower operational costs compared to large-scale chlorine gas systems. When Onsite Electro-Chlorination systems are chosen to replace a conventional chlorine gas system, part of the equipment can be retrofitted to reduce costs.

Social and Environmental Considerations: As for other chlorination techniques, acceptance in areas where it is unknown may prove problematic. It is therefore important to communicate with leaders and the community at the outset to avoid misunderstandings. Taste and odour objections may cause users to reject the water, and this is more likely when the water being treated is turbid or if the chlorine is overdosed. Leakage of concentrated chlorine into the environment is a severe environmental and health hazard.

Strengths and Weaknesses:

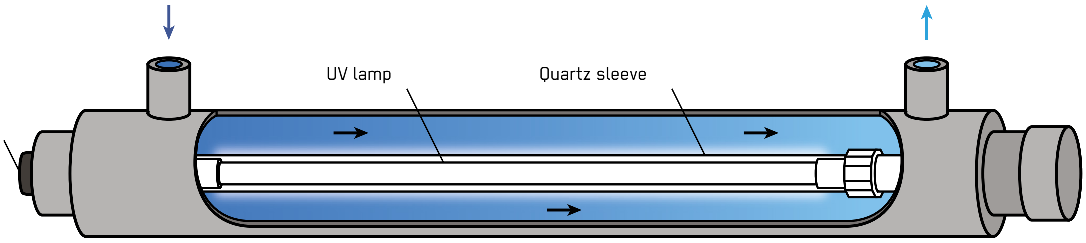
(+) Less dependent on chemical supplies, including their availability, transportation and costs
(+) Small batch systems are compact and portable
(+) Continuous systems are automated to a high degree and are less labour intensive
(+) Reduces risk from handling and storage of hazardous materials
(+) Lower operational costs compared to chlorine gas or liquid or solid chlorine systems

(−) Requires skilled operators in O & M for the continuous units or training for batch units
(−) Requires reliable source of electricity
(−) Requires good initial water quality to reduce fouling of electrodes

→ **References and further reading material for this technology can be found on page 218**

Ultraviolet (UV) Light

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



Under correct design and operational conditions, Ultraviolet (UV) Light can have anti-bacterial and anti-viral properties and can destroy pathogenic organisms in non-turbid water.

UV Light can cause irreparable cell damage to pathogenic microorganisms, and its effectiveness depends on the exposure time, the intensity of the UV light, the wavelength of the UV light and the raw water quality. UV provides a 3-Log inactivation of vegetative bacteria and protozoan parasites, including Cryptosporidium and Giardia at low exposures (1–10 mJ/cm^2). For the inactivation of enteric viruses and bacterial spores, higher exposures (30–150 mJ/cm^2) are needed. The exposure time depends on the design and the flow rate. UV is more effective on some pathogens (e.g. Cryptosporidium) that are resistant to the most widely applied chemical disinfectant (chlorine) and, unlike chlorine, UV does not form harmful disinfection by-products (DBPs). However, UV disinfection does not provide any residual protection from microbial recontamination and regrowth.

Design Considerations: A typical UV disinfection system includes a series of UV tubes. UV lamps are installed inside a tube in a covered channel, ensuring proximity of the water to the UV source. If the lamp is not placed directly in the flow, it will need a fused quartz sleeve to allow UV emission. The tube is usually made of plastic or stainless steel with a light-reflecting inner surface. To avoid unwanted turbulence, the inlet piping should have no upstream expansions for at least 10 pipe diameters, and all valves in the piping should be fully open during UV operation. The required UV dose for water disinfection is usually ≥ 40 mJ/cm², and only certified UV systems providing at least this dose under typical flow regimes should be used.
Turbidity and suspended solids reduce the disinfection efficiency. To be effective, turbidity should be < 1 NTU, suspended solids < 10 mg/L, no colour, iron < 0.3 mg/L, and manganese < 0.05 mg/L; otherwise, pre-treatment is required. Conventional clarification processes, such as Rapid Sand Filtration **(T.2)**, Microfiltration **(T.3)** or Ozonation

(T.14), can be used depending on the composition of the raw water and the context. Decentralised drinking water treatments most commonly use low pressure, low intensity mercury lamps that emit a single peak of UV radiation at 254 nm. For large-scale systems, medium pressure lamps are typically used that emit UV radiation over a very broad range (185–400nm). UV-emitting LEDs are also becoming more popular.

Materials: UV disinfection reactors can be skid-mounted and shipped to site. Validation can be conducted off-site, pre-shipment. UV requires reliable electrical power, so many installations include backup power, and specialised consumables, such as cleaning materials, chemicals and wipers, and periodic lamp replacements. UV lamps may not be readily available in some contexts and may have to be imported or flown in.

Applicability: UV systems can potentially be applied in all phases of an emergency and implemented quickly when materials, spare parts and skilled operators are available. These systems require a reliable power source **(see S.9–S.12)** and water pre-treated to a minimal turbidity (< 1 NTU). UV does not provide residual protection, so additional Chlorination **(T.6)** is needed.

Operation and Maintenance: UV systems require careful operation, knowledgeable and well-trained operators and monitoring to ensure effectiveness. Accurate measurements of flow rate, UV intensity, UV transmittance, and lamp status are required. Large-scale UV systems are designed for continuous operation and should be shut down only if there is no need for treatment for several days. Lamps need to be warmed-up for a few minutes before operation. For community and small-scale systems, daily operation includes switching the lamp on and off depending on the water flow, which is usually a fully automated process.
When the set lamp exposure deviates too far from the measured UV dose (~70 % or less from set/initial value), a number of reasons should be considered: (1) UV-absorbing matter (dissolved or suspended) may interrupt the path of light, and the reactor should be flushed. Upstream water should be checked for turbidity, and if necessary, pre-treatment must be improved. (2) The UV sensor or lamp may be dirty. Here, the reactor has to be opened, and the sensor, lamp and inner reactor surface should be cleaned with a soft cloth to avoid scratching. In many systems, an integrated sensor monitors the UV light intensity at each treatment tube. Some systems have an automated cleaning mechanism that wipes the quartz sleeves around the lamps once the sensor indicates a reduction of intensity below a certain set threshold. When fouling of the lamp chambers occurs too fast, any upstream treatment should be checked for proper operation. (3) If neither (1) or (2) applies, the UV lamp must be replaced. The nominal lifetime ranges from 8,000–12,000 operating hours (about 1 year of continuous operation) for mercury lamps. For LEDs, the life span varies depending on the specifications and manufacturer. During lamp replacement, the inner surface of the reactor should be inspected and cleaned.

Health and Safety: UV provides no residual protection from downstream microbial recontamination during transport or storage at home. UV-treated water should therefore be distributed and stored safely (constant overpressure in the distribution networks and/or adding residual chlorine). If the lamp breaks, toxic mercury may be released into the environment, potentially causing a health risk to the operator and harming the environment. Low pressure lamps represent less of a threat to operators in the case of breakage, and LEDs are generally safe. The operational monitoring of UV disinfection is less difficult than chlorine dosing systems, as it can be done by monitoring technical operational parameters of the UV lamp or through microbial water testing.

Costs: Capital costs vary depending on the system type. Low pressure systems will cost in the range of 50 USD/m^3/day capacity. Operational costs are context-dependent and vary in the range of 2.7–4 USD/m^3/day capacity and include electricity consumption and the periodic replacement of lamps and other specialised components.

Social and Environmental Considerations: UV treatment is usually well accepted by consumers, as it does not affect the taste of water. UV lamps should be disposed of safely and in accordance with national regulations to prevent harm to the environment.

Strengths and Weaknesses:

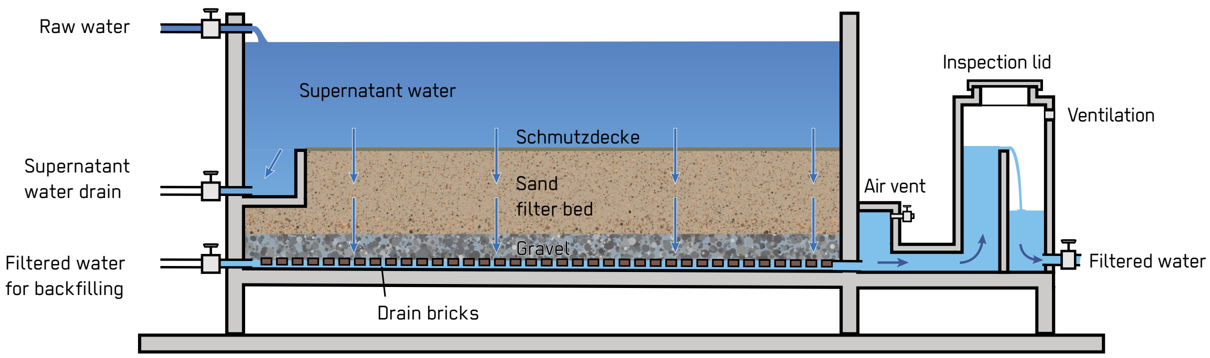
(+) Requires no chemicals and forms no disinfection by-products
(+) Does not modify taste and odour
(+) Efficiently disinfects microorganisms, including those with high chlorine resistance

(−) Requires reliable power supply
(−) Has no residual disinfectant (safe distribution and storage must be assured)
(−) Requires pre-treatment for turbid waters to reduce turbidity and total organic matter content
(−) Spare parts might be not available locally

→ **References and further reading material for this technology can be found on page 218**

Slow Sand Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	** Household ** Neighbourhood ** City	Household * Shared ** Public	Pathogen removal, fine sand filtration as part of final treatment process
Local Availability *** High	**Technical Complexity** *** High	**Maturity Level** *** High	



Slow Sand Filters remove suspended solids and pathogens from water with varying levels of turbidity (or 'muddiness') using fine sand as the filtration medium. They are used as a final treatment step and are most applicable in the stabilisation and recovery phases of an emergency.

Slow Sand Filters consist of a tank containing the filter media with a gravel support at the bottom, an underdrain to collect the filtered water, a flow control and a filter drainage system. They are unique in their ability to greatly reduce pathogens in the water through a combination of naturally occurring physical and microbiological processes within the filter bed (including sedimentation, straining, adsorption, adhesion, competition for food and predation). As such, Slow Sand Filters can be one of the most effective one-step treatment methods available and can be applied across scales, from large treatment plants to households.

Design Considerations: A raw water turbidity of up to 10 NTU is recommended for Slow Sand Filtration, with occasional peaks of up to 50 NTU tolerated. For higher turbidity, a pre-treatment such as Roughing Filtration **(T.1)** or (Assisted) Sedimentation **(T.4)** is needed. Slow Sand Filters can reduce turbidity to under 1 NTU and can also significantly reduce pathogenic organisms (> 95 % reduction in bacteria and viruses and > 99 % reduction in Giardia and Cryptosporidium). They improve colour and taste while reducing other organic and inorganic toxicants by at least 50 % (e.g. cyanobacterial toxins, mercury, polyaromatic hydrocarbons, iron, manganese, chromium, cadmium and arsenic). The effectiveness of these filters depends on the sand size, sand bed depth, temperature and hardness of the water (more turbidity removal with harder water). Sand size is a critical design parameter, with an effective grain size ranging from 0.15–0.35 mm (higher efficiency with smaller grains) and a uniformity coefficient of between 1.5–3 (meaning it is not too uniform or too diverse). When the sand size is correct, solids are strained out

within the top few centimetres only, but when the sand is coarser, solids will penetrate deeper such that maintenance procedures will not properly restore flow.
Slow Sand Filters must be kept saturated because they serve as the habitat for the organisms responsible for the biological filtration process. This diverse microbial community (known as the 'Schmutzdecke') forms during the first few weeks to months of operation, depending on the raw water quality. For larger-scale filters where water is flowing 24 hours a day to bring oxygen and food to the biological layer, the sand depth varies from 0.6–1.2 m, while the water height above the filter bed is usually between 1.0–1.5 m (Household Biosand Filters **(H.5)** have a different water level). The filtration rate should be slow—between 0.1–0.4 m/h (compaction of m^3/m^2/hour) to support the biological activity and allow adequate contact time for other physical processes. An underdrain system allows clear water to flow out, above which several graded gravel layers prevent sand from leaving the filter while improving flow velocity. Flow is always down and driven by gravity, and it will decline over time as the filter clogs. For larger filters, a constant flow is usually achieved by controlling water leaving the filter using valves or float controls to account for the increase in resistance within the filter bed. The filter must be designed so that incoming water does not disturb the Schmutzdecke. Once flow reduces below that which is needed, cleaning is required.

Materials: Materials include the filter compartment(s), water inflow and outflow system with control mechanism, underdrain system, filter media and equipment for washing and storing sand.

Applicability: Slow Sand Filters are not suited to the acute response, as it takes time for the biological activity to mature within the filter. They can be considered for the stabilisation and recovery phases as part of a wider treatment process, where time is available for plant design and construction. Household Biosand Filters **(H.5)** could also be considered in the recovery phase (initially as a pilot project to ascertain acceptance) for ongoing sustainable water treatment for dispersed populations. In cold climates, special measures may be needed to avoid freezing. The performance of biological processes also reduces in cold climates. In hot climates, some types of algae might proliferate on the surface of the open filters leading to clogging. This sometimes means the filters must be covered, though some types of algal growth combined with exposure to UV light in open filters might support biological processes.

Operation and Maintenance: Main O&M tasks relate to general plant maintenance, flow control and manual cleaning. Cleaning is done by draining the filter so that the water level is around 10 cm below the sand surface before manually scraping off the top layer. The quicker the cleaning process, the quicker the re-ripening period (placing geotextile over the sand surface has been found to speed up cleaning). Scrapings can then be washed and stored. Additional sand is only added when the filter bed reaches a minimum depth (0.6 m), which happens every few years. As it takes at least a few days for microorganisms to recover (and longer after sand replacement), it is normal to install multiple filter units in parallel so that water can still be treated while maintenance is ongoing.

Health and Safety: Slow Sand Filtration is considered a final treatment step and may be used as a single-step treatment process for drinking water, depending on the raw water quality. The effectiveness of pathogen removal depends on the filter design and operating conditions. In acute emergencies, however, the standard protocol is to always disinfect the water via Chlorination **(T.6)** to provide residual protection.

Costs: Filter capital costs vary around 100 USD/m^3/day capacity (similar to Rapid Sand Filters, **T.2**). Ongoing costs for O&M are around 3 USD/m^3/day capacity, which is lower than Rapid Sand Filters, as the intervals between maintenance tasks are longer. Slow Sand Filters require large areas, often up to 10 times greater than for Rapid Sand Filters and over 50 times greater than for membrane systems like Microfiltration **(T.3)** or Ultrafiltration **(T.10)**. The price and availability of land will influence the capital costs considerably.

Social and Environmental Considerations: Slow Sand Filters are very well accepted. Because it is known that clean water can be drawn from holes dug next to a dirty river, the concept of Sand Filtration is easily understood. Slow Sand Filters do not change or improve the taste of water.

Strengths and Weaknesses:

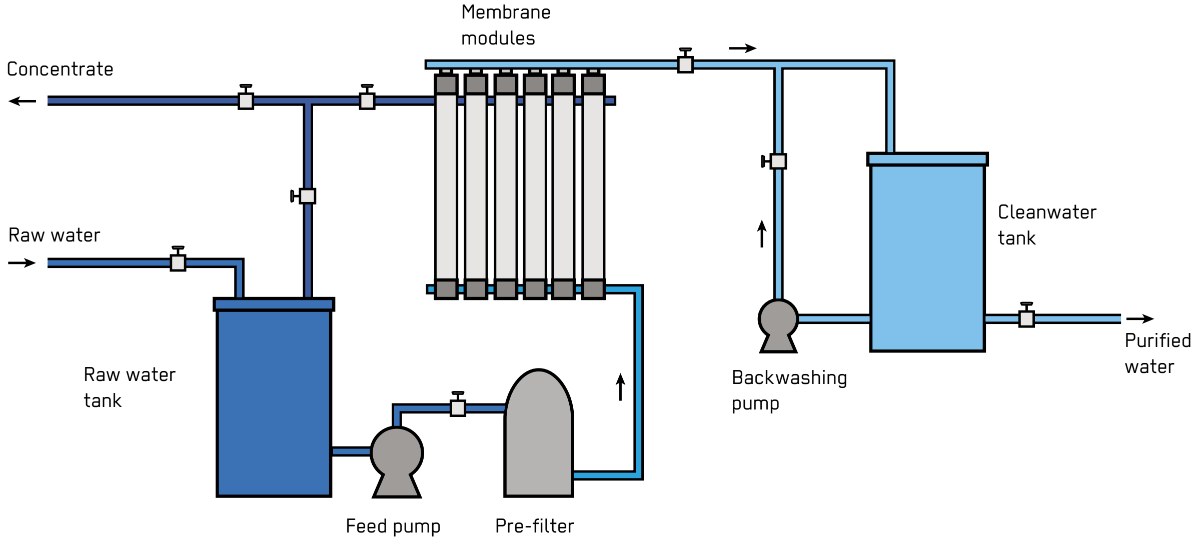
(+) Does not require the use of chemicals and needs no additional water for backwashing
(+) Can be constructed with local resources
(+) Requires no pump or power supply
(+) Has low life cycle costs (especially low operational costs)

(−) Needs proper design, operation and monitoring for best pathogen removal rates
(−) Reduced treatment efficiency against viruses and at low temperatures
(−) Requires time for recovery after cleaning
(−) Comparatively low flow rates

→ **References and further reading material for this technology can be found on page 218**

Ultrafiltration (UF)

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Pathogen removal
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	** Medium	*** High	



Ultrafiltration (UF) is part of the family of pressurised membrane filtration systems that can purify water from undissolved and most dissolved substances. UF is used as a final treatment step and can be applied in the acute response as well as in the stabilisation and recovery phases of emergencies.

UF uses membranes to filter water under pressure and functions the same as Microfiltration **(T.3)**. UF units can be prefabricated and skid-mounted or available as single-membrane modules. Most UF membrane modules in skid-mounted systems are made of small, string-like hollow fibres (polymer materials) that are mounted in cylindrical (pipe-like) vessels or tanks due to the high packing density (2,000–15,000 m^2/m^3 depending on system type). The main difference between MF and UF is the exclusion size, which for UF is 0.1–0.01 µm and for MF is 0.5–0.1 µm. This leads to similar filtration results for particles, protozoa, bacteria (3-log to 6-log) and a significantly better removal of viruses (1-log to 5-log) with UF membranes. Additional proteins and polysaccharides are removed by around 80 % and humic substances by 40–60 %. Post-treatment usually includes disinfection, such as Chlorination **(T.6)**, to provide residual protection.

Design Considerations: Membrane-based filters can be operated as dead-end-filters (feed is pushed completely through the membrane), or cross-flow filters (feed flows over the membrane, not all of the feed is filtered). Typical UF membranes are run as dead-end-filters. Depending on the intake water quality, particularly the turbidity (above 500 NTU), a pre-filtration **(T.2 or T.3)** or pre-treatment **(T.5)** should be considered to avoid membrane plugging. Pre-treatment always includes a protective pre-screen (typically an auto-backwashing type rated at about 300 micron). Additional pre-treatment, such as Assisted Sedimentation **(T.4)**, can improve the removal of dissolved materials and reduce the fouling potential of the water. Automatic in-line coagulation followed by direct microfiltration is also used for water with a high fouling potential.

Regular backwashing removes particles accumulated on the membrane surface. Prefabricated and skid-mounted UF systems usually include a control system to regulate operating conditions, including pump-driven filtration, backwash frequency, chemical cleaning (typically once a month), and integrity tests (to ensure the membranes are not damaged). Typically, systems backwash themselves with filtered water every 20–30 minutes depending on the raw water quality. During the 2–3 minutes of backwashing, the unit does not produce filtrate. Overall, about 85–95 % of the feed water becomes usable filtrate, and the rest is discharged as spent backwash or chemical cleaning waste. Typically, UF systems using the principle of dead-end filtration are operated in a constant flow mode with the transmembrane pressure in the range of 0.5–1 bar. Some systems are designed to work with Gravity **(S.7)**, so are under constant pressure and variable flux. To avoid reversible or irreversible fouling, regular chemical cleaning must be carried out. To avoid damage, UF membranes should never run dry. It is possible to store some UF membranes after a preservation process, and there is no need for a filter-to-waste step after backwashing.

Materials: Typically in emergency situations, the UF system is bought as one unit, not just the membrane elements. Ancillary equipment, including support racks, pumps, valves, pre-screen(s) and a computer control system (for backwash and water quality monitoring) are just as important as the membranes themselves. Consumables include membrane elements (8–10-year service life if operated correctly), membrane repair kits, electricity and chemicals (e.g. citric acid, sodium hypochlorite for cleaning and disinfection; caustic sodium hydroxide and sodium bisulfide for neutralisation).

Applicability: UF technology can be used in a wide variety of contexts due to its modular functionality, giving it a flexible filter performance. It can be a one-step treatment, as it has excellent filtration, though can also be used as a pre-treatment step to reduce turbidity for Reverse Osmosis **(T.15)**. Automated small-scale, skid-mounted systems are available and can be set up in a few hours. UF is sometimes applied in remote locations, though is typically reserved for a village or city. UF membrane filtration can be used in the acute response (as smaller units) and in the stabilisation and recovery phases of emergencies. UF membrane elements are modular, though adapting the number of modules in skid-mounted systems is not easy due to limitations of the auxiliary equipment (pumps, control systems).

Operation and Maintenance: Well-trained operators are required for a long, reliable service life. Although the systems are usually automated or semi-automated, operating mistakes can cause major damage to membrane elements (broken fibres, fouling). Regular O & M tasks include the daily verification of instrument accuracy and an integrity test, a daily check on chemical levels, a weekly calibration of chemical feed pumps, instrument cleaning, weekly review of data and consideration of revisions to operating parameters like flux, monthly (or sometimes more often) chemical cleaning and a volt-amp check on electric motors. Gravity-driven systems usually require regular manual backwashing (daily or weekly) and flow monitoring.

Health and Safety: Retentate disposal must be carefully considered, as it contains the contaminants found in the feed water. Depending on the makeup and local regulations, retentate can be directed back to the source, disposed of in the municipal sewer, diluted and used for irrigation or treated on-site before disposal. Treatment before disposal and reuse is recommended when disposal in municipal sewers is not possible. Cleaning chemicals can be corrosive and require trained operators and personal protective equipment.

Costs: Initial investment costs are comparatively high due to the cost of membrane modules and the need for advanced auxiliary equipment. While the UF membrane alone is relatively cheap (10–20 USD/m² of the membrane), the cost of the entire module varies between 70–120 USD/m² of the membrane, depending on the producer and membrane type. Regular maintenance will ensure a service life of up to 10 years (depending on the manufacturer), resulting in relatively low costs per user over time. A constant investment in cleaning agents, repairs and trained personnel is necessary and varies according to country and region.

Social and Environmental Considerations: Acceptance is high as the water produced is safe and clear, the colour is partially removed and there is no change in taste.

Strengths and Weaknesses:

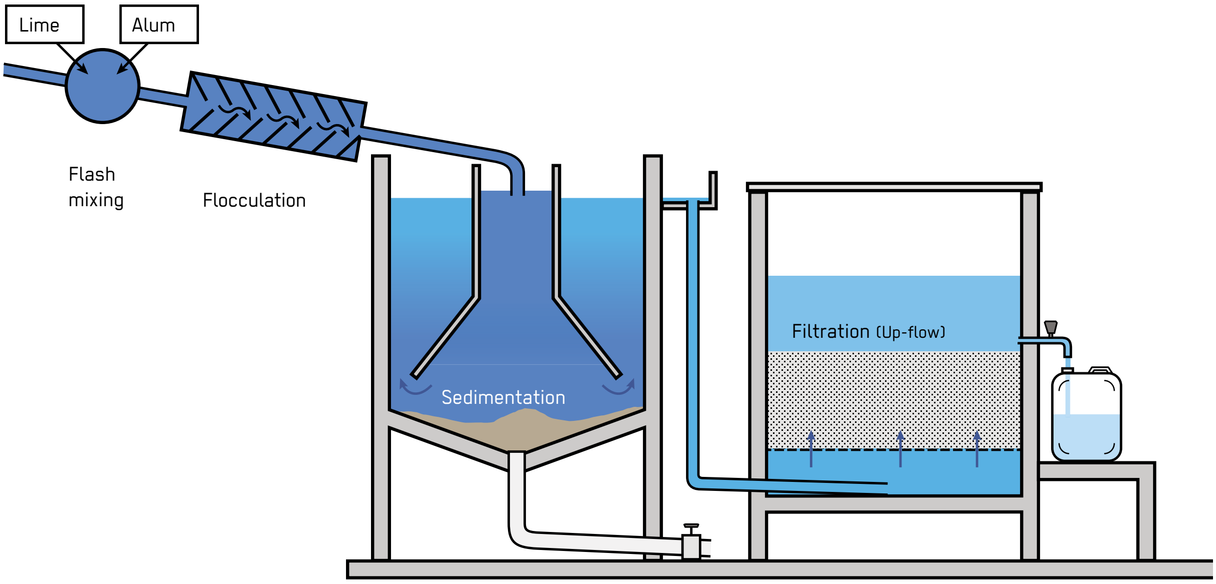
(+) High microbial removal performance
(+) Can be used as a one-step treatment
(+) Is very compact and easy to transport systems

(−) Requires a high-quality standard for materials and equipment to operate a UF plant
(−) Requires regular cleaning to keep the system running
(−) Requires qualified and trained staff for maintenance

→ **References and further reading material for this technology can be found on page 218**

Fluoride Removal Technologies

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Removal of fluoride
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



Fluoride is a groundwater contaminant derived from minerals present in rocks and soils (commonly volcanic-derived sediments). At levels over 1.5 mg/L, it can directly impact human health so must be removed to ensure a safe water supply. Nonetheless, as the negative health impacts only occur over the long term and because they are time consuming to establish, Fluoride Removal processes are more suited to the stabilisation and recovery phases.

The health impact of ingesting fluoride from various sources, including drinking water, over a long period includes the mottling of teeth (occurs in childhood), joint pain followed by skeletal deformities, and non-skeletal issues (e.g. lethargy, a decrease in cognitive capacity). It can be removed by adsorption/ion exchange on calcium–phosphate- or aluminium–oxide-based filter materials or by precipitation and coagulation treatment processes. Removal is possible at varying scales from large drinking water supplies to the household level using Fluoride Removal Filters **(H.13)**.

Design Considerations: No single Fluoride Removal technology is suited to all contexts, with the choice of technology depending on the local situation. Factors particularly affecting this decision include the available financing, fluoride concentration and pH of the raw water, O & M requirements, availability of raw materials and the acceptance of the technology by the population. While a variety of advanced removal technologies exist (e.g. Reverse Osmosis **(T.15)**, electro-dialysis and distillation), methods in low-income countries commonly rely on coagulation/precipitation or adsorption/ion exchange processes. For coagulation and precipitation, added chemicals such as calcium and aluminium salts form precipitates that bind fluoride and can then be removed using conventional sedimentation and filtration. The most established method at a community scale, the Nalgonda technique, uses added aluminium sulphate and calcium hydroxide (lime). The chemical dose varies according to the groundwater fluoride concentration and needs to be calculated to avoid over- or under-dosing. The main advantages of coagulation/precipitation are the moderate treatment costs and local availability of chemicals, though a daily supply of chemicals is required, and the sludge produced must be properly disposed of.

Adsorption/ion exchange passes the water through a layer of porous material ('contact bed') to remove fluoride through adsorption to the contact bed material. Appropriate contact bed materials include activated alumina or calcium–phosphate-based materials, such as synthetic hydroxyapatite and bone char. An important advantage of adsorption/ion exchange is that many filter materials can be regenerated once the uptake capacity is reached. Here, fluoride is removed by passing a basic (alkaline) solution over the filter bed followed by reactivation via an acidic solution before reuse, though the Fluoride Removal capacity of the filter media decreases with each regeneration cycle. Disadvantages of adsorption/ion exchange are that activated alumina is not always locally available or may be too expensive, while the quality of bone char can vary so considerably that the quality needs frequent monitoring and skill is needed in its production. Synthetic hydroxyapatite (HAP), chemically the same as bone char, generally has a higher uptake capacity with less fluctuation in quality. Other Fluoride Removal techniques include electrocoagulation (a mix of electrochemistry, coagulation and precipitation) and the Nakuru technique (a mix of precipitation and adsorption). Most techniques can remove over 90 % of fluoride, although a higher pH/alkalinity can make some techniques less effective (e.g. activated alumina and coagulation/precipitation are less effective at higher levels).

Materials: Materials depend on the type of removal process chosen and can include the physical treatment infrastructure, filter media and various chemicals for media treatment or regeneration. Some of these may not be available locally.

Applicability: Fluoride Removal is more suited to the stabilisation and recovery phases, as the negative health impact of fluoride results only from a prolonged use of the contaminated source. Higher levels of fluoride should be addressed, but in an acute emergency, the focus is primarily on providing sufficient quantities of drinkable water. Where coagulation **(T.4, T.5)** is used in an emergency setting, fluoride levels are reduced regardless.

Operation and Maintenance: Different O & M activities are needed for each system, but most have significant O & M requirements. For coagulation/precipitation, O & M includes the daily dosing of chemicals and sludge removal, and the plant often needs a power supply. For adsorption/ion exchange, O & M is less frequent, but when required, it involves regenerating the contact bed using alkalis and acids. These chemicals need to be stored and handled carefully, so this tends to be easier at a centralised level.

Health and Safety: Coagulation/precipitation produces daily sludge, and adsorption/ ion exchange saturates the filter material over time. Both can be an environmental hazard, and the waste needs to be disposed of safely (e.g. landfill away from drinking water sources). The regeneration of contact bed materials using alkalis and acids can be dangerous and requires the adequate training of operators as well as personal protective equipment (goggles, overalls, gloves, boots).

Costs: Some processes are more expensive than others. Cost is related to the actual materials used or re-used (e.g. chemicals or filter media), the infrastructure (e.g. treatment plant, stirrer or kiln) and the labour required to produce or regenerate materials (e.g. quite a lot needed for bone char production). For most processes, the cost is generally too high to be done at the household or community level without some form of external/ government funding, especially where fluoride levels are higher and regeneration cycles more frequent.

Social and Environmental Considerations: Bone char may not be acceptable in some areas due to religious or cultural reasons. For coagulation/precipitation, the high sulphates in treated water can make it unacceptable to users. Introducing fluoride treatment on a community scale requires the participation and involvement of all stakeholders from the outset. Where awareness is low, information and behavioural change interventions **(see X.16)** will be needed. The long-term effects of fluoride poisoning are not obvious, and users might be reluctant to accept this treatment it if it leads to higher costs. Regeneration solutions or saturated filter media pose environmental hazards and need to be disposed of safely away from sources of drinking water or land used in agriculture.

Strengths and Weaknesses:

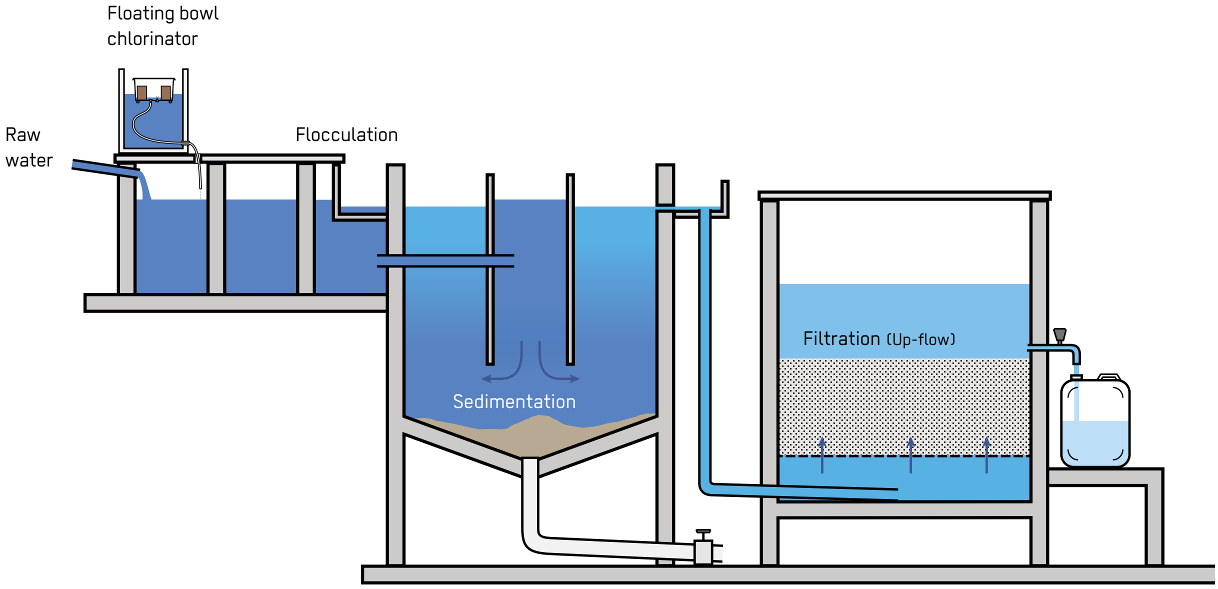
- (+) Chemicals are readily available and inexpensive (Nalgonda technique)
- (+) Has high fluoride uptake capacity for some processes (e.g. activated alumina)
- (+) Can regenerate filter media for some processes
- (+) Requires only short contact time for some processes (e.g. bone char)

- (−) Some processes are less effective depending on pH (activated alumina)
- (−) Produces sludge that needs safe/managed disposal (Nalgonda technique)
- (−) Requires skilled operation for regeneration of media
- (−) Bone char production needs skill (e.g. kiln at correct temperature), as the quality may vary otherwise

→ **References and further reading material for this technology can be found on page 218**

Arsenic Removal Technologies

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Removal of arsenic
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	*** High	*** High	



Arsenic is a groundwater contaminant derived from naturally occurring minerals present in rocks and soils (commonly in young alluvial sediments) as well as from industrial activities (e.g. mining). When present at levels over 10 µg/L, arsenic can directly impact human health and should be addressed as soon as possible at any phase of an emergency. Arsenic can be removed from groundwater by precipitation, adsorption, ion exchange or Reverse Osmosis (T.15).

The health impacts of ingesting arsenic over a prolonged period include changes to skin pigmentation, organ damage, anaemia, metabolic disorders, increased risk of various cancers and skin diseases, and other symptoms (e.g. bronchitis, vascular disease, depression). Short-term effects include increased risks of heart attack, diarrhoea and nausea. These health impacts can continue even after the arsenic is removed from the water. Soluble arsenic found in natural waters usually occurs as trivalent arsenite, As(III) (present under anaerobic conditions and lower pH), or pentavalent arsenate, As(V) (present in aerobic conditions and at pH values above 7). It can be removed by precipitation, adsorption and ion exchange processes varying in scale from large drinking water supplies to the household level **(see H.14)**.

Design Considerations: As(III) is the common form of arsenic found in anaerobic groundwater conditions and is more difficult to remove than As(V), which is strongly adsorbed onto various solids such as iron (hydr-)oxides. While some treatment processes can partially remove As(III), sufficient removal requires a preliminary conversion of As(III) to As(V) using a pre-oxidation step that is followed by a second process for As(V) removal. Pre-oxidation can be effectively achieved through the addition of chemicals (e.g. chlorine or potassium permanganate) or by filtering the water through a bed of manganese (IV) oxides. Once oxidised to As(V), there are different processes that can remove it, such as coagulation and co-precipitation, adsorption and ion exchange.

For coagulation and co-precipitation, chemicals such as iron and aluminium salts are added to form iron and aluminium (hydr-)oxide precipitates that adsorb As(V). Once these particles settle, they can be removed using conventional sedimentation and filtration steps. To be effective, the type of coagulant must be suited to the raw water pH, and dosing/mixing conditions should be optimised **(see T.4, T.5)**. Co-precipitation can also occur without a coagulant when there is enough naturally occurring iron in the water. Here, aerating the water creates insoluble iron (hydr-)oxides that in turn adsorb arsenic. This has worked well in some areas along with household level Biosand Filters **(H.5)**. The efficiency depends on the natural concentration of iron in the water and the presence of competing ions.
As(V) can also be removed through adsorption and ion exchange, in which water passes through a layer of porous material ('contact bed') that removes arsenic through an exchange of ions that allows its adsorption to the contact bed material. Appropriate contact bed materials include synthetic ion-exchange resins, activated alumina, activated carbon and iron-based solids (granular ferric hydroxide or iron-coated sand). The effectiveness of the contact material differs, where some are not affected by pH or the concentration of arsenic (e.g. ion-exchange resins, iron-based solids) though others are (e.g. activated alumina). Some materials also preferentially adsorb competing ions instead of arsenic (e.g. sulphate with ion-exchange resins). Additionally, some materials are easily regenerated with less dangerous chemicals (e.g. ion-exchange resins), while others may require strong acids and alkalis (e.g. activated alumina) and some cannot be regenerated (e.g. iron-based solids). Given the right conditions, though, these techniques can remove over 90% of arsenic. Other techniques exist that are more (e.g. electrocoagulation) or less (e.g. membrane-based methods like Nanofiltration/ Reverse Osmosis, **T.15**) effective.

Materials: The required materials depend on the chosen removal process and can include the physical treatment infrastructure, filter media and various chemicals. Some of these may not be available locally.

Applicability: Arsenic is a more serious health threat than fluoride, with some health effects occurring after only short-term ingestion. Therefore, it is recommended to begin Arsenic Removal as soon as possible in an emergency. Regardless, when coagulation is used in an emergency setting, arsenic levels would also reduce.

Operation and Maintenance: Different O&M activities are needed for each system, but most have significant O&M requirements. For coagulation/precipitation processes, O&M includes daily dosing of chemicals and sludge removal, and the plant often needs a power supply. For ion-exchange resins, O&M is less frequent and is a fairly easy process involving regenerating the contact bed, which is typically done using a concentrated salt (NaCl) solution. For activated alumina, regenerating the contact bed is done using a strong alkali followed by a strong acid.

Health and Safety: Establishing the presence of arsenic in water sources may prove difficult. Consulting health data and health centres on the number of cases of arsenicosis might be useful. The Groundwater Assessment Platform (GAP) provides information on high-risk areas. Water quality monitoring using arsenic test kits is recommended if the GAP or health information indicates an elevated risk. Arsenic-rich waste is produced by most of the Arsenic Removal processes and has to be disposed of properly (e.g. landfill away from drinking water sources). Contact bed regeneration using alkalis and acids can be dangerous and requires adequate training for operators as well as personal protective equipment (goggles, overall, gloves, boots) and adequate storage.

Costs: Indicative cost per litre for bulk treatment varies from around 8–120 USD/m^3, with the cheapest being coagulation and co-precipitation. Cost depends on the type of process and scale and is related to the actual materials used or re-used (e.g. chemicals or filter media), the infrastructure (e.g. the treatment plant, stirrer or kiln) and the labour required to produce or regenerate materials.

Social and Environmental Considerations: For coagulation/precipitation, high concentrations of sulphates in treated water may make it unacceptable to users. The introduction of arsenic treatment at a community scale needs to be participatory from the outset and involve all stakeholders. Information and behavioural change interventions **(see X.16)** will be needed to increase the awareness of the population in areas where this is not the case. The long-term effects of arsenic poisoning are not obvious, and users may be reluctant to agree to treatment if it leads to higher costs. Regeneration solutions or saturated filter media pose an environmental hazard and need to be disposed of safely away from sources of drinking water or land used in agriculture.

Strengths and Weaknesses:

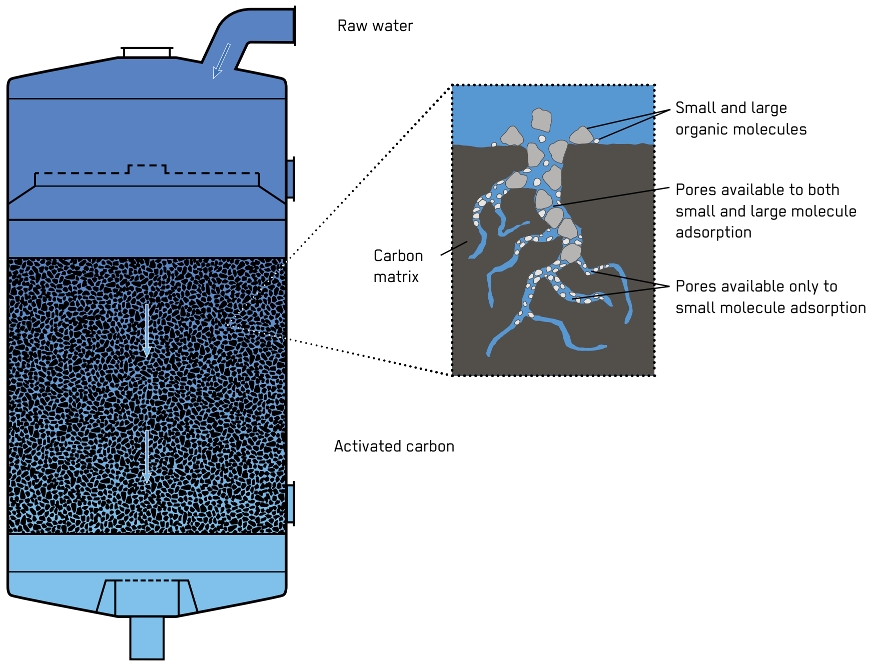
- (+) Uses readily available and inexpensive chemicals (coagulation and precipitation)
- (+) Has high arsenic uptake capacity for most processes
- (+) Filter material can be regenerated for some processes (ion-exchange resins, activated alumina)

- (−) Requires pre-oxidation for most processes
- (−) Can be less effective depending on pH (activated alumina) or competing ions in the water (ion exchange)
- (−) Produces toxic waste that needs proper, safe disposal
- (−) Requires skilled operation for media regeneration

→ **References and further reading material for this technology can be found on page 219**

Granular Activated Carbon (GAC)

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	* Household * Shared ** Public	Water quality improvement, taste and odour improvement, adsorption of chemicals
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



Granular Activated Carbon (GAC) is the most used adsorption method in drinking water to remove taste, odour and colour-causing compounds, natural organic matter, disinfection by-products and synthetic organic chemicals present in the source water. GAC is also used for vapour treatment to remove noxious odours and contaminants. In small-scale treatment plants, it is often used for chlorine and chloramine removal. GAC can be used in all phases of an emergency.

GAC is a form of granular porous carbon that is packed into a manufactured vessel, and raw media is pushed through the vessel using a powered pump to maintain flow within the design parameters. The GAC matrix acts like a sponge to adsorb small and large organic molecules from the media (water or air) that is then discharged from the vessel ready for use. GAC is a widely applied and accepted technology that is applied based on the concentration of contaminants, the number of people to be served and the available space.

Design Considerations: The GAC technology is mature and easy to use but does require an analysis of the medium/media (water and/or air) to be filtered to ensure that it meets the applicable initial quality standards. The higher the concentration of contaminants in the raw media, the faster the GAC will be exhausted and require replacement. GAC typically cannot be regenerated at the treatment facility and therefore will require off-site disposal or regeneration on a regular basis. The size of the GAC vessel can become a limiting factor depending on available resources (time, money, storage). Design and operations can vary depending on the available materials, specifically the availability and purity of GAC.
To design any GAC system, a qualified expert, the manufacturer and/or media supplier should be consulted. The quality and flow of the raw medium input are critical to proper design of the filter and media. Raw media flow rate and pressure must also be coordinated with the design inlet and outlet pressure and flow of the manufactured GAC vessel. GAC can also be used to treat foul

air or fumes typically found in industrial processes or municipal wastewater treatment. It is important to note that aqueous-phase GAC treatment removes chemical contaminants but not biological contamination, so a pre-treatment process for biological contamination, such as Chlorination **(T.6)**, should be considered.

Materials: GAC media is consumable and must be periodically replaced to maintain effectiveness. The media manufacturer should be consulted to determine the contaminant breakthrough point. Designed vessels, connection fittings, and piping/hoses to reach the intake and distribution connections are required for vessel installation. Properly designed powered media pump(s) capable of maintaining the raw media pressure and flow through carbon vessel are required and need a steady source of power and fuel. Pressure gauges are required to measure pressure drop across the filter and monitor hydraulic performance. Sample taps should be installed both upstream and downstream of the GAC filter to ensure the media is meeting quality metrics.

Applicability: For either air or water treatment, GAC can be used in a variety of settings and can be scaled up or down depending on need, but in an emergency, it is best used to treat a large volume of water for many people at a time rather than for individual households. Nonetheless, if sufficient small-scale systems are available, they can be used in conjunction with larger systems. GAC can be used in all phases of an emergency when readily deployable. Physically, the technology does not require much more than a flat surface that can support the vessel and the weight of GAC. If all materials are readily available, installation can take 30 minutes or less.

Operation and Maintenance: O & M tasks include ensuring all connections are watertight. A crew of up to three people will be needed to install the system and prepare for operation. For aqueous-phase GAC treatment, the vessels need to be hydrated after installation to activate the carbon. Unused fresh/virgin GAC should be stored away from the media. Monitoring of the effluent is required to detect an exhausted adsorption capacity and replace the GAC. Vessels can be emptied to exchange the carbon, or the entire vessel can be replaced with a virgin pre-packed GAC. The vessel manufacturer should be consulted to determine a media replacement period based on the raw water input. The vessel should not be over-pressurised, and vessels should not be used outside of the design parameters. More specific O & M tasks should be determined with the manufacturer.

Health and Safety: Wet GAC confined in large vessels creates an oxygen demand that is hazardous to human health and potentially deadly, so safety precautions for an oxygen deficient environment should be taken. Chemical-resistant gloves and safety glasses must be worn when operating and using GAC vessels. GAC filters may develop a biofilm that can subsequently remove some of the organic contaminants to increase the biological stability of the water. However, this process does not provide residual protection from contamination, so post-treatment Chlorination would be required.

Costs: Costs are dependent on the volume of water to be treated. Recurring costs include the replacement costs of GAC material (not always locally available), vessels, piping and transportation.

Social and Environmental Considerations: No cultural issues and considerations, user preferences and acceptability or local capacity issues are noted. GAC can improve the aesthetic properties of water (taste, smell, appearance) and is therefore well accepted by users. Saturated GAC should be disposed of safely.

Strengths and Weaknesses:

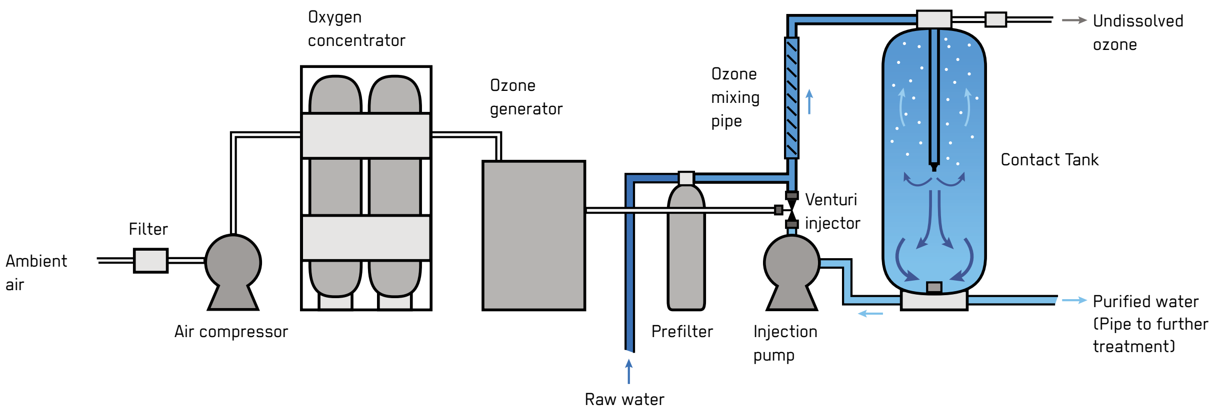
(+) Provides good removal of taste, odour, chlorine and organic contaminants
(+) Requires little maintenance
(+) Adapts to many designs and target compounds
(+) Simple replacements of filter elements and carbon blocks

(−) Loses performance rapidly if treating source waters with high turbidity or background organics
(−) Poor removal of microbial contaminants in aqueous-phase treatment
(−) Can result in higher costs due to regular replacement of GAC

→ **References and further reading material for this technology can be found on page 219**

Ozonation

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	Household Neighbourhood ** City	Household Shared ** Public	Removal of organic contaminants
Local Availability * Low	**Technical Complexity** *** High	**Maturity Level** ** Medium	



Ozonation is a water treatment process that destroys microorganisms and degrades organic pollutants through the infusion of ozone, a gas produced by subjecting oxygen molecules to a high electrical voltage. During emergencies, the technology is mainly applicable in the stabilisation and recovery phases in urban contexts, where the experience in using such systems already exists.

Ozonation (also referred to as ozonisation) is a chemical water treatment based on the infusion of ozone into water. Ozone is a gas composed of three oxygen atoms (O_3) and is one of the most powerful oxidants. In this advanced oxidation process, oxygen (O_2) is subjected to either a high electrical voltage or UV radiation to produce a very reactive species (O_3) that attacks a wide range of organic compounds and all microorganisms. Ozonation has a wide range of applications, as it is efficient for both disinfection and the degradation of organic and inorganic pollutants. The required amounts of ozone can be produced at the point of use, but the production requires a lot of energy and is therefore costly.

Design Considerations: The most common generators produce ozone (O_3) by subjecting oxygen (O_2) or air to a high electrical voltage ('Corona discharge-type generators') or to UV radiation (UV-type generators). Corona discharge-type generators are used for large-scale systems, producing ozone concentrations of 1–4.5 % by weight. UV-type generators achieve ozone concentrations of 0.1–0.001 % by weight and are used to treat smaller quantities of water. Ozone gas is transferred to the raw water via fine bubble diffusion or side-stream injection. In the contact tank, ozone reacts with the contaminants in the water, requiring only a short contact time (approximately 10–30 minutes). An off-gas system destroys any undissolved ozone.
The ozone gas molecule is highly unstable and therefore reactive toward a wide variety of water contaminants, such as inorganic (e.g. iron, manganese) and organic compounds (e.g. micropollutants) as well as microorganisms. Ozone attacks contaminants either directly or indirectly through its decomposition in water to form hydroxyl radicals (OH-), which react rapidly with many drinking water

contaminants. Ozone rapidly decomposes in water, making its lifespan very short (less than one hour) and rendering it unsuitable as a residual disinfectant, i.e. protecting the drinking water distribution system from regrowth/re-contamination. Ozonation and Chlorination **(T.6, T.7)** can be used in tandem to inactivate a wide range of microorganisms at the treatment plant and to protect water during distribution/storage. Ozonation of water containing organic matter will produce assimilable organic carbon that allows biological regrowth in subsequent processes and the network. Therefore, Ozonation should be followed by a treatment process allowing biological degradation, such as Slow Sand Filtration **(T.9)** or GAC **(T.13)**.

Materials: Materials include oxygen, oxygen concentrator, ozone generator, pre-filter, injection pump, venture injector, contact tank and a reliable power supply **(see S.9–S.12)**. Local availability of materials will be limited.

Applicability: Ozone can be added at several points in drinking water treatment: as a pre-treatment (pre-Ozonation), after sedimentation and before filtration (intermediate Ozonation) or as a final disinfection step. As a pre-treatment, it reacts with micropollutants, iron, manganese and sulphur as well as compounds affecting the colour, odour and taste. The subsequent removal of degraded compounds is improved in subsequent treatment steps, e.g. sedimentation or filtration processes including Sand Filters **(T.2, T.9)** and GAC Filters **(T.13)**. In low turbidity water, ozone forms colloids ('micellisation process') that can be transformed to micro flocs by adding a small amount of coagulant, and these micro flocs are easily retained by sand filters.
To target organic compounds, the required amount of ozone and subsequent ozone decomposition is highly dependent on the quantity and types of contaminants. As a rule of thumb, the initial ozone demand is 2.5 mg ozone/mg of Chemical Oxygen Demand (COD). As a disinfectant to inactivate microbial pathogens in water, required ozone concentrations and contact times ('CT values') can be found in the WHO guideline for drinking-water quality. In general, it is more effective against many bacteria and viruses than chlorine and UV. For inactivating Cryptosporidium, however, WHO states that there are currently no accepted CT values (ozone concentration multiplied by contact time), as the results vary widely between studies and even between replicate trials for different temperatures and levels of inactivation.

Operation and Maintenance: The design, construction and O & M needs well-trained operators. The high-tech equipment is costly and has a high-power demand. Systems occasionally develop ozone leaks, requiring an ambient ozone monitor and regular checks of the generator and contact tank. O & M also includes maintaining the required flow of generator coolant; regular inspection and cleaning of the ozone generator, feed gas supply and electrical assemblies; and monitoring the ozone gas-feed and distribution system to ensure that the necessary volume of ozone comes into sufficient contact with raw water.

Health and Safety: The Ozonation of bromide-containing waters can form bromate, a known carcinogen, though usually at concentrations well below the health concern threshold. Techniques to control bromate formation involve Ozonation at slightly acidic pH values, multi-stage Ozonation and the use of ammonia or chlorine. Once bromate is formed, GAC filters and UV irradiation can remove it to a limited degree. Ozone gas is possibly toxic and extremely irritating to the human body, so leaks must be controlled to prevent worker exposure.

Costs: The costs for Ozonation equipment, operations and energy are high.

Social and Environmental Considerations: Local capacities for managing such a sophisticated treatment process will be limited. Acceptance of the treated water is good, as the process does not include any chemical components, which could affect the taste. Ozonation has a high energy consumption. In areas where fossil fuels are used for power, it has a high CO_2 footprint.

Strengths and Weaknesses:

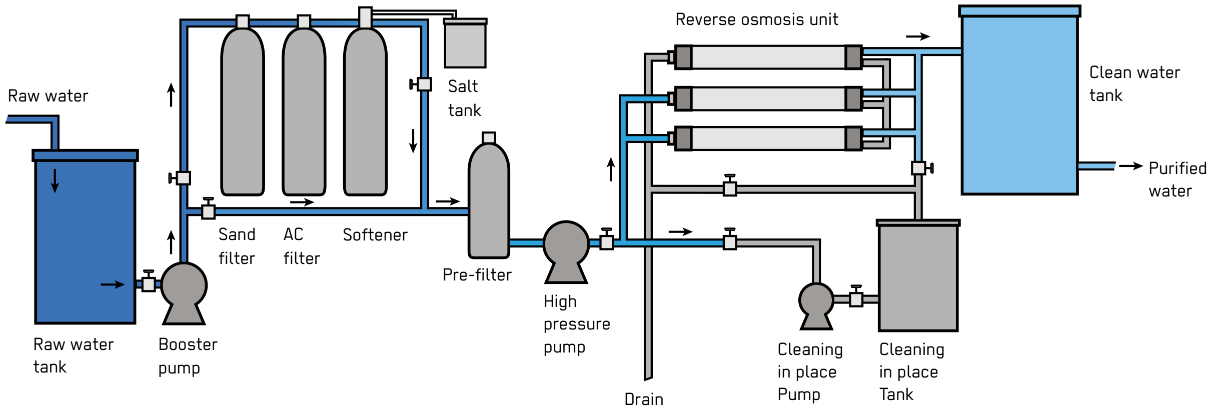
(+) Eliminates inorganic (iron, manganese, sulphur) and organic contaminants (micropollutants)
(+) Deactivates bacteria, viruses and protozoa effectively and rapidly
(+) Has stronger germicidal properties than chlorination and no chemicals are added to water

(−) Has high equipment, operation and energy costs
(−) Provides no residual protection in the distribution system
(−) Potential fire hazard and toxicity associated with ozone generation

→ **References and further reading material for this technology can be found on page 219**

Nanofiltration (NF)/Reverse Osmosis (RO)

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Removal of dissolved organic and inorganic contaminants
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	*** High	*** High	



Nanofiltration and Reverse Osmosis (NF/RO) have essentially the same equipment arrangements, and both remove contaminants by applying pressure to water across a semi-permeable membrane. RO is used to desalinate brackish water and seawater and removes organic and inorganic compounds (e.g. nitrate) and microorganisms. The key difference is that NF removes less salt (e.g. NaCl) and other monovalent ions than RO and is mainly used to remove colour, organic contaminants (e.g. pesticides) and lower the hardness (softening). Distillation, such as a solar still made of local materials, is a potential alternative. A related method, membrane distillation, is typically not commercially available.

Generally, NF/RO units are prefabricated. Some large systems are constructed on-site. RO/NF needs a reliable, uninterrupted, pressurised water supply, disposal locations for the concentrate (continuously generated) and cleaning wastes (intermittently generated), a reliable source of electricity, cartridge filters, specific chemicals for anti-scalant and cleaning, and typically pre- and post-treatment. Energy consumption is higher than for other treatment technologies except distillation. RO systems remove a wide range of contaminants, and element data sheets indicate new, single-element salt rejections above 99 % with full-scale performance typically providing over 95 % removal. NF generally removes > 95 % of organics (e.g. pesticides) and reduces hardness by about 50–80 % and NaCl by about 20–40 % (NF rejection is more site-specific than RO). RO water usually has a low pH that is unstable and corrosive. Re-mineralisation of the treated water might be required.

Design Considerations: Design considerations include pre- and post-treatment, waste disposal, membrane type and the presence of a reliable electrical supply. For low turbidity (< 0.3 NTU) water, minimal pre-treatment (5-micron cartridge filtration and anti-scalant addition) may be sufficient. Otherwise, additional pre-treatment is advised, such as Ultrafiltration **(T.10)** or granular media filters and support equipment. A silt density index of < 5 is required by warranties (< 4 is desired). Chlorine will damage the membrane so should be removed prior to RO filtration. Post-treatment usually includes adding

chemicals for disinfection and to prevent the downstream corrosion of piping and fixtures, such as by increasing the pH (via controlled addition of potable quality caustic, sodium hydroxide). Periodic cleaning in place (CIP) can recover the membrane permeability, which reduces over time due to scaling and fouling. Careful waste disposal is needed as the concentrate and spent cleaning solutions contain high concentrations of pollutants.
NF/RO parameters include feed water flowrate and pressure, flux (rate water passes through area of membrane) and recovery (ratio of permeate to feed flow). Feed pressure (and related electrical use) varies with feed water quality, salt content, temperature and membrane type. While difficult to generalise, the feed pressure for seawater is about 65 bar and, for water with lower salt concentrations, can be as low as 7–15 bar. Excessive flux results in a short service life, capacity shortfall and higher operating costs. Pilot testing can confirm stable flux, which is typically about 15–25 L/m^2/hour. NF/RO filters are operated in cross-flow mode and part of the feed is recirculated. Overall, about 50 % of a seawater feed becomes permeate, and with lower salt concentrations, the typical recovery is 70–85 %. A detailed evaluation of water quality is needed to properly design NF/RO. Manufacturers often provide software to aid calculations.

Materials: Membrane elements and vessels are made of special plastics. Low pressure piping (up to about 3.5 bar) may be non-metallic (e.g. fiberglass/plastics or stainless steel). Materials subject to corrosion (e.g. carbon steel, galvanised, ductile iron, copper, etc) are not used. Some materials may need to be imported.

Applicability: NF/RO can be used in the acute response and possibly the subsequent stabilisation and recovery phases. It can be used as a one step-treatment, as it has excellent filtration quality. Automated small-scale, skid-mounted systems are available that can be set up in a few hours and are sometimes applied in remote locations. In situations when only saline or brackish water is available or groundwater wells are contaminated with salt water (e.g. due to a tsunami), RO systems might be the only way of quickly desalinating water. Due to the high complexity, energy demand and costs particularly for longer-term operation, other technologies might be considered first, especially when the contaminants are primarily pathogenic microorganisms.

Operation and Maintenance: Key operational costs include electricity, chemicals, cartridge or membrane filters, operator and caretaker costs, and long-term replacement of the RO elements. It is imperative that the staff operating RO/NF are well trained and are supported on a long-term basis. As O & M procedures require experience with the respective system design as well as process automation, electronics and online monitoring, qualified personnel should maintain RO/NF for long-term viability. Thus, good after-sales and on-site support should be available locally through a distributor or manufacturer. To minimise membrane fouling and scaling, anti-scaling agents and other chemicals are frequently used. The membrane service life may reach up to 5 years before replacement.

Health and Safety: The removal of viruses, bacteria, Giardia and Cryptosporidium ranges from about 2-log (99 %) to 4-log (99.99 %) and higher. The operation of RO requires potentially dangerous chemicals, such as acids and bases. Proper transportation, storage and training are needed to ensure operator and public safety. The most common hazards are found in working at height, exposure to noise and chemicals, contact with rotating equipment, electricity, high-pressure fluids and fire. Waste (concentrate and spent cleaners) needs to be disposed of in a safe, environmentally acceptable way, as it contains concentrated contaminants.

Costs: Overall, RO/NF is a high-cost technology. Mobile RO plants with a capacity of 1,000–2,000 L/h cost from 10,000–100,000 USD depending on the manufacturer and configuration. Transportation costs could be high depending on location. Operational costs are also high due the requirements for power, special chemicals, cartridge filter replacement and skilled operators.

Social and Environmental Considerations: Due the complexity of the equipment and operations, specialised, educated, well-trained operators are needed, which may not be available on location. Water tastes flat, which can lead to user rejection. NF and RO produce brine (concentrated salt solution) as a waste product, which is harmful to aquatic environments. Both systems have high energy consumption. When fossil fuels are used for power, there is a high CO_2 footprint.

Strengths and Weaknesses:

- (+) RO technology is very effective in removing many types of contaminants, including salt
- (+) Proven technology, simple monitoring of water quality through basic parameters, such as conductivity
- (+) Is prefabricated and easily transportable in smaller sizes, with mobile modular systems available

- (−) Has high initial purchase and operating costs
- (−) Requires reliable power; power use is higher than conventional water treatment
- (−) Requires detailed design based on raw water chemistry and site-specific issues
- (−) Requires well-trained operators, high-quality materials and equipment, and expensive/imported and/or dangerous chemicals

→ **References and further reading material for this technology can be found on page 219**

Distribution and Transport refers to the technologies or services used to deliver water from the source, pumping station or water treatment plant to the point of use, such as a household or tapstand. Water distribution systems can be static, consisting of pipelines, storage facilities (D.5, D.6), pumps and other accessories, and can be organised as community distribution systems (D.7) or large-scale distribution systems (D.8). Distribution systems can also be dynamic, involving water trucking (D.3) with direct delivery to users or to tanks or via water vendor carts (D.2). In all scenarios, users typically collect and store water in household water containers (D.1) from tapstands, vendors, or water kiosks (D.4). During acute emergencies, a combination of water trucking with storage in flexible or demountable rigid tanks (D.5) from which people can collect water in containers is often required to have the flexibility to effectively deliver essential supplies.

D.1 Household Water Container
D.2 Water Vendor Cart
D.3 Water Trucking
D.4 Water Kiosk
D.5 Water Storage Tank (Transportable)
D.6 Water Storage Tank (Long-term Locally Built)
D.7 Community Distribution System
D.8 Large-Scale Distribution System

The choice of distribution system in any given context depends on:

- Financial resources
- Quantity of water
- Population density and the distance to the source or treatment plant
- Management considerations
- Availability of service providers
- Topography
- Road infrastructure
- Stage of the emergency (temporary systems during early stages)
- Availability of materials and skills

D

Distribution/Transport

Household Water Container

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household Neighbourhood City	** Household Shared Public	Household water storage and transport
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	

Household Water Containers are lightweight plastic or metal Containers with a lid that can be carried by one person. They are most often used to carry water manually from the point of collection to the point of use (usually the home) (see S.8) and can also be used as storage Containers in the home. They are suited to all phases of an emergency.

Household Water Containers are produced in different sizes (most commonly 10–20 L) and shapes (typically round or rectangular). They should have a lid and may come equipped with a tap. They are an economic way to distribute water from tapstands to households. Jerrycans are a common type of Household Water Container, but there are also others containers that are used for both transport and storage (e.g., clay pots, buckets). Jerrycans are not ideal for carrying water, as they are difficult to fill and empty and can overstrain the back and shoulders.

Design Considerations: Manually transporting water in Containers is a reality for many rural and urban families in areas that lack household connections and rely on communal tapstands for their water supply. Water points should be a maximum of 500 metres away from households (in the acute response phase), with this distance being reduced over time. In an emergency, Sphere indicators suggest that every family should have access to at least two Containers with a capacity of 10–20 litres, one for transporting and one for storing water. Plastic Household Water Containers are preferred due to their lower cost, flexible shape, robustness and weight. Household Containers used for transport can be carried in different ways depending on the context (e.g. on the head, by the side, by bicycle, on donkeys or carts).
Household Containers are also used for storage. The amount of household water storage required may vary based on the reliability of the water supply and the number of people per household. As a guide, 4 litres of storage per person could be sufficient where water supply is reliable. It is important that the water storage method is safe from recontamination. For this, jerrycans have the advantage of a narrow opening that reduces the possibility of recontamination by forcing water to be poured from the container rather than allowing a cup to be dipped into it **(see H.1)**. In emergencies where water should be chlorinated **(see T.6)**, any recontamination that does occur during transport or storage should be dealt with by the

residual chlorine in the water. The type of Container has also been found to impact water quality in an emergency context, with opaque Household Containers (rather than transparent) preserving the residual chlorine longer, and dark-coloured Household Containers reducing algae build-up.

Materials: Containers used in an emergency are usually made of lightweight plastic polyethylene (PE) or polypropylene (PP), which are highly durable and shock resistant. These Containers are lightweight, though their bulkiness means that transportation of large quantities for distribution in an emergency requires a lot of effort. Collapsible plastic Containers do exist that require less space for transportation but have reduced lifespans.

Applicability: Household Water Containers are suited to all phases of an emergency. If house connections are re-established, Containers used for transporting water may not be needed after the recovery phase. Containers used for storing water within the household can also be improved during the recovery phase and beyond (e.g. constructing water jars with a higher capacity). Fixing the size of Household Water Containers, such as at 10 or 20 litres, simplifies training users in applying the correct dose of point-of-use chlorine **(see H.6)** using standard chlorine tablets sized for such volumes.

Operation and Maintenance: In an emergency, the water supply should normally contain residual chlorine to reduce any recontamination of water and biofilm build-up. Occasional cleaning may still be needed, and it is particularly advisable to clean all Containers during diarrhoea outbreaks to ensure they are not the source of recontamination. Removing biofilms can be difficult for jerrycans due to the narrow opening but can be done using an abrasive agent (e.g. sand or small stones shaken inside the jerrycan) followed by chlorination. Alternatively, shock chlorination (e.g. 50 mg/L) may remove most of a biofilm, which is performed by dosing a chlorine product (like sodium hypochlorite) into the water. To complete the cleaning process, it is important to de-chlorinate the Container before use. Cleaning of bucket-type Household Water Containers with lids is easier.

Health and Safety: Allocating different Containers for different tasks is important to avoid cross-contamination, especially where the same type of Container is used for both transport and storage (as they can get mixed up). This is not a problem where there is only one treated water source, but where there are contaminated sources also in use (e.g. when water for washing clothes is taken from an alternative source to the treated drinking water source), it is important to differentiate between the Containers, for example by labelling them using a specific sign corresponding to each water source. Household Containers should always be closed with a lid during transport to avoid (re-)contamination **(see H.1)** and should be thoroughly rinsed before each new filling. These recommendations should be highlighted through hygiene promotion **(see X.16)**. Transporting water can also be physically hazardous, especially where paths are steep or slippery. It may also cause musculoskeletal injuries if the Containers are too heavy or poorly designed for the user. Lifting blocks (in two steps) near the collection point can ease the process of lifting Household Containers where they are transported on the head **(see X.15)**. There are protection risks for women where the source is remote and insecure.

Costs: Buckets, jerrycans or other types of Household Containers are normally low cost but are often airfreighted in an acute response, greatly increasing this cost. In an emergency, they will need to be replaced according to the breakage rate (maybe 5 % per year), so there will be some small ongoing cost. There is also a non-financial cost to the use of Containers, since water transport is often carried out by women and is a role with possible physical risks as well as economic and educational effects where less time is spent on more productive uses **(see S.8)**.

Social and Environmental Considerations: In an emergency context, Household Containers are often distributed as part of Non-Food Item (NFI) distributions. Users should be consulted about their preference of Container where possible, especially for second-wave distributions once there has been enough time for consultation. For example, people who prefer to carry water by their side will have more difficulties with a round jerrycan compared to a rectangular one. Alternatively, some communities have also innovated means for transporting jerrycans that would make other types inappropriate, such as attachments that would allow round jerrycans to be rolled but would not fit with rectangular jerrycans. The use of good quality water Containers with an extended lifespan should be promoted to avoid generating unnecessary waste. Care should be taken to assure the environmentally friendly disposal of water Containers once they are no longer usable.

Strengths and Weaknesses:

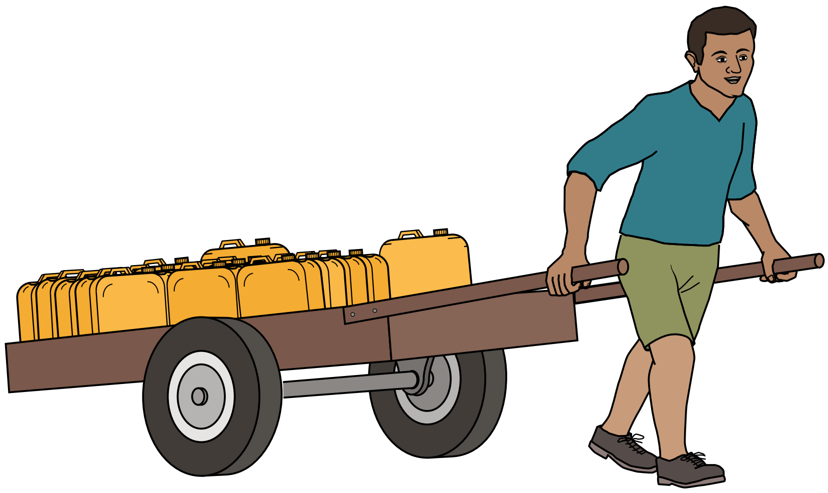
(+) Universally available and robust
(+) Come in many different designs and capacities
(+) Are very low cost

(−) Can be difficult to clean
(−) Have a risk of water recontamination when not cleaned or used properly
(−) Are heavy for children and women to carry
(−) Water transported by one person is sufficient to cover basic domestic needs for only one or two days

→ **References and further reading material for this technology can be found on page 219**

Water Vendor Cart

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood City	** Household ** Shared ** Public	Commercial resale of water
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



Water Vendors resell and distribute utility water or water from other sources. They fill a gap in water provision when there is no functional household distribution network or for places not covered by humanitarian supplies during (urban) emergencies. In cities, they can provide water to a significant proportion of the population and can play an important role in securing supplies. Where this service exists, it will most likely continue to function during an emergency.

Water Vendors can be grouped into three main categories: (1) Wholesale Vendors who obtain water from a source (or produce potable water) and sell it to distributing Vendors, (2) distributing Vendors who obtain water from a wholesale Vendor or other water source and sell it direct to consumers door-to-door, and (3) those that sell water direct to consumers who come to purchase water (e.g. Water Kiosk, **D.4**). Distributing Vendors exist at various scales and in various forms, from individuals on bicycles up to large water tankers **(see D.3)**.

Design Considerations: Where water points are more than 500 metres away from households, water collection takes increasing amounts of time while less water is collected, so Water Vendors can provide a valuable service. In urban areas, distributing Water Vendors can effectively act as an extension of the public supply distribution network, taking water to outlying areas not served by the network. In rural areas, the greater distance to water sources often drives demand for Water Vendors. Distributing Vendors can fetch water from a variety of sources including private or municipal taps, wells, water kiosks or public water vending points, which they then sell on to users at a higher price. Users tend to pay this price because of unreliable piped water supplies, perceptions of quality and taste, affordability (in terms of cash flow) and the added convenience of having water delivered. Water Vendors can operate either informally (e.g. non-licensed individuals using small-scale means of transport, such as jerrycans carried on bicycles or push carts or purpose-made oil drums converted to water tanks to be pulled by a donkey), or through a more formal arrangement (e.g. licensed water trucks managed by an enterprise). Water vending is not only limited to the resale of water. In urban areas, private entrepreneurs are emerging that invest in their own distribution or treatment infrastructure to fill the infrastructure gap. This includes direct Vendors that invest in small private piped networks that connect to households not served by the main utility, as well as those who set up water treatment and bottling services **(see D.4)**.

Where they exist, Water Vendors perform an essential role in water distribution. If present, an emergency response strategy should work with Vendors to restore livelihoods and increase the speed of water provision to as many people as possible. The success of this may depend on the legal framework for water vending (in some cases it is not legally recognised). Regardless, key aspects in an emergency will be ensuring water quality through chlorination at the source, monitoring chlorine levels at household level, as well as getting water sources back online as quickly as possible.

Materials: Materials include the water container(s) and the means of transport (i.e. the vehicle for carrying the containers, which may require fuel).

Applicability: Water Vendors will most likely continue to function after an emergency, although how well will depend on how much they have been affected by the emergency, as well as whether the water source has been damaged. Water vending of various types is more likely following an emergency, since the number of people without a piped water connection may increase due to migration into informal urban settlements and a possible loss of functionality of existing water networks during the emergency due to under-investment in infrastructure. After earthquakes or landslides, piped water connections can be severely damaged, and in these cases Water Vendors can be very useful in areas where they do not normally operate.

Operation and Maintenance: In an emergency, the water supply should normally have residual chlorine, which will reduce any recontamination. The water should be continuously monitored at the household level via random checks. Occasional cleaning of Water Vendor containers is particularly recommended during diarrhoea outbreaks to ensure that containers are not a source of contamination **(see D.1)**. The mode of transportation will require regular maintenance, which is up to the Vendor to address. In an emergency, water might be in short supply and Vendors may draw their water from polluted sources and charge inflated prices. Providers must therefore be independently managed to ensure they are delivering a safe produce at a fair price.

Health and Safety: The quality of water supplied by Vendors can vary and depends on the water source and its surroundings, the state of the transporting containers, the storage time, water handling practices and residual chlorine concentration (where chlorine is added). Water that is collected from an unsafe water source (e.g. river) will clearly be a health risk for users, but even water from a safe water source can be recontaminated easily during transfer to and from the containers, especially since this transfer can happen multiple times. Water that is collected at official water vending points may have better quality (since these are usually connected to the water distribution network), but recontamination can still be an issue here, especially if the water storage time is long and the temperature is high or if tankers are used for other purposes than water transport. Since most of the services provided by individuals are informal, quality control is often not done. Therefore, in an emergency where Water Vendors are operational, it is essential to ensure water quality through monitoring the water sources that Vendors use as well as by ensuring adequate chlorination dosing and monitoring chlorine levels **(see T.6)**. This should be the role of the local authorities, and one method of doing this in an emergency can be chlorination at the point of collection which can be effective in the short term (i.e. into the tank or jerrycan when it is being filled). Water vending itself can also be physically demanding work, with distributing Vendors often complaining of pains in the chest, back and joints.

Costs: Water sold by Water Vendors is more expensive per volume compared to that supplied via network-to-house connections because of the work that is done by middlemen to deliver the water. The cost of water varies significantly by context, but many studies indicate the median mark-up of Vendor water is about eight to ten times that of water from piped connections. This does not mean that distributing Vendors are rich; they are typically poor people themselves, supplying to other low-income people, and their earnings are generally low. In many countries, Water Vendors are just workers passing earnings on to employers.

Social and Environmental Considerations: Water vending is usually well accepted by people, especially in areas where these services existed before the emergency or where existing water services are insufficient or ineffective. If engine-powered water transportation and pumping is used, maintenance should be assured to limit pollution and health risks when the equipment is used in densely populated areas.

Strengths and Weaknesses:

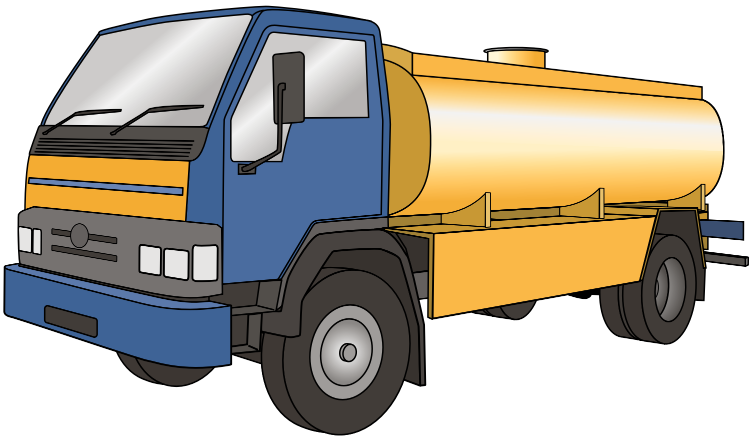
(+) Delivers water to the door, saving time for other activities
(+) Is financially sustainable, and water is given a value
(+) Can be purchased in small, household-sized quantities at flexible prices
(+) Can extend public utilities and can provide a solution where public utilities fail

(−) Is only available for those who can afford it
(−) Has higher costs compared to water obtained through household piped connection
(−) Lacks control over water quality and price
(−) Operates outside of legal structures

→ **References and further reading material for this technology can be found on page 219**

Water Trucking

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response * Stabilisation Recovery	Household ** Neighbourhood * City	Household * Shared ** Public	Short-term, bulk transport of water using vehicles
Local Availability *** High	**Technical Complexity** ** Medium	**Maturity Level** *** High	



Water Trucking (or water tankering) refers to the bulk transport of water from the source to a storage facility near a distribution point. During the acute and stabilisation phases of an emergency, these trucks may be used to provide short-term transport of water to communal water points.

Water Trucking is done using a tanker vehicle. This service may already exist in non-emergency conditions in the form of a distributing Water Vendor **(D.2)**. In emergencies, these trucks may be diverted as a short-term (and costly) transport option for moving large quantities of water.

Design Considerations: Where Water Trucking is considered for an emergency, it is important to keep in mind that a portion of the population may already rely on this as a water source and diverting these trucks for emergency supplies could have unintended negative consequences for existing users. In some cities or semi-arid areas, this can be a significant proportion of the population, with both household resellers and Water Kiosks **(D.4)** relying on Water Trucking for their supply.
The purpose of emergency Water Trucking is to provide an immediate water supply. If possible, Water Trucking should be avoided or used for as short a period as possible, as it has a high ongoing cost and can be difficult to organise. It should only be done if there are no alternatives (e.g. pumps and pipelines or treating a source closer to population), and in this case, it should be a short-term measure while other water supplies are developed (note that these other supplies should already be planned for during the acute phase). If there are no alternative water sources that can be developed to supply a community relying on Water Trucking, it may be preferable to relocate people where this is an option. Where neither is possible for political or security reasons (as is the case in some emergency scenarios), Water Trucking might be the only option that has to be continued, but it comes at a great expense.
Water tankers vary in size (5–20 m^3) and form (e.g. vehicle with integrated tank or tank pulled by a tractor). Tankers that previously carried non-food grade liquids (e.g. fuel) should never be used. A tanker should be easily cleanable, have a lockable cover and an air vent that is screened to keep out animals and insects. The number of tankers required must be calculated based on the time needed to fill and offload water, the return journey time and the number of working hours in a day (working at night might not be possible), while factoring in 30 % extra for contingencies. An extra tanker should be used to cover repair/maintenance and allow for driver rest days. Where there are not

enough available tankers, improvised Trucking can also be done using flatbed trucks with rigid or flexible tanks attached. Care should be taken in driving these, as they can be unstable due to water movement in the tanks during transport.
Water Trucking can be managed in-house or contracted out. Either way, it needs to be well organised, so having reliable supervisors is essential. Contracts should be based on the volume delivered, not time spent. A monitoring system to record deliveries needs to be agreed upon, which could also include real-time technical solutions for remote monitoring of tanks. It should also be clear who supplies and pays for various consumables (e.g. fuel and oil, maintenance, insurance). Where fuel supply is not reliable, consider a fuel store. The route needs to be surveyed from the source to delivery point to identify any potential difficulties (e.g. river crossings and bridge weight restrictions, road surface issues, effect of weather). Also, the use of a water source may need prior clearance from relevant authorities before it can be used. Water Trucking will only work efficiently where there is enough storage to offload into, although in some acute emergencies, people might need to collect directly from the tanker until storage tanks are installed. In such a situation, it is important to properly organise how people queue by creating a walking circuit. Offloading can be done by gravity (where the height of the receiving tank is restricted) or pumping (preferable, since offloading can then be quicker).

Materials: Materials needed include the tankers, preferably with offloading pumps. Improvised water tankers will require a separate tank with an attachment mechanism to the truck or trailer and a filling and emptying facility (see Water Storage Tanks, **D.5 and D.6**). Likewise, proper vehicle maintenance and cleaning facilities are essential to effectively operate Water Trucking services.

Applicability: As Water Trucking is an expensive method of providing potable water, it is most suitable for the acute response and possibly for the stabilisation phase. By the time of the recovery phase, another water source should ideally have been developed to replace Water Trucking.

Operation and Maintenance: Water supplied by tankers must be safe. This is ensured through an initial cleaning and disinfection procedure, as well as through ongoing chlorination. Cleaning and disinfection can be done using a brush, detergent and hot water, followed by shock chlorination for 24 hours **(see T.6)**, and hoses can be disinfected by recirculating water to the tank using the pump. After this, drinking water will be chlorinated at a lower dose (according to jar test, **see T.6**). For this, chlorine is normally added during filling, which usually gives adequate contact time before delivery and ensures good mixing. It should be clear who is responsible for chlorination, and the details must be recorded in a logbook. Trucks themselves (and offloading pumps) will also require maintenance, so it should be clear in the contract who is responsible for this and whether there are locally available spares. The quality and quantity of delivered water must be monitored. For this, the community must be involved as they have a vested interest in ensuring that safe and sufficient water is delivered.

Health and Safety: Cleaning water tankers can be dangerous due to slippery surfaces and hazardous gases given off from previous liquids held in the tank. The health risks to workers cleaning the tanker can be reduced by blowing compressed air into the tanker outlet while the inlet cover is open. Cleaners should have protective clothing, gloves, boots, hat, mask and goggles and, if available, a safety harness and rope. Ensure a monitor remains outside the tank in case the cleaner has an accident. Care should be taken about how and where detergent and strong chlorine is disposed of during cleaning (preferably a sewer, but never in a river or on cultivated land). Improvised tankers using portable storage tanks can also be dangerous if the tanks are not properly attached. The biggest safety issue is the vehicle and how it is driven, as driving a full tanker truck can be hazardous in the event of emergency braking or sharp curves. Around water points, there is major potential for accidents with children and other users waiting for water. Properly trained drivers are essential, but may be difficult to find in emergencies.

Costs: The median mark-up of vendor water from many studies shows that it is about eight to ten times that of water from piped connections, but varies greatly by region (variation from around 1.5–18 USD per m^3 in different countries). In emergencies, however, it is likely to be free due to government or donor subsidies.

Social and Environmental Considerations: Water Trucking tends to be well accepted by people, but this may not be the case where trucks are diverted from existing work for an emergency, causing some people to lose their water supply. Water trucks should be properly maintained to assure that pollution from exhaust gases and associated health risks are limited as much as possible.

Strengths and Weaknesses:

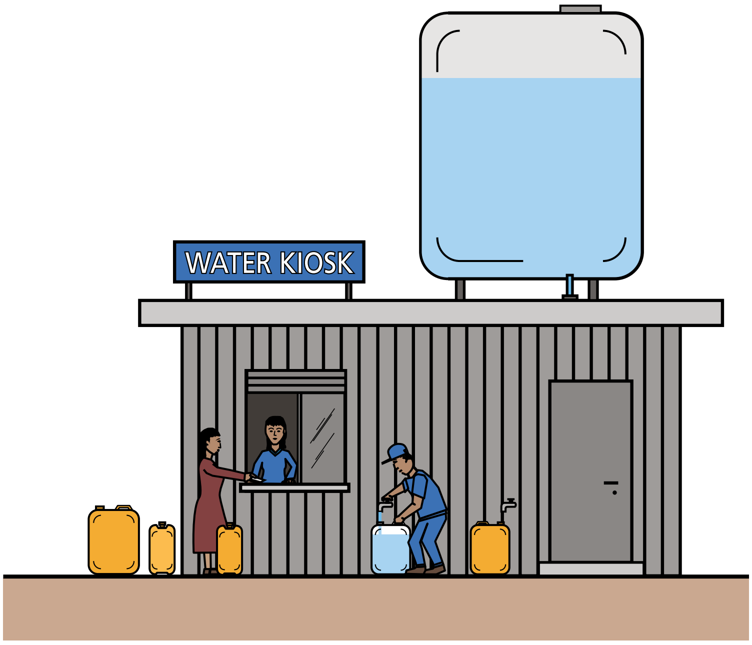
- (+) Can provide an immediate supply
- (+) Can transport large quantities of water

- (−) Has high cost, making it suitable only in the short term
- (−) The high cost is not reflected in an investment in the local water source
- (−) Needs good supervision and monitoring to ensure water is delivered
- (−) Might divert trucks from existing work, meaning some people may lose water supply

→ **References and further reading material for this technology can be found on page 219**

Water Kiosk

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood City	** Household ** Shared ** Public	Commercial resale of water
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Water Kiosks are a type of direct water vendor (see D.2) that is located at a fixed location from which consumers purchase and collect water, as opposed to distributing vendors who deliver to the purchaser. This stationary vending location might also store and/or post-treat the water. Water Kiosks help fill the gap in water provision, allowing water to be accessible to households in areas with insufficient water distribution infrastructure. Where this service already exists, it will most likely to continue to function or can be rebuilt during an emergency. During acute emergencies, they are commonly not operated commercially.

Water Kiosks can be public or communally operated, though are often small-scale private water vending enterprises and represent the main source of water in many cities for households not connected to the network (more than those served by distributing vendors or tankers). Direct vendors can be categorised as standpipe vendors (small entrepreneurs operating standpipes installed by the city water concessionaire), licensed water providers (often small entrepreneurs contracted to resell water piped to their homes and who may invest in standpipe installation and network extension) and unlicensed household water resellers (individuals who resell water piped to their homes). The scope for selling water is mainly related to the stabilisation and recovery phase.

Design Considerations: Formal Water Kiosks are most often a building of some sort with taps either outside or inside that are operated only by the Kiosk attendants, though some Water Kiosks now have automatic mobile phone or card payment systems (water "ATMs"). Water Kiosks often have a storage tank that covers water sales in case of intermittent supply or water shortage periods, and some Kiosks might incorporate a treatment system. In urban areas, entrepreneurs are emerging that also invest in small, private piped networks that they connect to households not served by the main utility, while others have set up bottling services in addition to treatment. Kiosks are also sometimes used by operators for other commercial activities (e.g. selling groceries), which makes the business more profitable.
Where they exist, Water Kiosks perform an important role

in water distribution. Where possible, an emergency response strategy should work together with this existing network to restore livelihoods and increase speed of water provision to as many people as possible **(see X.17)**, but the success of this may depend on the legal framework for water vending (in some cases it is not legally recognised). Regardless, a key aspect in an emergency will be to ensure water quality through chlorination at the source, monitoring chlorine levels at household level and getting water sources back online as quickly as possible. In some countries, it is also possible to shower with water provided by Water Kiosks.

Materials: Materials include the building and taps, as well as sometimes a storage and treatment facility.

Applicability: In the acute response phase, water vendors themselves could be affected by the emergency, and the Water Kiosks or source they rely on may have been damaged, though it is likely that services will resume at some point during an emergency. The demand for water vending of various types is more likely to occur after an emergency, as the number of people without a piped water connection may increase due to migration into urban areas. There may also be a decrease in functionality of existing water networks because of under-investment in infrastructure during the emergency or when pipes are damaged by a natural disaster.

Operation and Maintenance: The O & M of Water Kiosks is considerable due to high usage. Frequent routine maintenance is required, so there must be a clear understanding of who is responsible and who should pay. In an emergency, the water supply should have residual chlorine to reduce recontamination, and water should be continuously monitored at the household level via random checks. The occasional cleaning of water vendor storage tanks is encouraged during diarrhoea outbreaks to ensure that containers are not the source of recontamination. O & M of Water Kiosks could also just mean the upkeep of the building and taps. For Kiosks that involve storage, treatment or water bottling and distribution services, a higher level of skills will be required. Since the responsibility for O & M lies with the Kiosk operator and because Kiosks are most often run as private enterprises, they generally remain functional. This is one of the reasons why these types of Kiosks have been promoted by water utility companies in preference to unmanned public standpipes, as the risk of damage is reduced, while making fee collection easier.

Health and Safety: Water from direct vendors can be of good quality if it is drawn from the main water network. Water quality will still depend on the residual chlorine concentration, state of water storage facility, storage time, effectiveness of treatment process (where used) and water handling practices at the Water Kiosk. In an emergency where water vendors are operational, ensuring water quality through adequate Chlorination dosing and monitoring procedures **(see T.6, T.7)** is essential.

Costs: Water from Kiosks is sold at either a flat monthly rate or per Water Container **(D.1)**, although occasionally it is distributed for free. Water sold by formal or informal Kiosks tends to be around three to four times more expensive per volume compared to that from piped connections. However, it is cheaper than that sold by distributing vendors (about eight to ten times the cost). The high price markup is partly because the cost of bulk water supply is so low that there are no currency units small enough to pay for small containers of water. Usually, therefore, the poorest pay the most for water. In some cases, though, a deliberate government strategy can help regulate the price of water sold at Kiosks in low-income areas to make it the same price as that from piped connections. Here the cost might be cross subsidised from the sale of water to individual households and commercial connections. Since direct water vendors already have a water connection while some also invest in treatment and distribution, overall, they tend to be better off compared to distributing vendors.

Social and Environmental Considerations: Water Kiosks are usually well accepted, as they are a service that fills the gap where public infrastructure and services are insufficient, though this may not be the case where contaminated sources are readily available and where people do not understand why they should pay for higher quality water from a vendor. Users tend to buy water from Kiosks mostly out of convenience. They are sometimes closer (a benefit in areas of high crime where going out at night is dangerous), can have shorter queues than public standpipes, have more convenient hours of operation, can have a better water pressure level and sometimes provide more flexible payment mechanisms.

Strengths and Weaknesses:

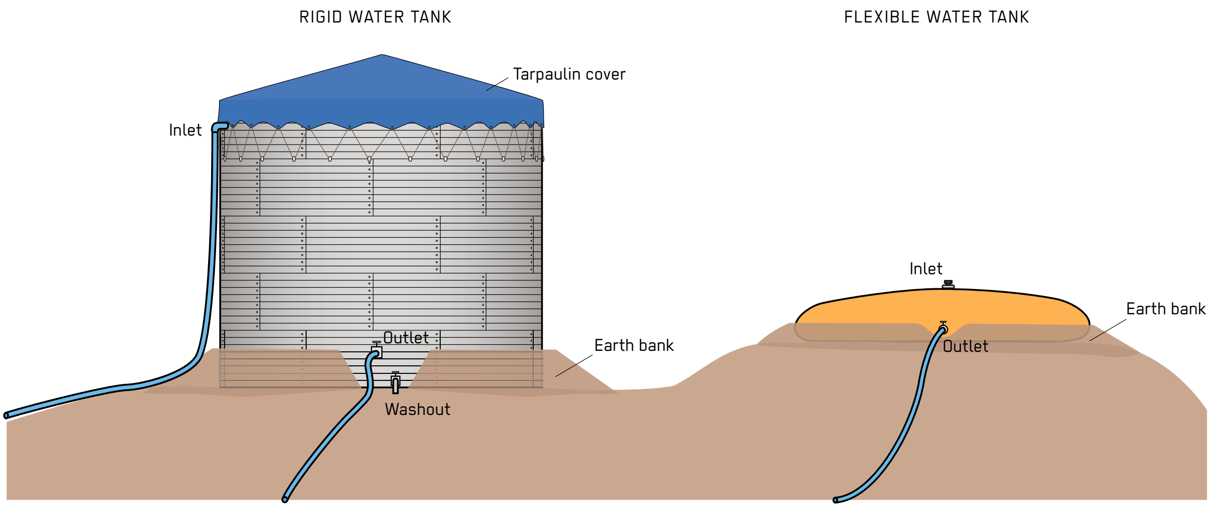
- (+) Is financially sustainable
- (+) Households can purchase small quantities at flexible prices
- (+) Has more reliable water supply compared to piped network because of localised storage and treatment (in case of intermittent supply)
- (+) Has better management of water point compared to unmanned public water points

- (−) Available only for those who can afford it
- (−) Has higher consumer costs compared to water obtained through household piped connections
- (−) Lacks control over water quality and price
- (−) Water quality can deteriorate during storage

→ **References and further reading material for this technology can be found on page 220**

Water Storage Tank (Transportable)

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation * Recovery	* Household ** Neighbourhood * City	* Household ** Shared ** Public	Water storage buffer
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	*** High	



A Water Storage Tank holds large volumes of water, usually balancing supply and demand of drinking water before distribution. Transportable Water Storage Tanks (flexible or demountable rigid) can be assembled rapidly when needed. They are mainly used at the onset of an emergency to enable immediate water distribution and may also form a part of the water distribution system in the medium term.

Flexible and demountable rigid transportable Water Storage Tanks compensate for disparities between the inflow of water from the source and water demand to be satisfied by distribution. They facilitate the quick establishment of water storage capacity in areas where this is not present or insufficient.

Design Considerations: The different types of transportable/flexible and demountable rigid Water Storage Tanks include bladder/pillow tanks, onion tanks and tanks made of a curved corrugated steel outer shell with a butyl rubber liner. Bladder tanks are typically used for treated water and come in transportable versions that can be mounted on trucks. Onion tanks are often used for storage or treatment of surface water (e.g. at water treatment plants using coagulation and flocculation) and are easier to clean than bladder tanks. Tanks made with a curved corrugated steel outer shell with a butyl rubber liner are relatively easy to install using prefabricated parts, are robust and often continue to be used after the emergency. They are used either as storage for treated water or for treatment processes (e.g. the flocculation and sedimentation stage of an upflow clarifier).
The tank used should withstand local climatic and geological conditions. In colder climates where the air temperature will drop below freezing for part of the year, tanks may have to be insulated to prevent water from freezing. This

can be achieved by placing tanks in (heated) buildings, constructing a (wooden) frame filled with sawdust around the tanks, creating 'duvets' for insulation (sewing plastic sheeting and filling with glass fibre), insulating using polystyrene boards, sinking tanks into the ground or lifting tanks off the ground and using sheeting to envelope the elevated construction to prevent cold wind reaching the underside. Moreover, the weight of snow on the roof of the tank should be considered.
In an optimal situation, Water Storage Tanks are sized based on the needs of the target population, the rate of supply and the fluctuation in user demand (see also D.6). In the acute response phase, the water demand will most likely be higher than supply, and therefore it is important that water collection from the tanks is regulated in collaboration with the users. Inlets and outlets must have screens to prevent insect breeding, and measures to reduce siltation and facilitate maintenance and cleaning must also be considered. For example, a drain and valve must be installed for cleaning, and for tanks intended for rainwater collection, a first-flush mechanism can be installed to reduce the amount of silt entering the tank. When using rigid tanks (e.g. a curved corrugated steel tank), a screened ventilation pipe is required to prevent excess pressure or vacuum build up when the tank is being filled or emptied, in addition to the screened overflow pipe.

Materials: Materials required include the storage tank itself and sometimes a stand structure (e.g. a mound or sandbags forming a wall infilled with soil, or oil drums filled with sand) along with pipes with valve controls. The advantages of these storage tanks are that they are quick to transport and set up. They can be made of food-grade PVC-coated fabric, rigid polyvinyl chloride, thermoplastic polyurethane, urethane fabric, polymers, low density polyethylen, and nitrile rubber. They should be UV-resistant, and the materials used should be suitable for chlorinated drinking water.

Applicability: Water Storage Tanks can be used in all phases of an emergency. In the acute phase, transportable Water Storage Tanks are often used, mainly because they can be set up quickly to give sufficient water flow. In the stabilisation and recovery phases, these types of tank tend to get replaced with larger, more permanent tanks that may have a more complex structure **(see also D.6)**.

Operation and Maintenance: O&M tasks include tank cleaning and opening/closing valves to prevent them from sticking. The amount of sediment to clean depends on the source (e.g. water from a spring is more likely to arrive with silt) and involves draining the tank using drain pipe/valve, washing out the inside and carrying out any necessary repairs to the structure. Shock chlorination (at a rate of 50 mg/L) can also be carried out for disinfection. Since transportable tanks are typically used for only a few months, they should be cleaned (chlorinated, flushed with clean water and dried) and stored properly after use so that they are instantly operational again for future emergency use.

Health and Safety: Larger Water Storage Tanks should be located at a safe distance from housing of the affected population to prevent damage in case of a leak or burst tank. The design needs to minimise insect breeding. Most flexible tanks must be erected on a flat level surface or they will be unstable leading to a higher risk of accidents.

Costs: Capital costs for storage tanks vary a lot depending on the type of tank and related structures. Transportable Water Storage Tanks are relatively cheap (about 100 USD/m^3). Ongoing running costs are also low, especially where gravity **(see S.7)** is used to distribute water.

Social and Environmental Considerations: Social considerations related to the use of storage tanks are limited, as these are merely physical structures present in a community that have only limited interactions with their surroundings. Transportable Water Storage Tanks should be maintained properly so that they can be used multiple times and should be disposed of safely once no longer usable.

Strengths and Weaknesses:

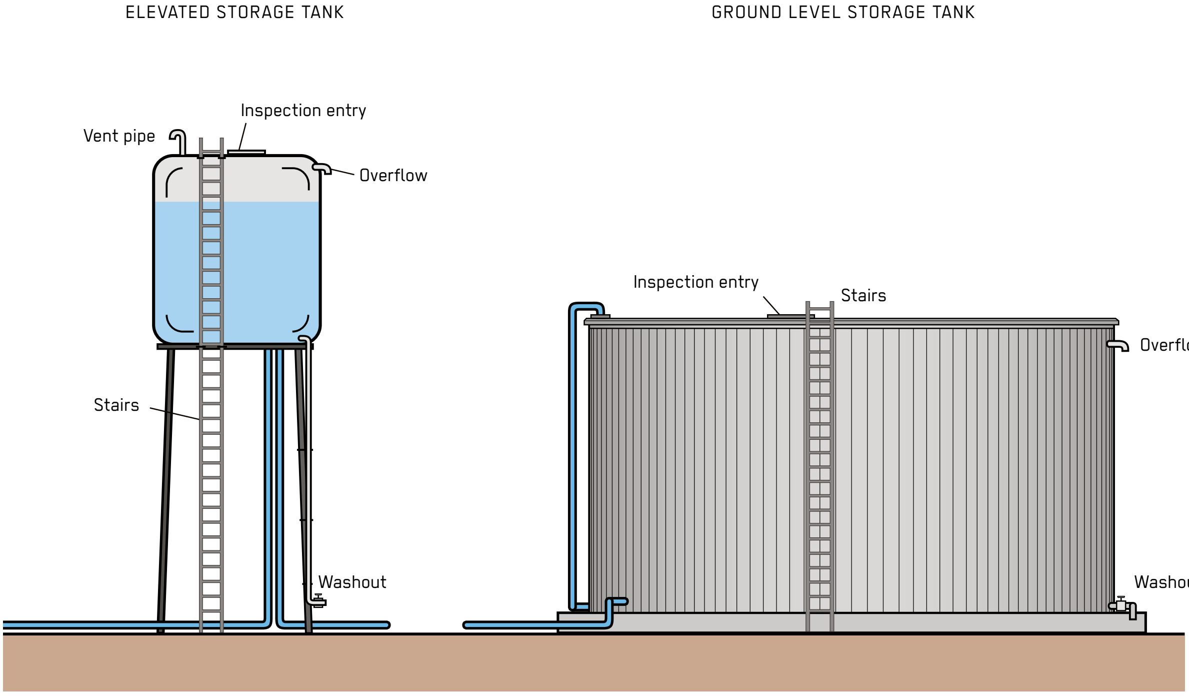
(+) Balances inflow with peak demand
(+) Has low ongoing costs
(+) Easy to transport

(−) Can fail if badly constructed or designed
(−) Has significant capital cost
(−) Does not often use locally available materials so needs to be imported
(−) Is only a temporary solution
(−) Needs a considerable plot of land that is elevated and reasonably levelled

→ **References and further reading material for this technology can be found on page 220**

Water Storage Tank (Long-Term Locally Built)

Response Phase	Application Level	Management Level	Objectives / Key Features
* Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared ** Public	Water storage buffer, network pressure generation
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	** Medium	*** High	



Water Storage Tanks hold large volumes of water, usually balancing supply and demand of drinking water before distribution. They are suited to all phases of an emergency.

Water Storage Tanks for drinking water are usually designed to balance water supply and demand while also ensuring sufficient pressure in a distribution system, but can also allow water to continue to flow during repairs to upstream infrastructure. Having sufficient water storage has other uses such as allowing sufficient retention time during a water treatment process or enabling pump and pipe design to be optimised.

Design Considerations: A Water Storage Tank can be situated either at ground level, elevated (can ease distribution through gravity) or subsurface. This placement depends on both the water source (e.g. at ground level if collecting rainwater from a roof, or subsurface when rainwater is harvested from ground collection surfaces) as well as where water will be sent to in relation to the topography (e.g. an elevated tank is needed in flat terrain for sufficient pressure, but a ground tank might suffice in a hilly area). Below-ground tanks generally require pumps to distribute the water to the target population, and leaks in these tanks are harder to detect.
The size of water tank depends on the quantity of water entering and leaving the tank over the course of a day. This should, at a minimum, meet the daily water demand, flow rates and number of water points based on agreed Sphere indicators, in order to avoid excessive queues and conflict. The tank design must account for the specific points of peak demand during the day (typically two peaks), compared to the slower inflow into the tank that occurs over

more hours (24 hours in the case of a spring or fewer hours when using pumps). When shown graphically, the storage requirement can be calculated as the difference between the lowest and highest peaks in water level over the course of a day, and for smaller systems is done usually assuming all taps will be open during peak hours. It is good practice to have enough storage for at least one day to allow for contingencies (e.g. problems or repair work in other parts of the system).
The type of pumping system can influence tank sizing. For example, a storage capacity to cover up to three days is recommended with solar- or wind-powered pumping **(see S.9, S.10)**. Where the tank volume required is too large for easy construction, more than one tank can be built and connected in parallel. The benefits of additional storage capacity need to be weighed against the costs.
Water Storage Tanks need to withstand local climatic and geological conditions and be designed and placed according to the local situation. Tanks for treated water are typically located nearer the population than the source to reduce the cost of pipework (since larger diameter pipes are needed to deliver peak demand from the tank than are needed to steadily supply the tank over a longer time period). Collapsing risks should be minimised, especially close to houses. In colder climates, tanks may have to be insulated to prevent water from freezing. For solid-walled tanks, this can either be done from the outside or by burying the tanks. Where snow is likely, the tank roof should also be able to withstand snow load. Where tanks are constructed in areas with expansive clays, care must be taken to have a strong enough foundation and connections from tank base to walls in order to avoid structural failure.
Tank accessories must also be carefully considered. A screened ventilation pipe is required to prevent pressure or vacuum to build up when the tank is being filled or emptied. A drain and valve are needed for cleaning, where it can also be useful to have a bypass line directly connecting the tank inlet and outlet (the total static pressure from source to taps should be checked first). For rainwater tanks, a first-flush mechanism can reduce the amount of silting. Inlet, outlet and overflow pipes need screens to prevent insect breeding. An access cover and external/internal access ladder will be needed for maintenance. Unsafe surroundings need to be prevented, which can be done using fences to prevent people from falling or drowning, which could occur if someone is able to climb up an elevated tank or access a lower situated tank. Lightning protection should also be added.

Materials: Materials required for locally built Water Storage Tanks mainly include the storage tank, where options include plastic prefabricated tanks, and those made from a variety of other materials including bricks/cement, reinforced concrete, ferrocement, stone masonry, metal, plastic and rubber lining. Elevated tanks also require a stand or tower structure and pipes with valve controls, and subsurface tanks require pumps to abstract and distribute the water.

Applicability: Long-term locally built Water Storage Tanks are mainly used in the stabilisation and recovery phases, since these tanks have a more complex structure compared to transportable Water Storage Tanks **(see D.5)**.

Operation and Maintenance: O&M tasks include tank cleaning and opening/closing valves to prevent sticking. The amount of sediment to clean depends on the source (e.g. water from a spring is more likely to arrive with silt), and involves draining the tank using drain pipe/valve, washing out the inside, and carrying out any repairs necessary to the structure. Shock chlorination (at a rate of 50 mg/L) can also be used for disinfection.

Health and Safety: Good structural design is required to prevent tank collapse. Tanks should also be fenced off to avoid people accessing them and injuring themselves. The design should minimise insect breeding. It is also recommended that control valves of overhead tanks be installed at ground level where possible to make it safer for the operator (to avoiding climbing) as well as to make operation easier. Elevated or ground-level tanks should be sited away from houses.

Costs: Capital costs for storage tanks vary a lot depending on the type of tank and related structures. Costs for elevated concrete tanks are at the highest end, at about 700 USD per m^3 storage. Ongoing running costs are low though, especially where gravity is used to distribute water.

Social and Environmental Considerations: There are not many social concerns since storage tanks do not affect users directly. Long-lasting materials should be used for storage tank construction to limit waste generation over time.

Strengths and Weaknesses:

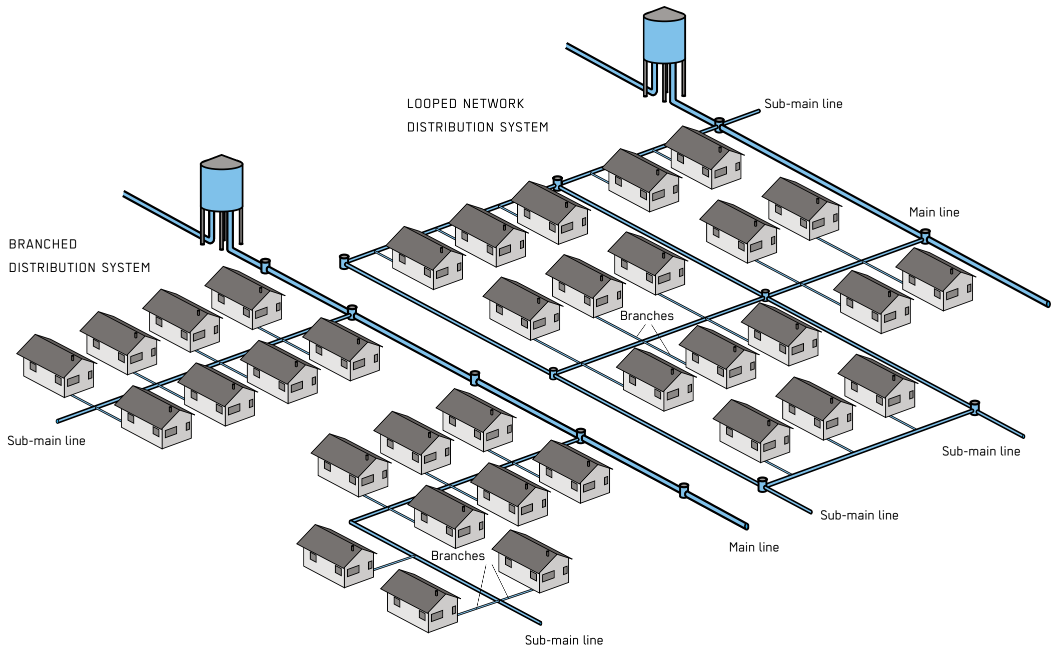
(+) Balances inflow with peak demand
(+) Has low ongoing costs
(+) Available in different designs for the whole range of needs

(−) Risk of failure if badly constructed or designed
(−) Requires significant capital cost

→ **References and further reading material for this technology can be found on page 220**

Community Distribution System

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Water distribution at small/medium scale using gravity or pumps
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	*** High	*** High	



Community Distribution Systems transfer water from a source or treatment facility via pipes to the final distribution point (communal or household taps) using various energy sources, such as gravity or pumps. In the acute response phase, small-scale systems can be used, while medium-scale systems are more likely in the stabilisation and recovery phases.

Water demand in Community Distribution Systems varies throughout the day. Consumption is lowest at night and highest at certain peak hour periods during the day when it is needed for personal hygiene, washing and cooking. These variations need to be addressed by water storage or pump control mechanisms **(see D.6)**.

Design Considerations: There are two types of Community Distribution Systems: Branched or looped. Branched networks consist of one or more main pipes that branch out into a number of dead-end connections. Looped networks (or 'grid' configuration) consist of one or several main loops of pipe (rings) through which water is conveyed to secondary loops or branches. Branched networks are simpler to design and easier to install than looped networks, which require more interconnecting pipes, valves, and special parts, and are more complex and expensive. However, the advantage of looped networks is that they have less head loss and fewer dead legs, and have greater flexibility for repair of pipes without affecting the entire system. In both, it is important to have enough residual pressure at the furthest tap (normally taken to be at least 5 metres at the highest tap, **see S.7**).
Community Distribution Systems need to be designed considering topographical survey data, population figures and location, current and future water demand, available water sources, water quality, distance and elevation difference from the source to storage and storage to taps, number and location of taps corresponding to where people live, storage tank volume, possible pipe routes and any technical issues (e.g. road/river crossings or minimising high/low points). Any new system should be constructed to meet agreed Sphere indicators and local regulations. These include a minimum flow rate per tap of 0.125 L/s with enough taps to ensure a maximum number of 250 users per tap (to avoid excessive queues and conflict), enough water for personal and domestic hygiene (at least 15 L/person/day), and adequate drainage at community taps to reduce water

pooling. The walking distance to the standpipe should not exceed 500 metres, and a round trip including collection should not take more than 30 minutes.
The pipe diameter should be chosen according to the required velocity (0.7–3 m/s to limit silting and scour), potential future expansion (e.g. potentially choosing a larger pipe) and economics (lowest total capital, maintenance and fuel costs are achieved with a velocity of around 0.75 m/s). Pipes and taps should withstand the pressure when all taps are shut. The choice of pipe material may be influenced by pipe jointing and repair considerations. While PVC pipes are cheaper and easier to maintain, they require more joints, which increases the risk for error and pipe leakage, and they are more brittle and susceptible to sun damage. PE pipes are more expensive, though come in long rolls requiring fewer joints. However, these joints need either expensive compression fittings or a butt-welding machine that uses a generator. When laying pipes, it is important to ensure correct trenching, bedding and backfilling to prevent damage and leaks (changes in pipe type, for example to galvanised pipe, are an option for road or stream crossings). In general, water pipes should be laid above wastewater pipes to reduce risk of cross-contamination. The geolocation and the depth of pipes and valves should be made before backfilling. In cold climates where the ground freezes yearly, pipes should be below the frost line.

Materials: Distribution Systems require a lot of different materials, including for the source intake, pumping system, storage tank, pipes/valves/fittings, tapstands and spare parts. Local availability depends on design and particular context.

Applicability: Community Water Distribution Networks are common in urban and peri-urban areas. In rural areas, simpler networks with household or yard connections or public standpipes may be more appropriate. While in the acute response phase, small-scale distribution systems can be set up quickly with minimal design (e.g. bladder tanks and tapstands), in the stabilisation and recovery phases, these get replaced with larger Distribution Systems where construction starts becoming more complex and substantial investment is needed. Therefore, proper design and planning are essential in these cases.

Operation and Maintenance: With gravity flow, O & M is moderate. Since O & M increases as soon as pumps are introduced, it is better to design for fewer pumps or for solar pumping. Leakage usually causes the biggest O & M challenge, and can occur for various reasons such as illegal connections, soil movement and structure, traffic loading, poor quality of pipe jointing, damage due to excavation for other reasons, ageing, corrosion, and high pressure or temperature changes. Siltation can be another challenge due to poor design of intakes and pipes, improper treatment or recontamination from leaking joints. This may require flushing, swabbing or air scouring and pipe disinfection. Other O & M tasks include replacing taps, valves, emptying washout valves (at low points in a piped system), carrying out tank repairs and water quality monitoring for residual chlorine levels **(see T.6)**. An air block can clog the pipes at high points, so air release valves can be installed.

Health and Safety: People can be injured falling into the trench during pipe laying, especially at night. There is also a big concern around elevated water tanks, where appropriate structural design is needed to prevent collapse **(see D.6)**. Health risks can arise from the more intermittent operation of smaller systems, which can cause negative pressure and subsequent contamination at leaking joints. This can reduce residual chlorine levels in the system and pose a microbiological health risk at the point of use.

Costs: Capital costs tend to be high, mostly because of the distribution network. Ongoing running costs can vary. Where only gravity is used, ongoing costs are low, but where water is pumped at any point in the system, ongoing costs will increase. Therefore, it is better to design out or reduce the need for pumps where possible and/or to opt for solar pumping. Solar pumps have much lower ongoing costs, with payback within a few years, as well as few carbon emissions **(see S.10)**.

Social and Environmental Considerations: It is important to involve users in certain aspects of the planning process (e.g. tapstand location and design). Land ownership should be clarified, and agreements should be made for all land where pipes, tanks and tapstands will be located to avoid future claims or conflict. Household connections may considerably increase water consumption (and wastage) and require proper subsequent disposal systems for grey or black water. Illegal pipe tapping can also be an issue. For larger numbers of consumers, the installation of meters is recommended.

Strengths and Weaknesses:

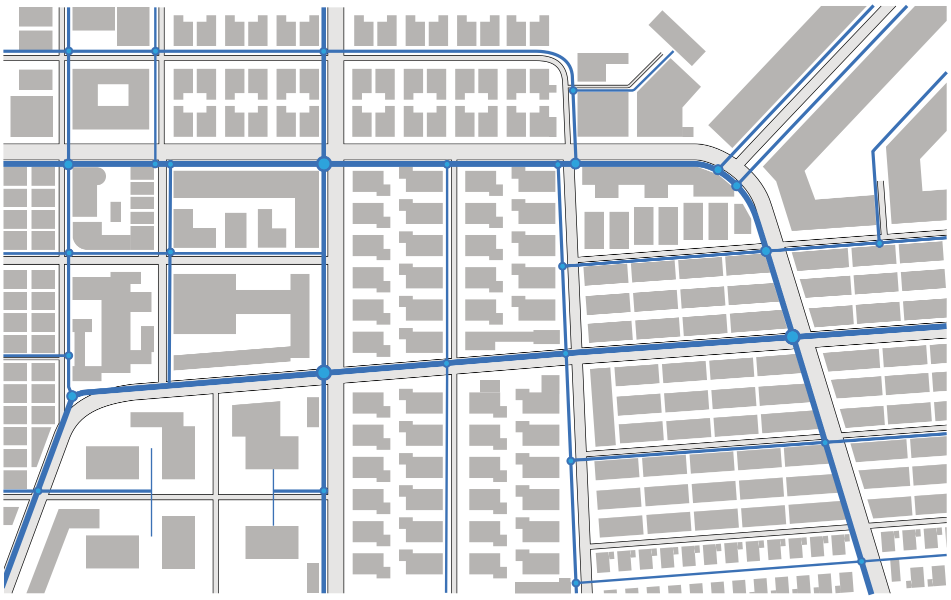
(+) A more convenient and desirable way of distributing water to users
(+) Has lower levels of contamination compared to water carried in jerrycans and trucks
(+) During continuous supply, no need for safe water storage or household water treatment
(+) Has low ongoing costs where gravity or solar pumping is used

(−) Needs significant topographical survey and design work and difficult terrain can restrict pipe laying
(−) Requires significant capital cost and often limited in availability of pipe material, valves/fittings and tapstands

→ **References and further reading material for this technology can be found on page 220**

Large-Scale Distribution System

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood ** City	Household ** Shared ** Public	Distribution at large scale using gravity or pumps
Local Availability *** High	**Technical Complexity** *** High	**Maturity Level** *** High	



Large-Scale Distribution Systems transfer water from a source or treatment facility via pipes to the final distribution point (communal or household taps) using different means of energy, such as gravity or pumps. In an emergency context, these are systems that already exist, but may need repair or rehabilitation.

The components of Large-Scale Distribution Systems are similar to Community Distribution Systems **(D.7)**, differing mainly in scale. Large-Scale Systems will typically serve urban communities and have more complex pipe design, more pumping and more storage facilities covering different areas. They will also have a greater density of connections at a household level.

Design Considerations: Large-Scale Distribution Systems tend to be looped systems which have the advantages of less head loss, fewer dead legs and greater flexibility for pipe repair without affecting the entire system. Design considerations are similar to Community Distribution Systems **(D.7)**, though at a larger scale. This means a tendency for a higher overall water demand due to the larger population served, an increased water demand per household (the more convenient the source, the higher the water use), an increased water demand from industry, public organisations, businesses and firefighting, and significantly more water unaccounted for (e.g. due to leaks and unauthorised connections). Water meters are needed to measure consumption and bill accordingly. Emergency workers may become involved with carrying out emergency repairs and rehabilitation of existing systems. Existing systems are usually operated by some other entity, so it is important to liaise with them before starting any work.
For smaller systems with tapstands and queues **(D.7)**, the design usually assumes all taps are open during peak hours. For slightly larger systems with no queues, the average flow (over 24 hours) is usually multiplied by a peak flow factor according to the number of taps in the system. With larger systems still (over 250 taps), the difference between the average flow and instantaneous flow will be similar,

and design can be based on the average flow multiplied by an average peak flow factor of 2.5, to which is added any additional factor for increased use during certain months of the year. In many cases, the overriding design factor for larger systems can be the water flow required for firefighting, as it can be far greater than peak flow needed for other uses. Standards vary, but typically a design considers supplying water to fight a fire for two hours, where the flow itself is determined by the population size. However, any design for firefighting needs to be made according to what is available to fight fires (e.g. availability of fire trucks).

Materials: Large-Scale Distribution Systems will require similar materials but in greater quantities than Community Distribution Systems **(D.7)**. Local availability depends on the design and the particular context.

Applicability: In an emergency where Large-Scale Distribution Systems are relevant, they will already exist, so work will involve repair or rehabilitation of a part of the system rather than design and construction of a new system. The exact parts in need of rehabilitation will depend completely on the emergency context. For example, where power has been disrupted, issues can occur with those parts requiring a power supply (e.g. pumping stations or treatment plants), or where a natural disaster has occurred, any part of the system could be affected (e.g. distribution network, pumping stations, power lines and treatment plants). In addition to the damage caused by the emergency, there may also be issues with a system that was old and possibly poorly maintained before the emergency occurred, or concurrent urgent issues with the wastewater system. Rehabilitation work may therefore be needed on both wastewater and water systems, while addressing both chronic issues and problems due to the acute emergency.

Operation and Maintenance: All tasks related to Community Distribution Systems also apply to larger systems, the difference being the scale and complexity. There will generally be more equipment that needs maintenance (e.g. more pumping stations, **see A.10**), the equipment might be more onerous to maintain (e.g. larger pumps) and leak management may require more advanced leak detection equipment. As such, these systems can be technically very complex, demanding advanced engineering skills related to urban water supply systems that are often beyond the scope of engineers whose experiences might be limited to the humanitarian sector. A major issue is knowing where all the pipes are and how they are connected, and because full maps of Large-Scale Distribution Systems are rarely available, it is important to link up with existing employees with respective knowledge.

Health and Safety: Larger systems tend to have an uninterrupted water pressure, so the risks from contamination through leaks is less but should not be neglected.

Costs: Rehabilitation capital costs can be very high with larger systems and will vary depending on what rehabilitation work is required. The following two examples give some indication. In Zimbabwe, rehabilitation of a smaller urban water distribution system serving 80,000 people was estimated to cost around 30 USD per inhabitant (where most of the work involved repair and replacement of pumping stations and parts of the water treatment works), while rehabilitation of a larger urban system serving 1 million people was estimated at costing around 13 USD per inhabitant (where work involved pumping stations, water/wastewater treatment plants and sewer replacement). After an emergency, ongoing running costs will need to be met. Larger-scale systems are often financed by user tariffs, yet after an emergency, tariff systems may have broken down. Getting these payment systems restarted will be an essential task if any rehabilitation work is going to be sustainable. Ongoing costs will be significant in these systems, so it may be better to design out or reduce the need for pumps during rehabilitation work where possible and/or to opt for solar pumping **(see S.10)**.

Social and Environmental Considerations: Since these systems generally predate the emergency, there should be no social or cultural issues to overcome. The aim should be to ensure an equitable supply, with particular focus on the requirements of vulnerable groups or access to informal settlements. Household connections may considerably increase water consumption (and wastage) and require subsequent management systems for grey or black water. Illegal pipe tapping can also be an issue.

Strengths and Weaknesses:

(+) Can result in better hygiene and health due to higher water use with more household connections
(+) Can assure water quality compared to community distribution systems, since collection and storage contamination pathways are removed
(+) Tends to have continuous supply, meaning less contamination in the distribution network
(+) Used mainly by urban residents who can afford tariffs, which can pay for the ongoing operation

(−) Requires significant capital cost for rehabilitation works
(−) Requires a comprehensive detailed plan to account for scale and complexity of large systems, which is not always easy given existing data constraints
(−) May be hard to restart cost recuperation systems after an emergency where personal resources are stretched

→ **References and further reading material for this technology can be found on page 220**

Household Water Treatment and Safe Storage (HWTS) technologies can be used as single-stage water treatment alternatives when centralised or community level treatment is not available or when the quality of water provided does not meet the required standards. Should (re-)contamination occur during transport between the point of collection and the point of use in the home, household water treatment can improve water quality before consumption. Drinking water should be stored safely in all cases. For the growing number of household water treatment products on the market, the WHO has developed a scheme to independently evaluate their performance in removing microbial contaminants. This performance is classified according to the three levels of protection and their corresponding Log Removal Values (LRV):

	(log_{10} reduction required)			
Performance Classification	**Bacteria**	**Viruses**	**Protozoa**	**Interpretation**
***	≥ 4	≥ 5	≥ 4	Comprehensive protection
**	≥ 2	≥ 3	≥ 2	
*	Meets at least 2-star (**) criteria for two classes of pathogens			Targeted protection
–	Fails to meet WHO performance criteria			Little or no protection

Table 1: International Scheme to Evaluate Household Water Treatment Technologies (adapted from WHO)

This chapter summarises the main household water treatment options **(H.3 – H.14)**, without focussing on specific brands. Safe Water Storage **(H.1)** and Handwashing Facilities **(H.2)** are considered an essential element of user safety at household level and are therefore included in the chapter.

- H.1 Safe Water Storage
- H.2 Handwashing Facility
- H.3 Ceramic Filtration
- H.4 Membrane Filtration
- H.5 Biosand Filtration
- H.6 Point-of-Use Chlorination
- H.7 Point-of-Supply Chlorination
- H.8 Coagulation, Sedimentation and Chlorination
- H.9 Boiling
- H.10 Pasteurisation
- H.11 Ultraviolet (UV) Lamp
- H.12 Solar Disinfection (SODIS)
- H.13 Fluoride Removal Filter
- H.14 Arsenic Removal Filter

The choice of household water treatment should be based on the performance as well as likelihood of achieving high rates of correct, consistent and continued use. Factors that support effective implementation, including supply chain and costs, should also be considered. Those factors include:

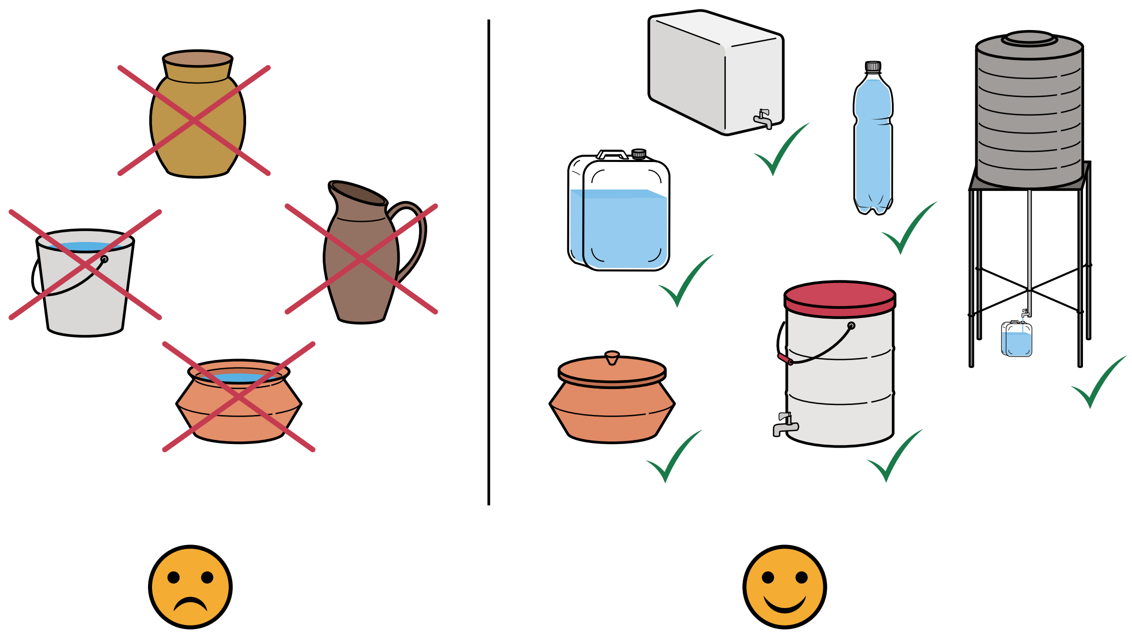
- Quality of water and type of contamination
- Level of protection required
- Local availability or access to HWTS products, consumables or spares
- Price of hardware and consumables
- Willingness and ability to pay for hardware and consumables
- Cultural preferences for a certain treatment method
- Motivation and awareness of consumers regarding water quality problems
- Quantity of water to be treated
- Available space
- Available energy sources
- Improvement of aesthetical water quality, including turbidity, colour, taste and odour
- Feasibility of using multi-barrier approach, combining filtration, disinfection and safe storage

H

Household Water Treatment and Safe Storage (HWTS)

Safe Water Storage

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household * Neighbourhood City	** Household * Shared Public	Protection from water (re-) contamination
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



Safe Water Storage prevents (re-)contamination during storage in the home, protecting water from contact with hands, cups/dippers, animals, dirt and pathogens. It is important in all phases of an emergency.

A Safe Storage Container has a lid, a tap or narrow outlet to pour water, is opaque or at most translucent and is easy to clean. Containers can be of various sizes, ranging from 10 L vessels, buckets or jerrycans **(D.1)** to 1,000 L storage tanks. Practicing Safe Storage in the household ensures an accessible supply to meet household demand.

Design Considerations: To be considered safe, storage containers must be sealed or covered and preferably have a narrow opening or tap for filling and pouring, preventing hands or contaminated dippers from entering the water. They should be made from materials that are durable, lightweight and non-transparent to avoid algal growth. Good storage containers are easy to lift and carry, are stable with a flat bottom and are easy to clean (e.g. have no small spaces such as hollow handles where dirt and algae can accumulate). Storage containers can be placed inside the house or outside (e.g. underground, on the roof of a house or on a specially designed stand or tower). They can be manually filled with water or connected directly to a distribution network, rainwater harvesting system or other storage tank. If water treatment occurs at home, it is important to have at least two separate storage containers, one for transporting untreated water and one for storing treated water. Safe Storage containers should be protected from animals.

Materials: Storage containers can vary widely in design and materials. Clay, gourds, copper, steel, aluminium and plastic are commonly used. Polyethylene jerrycans, collapsible jerrycans and plastic buckets with taps are also commonly distributed in emergencies. Non-transparent material is preferable to prevent algal growth. Storage devices can be equipped with taps. Low quality taps tend to leak relatively quickly and may need to be replaced more frequently to avoid waste, and the trade-off between the expense of durable imported taps and lower quality local taps should be considered. Drinking water containers should be made from new drinking–water-grade materials such as polypropylene, polyethylene or, if thoroughly cleaned to prevent bacterial growth, containers previously used for food storage (e.g. edible oil). Gas canisters, paint tins, or other vessels that have contained chemicals or substances harmful to humans should not be used.

Applicability: Safe drinking water storage is critical in emergencies where water quality and supply are affected. Sphere suggests ensuring at least 7.5–15 L per person per day for drinking, cooking and personal hygiene in emergency situations, depending on local habits, physiology and climate. Sphere also recommends that each household has at least two clean water collecting containers of 10–20 L. Additional clean water storage containers should be available to ensure there is always water in the house. Adequate Safe Storage requirements may vary based on the reliability of the water supply and the number of people per household. Different user groups (e.g. children, disabled or elderly) may benefit from smaller or specially designed containers **(see X.15)**. Safe Storage containers are often produced locally, making them readily accessible to many communities. In the acute response phase, the containers should be accessed and distributed quickly. In the stabilisation and recovery phases, they can be replaced by more durable options with tap and stand.

Operation and Maintenance: If the source water contains residual chlorine and containers are kept closed, the risk of recontamination is low and only occasional cleaning is needed. If there is no residual chlorine at the source, hygiene conditions are poor or silt accumulates in the container due to poor water quality, the containers must be cleaned regularly. Cleaning should occur weekly or whenever containers appear dirty. Depending on the type of container, cleaning can be done using soap and chlorine and scrubbing with a soft brush or cloth to prevent scratching the surfaces. Safe water handling practices for Water Storage containers include storing treated water off the ground in a shady place in the home and away from small children, animals and insects. Funnels used to fill narrow-mouth containers should be clean to prevent contamination. Users must be educated on the risks of post-treatment or post-delivery contamination via contact with hands, insects, animals, dust and dirty cups or dippers **(see X.16)**.

Health and Safety: Post-treatment contamination has been found in improperly stored water in households. Regardless of the microbiological quality of the water at the time of collection, it is often recontaminated during abstraction, transport and storage. Studies have shown that household water treatment more effectively reduces diarrhoea when combined with Safe Storage practices and corresponding devices. Where water is not treated at the source, it is important to designate separate jerry cans for transport and storage to avoid recontamination after treatment. This should be highlighted through hygiene educational messaging **(see X.16)**.

Costs: Costs for Safe Storage containers vary based on materials, design and location. Safe Storage containers produced locally are usually affordable for households, though where local products are not available, transportation costs can be high. Other costs include disinfection and cleaning products, which are often already available within households. Good quality, durable containers can typically be used for years before replacements are required.

Social and Environmental Considerations: Types of water storage containers vary across communities and cultures, so should be selected based on the preferences and physical abilities of the user, affordability, robustness and ease of transport, use and maintenance. In emergency settings, rapid assessments and consultations with households can guide the selection of appropriate containers. The distribution of Safe Storage devices should be combined with (recurrent) hygiene promotion activities **(see X.16)** to trigger and maintain desired transport and storage practices. It is also recommended to regularly monitor corresponding household practices and the water quality at the point of use.

Strengths and Weaknesses:

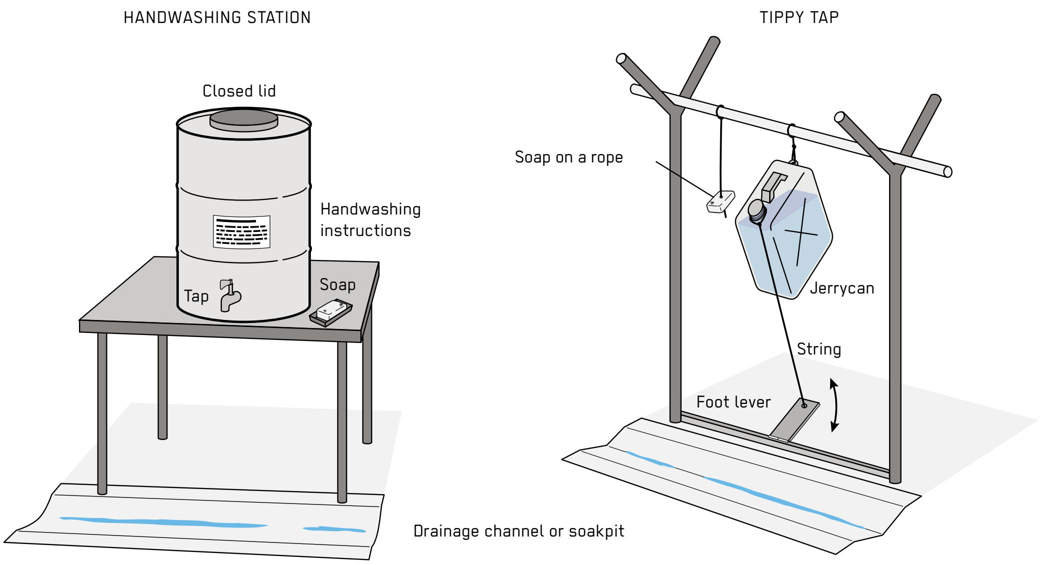
(+) Reduces likelihood of recontamination with correct container design
(+) Is generally affordable
(+) Is simple to use and maintain

(−) Containers with taps are more vulnerable to breaking
(−) Can be difficult to clean
(−) Has risk of water (re-)contamination when not cleaned properly

→ **References and further reading material for this technology can be found on page 221**

Handwashing Facility

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood ** City	** Household ** Shared * Public	Reduction of public health risks and pathogen transmission
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



Proper and frequent handwashing with soap is one of the most important measures to prevent the transmission of diarrhoea and respiratory diseases. Handwashing Facilities should be available next to toilets, food preparation areas and other critical locations in households, schools, health care facilities and other institutions and public spaces. When a piped water supply is not available, handwashing stations require constant refilling with water and a supply of soap.

Studies suggest that handwashing with soap reduces the morbidity rate due to diarrhoea and other water-related diseases by 35–45 %. The practise of handwashing must be strongly promoted in any emergency, and users should always have the means to wash their hands with soap and water. Handwashing stations must include a constant source of water and soap. If water and soap are not available, an alcohol-based hand sanitiser or ash may be used as an alternative.

Design Considerations: Handwashing stations need to be within a short radius (< 5 m) of each toilet (regardless if private, shared or public) and in all places where food is prepared or eaten, such as markets, kitchens and eateries. The recommended minimum handwashing water quantity at public toilets is 1–2 L per user per day. Usually around 500 ml is used per handwashing event when water is piped. The taps of Handwashing Facilities as well as the pressure in the pipe define the amount of water used and wasted. Water-saving taps can decrease this to about 100–250 ml. The minimum amount of soap required for personal hygiene including handwashing is 250 g per person per month. In public facilities, a constant supply of soap must be ensured, which are also a good point for distributing soap to the community. Drainage of effluent is required to keep the area around the Handwashing Facility clean, dry and hygienic. Effluent can be captured in a bucket for grey water or can be discharged into open drainage channels or a closed sewer. Where soil conditions permit, greywater can be disposed of on-site (e.g. pre-treated by a sand and grease trap and disposed in soak pits). Handwashing stations must be inclusive, such that children and people with reduced mobility should be able to reach and use the Handwashing Facilities.

Materials: Handwashing Facilities include taps of different sorts connected to a pipe or a container. When piped water is not available, a standard bucket with a tap and soak away can be used, though re-filling must be assured. Containers need to have lids to protect from contamination. Simple low-cost solutions, like Tippy Taps, consist of a suspended jerrycan that can be tipped with a foot lever to allow water to flow out. Taps should be robust to prevent theft or breakage. Liquid, solid or powder soap can be used, or ash can substitute when soap is not available. Soap might need to be attached to a Handwashing Facility to prevent theft (e.g. soap on a rope). Handwashing Facilities must be robust to prevent theft and vandalism and should, whenever possible, be located in secured areas.

Applicability: During all emergency phases, it is essential that water, soap and the hardware for handwashing are available. In the acute phase, the distribution of soap and water containers, as well as establishing handwashing systems in critical places (e.g. next to toilets) should be prioritised. Furthermore, the practice of handwashing needs to be strongly promoted in any emergency situation **(see X.16)** using multiple communication channels, and users should always have the means to wash their hands with soap. Handwashing promotion is especially important if the affected community is not used to regular handwashing or is traumatised. Five critical times for handwashing with soap should always be promoted: after using the toilet, after cleaning the bottom of a child who has been defecating, before preparing food, before eating food and before and after looking after someone who is ill. During epidemics related to respiratory infections, handwashing is also recommended after coughing and blowing nose.

Operation and Maintenance: In public facilities, water containers must be refilled and the soap constantly restocked. For private households, soap is usually periodically distributed. Drainage channels and soak pits used for effluent disposal must be controlled for clogging, which can be reduced through simple grease and sand traps. Handwashing Facilities and the tanks used for storing water need to be kept clean. In the acute response phase, health workers may need to promote basic hygiene and handwashing **(see X.16)** next to the toilet blocks, in health centres or as a part of other public health support activates. During the stabilisation and recovery phase, more sophisticated behavioural change measures might be required where handwashing is rarely or inconsistently practiced.

Health and Safety: Water quality and the use of soap are important factors affecting the efficacy of handwashing. Studies show that handwashing with contaminated water and soap still reduces the risks of diarrhoea compared to no handwashing at all. Nevertheless, water quality in handwashing devices may be improved by regular cleaning, disinfection and using Safe Water Storage **(H.1)** devices. In health care facilities during disease outbreaks, chlorine is added to the handwashing water in a concentration of up to 0.05 % **(see X.14)**.

Costs: Soap and containers used for handwashing stations are usually cheap and locally available. They should be bought in large quantities at the beginning of an emergency and adapted for handwashing (e.g. installation of taps). Other costs involve personnel for hygiene promotion and the construction of drainage or soak pits.

Social and Environmental Considerations: The promotion of handwashing is crucial during an emergency, though to ensure the efficiency of these promotional activities, Handwashing Facilities first need to be provided that are adapted to local context needs. Promotional messages can include social pressure or emotional or aesthetic appeals. Drivers or barriers for certain behaviours need to be assessed to effectively promote handwashing, such as health risk perceptions, cost-benefit beliefs, emotions, experienced social pressure, abilities, and action and barrier-reduction planning **(see X.16)**. Simple 'nudges', such as the presence of a mirror at the Handwashing Facility or signs pointing to the handwashing device, might be effective to support handwashing behaviour along other behaviour change interventions, though the involvement of local champions and hygiene promoters is key to a successful campaign. The drainage of contaminated greywater generated during handwashing needs to be considered.

Strengths and Weaknesses:

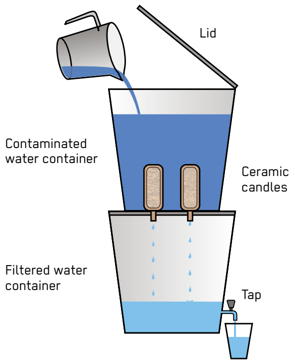
(+) Provides one of the most effective and low-cost methods to reduce diarrhoeal/respiratory disease outbreaks

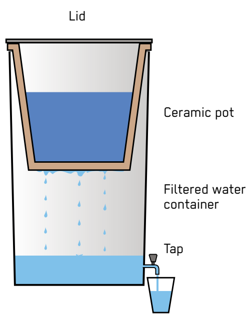
(−) Requires regular container refills when piped water is not available
(−) If devices use too much water, containers may not be refilled if the water source is far away
(−) Containers can be used for other purposes

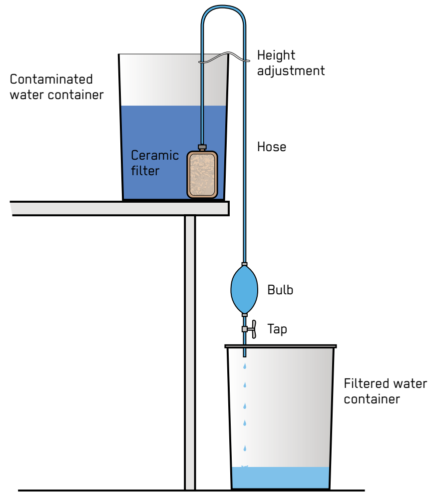
→ **References and further reading material for this technology can be found on page 221**

Ceramic Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household Neighbourhood City	** Household Shared Public	Point-of-use treatment, mechanical pathogen removal
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	







A Ceramic Filter is a mechanical filtration device made of clay that traps particles and micro-organisms within the ceramic element, which can be a pot, candle or disc. Ceramic Filters typically consist of two parts, the top containing raw water together with the ceramic element, and the bottom containing the filtered water and a tap. Ceramic Filters can also be plumbed directly into a pressurised water pipe.

Ceramic Filters have micron-sized pores that filter suspended particles and pathogenic microorganisms through mechanical trapping and adsorption, and the quality of the filter elements is essential for this process. Ceramic Filters usually do not remove viruses. Colloidal silver is sometimes used in Ceramic Filters to protect against recontamination, though its performance is doubted, with several studies showing limited to no effects. Some filters also contain activated carbon to remove organics or heavy metals. Ceramic Filters remove some iron and taste and improve the smell and colour of water.

Design Considerations: There are three types of filter designs. In pot filters, ceramic pots are placed in a bucket with a tap. The ceramic pot is filled with water, which drips through to a second container. In ceramic candle or disk filters, two containers are placed on top of each other. A hole is drilled in the bottom of the upper container, and a ceramic candle is screwed in. To increase the flow rate, multiple candles can be used. Water is gravity filtered through the candle and collects into the lower safe storage container, where it can be released with a tap. In ceramic syphon filters, the filter elements are placed into a bucket on a table, and an attached long tube hangs out of the bucket by 30–100 cm. To start operation, the filter tube needs to be filled with water, sometimes via an integrated rubber bulb. Water can be collected directly from the tube or in another Safe Water Storage container. Ceramic Filters operated by gravity usually have a flow rate of 1–3 L/hour per filter, depending on the quality of the ceramic element, its surface area and age as well as hydrostatic pressure difference. Storage capacity of the clean water tank is about 10–15 L.

Materials: Ceramic pot filters can be produced with locally available material in a specially designed workshop, though differences in clay composition across geographic regions can cause quality problems. Holes also need to be drilled in local containers to attach the candles and taps. Conversely, candle filters are usually imported, and pre-drilled containers are often supplied by the manufacturer together with the candle. Filters prepared in gas-fired ovens are often of better quality than those prepared in wood-fired ovens, as the right temperature for the firing process can be better maintained in gas ovens. Regardless, good quality control procedures and training are essential to achieve high quality products. Ceramic Filters can be stacked for storage but still require a relatively large storage place, which might not be available. Ceramic Filter elements are fragile and can be damaged during transport.

Applicability: Ceramic Filters can be useful in all emergency phases. Household water filters can be distributed in the acute phase, when water is generally available but is contaminated with bacteria, protozoa or macro-organisms or there is a risk of contamination of water during transport and storage at home. Like other household water treatment systems, Ceramic Filters are especially applicable when the population is dispersed such that the installation of large-scale water treatment systems is not feasible. Ceramic Filters efficiently reduce the turbidity of water, but a high content of particles and organic matter will lead to clogging and the need for more frequent cleaning, which in turn will reduce the lifespan of the ceramic element. The turbidity of raw water should not exceed 25 NTU (Nephelometric Turbidity Units) on a long-term scale, or 50 NTU when the periods of elevated turbidity are short.

Operation and Maintenance: Ceramic Filters are very simple, and daily operation is limited to filling the containers with water. Maintenance includes scrubbing with a soft brush or cloth, which should be done frequently if turbid water is used. Chlorine or soap should not be used to clean the ceramic elements but can be used for lids, clean water storage containers and the tap. Pouring boiling water over the candles has shown be an effective cleaning method in some studies. With more frequent cleaning, the thickness of ceramic candles and pots decreases and therefore the removal efficiency might reduce over time. One challenge for the user is therefore to know when to replace the candle. To overcome this, some manufacturers include a simple gauge to measure the thickness of the candle and to know when a change is required. With very turbid water generating high levels of clogging and frequent cleaning, pre-settling of the water may extend the life of the Ceramic Filter elements.

Health and Safety: The efficiency of Ceramic Filters in removing pathogens varies depending on the type, production conditions and quality of the ceramic element. In general, it varies from 88–99.99 % for faecal-indicator microorganisms and protozoa depending on the study, product used and context. Removal efficiencies for viruses are also highly variable, with some studies and products showing 90–99 % removal of viruses, and other products showing no or almost no viral removal. It is crucial to ensure that the Ceramic Filter elements are fixed correctly to avoid leakage and recontamination. The treated water storage container and tap may be recontaminated. The risk of recontamination is higher when no Safe Water Storage container **(H.1)** is provided, as is the case for some syphon filters.

Costs: Ceramic pot and syphon filters usually cost around 8–30 USD. The costs for the ceramic candle filters are > 30 USD depending on the manufacturer, quality and housing type. The life span of Ceramic Filter elements is usually around 6–12 months but varies depending on the raw water quality and cleaning frequency.

Social and Environmental Considerations: Ceramic pot or candle filters are well accepted in most contexts. The removal of turbidity makes water treatment visible and easy to understand, and filters are easy to use. Users who have never seen a filter before might experience difficulties in installation and maintenance, so one or several follow up trainings may be required.

Strengths and Weaknesses:

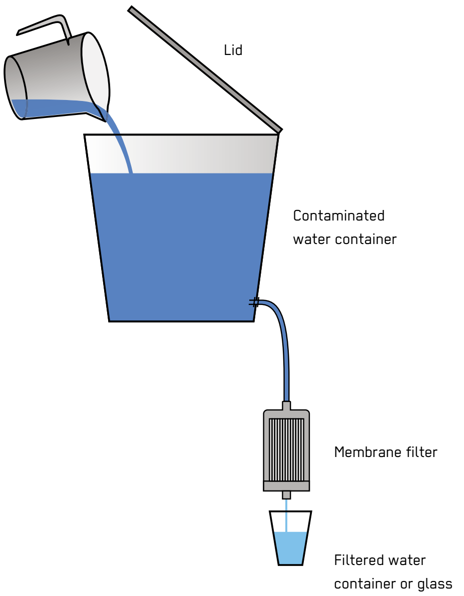
- (+) Provides simple one step filtration
- (+) Has high acceptance rates
- (+) Produced using locally available materials at low costs

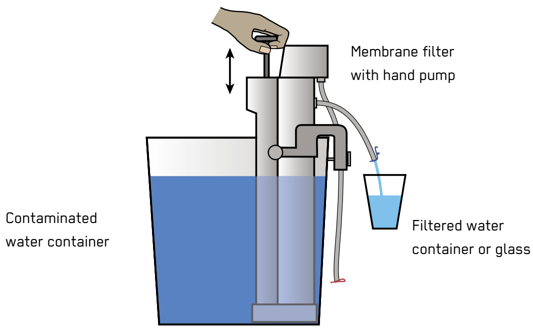
- (−) Provides limited protection from viruses, and bacterial/protozoa removal depends on manufacturing quality
- (−) Breaks easily if dropped, and cracks are not always visible
- (−) Clogs during filtration of turbid waters, requiring more frequent cleaning
- (−) Filters fairly slowly (unless using syphon or multiple candles)
- (−) Has relatively short life span for filter candles, and resupply of candles is challenging if there is no local supplier

→ **References and further reading material for this technology can be found on page 221**

Membrane Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household * Shared Public	Point-of-use treatment, mechanical pathogen removal
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	* Low	** Medium	





Household Membrane Filters generally use ultrafiltration (UF) or microfiltration (MF) membranes as flat sheet or hollow fibre modules. Water is filtered by gravity or manual pumping. Particles, colloids, protozoa, bacteria and viruses are retained on the membrane surface. The removal performance depends on the pore size of the membrane and its manufacturing quality.

Membrane Filtration refers generally to MF, UF, Nanofiltration and Reverse Osmosis membrane-based systems **(T.3, T.10, T.15)**. MF membranes usually have a pore size of 0.1–0.5 μm and remove particles, bacteria and protozoa from water. They are less efficient for viral removal. UF membranes have smaller pores (common membranes for drinking water treatment are in the range of 0.01–0.08 μm) and remove particles, bacteria, protozoa and viruses. Nanofiltration and Reverse Osmosis are usually used at household level as pressurised modules installed under the sink that filter piped water from the distribution network. These filters are not common in emergencies at a household level unless they were already in use, though they are sometimes applied in health care facilities for high-quality water. Therefore, the focus here is on MF and UF Membrane Filters operated by gravity or manual pumping as autonomous systems for single or multiple households.

Membranes can be fouled when a layer of retained material forms on the surface with time, reducing the flow rate. Depending on the filter design, this fouling layer is removed by backwashing (flow of a small amount of clean water in the reverse direction) or cleaning (addition of chemicals, shaking or flushing of the surface). Fouling is intensified by a high content of natural organic matter in the raw water and a high turbidity. Depending on the type and concentration of organic matter, membrane fouling can become irreversible, leading to a continuously reduced flow rate and increased clogging. This irreversible fouling can sometimes be recovered by chemical cleaning.

Design Considerations: Household Membrane Filters are usually simple and easy to use. Flow through the Membrane Filter depends on the membrane characteristics (permeability), surface area of the membrane as well as the applied pressure and degree of fouling caused by the raw water. For gravity-driven systems, a new membrane module can provide over 40 L/hour of treated water per m^2 of membrane where there is a hydrostatic pressure difference of around 100 cm.

Materials: Membrane Filters are supplied as ready-to-use systems that include storage containers or as modules that need to be placed into or attached to the locally available buckets or jerrycans. The filter material is light and difficult to break. Depending on the manufacturer, manual pumps are provided as an integrated part of the system to generate pressure and increase the flow rate. Manual pumps may require maintenance or replacement if damaged. The filters are often not freely available on the market in many countries.

Applicability: Household Membrane Filters can be distributed in all response phases when water is generally available but the quality is poor or unknown and there is a risk of contamination during storage or at home. Membrane Filters are particularly applicable when the population is dispersed and large-scale installations of the water treatment systems are not feasible. Some UF systems are also applicable in areas with turbid water or waters containing high iron content where other systems clog or fail. The number of systems and products on the market is rapidly growing, but distribution is still mostly conducted via NGOs and projects.

Operation and Maintenance: Most Membrane Filtration systems require backwashing and cleaning and will clog if this is not done regularly. The potential of filters to clog during operation with turbid waters is a function of the membrane type and configuration as well as the backwashing mechanism and frequency of backwashing. Some products have automatic backwashing systems. Sometimes, clogging can be reduced pre-filtration using simple screens, which should be cleaned regularly. Training is needed to operate some of the products available on the market. Irreversible clogging of Membrane Filters is an easy indicator of failure, showing that the filter must be replaced. Usually, a failure free operation of 1–2 years is guaranteed by the manufacturer for surface waters (with elevated turbidity and organic matter content), while filters can be operated longer with clear water and low organic matter content. Manufacturers usually specify the expected volume of filtered water before clogging for a defined water turbidity and organic matter content. When membranes are delivered, they may contain glycerol in the pores and on the surface, which is washed out during first use. This might generate some foam that can be discharged, but is usually harmless if consumed. After the glycerol is removed, the membrane can irreversibly clog if it becomes dried (e.g. during storage), so it should be kept wet or in humid environments when not in use.

Health and Safety: Although Membrane Filters show reliable performance, the quality of products may vary considerably. When production quality is assured and verified, UF filters are one of the most reliable technologies for removing protozoa and bacteria, achieving 6-log removal rates. For virus removal, membranes with small pores (< 20 nm) and a narrow pore size distribution perform well. Membranes with larger pores (> 40–60 nm, e.g. all MF membranes and some UF membranes) may have limited performance. Most systems produce concentrated effluent during backwashing, with a higher concentration of microorganisms than raw water, which must be discharged properly. Backwashed water used for other purposes in households can present a health risk.

Costs: Membrane-based filters cost between 15–100 USD per system. The design, membrane area and production quality define the filter costs. Usually, the systems operate without consumables and are robust. Therefore, there are no operational costs. The lifespan varies between 6 months and 5 years, depending on the quality of the product, backwashing/cleaning frequency and the quality of water filtered. Filters are usually not available locally, and transport costs and import regulations increase the costs and delivery times.

Social and Environmental Considerations: Membrane Filters are usually well accepted. Since suspended particles are fully removed without changing the taste and odour of water, treated water is usually perceived as safe and clean. Most membrane-based systems have relatively high initial flow rates compared to other HWTS products. Some systems are not self-explanatory to install and operate. To achieve good uptake of the technology, proper training and explanation of the principle of filtration and its operation and maintenance (O & M) is required. The membrane field is developing quickly, and new products and technologies based on UF appear on the international market every year.

Strengths and Weaknesses:

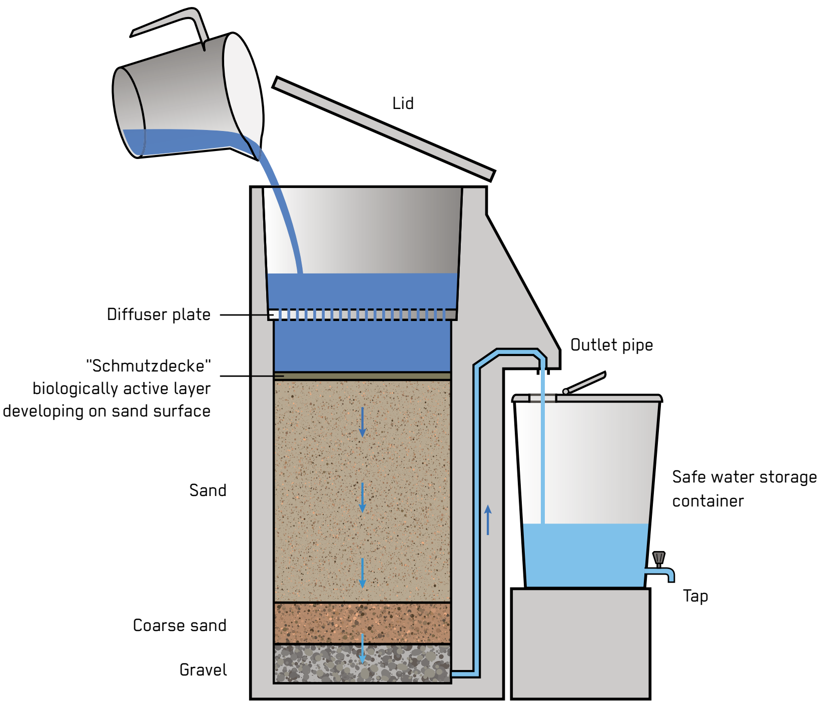
(+) Has high removal rates for bacteria and protozoa. Virus removal depends on pore size of the membrane. Dense, high quality UF membranes achieve high removal rates for viruses
(+) Many systems are able to handle turbid waters
(+) Are light, small and easy to transport; no damage during transport is expected
(+) Easy to operate and maintain when operation principle is understood

(−) Requires frequent backwashing, flushing or some sort of cleaning
(−) Filter operation is not always intuitive, and training is usually needed
(−) Clogs quickly when operated incorrectly

→ **References and further reading material for this technology can be found on page 221**

Biosand Filtration

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	** Household * Neighbourhood City	** Household Shared Public	Point-of-use treatment, mechanical and biological pathogen removal
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	



Biosand Filters (BSF) remove suspended solids and microbial contaminants from water with varying levels of turbidity through a combination of physical and biological processes. They are an adaptation of the continuous-flow traditional Slow Sand Filter (T.9) and can be used intermittently, making them suitable for household use.

A BSF consists of a container filled with filter media and a gravel support at the bottom. Contaminated water is poured into the filter and filtered by gravity. Filtered water flows through the outlet tube and into a safe storage container. BSFs can greatly reduce pathogens and suspended solids in the water through a combination of physical, chemical and microbiological processes within the filter bed **(see also T.9)**. These processes include predation, adsorption, natural death and mechanical trapping. Microorganisms in the source water develop into a biological layer in the top layers of the filter sand. Full development of the biolayer may take up to several months depending on the volume and quality of the source water used. During the first month, microbial removal performance of the BSF is low, and users should additionally disinfect the filtered water.

Design Considerations: The average BSF is 0.9 m high by 0.3 m wide. Empty containers weigh between 70–135 kg (concrete) or 3.5 kg (plastic). To ensure the required uniform flow, the outlet tube is embedded in the container wall or affixed to the outside and is free of taps, hoses or control valves and is above the sand layer. This ensures that when the filter is at rest, it maintains 5 cm of water above the sand surface, called the standing water. BSFs must be kept saturated, as the sand is the habitat for the organisms responsible for the biological filtration process. The filter is operated in batches of 10–12 L. Two layers of gravel at the bottom of the filter ensure uniform flow through the sand and prevent sand from entering the outlet tube. For slow sand filtration, a raw water turbidity of between 10–50 NTU is recommended. BSFs can be operated using water with a higher turbidity, but more maintenance is required.

Sand size is a critical design parameter, with an effective size ranging from 0.15–0.30 mm (higher efficiency at the lower end) and a uniformity coefficient of between 1.5–3 (meaning not too uniform and not too diverse). Sand depth tends to be between 0.45–0.5 m, while water height varies according to the flow. When filled, the water depth on the filter is usually around 20–30 cm, reducing to approximately 5 cm when not in use to allow adequate oxygen diffusion. A filtration rate of around 0.1–0.4 m/h, resulting in a flowrate of around 25 L/hour, is required to support biological activity. The inlet should be designed to ensure even flow distribution and reduce disturbance of the top sand layers.

Materials: The BSF container can be made of concrete, plastic, stainless steel, galvanised metal or any other waterproof, rust-proof and nontoxic material. Concrete containers, cast using a steel mould, galvanised iron filters or filters from available plastic containers can be made locally. Other container types may need a centralised manufacturing facility or can be imported. A simple lid can be made of wood or non-rusting sheet metal. A diffuser basin made from plastic or rust-proof sheet metal is preferable to a diffuser plate, as it eliminates spill over and resulting damage to the biolayer. Filter media, including two layers of gravel, must be free of contamination and sieved to achieve the proper size (sand < 0.7mm, separation gravel 0.7–6 mm and drainage gravel 6–12 mm). All filter media must be washed to remove organic matter. A simple jar test can be used to determine when sand has been sufficiently washed.

Applicability: The BSF is suitable for household use but is not recommended for the acute response because of the time required for biological activity to ripen within the filter. Household filters may be considered in the recovery phase for dispersed populations. The filter is heavy and difficult to move, making is unsuitable for people who relocate often. Concrete BSFs require a minimum of one week to cure before installation can occur. Plastic or metal BSFs can be installed more rapidly, but a maturing period is still needed.

Operation and Maintenance: Operation of the BSF requires the user to pour water from the same source into the filter each day to maintain the biological layer. Treated water must be collected with a clean, safe storage container. Over time, the sand surface becomes clogged with accumulated sediments and organic matter, slowing the flow. When the flow rate is no longer acceptable, the filter must be cleaned. For household BSFs, this involves a swirl-and-dump process, which is performed by agitating the surface of the sand and removing dirty standing water. After maintenance, the biological layer takes time to regain its efficiency level, though this takes less time than when the filter is first installed. The outlet tube, lid and diffuser should also be cleaned on a regular basis with soap or chlorine and treated water. BSFs should never be fed with chlorinated water, as this will damage the biological layers.

Health and Safety: BSFs reduce turbidity, organic content, microorganisms, oxidised iron and manganese concentrations in water. Protozoa are removed by over 99.99 %. The removal efficiency for bacteria and viruses depends on the operational conditions and varies in the range of 70–99 % for viruses and 98.5–99 % for bacteria. Design and operating conditions affecting performance include sand size, sand bed depth, temperature, water hardness and other water quality parameters as well as the time the filter has been in operation. The long-term effectiveness of BSFs depends on O & M quality, and close and comprehensive support is essential to retain effectiveness.

Costs: The total cost of the BSF ranges from 10–100 USD depending on the materials used and context. For users, a key advantage of the BSF is that there are no recurring costs for consumables, though lids, diffusers and safe storage containers may require periodic replacement. The sand does not require replacing. The filters have usually a long lifespan (5–10 years).

Social and Environmental Considerations: BSFs have been used in over 70 countries and are generally considered an affordable, effective and sustainable means of providing clean water to households. They provide an effective treatment of any non-chlorinated water, and anyone can be trained to construct and install filters locally. Concrete filters keep water cooled. However, regular ongoing support is required to ensure correct operation by users, the water quality remains stable and the filters do not fall into disuse.

Strengths and Weaknesses:

(+) Removes turbidity and iron and reduces microbial contamination. Can be modified to remove arsenic **(see H.14)**

(+) Has high user acceptability (easy to use, improves taste)

(+) Can be produced from local materials using local resources

(+) Needs only one-time installation with low maintenance requirements (no chemicals, energy or consumables)

(−) May take up to several months for biological layer to develop

(−) Less effective for virus removal (> 80 %) and at low temperatures

(−) Must be used regularly and with a consistent water source to maintain an effective biological layer

→ **References and further reading material for this technology can be found on page 222**

Point-of-Use Chlorination

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household Neighbourhood City	** Household Shared Public	Point-of-use treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	

Chlorination is a relatively quick, inexpensive and simple household disinfection method. Adding chlorine or chlorine compounds in either liquid form or tablets/powder to water effectively inactivates microorganisms. Sufficient chlorine levels can provide residual protection from recontamination.

Chlorine effectively inactivates microorganisms, and in sufficient quantities, the residual chlorine inhibits microbial re-growth and protects against recontamination. However, chlorine is ineffective against microorganisms with strong cell walls, such as Cryptosporidium oocysts and some bacterial spores at concentrations and contact times used for water treatment. Chlorine, as well as other chemical disinfectants such as bromine, iodine and peroxide, inactivate microorganisms by oxidising their biochemical building blocks, thus disrupting vital cell functions. The efficiency of chemical disinfectants depends on how reactive they are against specific microorganisms and their concentration, contact time and water quality characteristics, such as pH, oxidant demand and temperature. Chlorine reacts rapidly with (in)organic compounds in water, which exerts a demand on the chlorine, thus influencing the concentration available for microbial disinfection. Turbidity can shield microorganisms and reduce the effectiveness, so turbid water should be treated beforehand.

Design Considerations: All forms of chlorine-containing products for household use are designed for the treatment of 1–20 L of water using a small volume of chlorine (e.g. 2–5 mL per 20 L of water, or 1 tablet for 1.5–20 L of water), allowing users to treat multiple unit volumes. Usually, the user needs only to measure out the liquid or dispense the tablet, add it to the water, mix briefly and allow for the appropriate contact time as defined by the manufacturer (normally 30 min). Usually, the chlorine dose is proposed by manufacturers to assure at least 0.5 mg/L of residual chlorine concentration in treated water to protect from recontamination. For emergencies with normal or low risk of disease outbreaks, the recommended free chlorine residual should be 0.2–0.5 mg/L. In reality, concentrations vary widely depending on water quality, temperature, quality and age of chlorine-containing products. If the chlorine is under-dosed, the microorganisms may not be destroyed, and if overdosed, the taste and odour may be affected. For Chlorination to work effectively, the turbidity of the source water should be less than 5 NTU. For higher turbidity spikes, some pathogens may not be inactivated. Low temperature (under 20° C) and high pH (> 8) also affect the Chlorination process, and here the residual chlorine and/or the contact time need to be increased.

Materials: Chlorine exists in different forms with differing percentages of active chlorine. In emergencies, the most used products for household treatment are sodium di-isocyanurate (solid tablets also known as NaDCC) or sodium hypochlorite solution. Liquid chlorine can be locally or regionally produced and distributed in bottles that treat hundreds to thousands of litres before a repeat purchase is necessary. Chlorine tablets can be purchased in individual or multiple units (bottles and blister packs) and require regular or periodic repeat purchases or distribution. NaDCC tablets can be shipped by air without restrictions, while other forms of chlorine need to be shipped as hazardous materials.

Applicability: Disinfection using chlorine is relatively quick, simple and inexpensive. Chemical disinfectants are appropriate for places where water is bacterially contaminated and not very turbid. Chlorination has proved to be efficient in acute emergency situations and as a response to cholera epidemics **(see X.14)**. In locations also affected by chemical contaminants or very high turbidity and natural organic matter content, Chlorination should be used along with other treatments, such as Ceramic Filtration **(H.3)**, Coagulation, Sedimentation and Chlorination **(H.8)**, or Fluoride and Arsenic Removal Filter **(H.13, H.14)**.

Operation and Maintenance: Disinfection with chlorine can be easily learned and must be carried out regularly. Apart from cleaning and the occasional replacement of containers and utensils, no maintenance is needed. However, Chlorination requires a constant supply of consumables that users must be able to purchase regularly, or distribution must be organised frequently. Chlorine may degrade over time and if improperly stored. Liquid and solid chlorine should always be stored away from direct sunlight, excessive humidity and high or varying temperatures. Open packages should be used quickly, and the information regarding the shelf-life provided by the manufacturer must be respected. When water is turbid (> 5 NTU), it will need to be pre-treated, such as by filtering or coagulation **(see H.3 or H.8)** to remove particulate matter. A pH > 8 reduces the efficiency of Chlorination, and when pre-treatment is not yet in place, higher concentrations and longer contact times can be applied to counter this in the short term.

Health and Safety: Chlorination at concentrations used for drinking water treatment is very efficient at inactivating bacteria, less efficient against viruses and not efficient against some protozoa. Turbidity is an issue, as particles in the water may shield microorganisms from disinfection. High organic matter content leads to the formation of disinfection by-products (DBPs) that should be minimised due to the potential health concerns associated with their long-term exposure. However, the long-term potential risks to health from these by-products are low in comparison with the confirmed acute risks associated with inadequate disinfection, and disinfection should therefore not be compromised in attempting to control DBPs in the acute phase of an emergency. Chlorine products have to be handled carefully and kept away from children, as they can irritate the skin, eyes and respiratory system. Continuity of product supply and extensive education to ensure correct use are essential. Provided safety data sheets for chlorine-containing products should be consulted for safety and protection requirements.

Costs: Chlorination is a cheap water disinfectant with costs of around 0.1–0.5 USD per 1000 L for liquid chlorine solutions or 1.5 USD per 1000 L for tablets. However, if locally produced chlorine is not available, transport and logistics may increase the price considerably. Some countries have regulations limiting import of chlorine-containing chemicals.

Social and Environmental Considerations: Some users may be reluctant to chlorinate due to its impact on the taste and odour of the water. User scepticism about effectiveness might be supported by the unchanged appearance of water. The distribution of chlorine needs complementary hygiene promotion measures **(see X.16)** to ensure proper use and to avoid under or over-dosing.

Strengths and Weaknesses:

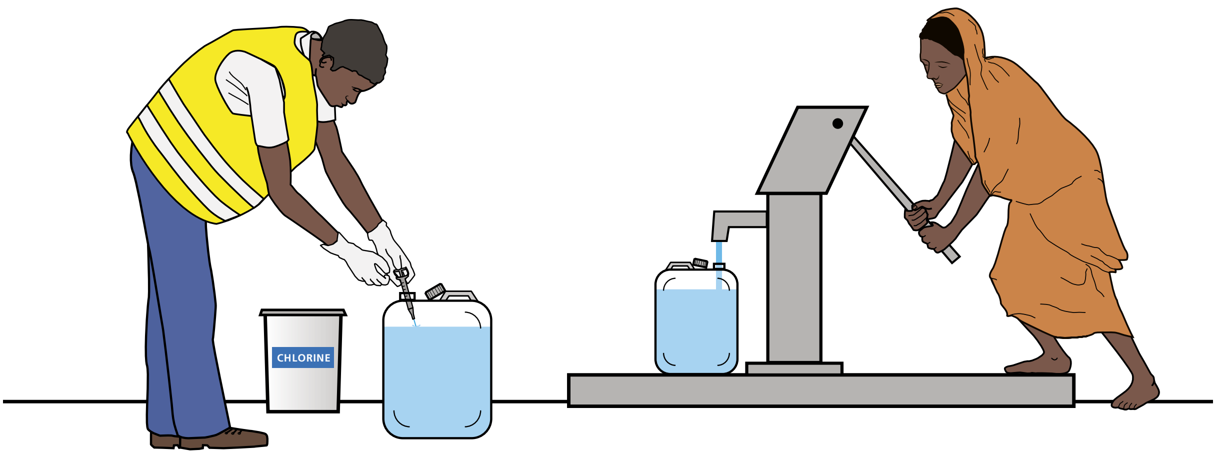
(+) Is easy to apply, inexpensive and reliable for inactivating bacteria and viruses if water is not too turbid
(+) Provides residual chlorine for avoiding possible recontamination
(+) Available in different countries

(−) Requires regular supply of chlorine
(−) Taste may not be acceptable to some users
(−) Requires water with low turbidity to be most effective
(−) Not effective against some protozoa
(−) Effectiveness depends on various factors like temperature, sanitary conditions and pH

→ **References and further reading material for this technology can be found on page 222**

Point-of-Supply Chlorination

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	Household ** Neighbourhood City	Household ** Shared Public	Point-of-supply treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	* Low	



Point-of-Supply Chlorination at community water points, schools, health centres and water tanks involves the installation of a device at the water point that is operated by water pressure. The device continuously releases a dose of chlorine into the collected water by dissolving solid chlorine media or by dosing liquid chlorine. Disinfection occurs during the transport of water to the home and storage in the container. During disease outbreaks, the dosing of chlorine can be done manually (bucket Chlorination).

The technology is compatible with systems supplying water intermittently, such as intermittently operated piped systems or boreholes with manual or mechanical pumping. The chlorine is released into the water at concentrations of around 2 mg/L of free chlorine, which can be adjusted based on the chlorine demand. Chlorine disinfects water during the transport and storage time in the jerrycans and protects the water from recontamination. In disease outbreaks and when the devices for continuous Chlorination are not available, chlorine can be manually dosed. Here, a person would add a required dose of liquid chlorine in every container of water collected at the supply point.

Design Considerations: There are two currently available types of device to automatically dose chlorine. The first is very simple to install and consists of a plastic housing containing a few solid chlorine tabs in the chamber. When water flows through the chamber with the available water pressure, it flows through openings to dissolve the chlorine. The size of the opening can be adjusted mechanically to influence the contact time and the concentration of chlorine released into the water. Once the flow is interrupted, the device drains, and chlorine release is stopped. The volume of water that can be treated with one tab depends on the manufacturer, the specific device used and the tablet concentration. Common commercially available tabs can treat between 1500–2500 L of water. Typical flows are around 10–30 L/min.

The second type of device doses liquid chlorine using a basic principle of fluid mechanics – the venturi principle. When water flowing at a defined pressure encounters a thin tube, the pressure drops and the lower pressure at this point sucks the liquid chlorine into the water. Liquid chlorine needs to be filled regularly in this device. The installation of the device should be done by a trained professional. Manual dosing of chlorine, also known as bucket Chlorination, can be done with a syringe or a small measuring cap, dosing an exact volume of liquid chlorine solution directly into a jerrycan. Chlorine dispensers dose a fixed volume of liquid chlorine into jerrycans or buckets by turning a tap or pressing a button.

Materials: Few devices are commercially available. In most cases, the devices need to be imported, although they are compact, and the installation is usually simple and fast. A constant supply of chlorine in a form required by the device needs to be assured locally. While liquid chlorine might be available locally, the solid chlorine tablets usually need to be supplied from abroad. Bucket Chlorination requires trained staff.

Applicability: The technology uses existing water supply points, such as boreholes or standpipes. It is appropriate for intermittently operated systems. Point-of-Supply Chlorination is suitable when water is contaminated at the tap or if contamination is expected to occur later. It is suitable for any stage of an emergency when water quality needs to be improved at the water point or at the household level and wells or where a distribution network is in place. It can be easier to manage than distributing liquid chlorine to households but requires a constant supply of chlorine in a form required by the device. Bucket Chlorination is mostly used during epidemics or as an epidemics prevention measure when there is a high risk. This is usually done only during defined periods, as it is resource and time intensive. In the long term, bucket Chlorination should be replaced by automated solutions, either at the point of supply or at the source.

Operation and Maintenance: Once installed, Point-of-Supply Chlorination devices are self-operating, and users do not have to expend any additional efforts at the water point. Bucket Chlorination at the point of supply requires the user to dose the chlorine. The chlorine concentration must be adjusted initially and monitored over time. Fluctuating water quality requires frequent monitoring and adjustment. Liquid and solid chlorine needs to be refilled regularly. Chlorine may degrade over time or if incorrectly stored and should always be stored away from direct sunlight, excessive humidity and high or varying temperatures. Open packages should be used quickly, respecting the information regarding shelf life provided by the manufacturer. If liquid chlorine is produced on site **(T.7)**, the staff should be properly trained. These systems cannot be used with turbid water (> 5 NTU), so an initial pre-treatment for turbid water is essential.

Health and Safety: Chlorination at typical concentrations used for drinking water treatment is very efficient at inactivating bacteria, less efficient against viruses and not efficient against some protozoa. Turbidity is an issue, as particles in the water may shield microorganisms from disinfection. High organic matter content in the water leads to the formation of disinfection by-products (DBPs) that should be minimised due to the potential health concerns associated with their long-term exposure. However, the long-term potential risks to health from these by-products are low in comparison with the confirmed acute risks associated with inadequate disinfection, and disinfection should therefore not be compromised in attempting to control DBPs in the acute phase of an emergency. Chlorine products must be handled carefully and kept away from children, as they can irritate the skin, eyes and respiratory system. Continuity of product supply and extensive education are essential. Safety data sheets provided with chlorine-containing products should be consulted for requirements regarding safety and protection.

Costs: The costs for a solid chlorine refill for a community water point are around 50 USD for around 100 000 L of water. Installation costs need to be added, with flow-through devices for tablets costing around 20–40 USD and venturi-based systems for liquid chlorine costing around 200 USD. If bucket Chlorination is used, respective staff time and salaries need to be considered.

Social and Environmental Considerations: Some users may be reluctant to chlorinate due to its impact on the taste and odour of water. User scepticism about effectiveness might be supported by the unchanged appearance of water.

Strengths and Weaknesses:

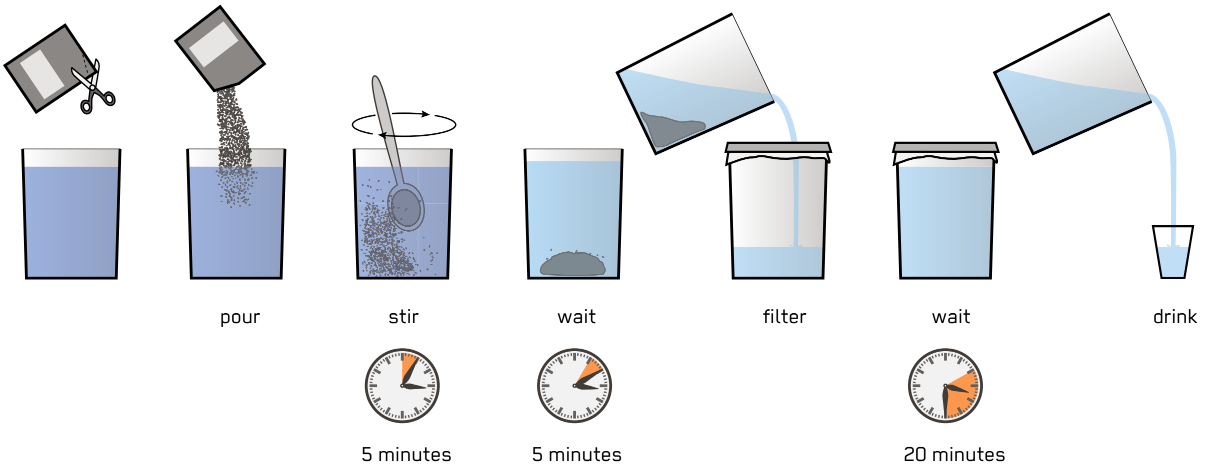
- (+) Requires almost no behavioural change, since it uses locally available and community water points
- (+) Easier to manage and lower cost due to its scale, as compared to household Chlorination
- (+) Requires no additional work for the users
- (+) Provides residual chlorine for avoiding recontamination

- (−) Requires regular supply of chlorine
- (−) Effectiveness will depend on various factors like turbidity, temperature, sanitary conditions and pH
- (−) Taste may not be acceptable to some users
- (−) Dose and contact times might need to be adjusted over time

→ **References and further reading material for this technology can be found on page 222**

Coagulation, Sedimentation and Chlorination

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response * Stabilisation Recovery	** Household Neighbourhood City	** Household Shared Public	Point-of-use treatment, mechanical pathogen removal and disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	*** High	



Combined Coagulation, Sedimentation and Chlorination is available for household use as small sachets of coagulant and a time-release form of chlorine. The coagulant reduces turbidity ('muddiness'), while the chlorine, which activates after some time, disinfects by inactivating pathogenic microorganisms. A single sachet treats a volume of water defined by manufacturer (e.g. 10 or 20 L) within 30 minutes.

In Coagulation, chemicals added to the water destabilise the electrostatic charge on colloids so they come together to form larger particles (Flocculation), which then settle out more quickly (Sedimentation). Since pathogens such as bacteria, protozoa and viruses tend to attach themselves to particles, a large reduction in pathogens occurs through Sedimentation alone. Chlorine is then released into the reduced-turbidity water to further inactivate the remaining microorganisms more effectively and at a lower chlorine concentration than would be needed to treat turbid water. With this dual-action system, considerable pathogen removal can be achieved, as chlorine alone does not inactivate certain organisms (e.g. protozoa such as Cryptosporidium and Giardia). The treated water containing free residual chlorine is protected against recontamination.

Design Considerations: The powder from the sachet is added to water and stirred vigorously for 5 minutes. The water then sits for a further 5 minutes, during which time the flocs (larger particles) settle. The water can then be decanted and/or filtered through a cloth made of cotton or synthetic fibre and left for another 20 minutes to allow enough contact time for the chlorine. Usually, the dose is proposed by the manufacturer to assure at least 0.5 mg/L residual chlorine is available to protect against recontamination, but in reality, concentrations can vary widely depending on factors such as the quality of raw water, type of coagulant, temperature and the age of the sachet. The method is most efficient for water with a pH between 5.5 and 7.5, although less efficient Coagulation will still occur at a lower pH. If the coagulant is over- or under-dosed, Sedimentation will not occur to the required extent, and the concentration of free chlorine may not be sufficient to disinfect. At a high pH (> 9), the method is unreliable.

Materials: The sachets are sold by only a few manufacturers. This method requires regular or periodic purchase or distribution of the sachets, as well as two containers of the required volume. Treated water should preferably be stored in a safe water container, such as a jerrycan or bucket with a tap and lid **(see H.1)**.

Applicability: Disinfection using chlorine is relatively quick, simple, inexpensive and applicable when water is bacterially contaminated. Combined with Coagulation, it is also suitable for turbid waters or when turbidity may vary. The method has proven to be very effective in acute emergency situations as a first response (e.g. to cholera epidemics) as well as for dispersed populations where setting up bulk water treatment is difficult.

Operation and Maintenance: Disinfection with combined Coagulation, Sedimentation and Chlorination can be easily learned and must be regularly carried out. Allowing sufficient time for particles to settle can be an issue for some users. If the source water is turbid, sediment may settle at the bottom of container, and the water must then be withdrawn carefully to not disturb these sediments. During cleaning, the sediments must be removed from the container. Apart from cleaning and occasional replacement of containers and utensils, no maintenance is needed. Coagulation combined with Chlorination requires a constant supply of treatment sachets that users must be able to purchase regularly, or the organisation needs to distribute chemicals frequently. Chlorine may degrade over time or if improperly stored. Usually the shelf life of sachets is 3 years, but this reduces at high temperature, humidity or exposure to direct sunlight. The open packages should be used quickly.

Health and Safety: Coagulation combined with Chlorination at concentrations provided by manufacturers is efficient for inactivating bacteria, viruses and protozoa. According to the evaluation of household water treatment performed by the WHO, it removes 99.99 % of viruses, 99.9999 % of bacteria and 99.9 % of protozoa under laboratory conditions. High organic matter content in the water leads to the formation of disinfection by-products (DBPs) during Chlorination. However, studies show that in combination with Coagulation, the formation of DBPs is reduced. Regardless, the long-term potential health risks from these by-products are low in comparison with the confirmed acute risks associated with inadequate disinfection, and disinfection should therefore not be compromised in the acute phase of the emergency by attempting to control DBPs. The powder must be handled carefully, as it can irritate the skin, eyes and respiratory system. The sediments formed during treatment should be disposed of with care as they might still contain pathogens and chemicals.

Costs: The in-country price of the sachet is 0.1 USD (or 0.01 USD per litre of water treated). For acute emergencies, the product might be sold by manufacturers at the factory price of around 0.0035 USD per sachet, without including shipping or import costs.

Social and Environmental Considerations: Acceptance is supported by the clear water that visibly results from the treatment of turbid water, and this method is usually well understood. However, the chlorine taste and odour after application can make some users hesitant. Waiting times might not always be respected. Users require basic training and ideally a follow-up training to assure consistent and correct use. Continuous monitoring of product use is required to assure the health risks due to potential misuse are low. Waste management recommendations for disposal of sediments and packaging might be required.

Strengths and Weaknesses:

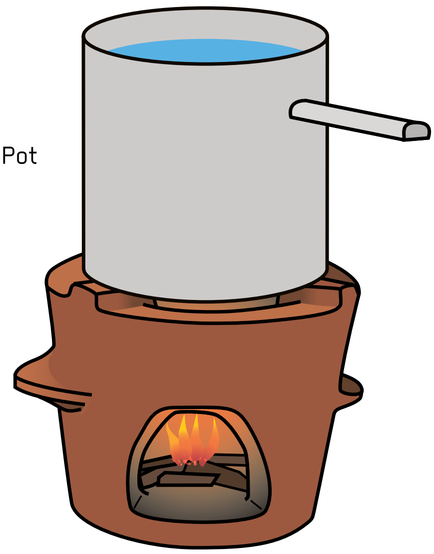
- (+) Is easy to apply and reliable for inactivating bacteria, protozoa and viruses
- (+) Provides residual chlorine for avoiding possible recontamination
- (+) Effectively treats turbid water

- (−) Requires the continual purchase or supply of sachets
- (−) May taste unacceptable to some users
- (−) May deteriorate over time and if stored inappropriately
- (−) Has high costs compared to Chlorination only

→ **References and further reading material for this technology can be found on page 222**

Boiling

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household Neighbourhood City	** Household Shared Public	Point-of-use treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



Boiling water is the oldest and most used method to disinfect small quantities of water at the household level worldwide. Boiling water inactivates all microorganisms including bacteria, protozoa and viruses, but does not remove turbidity or chemical contaminants from drinking water.

Inactivation of microorganisms already occurs below the standard Boiling point of 100° C, as most bacteria, viruses and protozoa are inactivated in less than one minute once temperatures exceed 70° C. However, to ensure user compliance it is better to recommend heating water to a boil, as the appearance of bubbles is a good visual indication of adequate disinfection. To avoid recontamination, water should be stored in a clean and covered container **(see H.1)** after Boiling. Despite its effectiveness and simplicity, Boiling has the disadvantage of requiring affordable and sufficient fuel as well as being quite labour-intensive.

Design Considerations: Normally, available pots and stoves are used. Indoor cooking spaces with an open fire should be well ventilated. Water containing high concentrations of iron and calcium form a white scale at the bottom of the container. The container should be washed properly after every use or cleaned with vinegar or lime juice regularly to remove the scale deposits. To avoid contamination, any clarification of turbid water should be done before Boiling. Boiling requires fuel, which needs to be available or made available. The feasibility of using alternative fuel sources as well as advanced stoves consuming less fuel compared to traditional methods should be considered.

Materials: Boiling requires a pot, stove and reliable source of heat. Where electricity and fossil fuels are not available, rudimentary (e.g. wood, charcoal) or non-conventional (e.g. biogas) methods of heat generation can be used.

Applicability: Boiling is simple, known to most households and well accepted. When fuel is available and accessible during the acute response phase, it can be fast and simple to advise users to boil water before consumption when water quality is unknown, when water is contaminated with pathogenic microorganisms or when water quality deterioration is expected. However, when fuel is expensive, poorly accessible or the environment is strongly affected by deforestation, other methods of water treatment should be introduced in the medium and long term to reduce expenditures, protect the environment and save limited fuel for cooking purposes.

Operation and Maintenance: If the fuel must first be collected or treated, this may be time consuming. At the kitchen level, everyday maintenance includes checking the stove and pots. The frequency with which the stove will need to be repaired or replaced will depend on stove design, the quality of materials and workmanship, and intensity of use. Pots are seldom repaired, and earthen pots often need to be replaced. The necessary skills for O & M activities are usually available in all communities.

Health and Safety: Boiling effectively inactivates pathogenic microorganisms of all classes, and it is currently the most effective method for household water treatment. However, contamination of the boiled water during and after cooling is possible. Water should be handled carefully, and no utensils should contact it when transferring to a clean container for consumption. Boiling may not be appropriate for chemically contaminated water, as the concentration of some chemical contaminants will increase after Boiling or be volatilised into the breathing zone, such as nitrates and solvents. Boiling water can cause burn injuries. Long-term exposure to smoke from fires and stoves may cause associated respiratory diseases.

Costs: Pots and stoves may already be available in households or need to be also distributed for cooking purposes. The fuel costs vary depending on fuel type, availability and local context. Costs of between 3–20 USD/year per person were reported in different contexts.

Social and Environmental Considerations: In many places, it is an ingrained cultural practice to boil water for drinking, so the acceptance of this method is very high. This makes it suitable for emergencies in any phase when fuel is or can be made available. As it tastes flat, which may impact its acceptance, boiled water is often consumed in the form of hot drinks such as tea that mask the changed taste, increasing its acceptance. Boiling can be used in combination with other technologies, e.g. Boiling for hot drinks but another treatment method for direct consumption of water. The taste might be improved by chilling the water (avoiding the addition of possibly contaminated ice). Depending on the fuel, Boiling may be environmentally unsustainable and contribute to greenhouse gas emissions, as well as other local problems related to deforestation, that will affect health and safety. Especially in densely populated areas, Boiling with firewood is not appropriate due to the overexploitation of the wood resources and the subsequent environmental damage.

Strengths and Weaknesses:

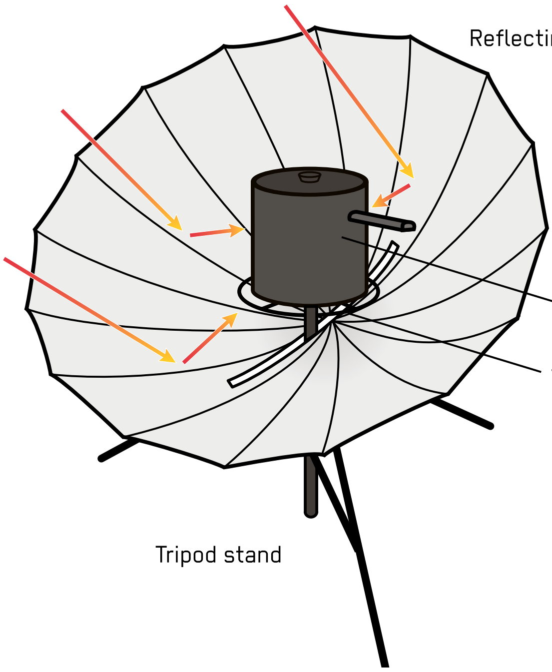
(+) Presents very effective method to inactivate pathogenic microorganisms of all classes
(+) Easy, simple and wide cultural acceptance

(−) Can be expensive due to high fuel consumption
(−) The use of traditional fuel (e.g. firewood, fossil fuels) can contribute to deforestation and carbon emissions, while creating indoor air pollution issues
(−) Does not remove turbidity, chemicals, taste, smell or colour and is time consuming
(−) Water needs to cool down before use, except for hot drinks

→ **References and further reading material for this technology can be found on page 222**

Pasteurisation

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	** Household * Neighbourhood City	** Household Shared Public	Point-of-use treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	** Medium	



Water Pasteurisation uses heat to inactivate pathogenic microorganisms. Most protozoa, bacteria and viruses are inactivated at temperatures between 60–70°C and an exposure time of at least 1 min, though some bacterial spores and protozoan cysts require longer exposure. In practice, water pasteurisation means maintaining water at 70°C for 15 minutes.

Water Pasteurisation can be referred to as solar cooking, which is one of the main methods of household-scale Pasteurisation. Solar cooking uses the energy of direct sunlight, which is concentrated onto a cooking pan using a mirrored surface with high regular reflectivity. In direct solar Pasteurisation, dark containers with water are placed under the sun until the temperature reaches 65–70°C. Other forms of heat can also be used for Pasteurisation at the household level, such as waste heat from cooking meals or an open fire, where water is passed through a metal tube installed around the cooking stove or flows through a short tube placed in an open fire.

Design Considerations: Unlike boiling, where the recommendation is to bring water to a rolling boil, there is no natural visual indicator for the required temperature for water Pasteurisation, and it can be difficult to maintain the correct temperature over the required period. To ensure the time of Pasteurisation and temperatures are correct, there are some products are available on the market. For example, thermostatic valves only dispense water when the Pasteurisation temperature has been reached, or indicators made of a transparent plastic tube partly filled with wax that melts at 70°C, indicating that Pasteurisation has been reached.

Materials: For solar cookers, the cooking pan is made from materials that conduct and retain heat well and are often black or dark in colour. A lid reduces heat loss. Glass lids may further increase the efficiency by a greenhouse effect, but in general, any metal pot covered with a lid can be used. Devices using the excess heat from conventional stoves through a very basic heat exchanger can be produced locally. Pasteurisation indicators are recommended to assure that the temperature has been reached.

Applicability: Household devices are usually very low cost and can be manufactured locally. Solar cookers can also be used for cooking meals, making them more attractive. Usually, the distribution of Pasteurisation devices is more suited to the recovery phase, as the know-how and materials may not be readily available during the acute response, and training might be needed for manufacturing and/or use of the devices. In general, for the proper use of household devices, only basic initial training is needed. However, with no indicator of time and temperature, there is a risk that Pasteurisation is not done properly. Generally, turbid waters can be pasteurised as well, although the turbidity will remain and it might be necessary to increase the Pasteurisation time to assure sufficient inactivation of microorganisms. When turbidity is removed for aesthetic reasons, this should be done before Pasteurisation to avoid recontamination of the water. For solar Pasteurisation, due to comparably low outputs and a high vulnerability to cloudy weather, good planning is important, and sufficient storage capacity is required.

Operation and Maintenance: Suitable containers for solar Pasteurisation incorporate some type of window for solar irradiation, which must be cleaned regularly and replaced when no longer transparent. For solar cooking, the solar collector surface must be cleaned every day. Cleaning can be done using a broom, brush or cloth, but scratching of the surface should be avoided. Pasteurisation does not provide residual protection, and treated water should be consumed shortly after Pasteurisation and stored in the safe water storage containers.

Health and Safety: For living cells of pathogenic bacteria, viruses and protozoa log removal values > 99.9999 % can be achieved at 60–70 °C during exposure times of less than 1 min. However, bacterial spores and protozoan cysts representing early stages in the life cycle of some microorganisms can be more resistant to thermal inactivation. To significantly reduce spores, a sufficient temperature and time must be ensured, usually corresponding to a temperature of 70 °C for at least 15 min. Burn injuries from hot surfaces are the major threat to human health while handling solar cookers or other Pasteurisation techniques, though direct eye contact with reflecting light from solar cookers should also be avoided. Children should not use solar cookers or other Pasteurisation equipment on their own, and the operating equipment should be placed out of reach of children when possible. If fire or fuel are used for Pasteurisation, long-term exposure to smoke may cause associated respiratory diseases. For this, the indoor cooking space should be made well ventilated.

Costs: The cost of a high-quality solar cooker is around 200 USD, although locally produced solar cookers at < 50 USD are available in some places. The costs of wax-based Pasteurisation indicators for direct solar Pasteurisation vary between 0.9–2 USD.

Social and Environmental Considerations: A warm unpleasant taste might be poorly accepted by consumers if the water is not left to cool. During Pasteurisation, water does not change appearance, which also might reduce acceptance of this method in areas with turbid water. If fire and fuel are used, Pasteurisation may be environmentally unsustainable and contribute to greenhouse gas emissions, as well as other local problems related to deforestation, that will affect health and safety. Especially in densely populated areas, using firewood for water treatment is not appropriate due to the overexploitation of the wood resources and the subsequent environmental damage.

Strengths and Weaknesses:

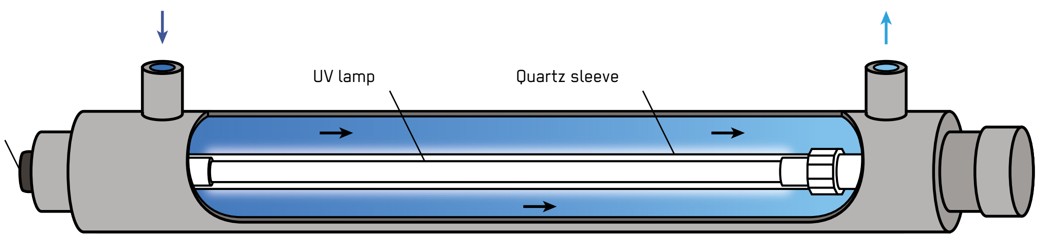
(+) Has almost no treatment cost, only requires suitable containers
(+) Is possible using any energy source

(−) Has rather small treatment capacity
(−) Results in unpleasant, warm water after treatment
(−) Remains vulnerable to unstable weather (if solar powered); clouds, rain and polar regions limit efficiency
(−) Contains no residual disinfectant (safe distribution and storage must be assured otherwise)

→ **References and further reading material for this technology can be found on page 222**

Ultraviolet (UV) Lamp

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response * Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household ** Shared Public	Point-of-use treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	** Medium	** Medium	



A UV Lamp is a non-chemical means of disinfecting water at household level, effective against all classes of pathogens and requiring only seconds of contact time. It uses short-wavelength UV irradiation in the range of 200–300 nm generated from mercury lamps or from UV light-emitting diodes (LEDs).

UV disinfection is a physical process that inactivates microorganisms by damaging their nucleic acids and proteins, which absorb light in the 200–300 nm range. Some bacteria can repair DNA damage, especially when exposed to wavelengths present in sunlight and when the radiation dose is insufficient. For household drinking water treatment with UV irradiation, low pressure mercury vapour lamps are typically applied, which emit a single peak of UV radiation at 254 nm. UV-emitting LEDs are rapidly gaining popularity and can be designed for different emission outputs, though are typically used at 255 to 285 nm.

Design Considerations: Water flows across the lamps from one end of the UV system to the other and is disinfected in a matter of seconds. The hydraulic retention time is a key factor in the design of the system to ensure that the UV radiation exposure time, along with the lamp output intensity, provides the proper UV dose to inactivate all classes of pathogenic microorganisms. However, water quality influences the UV transmittance and efficiency of UV disinfection. For example, high turbidity or suspended solids can reduce the disinfection efficiency due to shielding the pathogenic targets. Inorganic constituents such as iron or manganese can also foul the lamp and reduce light transmission. Ideally, turbidity should be < 5 NTU and transmittance > 70 % at 254 nm over the 1 cm pathlength. Pre-treatment may be necessary when water quality parameters do not meet the limiting values.
A typical UV system includes a single UV Lamp encased in a quartz glass tube and submerged in a closed system made of stainless steel, UV-reflecting Teflon or plastic. UV Lamps can be also placed above the water surface.

Small, battery-driven, point-of-use devices, so called UV 'pens' can treat water directly in a polyethylene terephthalate (PET) bottle. When UV LEDs are used, typically an array of LEDs is encased in a reflective chamber behind a quartz plate, and water flows through the chamber as it is irradiated.

Materials: Water treatment devices based on UV Lamps or UV LEDs are usually ready to use systems. They can be connected inline in piped water supply and are usually fully automated. UV pens are small, and usually include a protective cover which needs to be removed before use, as well as an indicator showing the lifespan of batteries and lamp. UV Lamps require a continuous power supply either from conventional electricity or solar or mechanical means. Ideally, the intensity status and expected remaining lifetime should be monitored by a UV sensor and a lamp status on/off indicator. The UV 'pens' require rechargeable batteries. UV-light systems are often not locally available in many countries.

Applicability: UV disinfection is possible only when reliable power is available at the household level, which will most probably not be the case in an acute emergency. Therefore, the systems are more suitable for the stabilisation and recovery phases. UV 'pens' can be useful in the acute response when there is a possibility to recharge the batteries once every 5–10 days. Household-scale systems or small-scale systems for large households and water kiosks can be used. Usually, the operation is simple and can be completely automated. Users need to be well trained on the maintenance of the systems, or maintenance support must be available from local service providers. UV irradiation does not eliminate physical or chemical pollutants.

Operation and Maintenance: For small household systems, daily operation includes switching the lamp on and off when water needs to be treated. Fully automated inline systems are switched on and off automatically when water flow is detected. If an intensity sensor is present, the operating lamp intensity can be tracked to when it falls below a set-point for validated performance (~70 % or less from initial design value). Regular maintenance of the system should include flushing the container (reactor) from any debris that may build up and wiping the UV tube or quartz sleeve with a soft cloth to avoid scratching. Usually, after 8,000 hours of operation, the UV mercury lamp will reach their end of life and should be replaced to assure proper disinfection. The lifespan of LED lamps varies depending on the specifications of the LEDs and manufacturer. For all types of lamps, the inner surface of the reactor should be inspected and cleaned at least yearly.

Health and Safety: Typical UV treatment provides at least 3-log inactivation of bacteria and protozoa, including Cryptosporidium and Giardia at low doses (1–10 mJ/cm^2). UV disinfection does not protect against microbial recontamination and regrowth after treatment, so treated water should be stored safely. Only validated UV systems providing the designed dose under typical flow rates and UV transmittance values should be used. Direct exposure to UV radiation must be avoided, as UV radiation can burn the skin and damage the eyes. If a mercury lamp breaks, toxic mercury may be released, potentially causing health risks and harming the environment.

Costs: Currently, the cost of a UV–light-based household system varies between 55–220 USD, though can be higher. With LED systems entering the market, the prices are expected to decrease considerably. However, UV systems are often not locally available, and shipment and import costs need to be considered. Due to a small logistical footprint, though, shipping costs are comparably low.

Social and Environmental Considerations: The systems are well accepted and are perceived as modern and convenient. The availability of power is a must for UV treatment, but electric power generated by fossil fuels contributes to CO_2 emissions. The release of mercury from broken UV Lamps harms the environment and is a health risks to humans. UV Lamps containing mercury should be disposed of properly as toxic waste, which might be impossible in some locations. Non-mercury lamps (e.g. LEDs) should be preferred when proper management of toxic waste is impossible.

Strengths and Weaknesses:

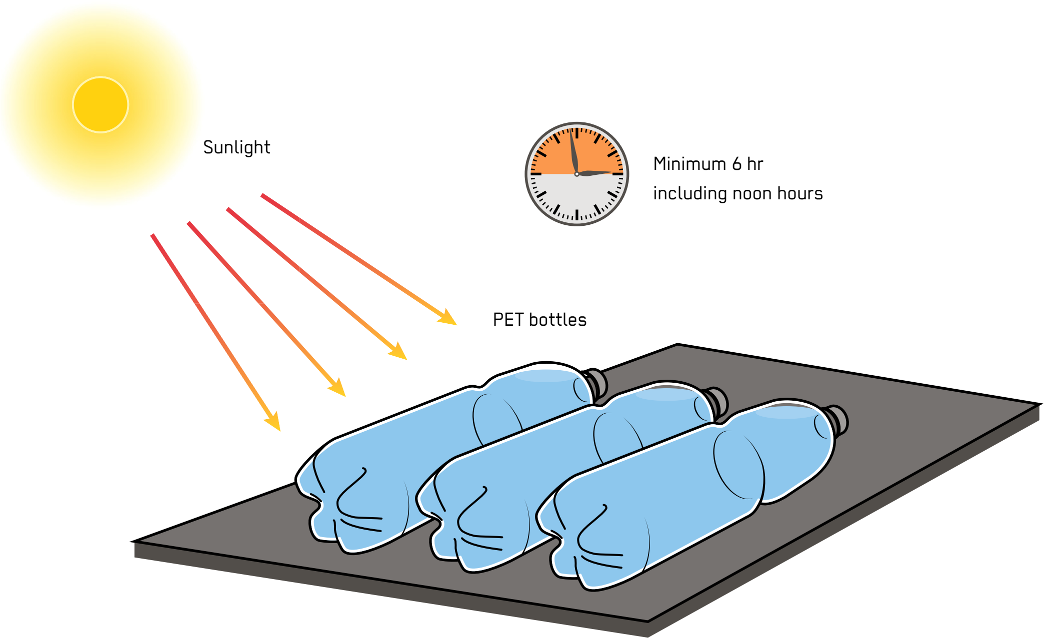
- (+) Operates simply, with no required supply of chemicals
- (+) Causes no change in taste and odour of the water, and no formation of disinfection by-products
- (+) Disinfects microorganisms with high chlorine-resistance (such as Cryptosporidium oocysts)

- (−) Requires reliable electricity supply
- (−) Requires occasional spare parts (mercury lamp)
- (−) Has no residual disinfection, so safe storage must be otherwise assured
- (−) Requires pre-treatment for turbid water

→ **References and further reading material for this technology can be found on page 223**

Solar Disinfection (SODIS)

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household * Shared Public	Point-of-use treatment, water disinfection
Local Availability	**Technical Complexity**	**Maturity Level**	
*** High	* Low	*** High	



Solar Water Disinfection (SODIS) purifies low turbidity water for drinking purposes through a combination of heat, ultraviolet (UV) irradiation and visible light radiation given by solar energy. It is appropriate for disinfecting small quantities of water with a low turbidity.

Used, clear polyethylene (PET) bottles are cleaned, filled with untreated water and closed tightly. The bottles are laid horizontally in the blazing sun for at least 6 hours. When the weather is cloudy, the duration of exposure should be extended to 48 hours. Alternatively, plastic UV penetrable bags, glass bottles or other containers, developed for SODIS, can be used. A good location for laying bottles is a reflective surface, like corrugated iron sheets. Reflection and higher temperatures accelerate the disinfection process. If reflective material is not available, bottles can also be set on any surface, as long as it is ensured that the containers are not shaded at any time.

Design Considerations: The bottles used for the disinfection process should be colourless and transparent, have no scratches/damage, have labels removed and be thoroughly cleaned. UV-radiation is reduced by increasing the water depth, which is why small bottles (1–1.5 L) are preferred over larger volumes (> 3 L). For example, at a water depth of 10 cm (usually the diameter of a 2 L PET bottle) and moderate turbidity level (< 30 NTU), UV-A radiation is reduced to 50 %. To achieve disinfection of > 99.9 % for bacteria and > 99 % for viruses, 3–5 hours of solar radiation above 500 W/m^2 is required. This depends on solar intensity, which depends on factors such as the geographical location, altitude and climate. In practice, this means exposure times from 6–48 hours. Therefore, when promoting SODIS, when it will not be clear to users at what point the water is safe, it may be best to just promote leaving the bottles out for 2 days. The containers should not be shaded by trees, houses or other objects. SODIS is not suitable for water with a turbidity over 30 NTU. In this case, other methods or pretreatment using clarification methods should be used.

Materials: No matter the material used, it must have a good UV-A transmittance and must be food grade. Good choices are PET or glass bottles with a volume of maximum of 3 litres or collapsible bags (e.g. specially produced SODIS bags or commercially available freezer bags). Bags have many advantages over bottles, such as being easier to store, transport, distribute and fill, as well as being easier to purchase in most markets throughout the world. The issue with bags, however, is that they do not last as long and create more of an environmental waste problem. It is recommended to replace plastic bottles after 6–12 months of daily use. Usually, PET bottles are labelled with a recycling sign 1 PET. Brown and green bottles should not be used, as these bottles partially absorb the UV light. A slight blue tinge, which many bottles have, is acceptable. Polyvinylchloride (PVC) bottles should not be used.

Applicability: SODIS is suitable for household use for microbially contaminated water. In particular, SODIS can be beneficial for disaster preparedness programmes. If people have been trained on SODIS and have access to suitable material, they can start treating their water before relief activities reach them. SODIS is not recommended in the acute response if people do not have previous knowledge, as the logistics of distributing empty bottles are not favourable, especially compared to other options (e.g. chemical disinfectants), and like all other household treatment technologies it is difficult in such settings to quickly introduce a new technology that requires significant training.

Operation and Maintenance: A prerequisite for SODIS is sunny weather. On cloudy days (where more than half of the sky is covered with clouds), the bottles must be placed in the sun for two consecutive days. On rainy days, SODIS does not work, meaning alternative options must be available (e.g. Rainwater Harvesting, **I.1 and I.2**). If the weather conditions are unsettled, electronic indicator devices or simple temperature sensors on paraffine bases can indicate the effectiveness of treatment. The SODIS method is appropriate only for water with a low turbidity up to 30 NTU. To decide if the water is too turbid and needs pretreatment, place the filled bottle on a newspaper in the shade (to avoid light interference) and look through the bottle from top to bottom. Being able to read the letters through the water indicates that water turbidity is less than 30 NTU. If the turbidity is too high, it can be reduced by flocculation/sedimentation (using alum sulphate or crushed Moringa oleifera seeds) or by filtration. To avoid recontamination, the treated water should be stored in the bottles in which water was disinfected until consumption. The treated water should be drunk directly from the bottle whenever possible to avoid recontamination.

Health and Safety: Studies have shown that SODIS significantly reduces the rate of disease linked to drinking contaminated water. This is mainly achieved by UV-A transmittance (wavelength: 320–400 nm) and temperatures above 50°C. Laboratory trials have demonstrated that disinfection with SODIS removes up to 99.99 % of bacteria and > 99 % of viruses as well as protozoa (Giardia and Cryptosporidium rendered noninfective after > 10 h of sun exposure).
Water contaminated with non-biological agents such as arsenic, fluoride or industrial agricultural organic contaminants or heavy metals require additional steps to make the water safe to drink.

Costs: If used bottles are available, there are no additional material costs. When used bottles are not available, freezer bags might be a low-cost alternative.

Social and Environmental Considerations: SODIS is a simple, affordable, effective and sustainable means of obtaining clean water used at the household level. SODIS provides effective treatment of any non-chlorinated water source with a low turbidity, and anyone can be trained to use SODIS locally. However, in some cases, the acceptance has been low. People stop using SODIS due to the time and efforts required to treat water for the entire household, concerns related to efficiency, limited access to bottles and unwillingness to pay for new bottles. Some people might reject the warm water, and it might develop an unpleasant taste. Empty PET bottles and plastic bags can cause a serious solid waste management problem. When empty bottles or SODIS bags are distributed in places without a functional waste management system, the impact of the distributed bottles and products should be considered. For example, the disposal of PET bottles in pit latrines can clog the vacuum truck pumping equipment, generating follow-up problems.

Strengths and Weaknesses:

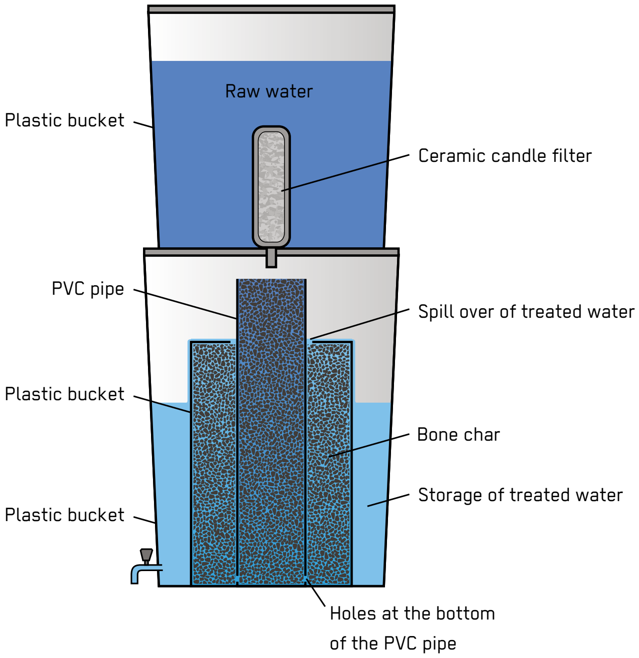
- (+) Provides a simple, easy-to-use and low-cost method, requiring no external energy sources except sunlight
- (+) Efficiently reduces bacteria, viruses and protozoa
- (+) Convenient for storage and transportation, treated water is protected from recontamination in the bottle
- (+) Requires no maintenance (no chemicals, energy, or consumables)

- (−) Only treats small amounts of water of turbidity less than 30 NTU, and there is no residual protection
- (−) Several bottles are needed to treat water for the whole family
- (−) Bottles need to be replaced every 6–12 months, creating a waste problem for the environment
- (−) Has a waiting period of 6–48 hours depending on solar conditions and is unsuitable during continuous rainfall
- (−) Generally low volumes produced

→ **References and further reading material for this technology can be found on page 223**

Fluoride Removal Filter

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household * Shared Public	Point-of-use treatment, removal of chemicals from water
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	** Medium	** Medium	



Fluoride is a groundwater contaminant naturally present in rocks and soils (commonly volcanic-derived sediments). At levels over 1.5 mg/L, it can detrimentally impact human health. As the health impacts result from prolonged consumption, Fluoride Removal is mostly relevant for the recovery phase and protracted emergencies.

Fluoride can be removed from groundwater by adsorption on calcium-phosphate- or aluminium-oxide-based filter materials, by precipitation and coagulation treatment processes or by reverse osmosis. By adding chemicals such as calcium and aluminium salts, precipitates form that bind fluoride and can be removed by conventional sedimentation and filtration steps. The Nalgonda technique uses aluminium sulphate and calcium hydroxide (lime) as coagulants. Other techniques include electrocoagulation and the Nakuru technique, the latter being a mixture of precipitation and adsorption processes. For adsorption and ion-exchange, fluoride-contaminated water is passed through a layer of porous material ('contact bed') that removes fluoride from water through ion exchange or adsorption to the contact bed material. Appropriate contact bed materials include activated alumina or calcium-phosphate-based materials such as synthetic hydroxyapatite and bone char. An important advantage of adsorption techniques is that many filter materials can be regenerated.

Design Considerations: Techniques requiring the daily addition of chemicals for fluoride Coagulation and precipitation (e.g. Nalgonda technique) are not so practical at household level, as the daily operation (chemical dosing, stirring, settling, sludge removal) is time-consuming and error-prone. Adsorption/ion-exchange methods are therefore preferred for household systems, where the amount of water filtered is usually in the range of 20–40 L/day. The filters are usually composed of two chambers, one filled with adsorbent or ion-exchange resin and the other for storing clean water. When water is bacterially contaminated, ceramic filter elements are used before or after the fluoride treatment. For filtration at household level, it is important is to calculate the predicted time of filter material saturation based on its uptake capacity, the fluoride concentration of raw water and the amount of water filtered per day. Close to the point of saturation, the fluoride in the treated water should be analysed by the filter distributor, and the material should be replaced or regenerated if necessary. Regeneration will need to be organised off-site and performed by trained staff (handling of acids and bases). The Fluoride Removal capacity decreases with each regeneration cycle. Most techniques can remove over 90 % of fluoride, although higher pH/alkalinity can make some techniques less effective (e.g. activated alumina and Coagulation/precipitation are less effective at higher levels).

Materials: Fluoride Removal Filters can be constructed locally using buckets. Bone char as well as synthetic hydroxyapatite can also be produced locally, though require training and investment in production facility. Activated alumina might not be locally available.

Applicability: Fluoride is an essential building block for the formation of tooth enamel and bones, but the consumption of drinking water with high concentrations over a long period can lead to the serious degradation of teeth and bones. The guideline value set by the World Health Organisation for fluoride in drinking water is 1.5 mg/L. Risk maps are available (e.g. at Groundwater Assessment Platform) showing regions with a high likelihood of elevated fluoride content in groundwater. Depending on the number of family members and capacity of the household system used, there may be a need to separate treated water used for drinking and cooking purposes and untreated water used for handwashing, bathing and laundry, and care must be taken not to mix the containers. As the health effects are due to long-term consumption, the technology is more suited to the recovery phase and protracted emergencies occurring in areas with a high risk of elevated fluoride content. When Coagulation is used for other reasons, the fluoride concentration may also be reduced.

Operation and Maintenance: The operation of household Fluoride Removal Filter systems is generally simple for users. The necessary contact time between the water and filter bed, which differs depending on the filter material, should be respected to ensure efficient Fluoride Removal. Regular water quality monitoring, replacement and/or regeneration of material should be organised by the distributor/vendor of the filters and requires user cooperation. When the uptake capacity of household filters is reached, fluoride is removed by passing a basic solution over the filter bed, followed by an acidic solution for reactivation. The chemicals need to be stored and handled carefully and should be done by well trained staff in a service centre. The filter media can then be reused for further Fluoride Removal.

Health and Safety: Fluoride Removal technologies do not remove microbiological contamination and post-filtration or post-disinfection might be required. Treated water must always be stored in filters or safe water storage containers. The sludge, regeneration solutions or saturated filter media pose health and environmental hazards and need to be disposed of safely (e.g. landfill away from drinking water sources). The operators involved in the production or regeneration of filter media need to be trained in personal safety measures, such as the correct use of protective equipment.

Costs: The costs of the simple locally made filters can vary between 20–40 USD when production facilities are in place. Bone char production is labour and infrastructure intensive, and these costs must be considered. For commercial products needing import and transport, the costs can increase up to 50–100 USD per filter. However, the regeneration of the material reduce the ongoing costs. In some affected countries (e.g. Ethiopia, Kenya), small providers adopted business models based on loans or service delivery.

Social and Environmental Considerations: Bone char may not be acceptable in some areas due to religious or cultural reasons. The need for water treatment may not be obvious to users, and information campaigns and behavioural change interventions **(see X.16)** might be needed. The sludge, the regeneration solutions or saturated filter media pose environmental hazards and need to be disposed of safely away from sources of drinking water or land used in agriculture.

Strengths and Weaknesses:

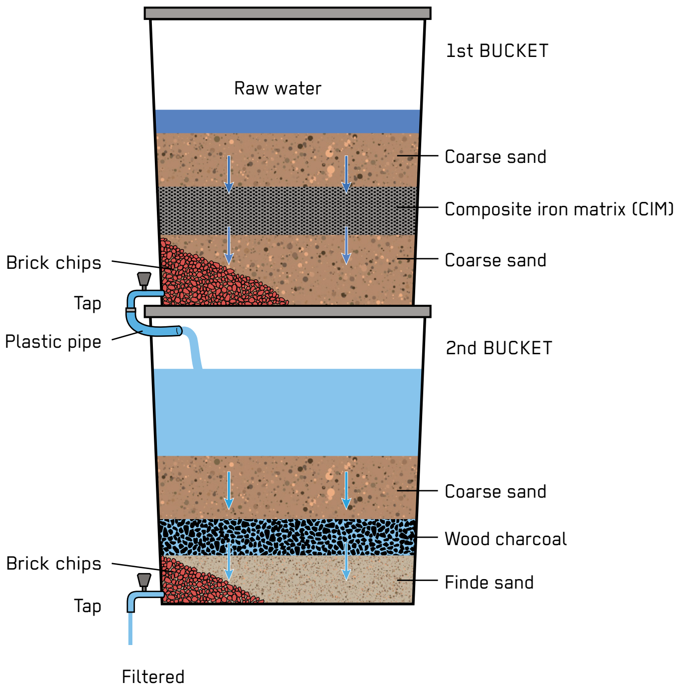
(+) Has high fluoride uptake capacity for some processes (e.g. activated alumina)
(+) Can regenerate filter material for some processes
(+) Requires only short contact time for some processes (e.g. bone char)

(−) Can be more labour-intensive (e.g. bone char production)
(−) Can be less effective depending on pH (activated alumina)
(−) Requires skilled operators for media regeneration
(−) Bone char production requires skill (e.g. kiln at correct temperature) to prevent variations in quality

→ **References and further reading material for this technology can be found on page 223**

Arsenic Removal Filter

Response Phase	Application Level	Management Level	Objectives / Key Features
Acute Response ** Stabilisation ** Recovery	** Household ** Neighbourhood City	** Household * Shared Public	Point-of-use treatment, removal of chemicals from water
Local Availability	**Technical Complexity**	**Maturity Level**	
** Medium	* Low	** Medium	



Arsenic is a groundwater contaminant naturally present in rocks and soils, though may also result from industrial activities. When present at levels over 10 µg/L, arsenic can detrimentally impact human health and should be addressed as soon as possible. It can be removed from groundwater by oxidation followed by filtration, precipitation, adsorption, ion exchange processes or reverse osmosis.

The predominant form of arsenic in groundwater is trivalent arsenic (As III), which is not as easily removed as pentavalent arsenic (As V) that attaches to various solids, such as iron oxides. Therefore, a pre-oxidation step of As III by air or chemicals is recommended prior to water treatment. Once oxidised to As V, household systems can remove it through adsorption, precipitation and ion-exchange.

Design Considerations: Most Arsenic Removal household systems are composed of two buckets/compartments, wherein As III is first oxidised to As V and then, in the second compartment, As V is removed by precipitation or adsorption on a prefabricated commercial filter material. The volume of water that can be filtered by household systems is in the range of 20–60 L/day. Removal efficiencies depend on the design and components of the filter, though are in the range of 85–99 %. Arsenic household filters are simple to operate, but the contact time must be respected, and filters generally need to run slowly. All materials will require regeneration once saturated, which is difficult to determine and requires water quality tests. A functional service chain must thus be established.
One low cost and commonly used technology is the Kanchan Arsenic Filter (KAF). It is a modified Biosand Filter **(H.5)** with zerovalent iron (often in the form of rusty nails) added to the diffuser basin. Arsenic in the water gets adsorbed onto iron oxide (from the rusty nails) and then becomes trapped on the surface of the sand within the filter.

Like other Biosand Filters, the body of the KAF can be made of concrete, plastic or stainless steel. It contains a column of finely crushed rock (sand) on which microorganisms live.

Materials: Appropriate filter materials include ion-exchange synthetic resins, activated alumina, activated carbon and iron-based solids (granular ferric hydroxide or iron-coated sand). An example low-cost material is a composite iron-matrix consisting of iron scraps that produce new adsorbent by the continued corrosion of iron. The precipitated arsenic containing trivalent iron is than removed by filtration through sand and activated carbon layers. Various strong-base anion exchange resigns are available, though they should be used only for low-sulphate waters due to a risk of releasing large amounts of arsenic in the presence of sulphate. Activated alumina is available in a granular form or as aluminium oxide, and the contaminants are exchanged with surface hydroxides of the alumina. The filter media can be filled in locally available buckets. For households connected to distribution network, membrane filters (nanofiltration or reverse osmosis) operated using available tap pressure might be an option.

Applicability: Consumption of water that is contaminated with arsenic over a long period can result in chronic arsenic poisoning. Long-term exposure to arsenic leads to changes in the pigmentation of skin and increases the risks of various diseases of the lung and heart. WHO set a guideline value for arsenic in drinking water at 10 μg/L, which is provisional based on treatment performance and analytical achievability. When present in moderate concentrations, the health effects are caused by long-term consumption, and the technology is relevant mainly for the recovery phase and protracted emergencies occurring in areas with a high risk of elevated arsenic content. However, when present in high concentrations, arsenic needs to be removed as soon as possible. Therefore, in high-risk areas, the arsenic measurements need to be carried out prior to the choice of water source, and when alternative sources are available, the source with no or low arsenic concentrations should be used. Risk maps are available at the Groundwater Assessment Platform showing regions with a high likelihood of elevated arsenic contents in groundwater.

Operation and Maintenance: The operation of Arsenic Filters is relatively simple, requiring a daily filling of water. The necessary contact time between water and filter bed, which depends on the filter design and material used, should be respected to ensure efficient Arsenic Removal. Maintenance activities include periodic cleaning/flushing and the disinfection and exchange of sand, activated carbon or iron elements in the filters. Regular water quality monitoring and maintenance should be supported by the distributor/vendor of the filters and relies on the cooperation of the user. When filter materials requiring regeneration are used, the regeneration should be done in service centres by well-trained staff, as the chemicals required must be handled carefully.

Health and Safety: The health impacts of ingesting arsenic over a long period include changes to the pigmentation of skin as well as other symptoms (e.g. bronchitis, vascular disease) and an increase in the risk of various cancers. In the short term, arsenic can increase the risk of heart attacks. These health impacts can continue even after the arsenic is removed. Arsenic-rich waste is produced by the filter systems and must be disposed of properly due to the high toxicity (e.g. landfills away from drinking water sources). The Arsenic Filters do not remove microbial contamination. There is a risk of contamination of water through poor hygiene practices, and post-filtration or post-disinfection might be required. Treated water must always be stored in filters or safe water storage containers. When ion-exchange resins are used, the raw water quality needs to be considered carefully, as other ions with a stronger affinity for the resin can displace As V, leading to an uncontrolled release of large quantities of arsenic into treated water.

Costs: Filters that can be constructed using locally available materials have costs starting from 20–40 USD. The costs of activated alumina and ion-exchange resins are high, and they might not be available locally.

Social and Environmental Considerations: Arsenic Removal Filters are well accepted when the population is aware of the health issues related to arsenic in water. However, introducing a new technology is a complex process that needs to be participatory from the outset and involve all stakeholders. Information and behavioural change interventions **(see X.16)** will be needed to increase the awareness of population in areas where this is not the case. The long-term effects of arsenic poisoning are not obvious, and users might be reluctant to use filters regularly. Regeneration solutions or saturated filter media pose environmental hazards and need to be disposed of safely away from sources of drinking water or land used in agriculture.

Strengths and Weaknesses:

- (+) Is relatively inexpensive and easy to use
- (+) Uses locally available materials

- (−) Water quality and composition strongly affect the removal efficiency; filters are not ideal for anion-rich water (e.g. sulphate and phosphate are competing ions)
- (−) Difficult to predict filter lifetime and the subsequent replacement time
- (−) Requires functional supply chain for effective replacement

→ **References and further reading material for this technology can be found on page 223**

The evaluation, identification and selection of appropriate, context-specific combinations of water supply technologies not only relies on purely technical considerations but also on surrounding factors, such as prevailing local conditions, social norms and culture and the 'enabling environment'. To help make the appropriate decisions, the WASH history of the intervention area must be considered, particularly regarding local practices and preferences, specific needs of the population, existing regulatory frameworks and the status of existing infrastructure. Water supply interventions must be based on comprehensive assessments and consider the monitoring requirements and strategies for transition and exit. It is also important to plan context-specific approaches, such as for urban settings, cholera prevention, community engagement and market-based programming. This section introduces the most relevant cross-cutting issues clustered into four groups:

Initial Situation

X.1 Assessment
X.2 Area- and Situation-Specific Conditions
X.3 Institutional/Regulatory Environment and Coordination
X.4 Community Engagement and Accountability

Monitoring and Quality Control

X.5 Monitoring
X.6 Groundwater Monitoring
X.7 Water Quality Monitoring
X.8 Water Safety and Risk Management
X.9 Data Flows, Information and Communication Technology

Conceptual Aspects

X.10 Resilience, Preparedness and Disaster Risk Reduction
X.11 Exit Strategy and Hand-Over
X.12 Water for Multiple Use and Water Reuse
X.13 Urban Water Supply in Protracted Crisis
X.14 Cholera Prevention and Epidemic Management

Design and Social Considerations

X.15 Inclusive and Equitable Design
X.16 Hygiene Promotion and Working with Affected Communities
X.17 Market-Based Programming

X

PART 2:
Cross-Cutting Issues

Initial Situation

X.1 Assessment

In the event of an emergency, prior to any intervention, a clear analysis and prioritisation of humanitarian needs should be established through a well-coordinated and planned assessment. Assessments are the foremost step in the Humanitarian Programme Cycle (HPC), allowing indicators such as those listed in the Global WASH Cluster (GWC) indicator bank to be measured, with weak points then specifically addressed to optimise impact in a coordinated manner. The assessment must answer the following five questions for both rapid onset emergencies and/or protracted crises:

1. What are the priorities?
2. Which groups are the most in need?
3. Where should interventions focus first?
4. Over what prospective timeframe will the interventions be required?
5. Against which standards and indicators should progress be measured?

The assessment will either be a comprehensive inter-agency sector-wide assessment or a specific WASH sector assessment, depending on the scale of the emergency and the context, the degree of coordination between partners, the available resources and the overall capacity. Specific WASH sector assessments should always include cross-sector data collection and an analysis of the context through secondary data reviews. As an important first step, primary contact will be crucial to understanding the enabling environment including the various governmental stakeholders, community representatives, affected communities, key informants and humanitarian and development actors that are present. If the state leads in any intervention, understanding the institutional landscape and existing contingency and disaster preparedness plans will be paramount. The national government may request surge capacity from humanitarian actors, especially for medium to large-scale emergencies where cluster activation may be triggered.

Rapid assessment approaches, such as the Multi-Sector Initial Rapid Assessment (MIRA) or those used by organisations such as UNHCR, are relevant during a rapid onset event, such as a natural disaster or an additional unexpected event during an ongoing, protracted crises or mass movement of people. For more complex long-term, slow onset disasters or protracted crises, more complex assessments could also be used, such as the Multi Sector Needs Assessment, that is used to inform the Humanitarian Needs Overview (HNO). The HNO, which is undertaken annually as the first step in the UN funding appeal process, results in a Humanitarian Response Plan (HRP) as part of the overall UN appeals system. For previously existing water supply systems and/or those newly established for medium- to long-term use, a more systematic risk-based approach, such as a Water Safety Plan (WSP), is recommended **(see X.8)**.

For conducting assessments, the following factors must be considered:

1. The relevant authorities and stakeholders from the community take the lead and take ownership based on their resource availability and their capacity to respond;
2. The assessments are coordinated and designed with the specific context in mind (rural, peri-urban and/or urban) depending on the type of emergency and accounting for existing capacities and norms;
3. The assessment is inclusive and covers the needs and capacities of boys, girls, women and men, regardless of their age, nationality, race, disability, religion/beliefs, political affiliation or sexual orientation, etc.;
4. Protection threats and risks are addressed;
5. Security and safety issues, including access, are addressed;
6. Community engagement to ensure interventions are designed for their needs;
7. Accountability to the affected population;
8. Availability of goods and services, a market analysis, cash and logistics; and
9. The assessment includes an environmental impact analysis according to the concepts of building back better (more resilient) and doing no harm when feasible.

→ **References and further reading material can be found on page 223**

X.2 Area- and Situation-Specific Conditions

Contextual Level Assessment

A contextual assessment is rarely exact in nature, as it must weigh many complex factors and consider a wide range of opinions. Furthermore, these can be very political, with vested and sometimes hidden interests at stake. The nature of an emergency means major decisions often need to be made based on limited, incomplete and approximate or inaccurate information. With this in mind, short term commitments are prioritised initially until information is available, which enables mid-term commitments to be made with greater confidence.

Roles, responsibility and capacity: As national governments bear the responsibility for ensuring access to safe water and sanitation (as human right), those governments that have the capacity usually take the lead in an emergency with support from local first responders. Here, external agencies might only provide supplementary capacity and support (or none at all). If the government is unable (or unwilling) to provide the capacity and coordination necessary for effectively managing the WASH response, external agencies play a more significant role. In this case, they may have greater latitude for technology choices, as short-term budgets often support this. However, mid-term consequences and exit strategies **(see X.11)** must be considered.

Estimated duration of the emergency: For displaced populations, it is important to understand for how long any new systems may be needed or how long the surge of existing capacity might last. Typically, flash flooding and limited storm damage means days to months of displacement, while earthquakes and conflict may require immediate solutions that either have the potential to last for years, or at least do not interfere with likely long-term solutions. Rapidly available means for service provision: In acute large-scale emergencies, it is important to consider what can be deployed most rapidly to provide a stop-gap solution, even though it may not be the best fit technical or cost-effective solution in the medium or long term. In contrast, for non-emergency situations, WASH service providers consider the local capacity and knowledge, social-cultural aspects, cost-effectiveness, post-construction support and sustainability at the early stages of the planning phase. These considerations must be recognised from the outset so that the initial emergency solutions can be phased out as soon as feasible rather than perpetuated longer than required.

Nature of the built environment and extent of population concentration: In urban areas where service levels are often higher, the government is more present, networks are more established and service provision is often through utilities, municipalities or private companies such that the choice of technology will often be driven by these actors. However, simple first-phase responses (e.g. tap stands, localised storage, household containers), sometimes thought of as 'rural', may still play a major role. In contrast, in rural areas where populations remain disbursed, centralised systems such as bulk water treatment are seldom useful, and household water treatment options (see HWTS chapter) may be more appropriate.

Technical Level Assessment

This section provides a high-level overview of existing technologies. Please refer to the Sphere handbook for a more detailed explanation. Prevailing national standards in relation to Sphere should be checked, and the higher standard or respective indicators should be used wherever possible. Where expectations of the affected people exceed standards, these need to be understood and discussed, and the service delivery should be negotiated accordingly within financial and feasibility constraints. The most relevant parameters to be assessed include:

Source/Intake/Abstraction/Treatment

- Existing supplies. Any existing supply may be able to cover some of the water requirement and should be assessed alongside potential supplementary 'emergency' sources. It is important to assess the state of the existing supplies, especially after earthquakes, landslides, floods and long-lasting conflicts.
- Quantity of additional water required and the time period over which it will be needed.
- Quality of water (both at the source and what is ultimately required). Analysing the quality includes checking the total suspended solids (TSS), total dissolved solids (TDS), temperature and pH to guide required treatment processes. Chlorine disinfection is generally used in emergencies, so microbiological testing is not a first priority, though this should follow later. However, water turbidity needs to be tested to assess the feasibility of chlorination and additional pre-treatment needs. For the stabilisation and recovery phases, national regulations should be consulted to identify additional water quality assessment needs. Chemical health hazards are often less of a short-term health risk, so testing for chemical parameters may also not be of immediate concern, though in urban areas and in areas with known risks of geogenic contamination (e.g. arsenic), this may be required.
- Feasibility for short-term physical and microbiological treatments, as these generally pose the greater short-term health risk, and the potential for later treatment of chemical contaminants. This also includes aspects such as the speed of implementation and potential impact on other communities.

Distribution/Transport

- The location and distribution of population to determine the number of sources which may be needed and/or the extent of the systems. It is most helpful to work backwards from the designed location of water points to understand how water will be provided there. For example, storage tanks with tap stands may be initially served by water truck and only later connected into distribution points.
- Optimum locations of water points, likely to be communal/shared. A sufficient number of water points should be provided to ensure that standards and indicators are respected, such as the maximum distance

to households, norms to ensure that water is available at key times morning and evening, limiting waiting times at water points, minimising waste, drainage is adequate and water points are safely accessible by minorities, people with disabilities and children.

Water Management at Household Level (including HWTS)

- Need and location for shared bathing facilities (household or gender disaggregated at the communal level). Households are more likely to expect bathing facilities to be within the shelter/house for dignity and safety reasons, and here it may be better to provide materials to households to build their own rather than building communal facilities. This may however lead to drainage problems. Additionally, there may be a need to heat the water, either centrally in shower blocks or through a potential fuel allowance, to encourage regular personal hygiene, particularly in areas with lower temperatures.
- Menstrual hygiene management arrangements in association with bathing facilities. This is likely to require dedicated space in the bathing facilities or other adequate arrangements.
- Laundry facility needs. Households can often make their own ad hoc arrangements in the short term, so this is often a mid-term priority.
- Need for household water containers. Typically, households do not have these on hand and they must be provided for domestic water use and potentially household treatment, as well as for carrying water for bathing and latrine use, if needed. Water container distribution and/or cash/vouchers for purchase could be a consideration.
- Household Water Treatment and Safe Storage (HWTS). Particularly in rural areas, HWTS can be a viable option to improve water quality in the short term when bulk water supply is not feasible.

Disposal

- Quantity of wasted (spillage) water at water collection points. This should be minimised using self-closing taps, pressure-reducing valves or other means, but some waste will occur and this needs to be designed for and observed in practice to determine drainage requirements. Consider localised drainage soak pits and/or use for food cultivation/livestock.
- Need for greywater sullage arrangements for household washing, bathing and laundry facilities. These should be designed for reuse where water is in short supply.

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X.3 Institutional/Regulatory Environment and Coordination

Institutional Roles

States are responsible for their citizens, and this mandate, duty and leadership role must be respected by external actors. During emergencies, this duty is generally readily assumed by the government and is often expressed clearly in national disaster management policies. The capacity of the government to respond depends to some extent on the wealth of the state, with middle income countries consistently able to deploy more assets and with greater institutional capacity. International non-state actors such as the UN, INGOs and the Red Cross/Crescent Movement provide significant support to supplement the capacity of low-income countries and, to a lesser extent, middle-income countries. However, in armed conflicts involving the government, populations in areas not controlled by the government are often not provided with governmental assistance such that the international community mobilise to provide the relief required. Where conflict results in refugees taking shelter en masse in third countries, even when the government is a signatory of the 1951 refugee convention, the government's capacity to respond may be exceeded. Here, considerable resources are typically deployed by the international community, and agencies often play a strong service provision role.

Legal and Regulatory Framework

Whatever the balance between national capacity and international support mobilised in response to a crisis, all parties must respect and observe the regulatory environment, including relevant national policy, standards held by ministries and local government regulations. Local/municipal-level regulations are likely unfamiliar to external actors but must be understood. Finally, regulations like tariff setting for water charges are often suspended when 'free' water is made available for the period of the emergency. It is therefore critical that all actors providing water in a locality understand the tariff regulations and agree with the local government and utilities about when water charges will be reintroduced. Here, the reinstatement of water tariffs should not lead to households relying on negative coping mechanisms to meet basic water provision needs.
National governments can find broad developmental targets they can aspire to meet in the Sustainable Development Goal (SDG) target 6.1 of "Safe and affordable drinking water for all by 2030". While the SDGs are broad targets for normative development, disruptions due to emergencies should first be stabilised, and then the country should be put back on track to achieve these targets. To aid in this, emergency responders should keep target 6.1 in mind for the emergency phase and actively look to contribute to

this for the recovery and long-term development phase. Regulations and standards may be interpreted and applied differently for refugees, even though the SDGs aspire to leave no one behind.

National water standards, whether developed by the sector ministry or as part of national disaster management plans, are not always adapted for crisis situations, meaning it might not always be appropriate or feasible to deliver non-adapted standards. If national emergency guidelines are not specific or do not exist, the Sphere Humanitarian Charter and Minimum Standards in Humanitarian Response should be referred to for guidance (**see Sphere chapter** in the introductory section of this compendium). It may be necessary to engage government stakeholders in discussions about the application of these standards.

Coordination Mechanisms

In large-scale crisis situations, ad hoc time-bound coordination mechanisms are often introduced. Where these features are part of a national disaster management plan, government leadership will probably be strong, and international agencies must support such established mechanisms. The internationally developed cluster-coordination system gives UNICEF global and often national WASH cluster/sector leadership. This is sometimes adopted as part of a government coordination plan or it may sit alongside other government mechanisms, wherein it must still support government plans to fulfil their obligations. The refugee coordination mechanism, led by UNHCR, may maintain distance from the national government to remain an impartial protection oversight, but ultimately there still needs to be communication between the parties. Because of the life-saving (rather than development) focus of general emergency coordination mechanisms, these tend to have poorly defined links to normative developmental sector coordination platforms. During the recovery phase, it is particularly important that the government, the UN agencies in lead coordination roles and other agencies align their coordination efforts with the normative development sector coordination platform. This should also include coordination between implementing organisations at the field level to ensure continuity of service and technology and long-term operation and maintenance.

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X.4 Community Engagement and Accountability

The Humanitarian Programme Cycle (HPC) consists of the following five elements: (1) needs assessment and analysis; (2) strategic response planning; (3) resource mobilisation; (4) implementation and monitoring; and (5) operational review and evaluation. Successful implementation of any humanitarian intervention depends on the coordination and combination of all of these elements with good information management and continuous prevention and preparedness activities. This should help with real-time mitigation of the negative impacts related to lack of access to safe water supplies and avoid exacerbating the problem. Most importantly, people should be placed at the centre of this cycle to ensure that the protection principles are addressed, which are:

1. Enhancing the safety, dignity and rights of people while avoiding exposing them to harm;
2. Ensuring people's access to assistance according to need and without discrimination;
3. Assisting people in recovering from the physical and psychological effects of threatened or actual violence, coercion or deliberate deprivation; and
4. Helping people claim their rights.

To ensure that all affected people get access to equitable safe water, communities must be consulted and actively involved in every phase of the HPC. Communities should be provided with opportunities and operational space to provide feedback, which must be heard and acted upon to ensure the interventions are appropriate and allow for sustained service delivery. This is often referred to as Community Engagement and Accountability (CEA). The main objectives of CEA are:

1. Encouraging community engagement, participation and feedback to allow two-way information sharing on all aspects of the programme assessment, design and delivery with opportunities to complain should infrastructure and services not be up to standards;
2. Providing information to aid in sharing life-saving and/or sustaining key information prior to or during a crisis at scale using mass media, such as text messages, social media and or radio;
3. Including behaviour and social change communications with the messages to promote safer and/or more appropriate behaviours in WASH interventions; and
4. Using evidence-based advocacy to provide a safe platform for those affected by crisis to influence decision makers for better outcomes.

Monitoring and Quality Control

X.5 Monitoring

The ultimate goal of any water intervention is to ensure access to sufficient safe water to save and sustain lives. This means that operational monitoring throughout the course of the intervention is extremely important to gauge whether the interventions are having the planned impact and the performance targets are being met. For coordination purposes, monitoring is also important to ensure all stakeholders are contributing to achieving the target indicators to a high degree and are working with the same standards in the same operational space. Routine monitoring should continue after the acute phase, regardless of the context, at least until durable solutions are established. Cost is also an important indicator to track the efficiency of the programme and ensure that water supply systems can be sustained by those who are handed long-term control. Additionally, inclusion, protection and accountability indicators should not be neglected **(see X.4)**. As an example, UNHCR water indicators for the acute emergency and the post-emergency (stabilisation and recovery) phases for a refugee camp setting are presented in **Table 2**.

To ensure a seamless transition from the emergency phase to long-term development, monitoring should be managed by the coordinating body led by the local authorities with the support of other humanitarian and developmental actors. The support could come from an existing WASH sector or cluster that will advise on indicators and targets as part of the coordination mechanism **(see X.3)**.

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Table 2:
UNHCR Water Indicators (adapted from UNHCR Emergency Handbook)

Indicator		Emergency Target	Post-Emergency Target
Water Quantity	Average # of litres of potable water available per person per day	≥ 15	≥ 20
	Average # of litres per person per day of potable water collected at household level	≥ 15	≥ 20
	% Households with at least 10 litres per person of potable water storage capacity	≥ 70 %	≥ 80 %
Water Access	Maximum distance [m] from household to potable water collection point	≤ 500 m	≤ 200 m
	Number of persons per usable handpump/ well/ spring	≤ 500	≤ 250
	Number of persons per usable water tap	≤ 250	≤ 100
Water Quality	% Households collecting drinking water from protected/ treated sources	≥ 70 %	≥ 95 %
	% Water quality tests at non-chlorinated water collection locations with 0 CFU/100 ml	≥ 95 %	≥ 95 %
	% Water quality tests at chlorinated collection locations with Free Residual Chlorine (FRC) in the range 0.2–2 mg/L and turbidity < 5 NTU	≥ 95 %	≥ 95 %

X.6 Groundwater Monitoring

Groundwater is the most abundant source of readily available (unfrozen) fresh water, making up 97 % of the global supply, with the rest found as surface and rainwater. Although it is mostly not visible, its importance is paramount in achieving positive human, environmental and economic benefits. In a humanitarian context, the preference is often to source groundwater over surface water, as surface water is generally contaminated and requires treatment prior to consumption.

For effective groundwater resource management, it is essential that resources are monitored and the appropriate data pertaining to their use, relating to both quality and quantity, are collected. The logical steps in groundwater monitoring include: (1) defining the problem; (2) drafting management objectives; (3) assessing information needs; (4) collecting data for these needs (water levels, discharge rates, water quality); (5) setting or using data storage systems (i.e. UNHCR borehole database); and (6) interpreting and disseminating the results. The development of effective management objectives is essential, and these steps can include:

1. **Resource monitoring and evaluation:** To understand the existing groundwater resource spatially, temporally (over time), locally (i.e. at and around the installation), and at a distance to determine if adequate safe water can be supplied based on demand;
2. **Compliance monitoring:** To ensure that groundwater abstraction does not adversely affect other boreholes in a well field, users of the same resource or water quality. Such compliance targets could be set and monitored by the authorities;
3. **Protection monitoring:** For groundwater-dependent ecosystems, other users of the aquifer, spring, and/or river must be monitored to mitigate impacts of subsidence from abstraction in urban contexts;
4. **Pollution/contamination monitoring:** To provide an early warning system of the potential hazards to an existing, uncontaminated resource stemming from activities such as agriculture, industry, landfills, etc.; and
5. **Optimisation of pumping boreholes and/or well fields:** To both meet daily demand as well as manage energy consumption.

Having well-defined monitoring objectives at the start of an intervention that are intrinsically linked to the given water indicators will ensure that strategic decisions are evidence-based. This will also help to prevent potential conflicts, such as between a refugee camp and a host community sharing the same aquifer or the negative impact on water quality from densely spaced latrines on an alluvial plain with a shallow water table and rapid infiltration rates. Monitoring resources from the beginning of the intervention will provide an alert to issues arising from sharing and public and environmental health concerns as well as greatly contribute to understanding the groundwater system in terms of aquifer types; resource availability (recharge/discharge mechanisms; aquifer properties; groundwater flow); and ultimately, response to various natural and man-made stressors (recharge and abstraction).

The data collection requirements and the frequency, scale and scope of groundwater monitoring will depend on the drafted objectives, the complexity of the context and the phase of the emergency. For example, when an affected population uses boreholes with hand pumps in the acute phase of an emergency, monitoring should at least cover the water quality parameters such as bacterial content (0 CFU/100 ml), electrical conductivity (EC or salinity), pH, temperature; the rate of abstraction (as average number of standard water buckets (5, 10 or 20 L) per family per day); and if possible, groundwater levels. Once supply is assured, more comprehensive monitoring should be included through the establishment of rainfall measurement stations and surface water measurements. The growing trend to establish a solar-powered pumping system assumes that existing boreholes are in an adequate condition to install pumps, ideally including being cased and having recently had their capacity tested. As a criterion for deciding if a borehole should be motorised as a small pumped system, the borehole safe yields should range between 5,000 and 10,000 L/hr, as compared to 1,000 L/hr for a standard hand pump. At the very least, a proper hydrogeological assessment of both the aquifer capacity (hydraulic conductivity and storage) and resource availability (recharge and discharge area) should be conducted prior to motorising boreholes. Again, this would require that the appropriate monitoring objectives are first defined and, ideally, that monitoring data is available. It is therefore recommended that boreholes be equipped with devices to monitor the groundwater level to support responsible water resource management and to avoid the over-exploitation of groundwater resources.

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X.7 Water Quality Monitoring

Drinking water systems must be routinely monitored to: (1) control operational processes and verify treatment effectiveness and (2) to surveil compliance, ensuring that drinking water meets regulatory standards and protects public health. Regular sanitary inspections are crucial, and sanitary checklists for water supply systems can be a useful complement for monitoring water quality by observation that allows user groups to monitor their own supplies.

Monitoring Parameters

Microbial contaminants: Waterborne diseases are caused by pathogenic bacteria, viruses, and parasites that originate from human and animal excreta. These microorganisms are diverse in their characteristics, fate and transport and may cause acute or chronic health effects. The risk of illness from these organisms depends on the dose and virulence of the pathogen as well as the immune function of the person exposed. Since direct detection of pathogens is costly and technically challenging, the verification of microbial safety relies on indicator organisms, such as Escherichia coli (E. coli) or thermotolerant coliforms. Currently available test kits provide results in terms of presence/absence (P/A), most probable number (MPN), or colony enumeration (in units of colony forming units [CFU]/100 mL), and it usually takes at least 24 hours for the results.

Chlorine disinfection: Disinfection using chlorine is the most common treatment to destroy pathogenic microorganisms in drinking water and to provide residual protection against low-level contamination and bacterial growth in the system. The effectiveness of chlorination depends on the turbidity of the water. Residual chlorine levels should be frequently monitored, as concentrations can vary over a short timescale. Testing procedures are relatively cheap and simple. A common test is the dpd (diethyl paraphenylene diamine) indicator that uses a comparator, often found commercially as a simple and cheap 'swimming pool tester'. The dpd test adds a tablet reagent to a water sample, and the strength of the colour change compared to a standard colour chart determines the chlorine concentration range. Simple test strips are also easy to use and sufficiently accurate for verification purposes.

Chemical and physical contaminants: There is a wide array of chemical constituents that may occur in drinking water supplies. Chemical contaminants can occur naturally (e.g. geogenic contamination such as fluoride or arsenic), originate from human activities (industrial, residential, or agricultural) or stem from the drinking water distribution system itself. Only a small share of the chemicals found in drinking water supplies have an adverse health impact, and usually only after prolonged exposure. The naturally occurring chemical contaminants with the most significant health impacts are arsenic, fluoride, barium, boron, chromium, selenium and uranium. Significant chemical contaminants from human activities or the water system itself include lead, pesticides, nitrate, persistent organic pollutants (POPs), pharmaceuticals and heavy metals. Aesthetic parameters, such as turbidity, colour, odour and taste, are not a health concern but can greatly influence the users' acceptance of a water supply, and turbidity in particular can negatively affect the efficiency of treatments such as chlorination. Due to the analytical sensitivity and less frequent monitoring intervals required, chemical constituents are usually analysed in a laboratory setting. Field test kits can be useful in regions where known hazards exist or are assumed and where laboratories are not easily accessed. Local water sector professionals are likely to be aware of the main chemical hazards in local drinking water, so it is important to draw on this expertise to prioritise chemical contaminants of concern and develop an effective and resource-efficient monitoring programme. **Table 3** presents a summary of common chemical contaminants in drinking water, with examples of field- and laboratory-based testing methods.

System inspections: Water quality monitoring should be supplemented by full-system inspections and should assess the adequacy of source protection measures, structural integrity of the intake, operational status of treatment devices and pressure readings throughout the distribution network. Leak detection and repairs will reduce the risk of infiltration and backflow. Regular inspections can also identify hygienic problems near collection taps that require education or awareness raising among water users.

Operational Monitoring Strategy

Sampling frequency: The frequency of monitoring should be in line with the expected variability of each water quality parameter. Long and short-term variations, such as equipment wear (years), seasonality (months), chemical usage (weeks), filtration cycles (days), weather events (hours) and process control (minutes), all affect water quantity and quality. For example, turbidity levels may change rapidly following rain or the implementation of new treatment processes (e.g. sedimentation or filtration). Especially in intermittent piped supplies, microbial quality may degrade rapidly and by orders of magnitude if impacted by intrusion and backflow or biofilms, loose deposits, and microbial growth. Geogenic contaminants such as arsenic and fluoride typically vary only gradually, although fluctuating groundwater levels due to seasonal variations or abstraction can mobilise contaminants. For most water quality parameters, time lags exist between sampling intervals and between the time of sampling and the analysis of results. These time lags may impede the timely implementation of interventions, leaving consumers exposed to health risks due to poor water quality. Approaches such as water safety plans and sanitary inspections try to address this issue by focusing on problem prevention and identifying problems before they affect water quality **(see X.8)**.

Supporting Infrastructure: In addition to sampling frequency, an effective monitoring strategy must consider sample transport and storage, data analysis, results interpretation and supports for corrective actions. Centralised water supplies will generally follow legal requirements and standard operational procedures for monitoring, and analyses are performed in accredited laboratories that provide reliable results. Operational parameters may be determined with in-line sensors or within an on-site laboratory. Rehabilitation of the water quality monitoring system should be one of the objectives in emergencies. In emergency water supply systems as well as rural and community-scale systems, the frequency and scope of water quality monitoring is typically defined by factors such as road access, material supply chains and availability of technically trained staff. Therefore, an effective and sustainable monitoring program is context dependent and should be tailored to local conditions rather than copying standard protocols from another location. Risk assessment and mitigation approaches, such as those described in the WHO's Water Safety Plan (WSP) manual, provide a systematic framework for designing site-specific monitoring programs. The WSP approach also encompasses the organisation of the reporting, its interpretation and corrective actions drawing on monitoring data **(see X.8)**.

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Table 3:
Selected Chemical and Physical Parameters with Field- and Laboratory-Based Testing Methods (adapted from WHO, 2011)

	Chemical	WHO Guideline value (µ/l)	Testing methods	Health effects through drinking water
Naturally occuring	Arsenic	10[a, b]	Absorptiometry[c], colorimetry[c], EAAS, ICP, ICP-MS, FAAS	Long-term exposure causes cancer, skin lesions, cardio-vascular disease, and diabetes. In utero and early childhood exposure linked to cognitive impairment.
	Fluoride	1,500	Absorptiometry[c], colorimetry[c], IC	Prolonged high exposure causes enamel and skeletal fluorosis.
	Total Chromium	50	Absorptiometry[c], EAAS, ICP, ICP-MS	Carcinogenicity of chromium (VI) via inhalation route.
	Iron	None	Colorimetry[c], FAAS	Not of health concern at levels below acceptability threshold in drinking-water.
	Total dissolved solids	None	Gravimetric analysis, conductivity probe[c]	Not of health concern at levels below acceptability threshold in drinking-water.
Industrial	Cadmium	3	Absorptiometry[c], EAAS, ICP, ICP-MS	Carcinogenicity via inhalation route.
	Mercury	6	FAAS	Toxic to the nervous, digestive and immune systems, lungs and kidneys.
	Trichlorobenzenes	None	LC-MS	Not of health concern at levels below taste acceptability.
Agricultural	Nitrate	50,000	Absorptiometry[c], colorimetry[c], IC	Methemoglobinemia in infants following short-term exposure.
	Nitrite	3,000		
	Atrazine	100	GC-MS, HPLC	Occur in drinking-water at concentrations well bellow those of health concern.
Water system	Chlorine	5,000	Colorimetry[c]	Not of health concern at levels below acceptability threshold in drinking-water.
	Chlorate/chlorite	700	IC	Oxidative stress to red blood cells threshold in drinking-water.
	Lead	10	Absorptiometry[c], EAAS, ICP, ICP-MS	Inorganic lead is a probable human carcinogen. Cumulative effects on cognitive development, renal function, hypertension and fertility.
	Nickel	70	Absorptiometry[c], EAAS, ICP, ICP-M; FAAS	Carcinogenicity via inhalation route. Allergic contact dermatitis.

[a] Provisional guideline value because calculated guideline value is below the achievable quantification level
[b] Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source, protection, etc.
[c] Field method

EAAS Electrothermal atomic absorption spectrometry
FAAS Flame atomic absorption spectrometry
GC-MS Gas chromatography-mass spectrometry
HPLC High performance liquid chromatography
IC Ion chromatography
ICP Inductively coupled plasma
ICP-MS Inductively coupled plasma mass spectrometry
LC-MS Liquid chromatography-mass spectrometry

X.8 Water Safety and Risk Management

Drinking water should not pose a risk to human health. As water safety measures cannot be directly observed or measured, a risk assessment and management approach is required. Risk management from source to consumer enables the prediction of possible risks and provides the most efficient protection against exposure to waterborne contaminants. This includes protecting the water against contamination and/or treating water to remove contaminants. In emergencies, it may also include other risks such as user, system and operator security (e.g. from violence) as well as risks related to institutional and financial weaknesses.
The goal of a Risk Management Framework is to control, prevent or reduce risks. This framework can be used as a tool to design, implement and improve risk management strategies as a part of an overall strategy or governance. The risk management process is used to effectively implement risk management principles at all levels and functions of the organisation or institution. The key steps of the risk management process include:

- Characterisation of the context
- Risk assessment, which includes risk identification, risk analysis and risk evaluation
- Risk treatment, which includes the choice and implementation of practices for risk treatment
- Monitoring and review of the process and risk-treatment measures
- Communication and consultation

A Water Safety Plan (WSP) is a risk management approach specific to drinking water supply systems. Its major focus is on the risks related to the health of a user group or consumer of the drinking water. The WSP has been developed for practitioners to apply the WHO framework for safe drinking water to all types and sizes of drinking water supplies in urban and rural contexts. In an emergency context, the implementation of the WSP is essential to guarantee long-term water safety in recovery and protracted contexts. A WSP enables source protection, contaminant removal during treatment and prevention of recontamination during distribution, transport, storage and handling.
For a specific water system, each step of the supply chain is scrutinised to identify the severity of potential hazards and the likelihood these hazards will either enter the system or not be properly removed. Risks are assessed and prioritised, and an improvement plan is developed to address the identified risks. An operational monitoring plan is essential to verify that the WSP is always working properly and to prepare adequate management and communication strategies. When implemented properly, a WSP will improve system understanding, stakeholder collaboration and knowledge sharing, and skills and capacities. It will also help prioritise optimisation needs and improve operation, management and infrastructure, increase user or community confidence in their water supply system, strengthen the sense of ownership, and leverage financial support.

WSP implementation

The WSP approach is flexible and must be continuously adapted to local conditions and circumstances.

The implementation consists of eleven steps (also called modules):

1. **Assemble the WSP team.** Engage senior management, identify required expertise, set an appropriate team size, appoint a team leader, define roles and responsibilities and define a time frame for developing the WSP.
2. **Describe the water supply system.** Draw a detailed map of the system, identify users and uses of the water and gather detailed system information. Perform a field visit to verify that the description is accurate.
3. **Identify hazards and hazardous events.** Identify all potential hazards and all hazardous events that could affect water safety throughout the supply chain.
4. **Determine and validate control measures and assess and prioritise risks.** List the existing control measures for all hazardous events and obtain evidence that they can be controlled. Evaluate the risks associated with each hazardous event while considering the effectiveness of the existing control measures.
5. **Develop, implement and maintain an improvement plan.** For risks that are not appropriately controlled, decide on actions and make an improvement plan with defined roles and responsibilities to ensure their implementation.
6. **Define monitoring of control measures.** Establish an operational monitoring programme to assess the continued effectiveness of control measures and to allow for timely action to prevent problems from occurring. This includes checklists, a monitoring plan with assigned responsibilities, record keeping and data analysis.
7. **Verify the effectiveness of the WSP.** Confirm that the WSP as a whole works effectively through three verification-monitoring activities: compliance monitoring, audits and consumer surveys. WHO and IWA have developed a specific guidance manual for auditing a WSP.
8. **Prepare management procedures.** Document the actions to be taken and the steps to follow during normal operating conditions and emergency situations.

9. **Develop supporting programmes.** Develop or improve operator training programmes, consumer education programmes, training on laboratory quality control, etc.
10. **Plan and carry out periodic review of the WSP.** To maintain an up-to-date WSP, the complete plan should be reviewed periodically and revised if necessary, particularly after an improvement plan is implemented and to consider any new hazards that might arise.
11. **Revise the WSP following any incident.** Reflect on lessons learned from near-misses, unforeseen events or emergencies.

Potential barriers leading to low managerial commitment to a WSP include:

- Water suppliers might view a WSP as creating additional work
- High operator turnover might jeopardise WSP implementation
- Lack of financial resources
- Challenges of designing and carrying out audits

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X.9 Data Flows, Information and Communication Technology (ICT)

Data on water system functionality, performance, operational costs and quality can be collected, analysed and organised to improve the management, operation, and safety of urban and rural water supplies. To be effective, these data, consisting of measurements, statistics, geo data or qualitative data, must be both processed into information (defined as the knowledge gained from the data) and transferred to relevant actors. This information can then be used to assess, monitor, manage and improve water supplies, advocate for resources, and plan water sector projects.

Evaluating existing information systems

Information systems comprise the tools and components for organising and communicating information within an institution or program, including those based on human interactions, paper, audio and digital tools. Information and Communications Technology (ICT) encompasses the electronic tools used to collect, organise, store, access, process or convey data.
Country policies on ICT (if existing) should be respected, and water authorities should be involved, where possible, in the selection of the appropriate ICT. Before deciding whether a new system for collecting and managing information is necessary, existing systems, which may have been in place prior to the emergency, should be evaluated. One tool for mapping these systems is a data flow diagram (DFD), which is an analysis method that maps inputs, processes and outputs within a system, thereby modelling how data are collected and transferred. DFDs have four elements: (1) external entities (organisations outside the system boundaries); (2) processes (transformations of or changes to data); (3) data stores (physical data storage, like a notebook or computer file) and (4) data flow (transfer of data between the previous elements). These elements are captured through interviews and by observing data management and existing records. The resulting DFDs can then be used to understand existing processes (e.g. Which data are collected? Who is involved? How is data distributed? Who has access to the data?) and to model potential changes to the information systems.
When evaluating current information systems or considering modifications, it is important to consider questions such as:

- What types of decisions can be made to maintain or improve this water system (e.g. repair water points, treat water)?
- What information is necessary for making those decisions (e.g. functional/ not functional, contaminated/safe)?
- How will those data be collected, and who (or what) will process and analyse the data (e.g. local NGO staff, water point committee, sensor)?
- Who needs to see the information to make the decisions (e.g. local authorities, the humanitarian organisation, local health staff, a household)?

Information and communication technology (ICT) tools for the water sector

The optimal information system depends on the types of data to be collected (e.g. numeric, text, visual), when it is needed (one-off, periodic, or routine; feedback or interactive system), which direction it will flow (one-way or interactive) and how it will be transmitted (e.g. manually or electronically). There are many paper and mobile–phone based tools for collecting information related to the provision of safe water, often based on spreadsheets and word-processing software. These tools can be used for a single system or for synthesising information from multiple water systems, such as within a region or water utility. Important mapping technologies in the water sector include GPS (global positioning system) for establishing the location of a water system or its components and GIS (geographic information system) for visualising and analysing location-based data. Mobile–phone-based tools for water point mapping use GPS and camera features to inventory rural water points by collecting data about the water point and its location; previously, these activities were recorded on paper and with special GPS devices.

Mobile phones have also been used to improve water utility billing operations, such as customer tracking and issuing (and allowing payment of) water bills via mobile money, contactless payment cards or text-based and smartphone interfaces as well as to notify customers of service interruptions. Mobile phones have also been used to collect and collate the results from water quality tests, which are either entered into the phone manually, use the phone camera or rely on attached sensors to record and process the results.
Finally, while most mobile phone systems rely on people to enter data, automatic data collection systems that directly record, process and transmit data do exist and are essential when access and human resources are limited. Examples include sensors that measure handpump or water treatment functionality, operations and use; asset management; water storage tank levels; post-treatment water quality parameters, such as chlorine residual, and water production and consumption rates.

Sustainability of information systems

While information systems optimally improve the sustainability and operations of water systems, these information systems themselves also have to be maintained. They may also suffer from challenges, such as a lack of user engagement and a failure of the system to perform as expected or provide useful information.
With the rapid pace of technological development, new ICT tools are constantly being introduced. Different humanitarian actors may use different tools, which might require additional efforts in harmonising the data and information flow. The sustained function and use of ICT systems can be assisted by ensuring that new tools and information systems enhance existing practices. Since data must be processed, updated and converted into information to be useful, information systems or ICT tools should be carefully evaluated for their full lifecycle costs and weighed against potential benefits to ensure the commitment and resources are available to justify such an investment.

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Conceptual Aspects

X.10 Resilience, Preparedness and Disaster Risk Reduction

Preventative measures in advance can help reduce the severity of a disaster and streamline disaster management. Many emergency situations follow predictable patterns, and most disaster-prone regions are well known. At the same time, disaster and crisis scenarios are becoming increasingly complex, and traditional reactive relief interventions are proving insufficient. Disaster prevention or mitigation thus has an important role to play and must be considered by both relief and development actors to address underlying vulnerabilities and to build capacities to better cope with future shocks. Preventative measures that serve as an integral part of both water supply planning and national, regional and local development strategies include strengthening resilience, increasing preparedness for acute emergencies and disaster risk reduction.

Resilience

At its core, resilience can be described as the ability of countries, communities, individuals or organisations that are exposed to disasters, crises, and underlying vulnerabilities to manage change. This can be achieved by anticipating, reducing the impact of, coping with and recovering from effects of adversity without compromising long-term prospects. The goal of strengthening resilience is to develop locally appropriate measures that can be incorporated into existing structures and processes and increase the capacity and capability of involved stakeholders and their self-organisation potential. This process requires longer-term engagement and investments as well as an in-depth analysis of previous emergencies, underlying causes of vulnerability and existing human, psychological, social, financial, physical, natural or political assets at the different levels of society. Important components to enhance resilience include capacity development, trainings, education, awareness raising, sensitisation and advocacy as well as improvements to the robustness and durability of implemented water supply technologies and services. Key resilience measures related to water supply include:

- Implementing robust and durable water supply infrastructures adapted to local extreme conditions and potential emergency scenarios
- Considering climate change adaptation measures to assure a sustainable water supply
- Considering the effects of water supply on the natural water cycle and the sustainability of the water source, including accounting for climate change effects
- Considering future population and settlement developments and their impact on water sources
- Expanding capacity building to build, repair, operate and maintain water supply infrastructure
- Conducting hygiene promotion and awareness measures
- Establishing community structures (e.g. WASH committees and health clubs) and involvement of users in demand management
- Developing and improving contingency management and innovation protocols

Robustness is the ability of a technology to provide a satisfactory outcome in variable environment. In emergencies, especially, it is important that water supply technologies be resilient against failure and function despite disruptions (such as power cuts, water shortages or floods). Therefore, robustness must be considered early in the planning. Given the possible uncertainties, it is advisable to consider water supply systems that are functional in a range of scenarios (e.g. elevated water points in flood-prone areas). There is no 'silver bullet' for planning a robust water supply option — each technology has specific strengths and weaknesses depending on the local context and available skills and capacity.

Durability is the ability of a technology to last a long time without significant deterioration. The longer a technology lasts, the fewer the resources needed to replace it. The more resistant it is to wear and tear, the fewer resources are required for operation and maintenance (O&M) and there is a lower risk of failure. Technologies should be chosen after accounting for local capacities for O&M, repair and the availability of spare parts. In some cases, it may be necessary to choose a lower level of service to avoid having essential equipment that cannot be repaired when it breaks down (e.g. pumps, grinders etc.). To increase the durability of most treatment technologies, appropriate pre-treatment needs to be considered.

Climate Change adaptation measures are becoming increasingly important to assure a sustainable water supply. Although some of the climate trends at a regional level are uncertain, there is sufficient knowledge to inform water supply policy and planning in most regions. To build resilience to climate change, emphasis should be put on both the available water resources and the demand. This includes measures to protect the water source, improve natural storage/recharge and monitor the water source, while simultaneously reducing consumption and water losses becomes even more important.

Preparedness

Preparedness includes all precautionary measures taken in view of anticipated disaster or crisis scenarios to strengthen the ability of the affected population and organisations to respond immediately. Preparedness is the result of capacities, relationships and knowledge developed by governments, humanitarian agencies, local civil society organisations, communities, and individuals to anticipate and respond effectively to the impact of likely, imminent hazards. People at risk and the responsible organisations and institutions should be able to make all necessary logistical and organisational preparations prior to the potential event and know what to do in case of an emergency. In addition to early warning systems and evacuation plans, key preparedness measures related to water supply include:

- Contingency planning and developing emergency preparedness plans (EPP) for potential emergency scenarios
- Stockpiling of WASH equipment and consumables
- Preparing emergency services and stand-by arrangements with a clear assignment of responsibilities and jurisdiction
- Establishing support networks among different regions
- Capacity building and training of volunteers and emergency personnel
- Strengthening of local structures through community planning and training

Disaster Risk Reduction and Prevention

Disaster Risk Reduction (DRR) is an umbrella term for all preventive measures, including those described under resilience and preparedness. It aims to reduce disaster risks through systematic efforts to analyse and reduce causal factors of disasters. Examples of DRR include reducing exposure to hazards, reducing the vulnerability of people and property, properly managing land and the environment, and improving preparedness and early warning systems. A proper risk analysis forms the basis of adequate DRR measures by assessing the potential exposure of communities to these risks, the social and infrastructural vulnerability, and a communities' capacity to deal with risks.
The importance of a DRR approach is being increasingly recognised by the international community. Historically, development actors have not invested significantly into

DRR and prevention. In recent years, however, DRR and conflict prevention have turned into cross-cutting issues that are addressed through relief, recovery and development instruments. Non-functioning or insufficient water supply services can potentially cause disasters, and hazards in turn can degrade water services, resulting in increased disaster risk. It is therefore inevitable to consider potential disaster risks when setting up or developing water supply services, whether in relief, recovery or development. Key DRR measures related to water supply include:

- Reducing the potential impact of hazardous events on water supply hardware and services (resilience and mitigation)
- Ensuring a rapid service level and structural recovery of water supply hardware and services after hazard events (preparedness)
- Ensuring the water supply system design addresses earlier vulnerabilities (build back better and resilience)
- Ensuring water supply services have minimal negative effects on society and on the natural water cycle and environment (do no harm)

→ **References and further reading material can be found on page 224**

X.11 Exit Strategy and Hand-Over

An exit strategy in the context of emergency water supply interventions is a planned approach of why, what, when and how implementing organisations will end their water–supply related humanitarian engagement. This process should be considered and planned for from the start of activities. Addressing the exit strategy at an early stage of an intervention provides transparency to partners and promotes a seamless handover to respective government departments or development agencies. Overall, an exit strategy includes the process of transitioning, handing-over and possibly decommissioning infrastructure and exiting or disengaging from activities, projects, programme areas or countries. This is particularly important once the acute phase has passed and should be implemented as soon as basic water supply services are (re-)established at a level that successfully reduces the vulnerabilities. For post-acute, chronic and protracted crises, exit criteria are applied that compare the advantages and cost-effectiveness of a sustained humanitarian intervention with those of an intervention led by local authorities and agencies or other donors and/or partners. As with other water supply considerations, exit and transition strategies are context dependent.
Exit strategies must also align with national strategies and policies **(X.3)**. If the local situation allows, they should be carried out in coordination with the government and/or relevant developmental actors to jointly define the scope and focus of the interventions to ensure a smooth transition. Implementing partners must specify when and how project support will be terminated and handed over to the local government, other local organisations or service providers capable of sustaining/maintaining the achieved service levels or clarifying whether and how projects will be followed up (e.g. by another phase with the potential for follow-up funding to continue WASH activities where necessary). The following sustainability criteria should be addressed as early as possible to allow for a successful hand-over to local governments or other developmental actors and guarantee the future viability of the system:

- **Technical sustainability:** Water supply interventions must support locally appropriate technologies and designs as well as available and affordable local construction materials. Water systems must be in sound technical shape at the time of a handover to a local entity. For water supply services to remain operational, interventions need to be balanced between technically feasible solutions and what the affected population, local government entities or service providers desire and can manage after the project ends.
- **Financial sustainability:** The respective costs for the long-term O&M of water supply infrastructures must be considered as part of the technology selection. While cost recovery is not a priority in the acute humanitarian response, awareness of the protracted financial consequences of (re-)establishing water supply services is essential from the outset.
- **Socio-cultural and institutional sustainability:** Water supply interventions need to consider local acceptability and the appropriateness of the implemented technologies, convenience of the services, taste and odour of water, perceptions of users and service providers, gender issues and impacts on human dignity. When water facilities are provided for displaced people, care should be given to maintaining a similar service level to host communities. Actions need to be taken to ensure that hygiene promotion activities and behavioural change interventions **(X.16)** are sustainable. Ownership of the infrastructure, including responsibilities for O&M, must be clearly defined. To identify the requirements of an enabling environment, it is important to know the capacity of the affected population, community-based organisations, service authorities and service providers to plan, manage and monitor water-supply services, including financial aspects, asset management and O&M. Organisations and structures (public, private and community) need to be in place to provide the necessary support.

- **Environmental sustainability:** The impact of interventions on local water resources needs to be assessed prior to the intervention. To build resilient water supply systems, the design needs to be adapted to the identified risks. The inclusion of integrated water resource management and water safety plans **(X.8)** is considered an integral part of the response. The design involves a comprehensive evaluation of water resources; an assessment of current and future demand; the definition of roles and functions of local and national authorities; and the identification and enforcement of water-use rules and/or master plans for water/wastewater systems in urban settings.
  In acute scenarios involving temporary solutions, it may be necessary to consider dismantling and decommissioning water supply facilities. The implementing organisation responsible for construction and service provision is usually also responsible for decommissioning.

→ **References and further reading material can be found on page 224**

X.12 Water for Multiple-Use and Water Reuse

Water for Multiple-Use

Multiple use of water is the practice of using water from the same natural or man-made system or infrastructure for variety of uses and functions. During the acute emergency phase, the focus is on providing a sufficient quantity of safe drinking water, as this is critical for maintaining good health. The demands of climate (e.g. dry climates) or health status (e.g. nursing mothers) may require additional water. Likewise, health-related emergencies must be prioritised for access to water to assure sufficient quantities for clinical use (i.e. hand washing, cleaning, equipment washing, medical care or oral medication). Additional water may be necessary depending on the population and situation. In any situation, water users, not water providers, will choose how they allocate water, so it is important for water providers to understand user priorities and identify where the priorities of users and providers do not align (i.e. users may prioritise watering livestock over handwashing). In these cases, providers should aim at providing enough water for both users and other priorities, although not necessarily from the same source or of the same quality.
During the post-emergency phase (stabilisation and recovery), additional water is required at the household level for small-scale productive uses, such as backyard gardens, livestock, or micro-enterprises. Wherever possible, emergency water systems should be designed to consider possible future applications to sustain multiple community water-use needs in the post-emergency phase. For example, spillage water from tank overflows or tap stands can be led to nearby run-off gardens or animal troughs. Rainwater harvesting systems can have a portion of harvested water treated for drinking purposes, and the remaining quantities can be used for productive use or livestock. In water scarce areas, communities often do not differentiate between water for domestic and non-domestic uses, so the water supply systems should be designed with multiple water uses in mind to achieve the desired impact and avoid competition within the community. Emergencies also affect commercial, agricultural, institutional and industrial users who will also see their water needs as essential. Although not a key priority in the acute phase, these additional water use requirements need to be considered (and balanced) during the stabilisation and recovery phases.
To successfully operate multiple-use water systems, an advanced level of organisational management and a stable communal context is needed. Proper assessments should assure that the water use requirements of different user groups are considered so that all are willing to fully collaborate with the operational and maintenance aspects of the water system. For this reason, it is essential that the assessment is conducted inclusively and considers social norms and habits to assure that multiple-use and reuse water are applied in a way that is acceptable for the community.

Water Reuse

Water reuse is the use of (treated) wastewater for alleviating water shortages and increasing a community's available water supply. This is particularly important to counter the decline in available water resources for agriculture, domestic, livelihoods and industrial uses due to climate change, population growth or droughts. Water might be used directly without treatment (e.g. for flushing toilets) or be treated to the level required for the reuse purpose (reclaimed water).
Water reuse can be divided into potable and non-potable purposes. Design considerations for potable water reuse are complex and beyond the scope of acute emergency interventions if such technologies are not already applied in the affected area. Municipal water reclamation is therefore not often available in the acute phase, though could be useful for longer-term situations, particularly in areas with limited water access. Water reuse for non-potable purposes, (e.g. watering gardens, cleaning) is feasible in a post-emergency context after careful consideration and management of the contamination risks. Spillage water from tap stands can be used to water animals or, along with un-treated water and reclaimed water from bathing, handwashing and cleaning can be used for agriculture. Water that has been biologically contaminated should only be considered for non-drinking purposes (e.g. irrigation).

Greywater (water from bathing, cooking and cleaning dishes or clothes) offers a lot of opportunities for reuse in gardening and agriculture, as it is less contaminated than wastewater. Rainwater can be reused for artificial recharge to replenish groundwater basins in areas that depend on groundwater extraction for drinking water supplies. Necessary precautions (e.g. filter systems) may be needed to avoid groundwater contamination.

→ **References and further reading material can be found on page 224**

X.13 Urban Water Supply in Protracted Crises

The trends in human development shape the subsequent development of humanitarian operations, with urbanisation representing the defining trend of recent decades. Population growth and migration is such that over half of the world's current population resides in urban areas, and is set to rise to an estimated 68 % by 2050. Most of this increase is projected to take place in lower income countries across Africa and Asia, driven largely by economic opportunity, conflict and/or climate change. Large influxes of people into cities significantly increase the pressure on services relied upon by the host and displaced populations, especially with poor-quality services to begin with. Residents of urban areas are usually reliant on essential and interconnected services, such as water, sanitation and electricity, and are thus vulnerable to service disruptions, and the increasing pace of urbanisation adds additional strain on these systems. Water, in addition to direct supply to households, enables other services such as healthcare and education, so the failure of a single power line can completely or partially shutdown a water supply system for all end users. Such infrastructure deterioration can have dramatic and sometimes unexpected ripple effects on other critical infrastructure sectors, which are often difficult to predict during times of crisis without a proper emergency preparedness plan in place.

The quality of service in urban contexts is not necessarily homogenous, as poor or informal areas are often not as well served as affluent neighbourhoods. Even formal parts of the city may be neglected by local authorities for political or other reasons, which can exacerbate previously existing tensions or social grievances. A complex tapestry of technical, organisational and socio-political issues therefore exists that underpins water supply in urban contexts. As a result, classical humanitarian response mechanisms developed in rural areas or displacement camps are often poorly suited to the urban environment, and NGOs are frequently ill-equipped to understand and manage the complexities of large towns and cities.

Understanding Urban Water Supply in Protracted Crises

Essential urban services are understood to be the provision of commodities, actions or other items of value that are vital to ensure the subsistence of the urban population (e.g. water, wastewater, energy, solid waste, health care). All urban services require three elements in order to function: people (service provider staff, private-sector contractors and entrepreneurs), hardware (infrastructure, equipment, heavy machinery) and consumables (fuel, chlorine). External forces that negatively impact any of these three pillars of water supply will therefore degrade service delivery.

Unfortunately, while each individual incident can be handled and service levels restored, long drawn-out crises tend to cause cumulative impacts. The subsequent gradual but continuous decline in service delivery ultimately reaches critical points beyond which public health substantially deteriorates and the water supply system collapses. Crises that affect urban areas are diverse, such as armed conflict or prolonged violence (e.g. gangs), repeated natural disasters (floods, famines, hurricanes, epidemics, etc.) or recessions (commodity price fluctuations, sanctions, high national debt, excessive money printing, financing a war, etc.), and affect necessary income sources including government subsidies as well as the ability of consumers to pay. Under such circumstances the pillars underpinning urban water supply are gradually but significantly eroded. These pillars are:

- **People:** The sophistication of large-scale urban water supply infrastructure requires specialist expertise. The delivery of services therefore goes beyond the technical capacity and the direct physical control of local residents. In such crises, trained professionals can often be killed or flee either for their safety or for the well-being of their family if their income is too sporadic or insufficient due to the service provider's inability to cover salaries. Knowledge of the system therefore decreases, poor operational decisions are made, longer-term planning capacity reduces and the overall system becomes increasingly vulnerable to shocks.
- **Hardware:** Considerable infrastructure and equipment may be required for the abstraction, treatment, storage and distribution of water. Direct destruction of, or damage to, any of these elements will limit service delivery. Furthermore, infrastructure will degrade over time if proper operation and routine maintenance are not performed. As such, a lack of funds over an extended period will lead to a lack of spare parts and non-functional tools and machinery, which collectively hinders preventative maintenance. Negative coping mechanisms, such as the cannibalisation of other equipment, can set in and even accelerate decline. As service delivery degrades,

willingness to pay also diminishes, leaving the utility with dwindling income to cover the costs associated with ensuring proper operation and maintenance, which in turn feeds this vicious cycle. Even if a utility is successfully responding to repeated incidents of breakdown maintenance, it is already in a precarious situation and increasingly vulnerable to system collapse.

- **Consumables:** Similar to hardware, stocks of fuel and chemicals for treatment can be destroyed by any direct impact (bombing, earthquake, etc.), and a lack of cash flow from an economic squeeze can also indirectly disrupt supply. In addition, there may be embargos (e.g. on gas chlorine, aluminium-based coagulants or chemicals for laboratory analysis) as well as disrupted supply chains due to security or access limitations. A lack of consumables will reduce distribution times and/or water quality at a time when demand is at its highest, considering situations where utilities have to serve both host and displaced populations. This will affect consumer willingness to pay, often leading to a decline in cash flow and accentuating the paucity of funds available to the utility.

Overall, cumulative impacts lead to the long-term deterioration of urban water supply systems through incremental direct and/or indirect impact(s) on one or more of the critical components of service delivery. This is difficult to recover from due to the sheer scale of the infrastructural rehabilitation work needed to restore any service. The interconnectedness of urban services (such as water supply on electricity supply) creates additional vulnerabilities and complexity. For most humanitarian organisations, the expertise needed to address these interdependencies between services may not be within their capacity and capabilities, and the budget required to do so at scale could be orders of magnitude above that generally available in emergency contexts.

Notes for Practitioners

When involved in an emergency response in an urban context it is important to recognise the importance of the 'organism' that is the utility and avoid remaining focused on the beneficiary. For the utility, as a centralised entity, no action is carried out in a vacuum, and actions taken at one location can have unexpected consequences elsewhere in the system as well as on other interconnected critical infrastructure. For example, water trucking or pipeline extensions may simply deprive certain neighbourhoods of water for the benefit of others, which can lead to tension, especially if those areas are tribally, religiously or politically distinct. Additionally, even if water is abstracted for 'humanitarian purposes', a failure to pay deprives the utility of much needed cashflow for the maintenance of service delivery and even the salaries of their staff. Along the same lines, providing fuel or chemicals may be a worthwhile intervention, though it can breed dependence on handouts and should be avoided unless specific circumstances require it (i.e. sanctions) or a clear exit strategy is in place.

Protracted armed conflicts are characterised by their longevity, intractability and mutability, and as such it is important to invest in a relationship with the utility, and the earlier the better. It is by understanding the people, the hardware and the use of consumables that the most appropriate interventions can be identified.

The replacement of parts and donations of goods in kind are simple and may provide temporary respite, but without detailed knowledge of the entire system, they can often miss the critical underlying issues. Replacing a broken centrifugal pump, for example, will not resolve the preventative maintenance issue that could triple the lifetime of a pump. Similarly, providing more aluminium sulphate will not correct inefficient coagulation through improper pH control or reduce consumable costs, and paying salaries will not improve revenue collection that is suffering because of the utility's poor image with consumers due to the unreliable service. Treating the symptoms will only temporarily mask the true challenges of the utility and could even lead to a misappropriation of funds. While potentially challenging, a systems approach will generally be cheaper and more effective in the long-term.

Whilst responding to clearly urgent needs may involve the quick-fix interventions alluded to above, taking the time to carry out technical and institutional diagnostic studies is essential for identifying and prioritising the critical weak points in the system to improve the targeting of interventions and help ensure service continuity. Support to service providers should also include developing emergency preparedness plans (e.g. locating and preparing alternative water sources), building in redundancies to boost system resilience or, if appropriate, constructing extensions to displacement settlements — though this requires decent spatial knowledge of consumption as well modelling of the infrastructure to avoid causing shortages outside the target location. A humanitarian organisation can also act as a convenor between interconnected sectors and service providers to ensure, for example, sufficient energy supply to critical water installations. The results will be a broader, multifaceted programme of interventions, including infrastructural improvements, technical or managerial capacity building plans and material support (fuel, spare parts, chemicals, excavators, vehicles, computers, etc.), which will boost a utility's resilience in the face of a crisis and ensure a longer-term benefit for public health.

Once interventions to mitigate decline or reinstate capacity are underway, utilities can then be supported in planning for the future. In cases of armed conflict, development actors may withdraw from a country, either for safety reasons or as their statutes prevent them from working with 'illegitimate' governments. Depending on the context, humanitarian organisations can provide support by developing Master Plans that plot the required trajectory of a utility for 20 to 25 years in the future. These serve as both a financial and technical planning document for the utility as well as a basis for fundraising by the state or even the humanitarian actor. This ensures an anchor against service decline by providing first and foremost a preventative approach that aims to safeguard public health and mitigate other humanitarian consequences, while securing 'development holds' against the development reversals caused by protracted conflict, which can be built upon by donors upon their return during reconstruction.

More innovative options could also be attempted, but their relevance will depend highly on the context. Cash transfer projects **(see X.17)** that pay consumer water bills (especially for the vulnerable or displaced) could be piloted, as these will maintain cashflow to the utility and provide temporary respite from financial burden for families in crisis. However, this will require a significant effort in communication, registration and follow up as well as cost. In areas that are insufficiently dense for Water Kiosks **(D.4)** to be financially viable, solar pre-paid dispensers could be tested, though they have yet to be proven to work over the long-term. Finally, remote data collection technologies can monitor the operation of a system and accurately inform decisions that guide maintenance operations by reporting on flow, energy consumption, aquifer level, and water quality amongst many other parameters.

→ **References and further reading material can be found on page 224**

X.14 Cholera Prevention and Epidemic Management

Cholera is an epidemic faecal-oral disease caused by the bacterium Vibrio cholerae entering the body through the consumption of contaminated water and/or food, due to poor water and sanitation systems and inappropriate hygienic practices. It infects the small intestine leading to severe watery diarrhoea, rapid dehydration and death if left untreated. Most infected people do not develop any symptoms. They can, however, spread cholera further if water sources become contaminated with faeces containing the bacterium, usually when hygiene conditions are poor and open defecation is prevalent.

There are many ways to prevent and control the spread of cholera requiring actions within the health sector and beyond, including ensuring access to safe water, sanitation and good hygiene practices (WASH). Some countries suffer from endemic cholera and experience frequent outbreaks, which are mostly seasonal. Others can experience occasional outbreaks but these are not necessarily endemic. Both require an emergency response, but do not necessarily result in a humanitarian crisis.

However, in most cases, cholera outbreaks impact nations/regions already dealing with a pre-existing fragile context, including poor hygienic conditions and limited access to drinking water and sanitation facilities. Although the focus here will mainly be on cholera in emergencies, it is important to recognise that wherever possible, efforts to control cholera should seek to build long-term systems and consider long-term prevention beyond reactive approaches. Targeting multisectoral interventions in cholera hotspots is also a key point in the Global Task Force on Cholera Control (GTFCC) roadmap. According to the roadmap, interventions should include strengthening surveillance (of outbreaks) and health systems and the implementation of sustainable, long-term WASH solutions alongside the promotion of strong community engagement and cross-border collaboration.

Relevant WASH and Infection Prevention and Control (IPC) Interventions

The provision of WASH services is a key element of both the prevention of and response to cholera outbreaks. In cholera endemic and risk prone areas, efforts must be made to ensure safe and adequate water supply and disinfection, water quality monitoring **(X.7)**, hygiene promotion **(X.16)** and sanitation and safe excreta disposal at household and community level, in healthcare facilities or in special units called Cholera Treatment Centres or Units (CTCs/CTUs). In terms of water supply, the focus should be on the following:

Ensuring sufficient and safe drinking water at the point of consumption: Water is needed for drinking, preparing oral rehydration solution (ORS), washing (hands, body, laundry), cleaning/disinfection, cooking, toilets and preparing dead bodies for burial. In CTCs, at least 60 L per patient and 15 L per caregiver of chlorine-treated water should be available per day. Water for drinking and washing (e.g. hands, food), and other purposes, needs to be treated to a free residual chlorine (FRC) level of at least 0.5 mg/L at pH < 8.0 after 30 minutes of contact time, 1.0 mg/L at the water source and a minimum of 0.5 mg/L at the point of delivery. Treated water should be delivered in separate and clearly marked containers.

Overall, it is necessary to consider treatment before providing water to the user (both in rural/low-density areas and urban areas where contaminated piped water may be prevalent) and ensuring safe storage **(H.1)** and preventing (re-)contamination at the point of consumption. This requires hygiene promotion interventions **(X.16)**, where information is provided on safe water collection, transport, handling and storage, safe use of cups and dishes, handwashing, etc. Household water treatment options like Ceramic or Membrane Filtration **(H.3, H.4)**, Point-of-Use Chlorination **(H.6)** or Boiling **(H.9)** may require behavioural changes for people who do not have prior experience with the technology. Therefore, the introduction of household water treatment methods must be combined with respective hygiene promotion activities to ensure safe water at the point of use.

Latrines and bathing units: These should be available in sufficient numbers and at a suitable distance from water sources (see Sphere for further guidance). In CTCs, one latrine can serve up to 20 people in the observation and recovery area and up to 50 in hospitalisation, and one or two latrines should serve the staff. Newly constructed latrines should be connected to a septic tank at least 30 m away from the next water source. One bathing or shower unit for a maximum of 50 people should be considered. Both latrines and bathing units should be gender separated and adapted to local customs and specific needs of elderly, pregnant women or people with disabilities, and functional handwashing facilities need to be installed next to latrines.

Preventing the contamination of water sources and the environment: Faecal matter needs to be kept away from human contact, water and food. This containment is done by providing functioning, accessible, appropriate and safe toilets for affected communities (as well as staff, patients and caregivers) that do not contaminate the healthcare setting or water supplies. The entire sanitation service chain must be designed (see Compendium of Sanitation Technologies in Emergencies) to ensure proper collection, transport, treatment and safe disposal or reuse. Furthermore, hygiene promotion **(X.16)** is necessary to ensure that people prioritise the importance of cleanliness of the environment and act out healthy behaviours.

Handwashing: Handwashing facilities **(H.2)** with soap and clean (chlorinated) water must be available and accessible, and proper handwashing practices must be promoted, particularly at key times (before cooking, eating and feeding and after latrine use or cleaning a child's bottom). For healthcare workers, handwashing is necessary before (1) touching a patient and (2) performing cleaning procedures, and after contact with (3) the patient, (4) body fluids (or risk of contact) and (5) their surroundings. The water for handwashing must be safe, and soap should always be used. Alternatives are Alcohol-Based Hand Rub (ABHR) or water treated with a 0.05 % chlorine solution where soap is not available.

Isolation of patients: Every cholera case should be investigated to assess and break the chain of transmission. Suspected and confirmed cholera patients should be isolated from other patients and treated in CTCs to prevent the spread of the disease in the community and prevent deaths. Cholera may also be treated in health centres and isolation units of hospitals, especially at the beginning of the outbreak when CTCs are not yet established.

Personal Protective Equipment (PPE): For cholera outbreaks, appropriate PPE needs to be provided and used if there is a chance of contact with body fluids of any kind. This includes waterproof gowns (or if not available: waterproof aprons), mask and goggles, boots and gloves. The use of PPE is of particular importance for personnel involved in cleaning, waste management and using/preparing high-strength chlorine solutions.

Food hygiene: Food hygiene is essential and includes proper preparation (cooking raw food thoroughly and heating it to >70° C, washing vegetables with soap and safe water, peeling fruit and vegetables), eating food immediately while it is still hot, reheating it thoroughly (once only), safe food storage and cleaning of cooking utensils (cutting boards, utensils and dishes with soap and safe water). After use, surfaces used for preparation and eating and cooking utensils as well as food containers need to be washed with detergent and a 0.2 % chlorine solution. Different utensils should be used for raw and cooked foods.

Laundry: Protective clothing as well as the patient's clothes, blankets, gowns and staff uniforms should be washed with a 0.2 % chlorine solution for 10 minutes. These should then be washed in water with detergent and air-dried in sunlight, when possible.

Safe and dignified burials and burial preparation: If someone dies of cholera (or a condition suspected to be cholera), trained personnel should be asked to assist with a safe and proper burial. The body needs to be disinfected by people wearing PPE and carried in body bags or cloths soaked with 2 % chlorine solution. Funeral participants need to be made aware of the risks during the funeral, if necessary, and variations to traditional rituals may need to be discussed. Direct physical contact must be avoided. If unacceptable, PPE should be worn, and hands should be washed immediately after contact. The burial site or cemetery should be at least 50 m away from water sources and at least 1.5 m deep. No food should be served during the funeral. In case it is served, it needs to be hot, and hand hygiene must be enforced.

Cleaning and disinfection: The appropriate chlorine solutions must be available for each required purpose, and these solutions differ in their required percentages of FRC: (1) 0.05 % for hand disinfection when neither soap nor ABHR are available. (2) 0.2 % for disinfecting entire cholera wards, including (affected) latrines and bathing units, the laundry area, kitchen and morgue. Additionally, beds and cots, bedding and linen, PPE, waste containers and covers, food utensils, food containers and dishes and vehicles used for patient transport should also be treated. (3) 2 % to add to highly infectious excreta and vomit from cholera patients for disinfection and to wash dead bodies (or alternatively lime treatment).

WASH- and IPC-related cholera relief interventions can be broadly distinguished between households, institutions, and CTC/CTU facilities **(see below)**.

Households:

Risk of contamination is particularly high in household settings, and members of households of cholera patients are 100 times more at risk of contracting the disease than other community members.

- A safe water supply system must be established, with sufficient quantities available from the acute phase that include the respective percentages of FRC depending on the intended water use. The water should be collected from known safe (frequently monitored) sources. A community water safety assessment should be conducted to eliminate potential contamination.
- Water supply extraction points (e.g. wells, tap stands) should not be used for washing (e.g. clothes and dishes) and bathing, especially not of infected persons. Covering open wells, keeping them and their surroundings clean, eliminating stagnant water around the source, and hanging buckets when not in use helps to avoid contamination.
- Household water treatment and safe storage should be promoted **(see chapter H)**.
- Handwashing with soap (or ash/lime if no soap is available) and safe water should be promoted, especially before eating; cooking; after cleaning a baby, child or adult's bottom; after using the latrine and when caring for/touching a sick person.
- Food hygiene should be promoted: Cook it, peel it or leave it. See more above under food hygiene.
- An excreta-management system needs to be established immediately in the acute response phase to properly dispose of excreta and avoid groundwater and water source contamination. Latrines need to be regularly used, cleaned and maintained, and privacy and safety must be ensured to encourage usage.
- If somebody is infected with cholera, immediate measures should be taken. Infected persons should drink ORS made with safe water and see a health worker immediately. The continuation of breastfeeding is encouraged. Direct contact with an infected person's body fluid should be avoided.
- If someone dies of cholera (or a condition suspected to be cholera), the above-mentioned corresponding IPC actions should be taken.

Institutions:

- Safe drinking water should be available in institutions that adequately manage cups and water storage **(see H.1)**, and a safe water source should be available on institutional premises to ensure sufficient water for drinking and cleaning.
- Depending on the intended water use (e.g. drinking water, handwashing, cleaning, etc.), respective levels of FRC in the water must be ensured.
- Safe sanitation facilities should be available in sufficient numbers (based on the number of people using the institution).
- Handwashing stations with soap should be available in all public places, especially near toilets and food establishments.
- Signs/posters can encourage people to wash hands with soap after toilet use and before cooking/eating.
- Food safety should be addressed in institutions/public places (e.g. schools, government buildings and markets).

Cholera Treatment Centres/Units:

- CTCs/CTUs should be easily accessible for patients (e.g. close to a health care centre that patients habitually access) and vehicles (e.g. water trucks, ambulances, patient transport). It is important to ensure that the community and local authorities are involved in the selection.
- A facility needs room for admission, observation, cholera wards with isolation areas (may have to be gender separated to respect cultural values), a recovery and a neutral zone as well as space for a kitchen, laundry (close to wards), waste, morgue, latrines, showers and bathing units with the possibility to expand the site. All zones should be clearly marked.
- Access to electricity and light should be ensured at all times. Proximity to reliable and sufficient water sources is important, and these should be chosen or designed to keep potential sources of contamination away. An area exposed to natural hazards should be avoided, and the space should have good drainage and ventilation.
- The site should be fenced (with low fences to allow people to see into the facility) with a clear entry and exit. It must not pose an infectious risk to the surrounding community.
- The morgue is best located close to the fence. Access to it (and other critical zones such as waste management) should be prohibited to everyone but authorised personal. This ward should not have windows, though needs to have ventilation and sufficient storage for the deceased's personal items.

- CTCs/CTUs should be constructed to facilitate cleaning and disinfection of floors (e.g. use of concrete, tiles, plastic sheet covers), of materials and of vehicles that go in and out.
- Handwashing stations should be placed in the entry and exit area of each facility as well as in kitchen, laundry area, latrines, waste management area and morgue. These stations should be easy to access with clear labels and instructions.
- Patient inflow should go in only one direction with only one caregiver present per patient.
- Sufficient cleaning materials, equipment and handwashing facilities for healthcare workers, patients and visitors must be provided to maintain proper hygiene. There should be a supply of PPE for one month.
- Before starting to work at a CTC/CTU, staff must be trained in relevant IPC protocols. Training and maintenance with PPE items must be ensured. All kitchen staff should be trained in food hygiene practices.
- Waste management: All waste generated in these facilities is potentially infectious and must not leave the area. Sharp, soft and organic waste have to be treated differently, though all are labelled and disposed in a restricted and fenced waste zone. Cholera waste should be emptied in a dedicated pit or latrines and treated with a 2 % chlorine solution.
- As patients are often too weak to use a toilet, buckets (10–15 L) are placed under a purpose-built hole in the cholera bed and at the bedside. Buckets can be raised on a block to prevent splashing to the surrounding area. Approximately 1 cm of a 2 % chlorine solution should be put into the bucket before it is placed under the bed. Buckets should be emptied in cholera patient toilets and rinsed afterwards with a chlorine solution.
- The above-mentioned WASH and IPC interventions should all be applied in CTCs/CTUs.

→ **References and further reading material can be found on page 224**

Design and Social Considerations

X.15 Inclusive and Equitable Design

Access to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use is a recognised human right. Water services and facilities are often designed in a standard way, without considering the diversity of requirements of different user groups. Particularly in the rapid response phase, where time and money are limiting factors, traditional and standard designs are often preferred. However, there is a wide range of different abilities and requirements in any affected community, and traditional designs will inevitably result in people being excluded from otherwise well-intentioned water facilities and services. Inclusive designs should be considered in all phases of the response and throughout the complete humanitarian programme and project cycle and in Standing Operating Procedures (SOPs). Protection principles and mainstreaming disability, age and gender in the assessment, planning, design, implementation, monitoring and evaluation stages are humanitarian standards that must be followed to ensure everyone can exercise their right to water.

An inclusive and equitable (or universal) design approach considers diversity as an integral part of society, and the requirements and rights of different groups and individuals are equally valued and properly balanced. Persons with disabilities are estimated to represent 15 % of the world's population and include persons of different genders and ages with long-term visual, hearing, speech, physical, psychosocial or intellectual impairments. Too often, institutional, social or environmental barriers prevent them from equally and meaningfully participating in society, and because they are among the most marginalised persons in crisis-effected communities, they are also disproportionately affected by emergencies and conflicts.

Inclusive programming aims to actively engage all user groups and to identify and remove such barriers. Inclusive design aims to create facilities and environments that can be used by everyone, irrespective of age, gender, disease, impairment or other discriminative characteristics. Safety, protection, dignity and autonomy, improves health and well-being, provides social support systems and counteracts stigma, targeted violence and ignorance. Often only minor adaptations or design improvements are needed to make WASH facilities more inclusive, and these generally come with little additional costs, particularly when considered in the design stage. For physical accessibility, an additional budget of 0.5–1 % should be considered, and for non-food items and assistive devices, an additional 3–4 % may be needed.

To be inclusive, all potential user groups need to be adequately considered and actively engaged in the design of water supply facilities and services. This inexhaustive list includes persons with different disabilities, people of different ages (especially older persons and children), sick or injured people, pregnant women, and women and girls who have specific requirements for their safety. People may belong to different user groups at the same time (intersectionality), and some of the potential user groups may be hidden or less visible. It is essential that facilities are built from the perspective of the persons concerned, and those concerned should be consulted and actively involved in the program design and implementation process. Otherwise, invisibility in data leads to invisibility in programs. Data needs to be disaggregated based on at least gender, age and disability, and the different user groups should participate meaningfully in all phases of the project cycle to identify requirements, barriers, enablers and risks.

Inclusive programming requires a twin-track approach that combines inclusive mainstreaming in WASH programmes with targeted interventions for persons with disabilities. First, mainstream interventions designed for the entire population need to include persons with disabilities, e.g. accessible water points with clear signage. Second, WASH programmes need to address the specific requirements of persons with disabilities by providing targeted interventions, e.g. transportation allowances and adapted jerrycans. Within both tracks, the meaningful participation of persons with disabilities is crucial and can be achieved through the development of collaborative partnerships with the disability community.

Interventions, adaptations and/or design improvements to ensure an inclusive approach to water supply may include:

Assessment and monitoring

- Collecting quantitative and qualitative user group data and ensuring that it is disaggregated by gender, age and disability.
- Raising awareness and building capacity of staff, outreach workers and partners for understanding gender, age and disability, universal design, the identification of specific requirements, risks and the capacities of different user groups.
- Inclusive monitoring of the response to ensure inclusion of all user groups.
- Consulting different user groups, including persons with different disabilities, genders and ages to both inform the location, accessibility, design and use and to understand barriers of water supply facilities and services.
- Involving organisations of persons with disabilities and the elderly in WASH responses and seeking advice from specialist organisations on how to ensure that sanitation facilities are accessible.
- Partnering with local and national organisations of persons with disabilities (OPDs) in WASH responses and strengthening OPD capacities where needed.
- Ensuring that all relevant user groups are represented in community WASH committees and WASH program evaluations. Ensuring that OPDs and other relevant organisations have meaningful access to the WASH cluster or similar WASH coordination mechanisms. Ensuring that sufficient funds to support meaningful access are available.
- Providing and budgeting for reasonable accommodations where no mainstream solution is available to ensure participation of and access for persons with disabilities on equal basis with others.
- Ensuring accessible feedback and complaint mechanisms for persons with diverse disabilities.

Availability of accessible water facilities

- Designing a minimum of 15 % of all public water points as barrier-free and as accessible as possible.
- Considering individual inclusive water points.

Reaching the facility

- Minimising distance between public or shared facilities to homes and shelters by locating accessible water points and other WASH facilities within 50 meters of individual shelters in emergency phases and 30 meters in long-term interventions. This can be done by, for example, providing piped water into or next to a house, installing a rainwater tank or storage facility near a house, installing a household well in the compound of the home of the person with a disability or installing a communal well in close proximity. Individual solutions as targeted actions should be accompanied by community awareness raising to avoid increased stigma and potential harm.
- Offering shaded resting places on the way to the source.
- Providing clear signage of accessible water points and information in different formats, such as pictograms, text and/or audio.
- Providing artificial lighting at and on the way to the water points to ensure safety and accessibility. Other water-related activities (e.g. washing clothes, food cleaning, etc.) can be taken to the water source to avoid issues with carrying large quantities of water.
- Improving ability to reach water sources through a level, firm, even and non-slip path (ideally 180 cm wide, minimum 90 cm) lined with rocks or providing guide strings or other landmarks for persons with visual impairments to find the water.

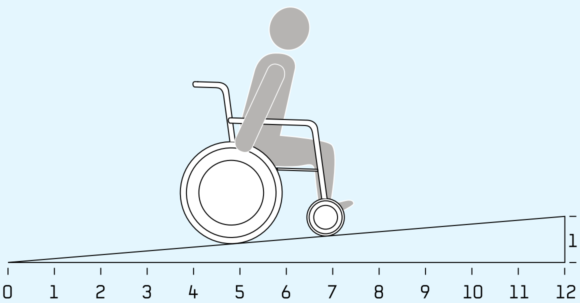
Accessing the facility

- Signalling the entrance for people with poor vision, such as by a changing floor texture or contrasting colours.
- If stairs or a ramp are necessary, providing both if possible, or otherwise prioritising a ramp over stairs. The slope should be as gentle as possible (ideally 1:20, and no steeper than 1:12) with intermediate platforms if it is long. Steps should be of the same height and depth, with highlighted edges and handrails. Double handrails on both sides are especially necessary in hazardous areas (e.g. close to a pond/river). Care should be given to the path leading to the stairs or ramp, which should also be easily accessible.
- If the water point is fenced (e.g. to keep animals out), providing a gate that is at least 90 cm wide and opens outwards with the least possible effort and with a large lever handle (no round handle) to allow wheelchair users to enter.
- Installing the pump near the edge of the apron and building a concrete sitting platform allows wheelchair users to sit whilst pumping water, without having to enter the normally slippery apron area.
- If entering is necessary, the apron should be at the same level as the surroundings with a kerb or a ramp to allow wheelchair users to enter. The surface should be slip-resistant and provide space to manoeuvre.

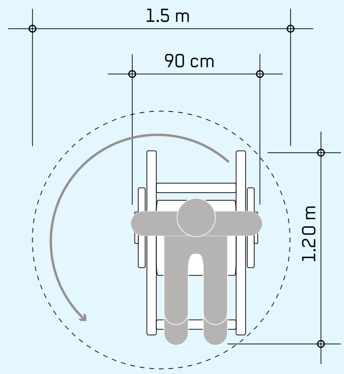
Using the facility

- Providing a pump with a long T-bar or P-handle (length around 105 cm) at a suitable height to be reached by persons using a wheelchair, children or persons of short stature. To enable simultaneous pumping and container holding, the spout and the pump handle should stand at a 90° angle to each other, and the spout should be located around 70 cm above the apron.
- Fitting open wells with simple pulling devices (such as a pawl winding mechanism) and treadle pumps (foot power). When no lifting mechanism is possible, a safe place to stand or to sit should be provided together with a raised well wall (between hip and waist and lower for wheelchair users; minimum height 50 cm).
- Providing lifting blocks near the water collection facility to make it easier and safer to lift the container in two steps when carrying on the head.
- Preferably installing two taps: One between 80–100 cm in height for people using a wheelchair and one higher for people who struggle to bend. In both cases, this should be high enough to fit a container underneath. If the tap is located over a basin, it needs to be reachable sitting and standing. Large taps are better than small ones, and so-called hospital taps are especially recommended. Screw-down taps are to be avoided and should be replaced by lever-type taps.

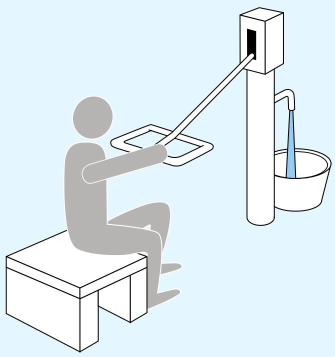
Figure 4:
Accessible Design Examples
(adapted from Jones & Reed 2005
and Jones & Wilbur 2014)



max. ramp steepness of 1:12



space to manoeuvre


P-handle: provides choice of position to operate handle (from side or front) according to user preference


Lifting block: allows lifting the container from floor to head in two actions and allows people to sit and rest

Carrying, storing and using water

- Potentially providing accessible containers or mobility aids to facilitate water carrying. Water containers can either be carried directly on the head, on the back, or by hand while using crutches or a wooden yoke, or indirectly using a wheelbarrow, for example. Water containers can also be carried on the footrest or under the seat of a wheelchair or on a wheelchair trailer. Useful containers include jerrycans, buckets and bowls, jars or soda bottles (with different advantages and draw backs to each). For people using wheelchairs, carrying water may be easier than drawing it, and this can be their contribution to the family's tasks.
- Distributing drinking water through a tap attached to the storage container. Whilst the container may be filled by a family member, its position within the household and its height from the floor should ensure that a family member with a disability can access and use it at ease to guarantee his/her autonomy.
- Securing privacy for bathing needs for people with disabilities. An internal water source with good drainage would be optimal. To rest and sit while bathing, benches might be necessary, though water-resistant wheelchairs can be an alternative. In natural water sources, a rail of rope or bamboo that leads into the source can be useful, as well.
- Considering washstands and laundry slabs for clothes and dish washing.

Information dissemination

- Disseminating all relevant WASH information and hygiene promotion messages using appropriate and various communication means (e.g. large print, loudspeaker, easy-to-understand language, sketches and diagrams).
- Communicating accessible WASH facilities, including water points and washing areas, with clear signage.

X.16 Hygiene Promotion and Working with Affected Communities

Hygiene Promotion (HP) is a planned, systematic approach to enable people to act and adapt their behaviour to prevent or reduce the impact of WASH-related diseases. It is about making water and sanitation services work or work more effectively, and must be supported by all involved in the response, including government, local or international agencies, NGOs and the affected communities. To address WASH-related disease risks, HP uses a variety of strategies and tools, which can involve: advocacy, community mobilisation, interactive education and learning, behavioural change communication, participatory research, market-based approaches and people-centred design. The 2018 edition of the Sphere handbook makes clear that community engagement is central to all WASH interventions, including HP. The crucial elements of community engagement are shown in **Figure 5**. To ensure these are met, water supply interventions should always be undertaken with the corresponding community engagement measures. HP should recognise the differences within any population and aim to respond in various ways to the different WASH needs of women, men, girls and boys of different ages from different backgrounds, with different cultural and social norms, beliefs, religions, needs, abilities, health conditions, gender identities, levels of self-confidence and self-efficacy, etc. **(see X.15)**.

In an emergency, community structures and cohesion may become disrupted, and people will often be traumatised and grieving for the loss of loved ones. Hygiene promoters working with community members must be sensitive to this, and at first may need to simply listen to people to understand their experience and develop trust. There will almost always be members of the affected community who are keen to engage immediately and who can support the process of ensuring there is equitable access to a safe water supply and improved hygiene. By involving people in decisions regarding the water supply, the intervention can help to restore people's dignity and strengthen their capacity to take ownership and action and improve their own situation. Community engagement can ensure that water facilities are well managed, maintained and accessible for everyone. Different degrees of participation (information, consultation, collaboration or delegation of power) may be possible at different times in the emergency, but there will always be space for some level of consultation.

Hygiene Promotion Principles in Relation to Improving Water Supply

It is vital to try to understand the affected community's different perspectives on water supply (involving all relevant user groups), including how it will be effectively used and managed, and to involve them in decisions about the programme.

1. Listen and ask: It is vital to learn about water use and related hygiene practices and norms. For example: How do different people usually collect, store and use water? What is happening now and what has changed as a result of the emergency? What do different people need and want, to ensure that water facilities are effective and have a positive impact on health? What are the priority water-related risks? Who are the most vulnerable and what support do they need to access water facilities? Who can help from the affected population (and who has the requisite skills and capacities), local agencies or government departments? It is important not to treat everyone the same and to identify different groups to work with,

Figure 5:
Community Engagement
(adapted from Sphere 2018)

such as youth, mothers and fathers of young children, religious leaders, primary school children, canteen workers, hairdressers, people with disabilities, etc. See also cross-cutting chapters on inclusive and equitable design **(X.15)** and assessment of the initial situation **(X.1–X.4)**.

2. Involve and enable action: Interactive discussions can support different user groups to identify what they can do immediately to improve health and hygiene. It is important to find out what is potentially stopping them from acting (the barriers and obstacles to improved hygiene) and to find out what help they need, if any. By conducting surveys and differentiating between doers and non-doers, users and non-users of facilities, the drivers that motivate action can be identified. Supporting community organisation and civil society structures is also useful and can ensure that people motivate each other. A variety of interventions can help respond to the immediate risks, but the actual interventions used will depend on the context, such as interim water supply solutions like household water treatment and safe storage, the provision/cleaning of water collection and storage vessels and the provision of laundry facilities. Consider how water facilities will be maintained from the beginning and the community's involvement in this, such as through the formation of committees or user groups.

3. Focus on vulnerability: People with specific needs (e.g. women and girls, elderly and people with disabilities) must be identified and their needs for adequate and equitable access to water ensured (e.g. for menstrual hygiene management). Ensuring women are on the response team is essential and ongoing outreach to women and girls is essential. Women and children are often responsible for collecting water in many communities, so discussions with them are crucial to ensure safety and access, such as by locating taps within reach and installing pumps that can be used with ease. Working with local organisations representing vulnerable groups, such as disabled people, is also important and essential. See also cross-cutting chapters on inclusive and equitable design **(X.15)** and assessment of the initial situation **(X.1–X.4)**.

4. Plan together: Setting practical objectives and indicators and compiling a WASH strategy with others involved in the WASH response are key processes in an HP intervention. In this process, the 'doable' actions that can impact hygiene should be identified, and the monitoring of the impact of these actions must be defined. The affected community should contribute to this strategy. The recruitment, training and support of existing and new team members will help to ensure that plans come to fruition.

5. Collaborate and coordinate to implement: A variety of methods and tools can be used with different groups to motivate action to improve and effectively use and maintain water facilities and services for women and men, people in different age groups and with different abilities. Working closely with others involved in the response, especially the government, local authorities and other sectors, is also important. To minimise duplication and increase the efficient use of resources, the sharing of plans and ideas should be coordinated. It should be possible to undertake joint activities, such as assessments or evaluations, or HP outreach workers can focus on other priority health issues as well as hygiene.

6. Monitor and review: Through observation (are all people able to use the facilities safely, effectively and without waste?) and surveys (did people change their behaviour?), the effectiveness of HP and behavioural change efforts can be monitored. Continually seeking feedback from the population will enable adaptations in programming and improve effectiveness. It is also important to keep track of any rumours that might be detrimental and to respond to these as soon as possible, such as by incorporating them into discussions with community groups or providing information on social media.

Hygiene Promotion Methods

Interactive methods: Methods that encourage dialogue and group discussion, such as 'community mapping' and 'three-pile sorting' using pictures and visual representations, require the active participation of community members and are usually more effective than just 'disseminating messages', as the latter erroneously assumes that people will passively internalise and act upon the information provided.

Access to hygiene, water supply items and infrastructure: It is important to consider the different needs of groups such as men, women, boys, girls or people with disabilities. For example, women and adolescent girls will often need support with managing menstruation, and consultation on this should be included in any water and hygiene programme. It is also important to note that hygiene promotion methods and access to WASH infrastructure go hand-in-hand, as hygiene promotion will not be effective without the appropriate infrastructure required for the desired behaviours.

WASH Behavioural Insights

In recent years, there has been a significant amount of work on trying to understand different influences on hygiene behaviour. It is clear that knowledge of germs and the transmission of disease is often insufficient and inadequate to change behaviour. The following suggestions can help make programmes more effective:

1. Make the practice (e.g. water treatment, water conservation, handwashing) easy and attractive: Products and supplies (e.g. a handwashing station with soap and water) should be easily accessible in each location where the desired behaviour should take place. Emphasising convenience and ease (small, immediate, doable actions) is often more effective at promoting behavioural change than focussing on the 'ideal' behaviour. Rewards and incentives, such as competitions, should be considered, and it is useful to find ways to attract attention, such as painting colourful latrine doors or installing handwashing facilities with mirrors.

2. Consider when people are likely to be most receptive: Disruption in context, such as that associated with most emergencies, or significant life changes, such as giving birth, may provide a window of opportunity for shifts in habit, because people become more mindful of what they are doing. Linking the desired behaviour to an existing habit is also more likely to succeed. For example, encourage handwashing at the same time as behaviours associated with infant care, such as feeding or nappy changing.

3. Draw on social norms and motivations: Psychosocial approaches to behavioural change have shown that it has many drivers and that behavioural change techniques should be applied according to these. To change health risk perceptions, personal information about these risks should be delivered. To change attitudes, beliefs about costs and benefits of a behaviour should be discussed. Appealing to people's sense of disgust, nurturing behaviours and affiliation with a group can change emotional components of behaviours and motivate action. To change perceived norms, it is useful to convey the idea that most people perform the desired behaviour. Identify what people perceive others will think of them if they engage in the practice and try to change this perception if required. People can be encouraged to make public commitments to washing hands, using the water treatment facilities or supporting others in managing water supplies, with a focus on groups and communities instead of just on individuals. To change perceived abilities to perform a behaviour, one might demonstrate the behaviour and prompt behavioural practice. To foster behavioural realisation (self-regulation), action and barrier planning is vital, but memory aids are also useful for remembering the behaviour in key situations (e.g. handwashing before touching food). Community approaches, such as

Community Health Clubs, have been found to be effective at promoting hygiene, and other strategies, such as behaviour-centred design and in-depth assessments of motivation, are worth exploring.

4. Encourage the habit: The promotion of the habitual behaviour through use of cues (nudges), such as footsteps leading to the handwashing facility, can be considered. In addition, behavioural trials may be useful wherein, for example, people may be asked to use soap or a handwashing facility for two weeks to be later interviewed about their experiences. Games with children can also help internalise the link between handwashing and germs.

Common Pitfalls

Several reports, reviews and guidelines have observed the following weaknesses in hygiene promotion programmes:

- Focussing too much on disseminating one-way messages without listening, discussing and engaging in dialogue to allow people to clarify issues and work out how to adapt the changes to their specific situation.
- Focussing too much on designing promotional materials such as posters and leaflets before properly understanding the problem.
- Focussing too much on personal hygiene and not enough on the use, operation and maintenance of facilities.
- Focussing too little on practical actions that people can adopt and how to communicate these.
- Targeting too many behaviours and audiences at once. Hygiene promotion interventions in emergencies should focus on changing only a few key behaviours that are known to have the greatest health impacts (handwashing with soap, safe excreta disposal and safe water use practices at household level).
- Believing that people will always be motivated by the promise of better health in the future while failing to explore other motivations, such as nurture and disgust.
- Assuming that all water supply solutions are appropriate for all users. Specific needs of different user groups must be identified, and facilities and services have to be adapted accordingly **(see X.15)**.

→ **References and further reading material can be found on page 225**

X.17 Market-Based Programming

Market-Based Programming (MBP) refers to a range of programme modalities to understand and support local WASH-related market systems. Implementing MBP is not new to the WASH sector, with programmes that have traditionally functioned in a variety of capacities, such as including cash for work as part of water infrastructure reconstruction programmes (e.g. pipeline excavation), vouchers for water containers, fairs to present household water treatment products (e.g. filters or chlorine), capacity building of plumbers and masons, technical support to water utilities, and support for access to financial services (e.g. microfinance loans for reconstruction). Many of these approaches have worked well and at scale as well as in settings where technical and quality standards must be met.

MBP is often distinguished from in-kind delivery of goods or services, such as water treatment items, jerry cans and directly building water and sanitation infrastructure, although the boundaries between a perceived traditional in-kind assistance and MBP are fluid. The choice of the appropriate modalities depends on:

- Humanitarian context
- Type and phase of emergency
- Affected population's WASH and other needs and vulnerabilities
- Potential public health risks
- Target groups and delivery platforms (individual, household, communal and institutional levels)
- Knowledge, attitude and practice of the affected population
- The need to go beyond the usual emergency outcomes to build resilience.

Thus, appropriate levels of needs assessments, technical WASH assessments and WASH market assessments should inform a proper response analysis, programme design and implementation.

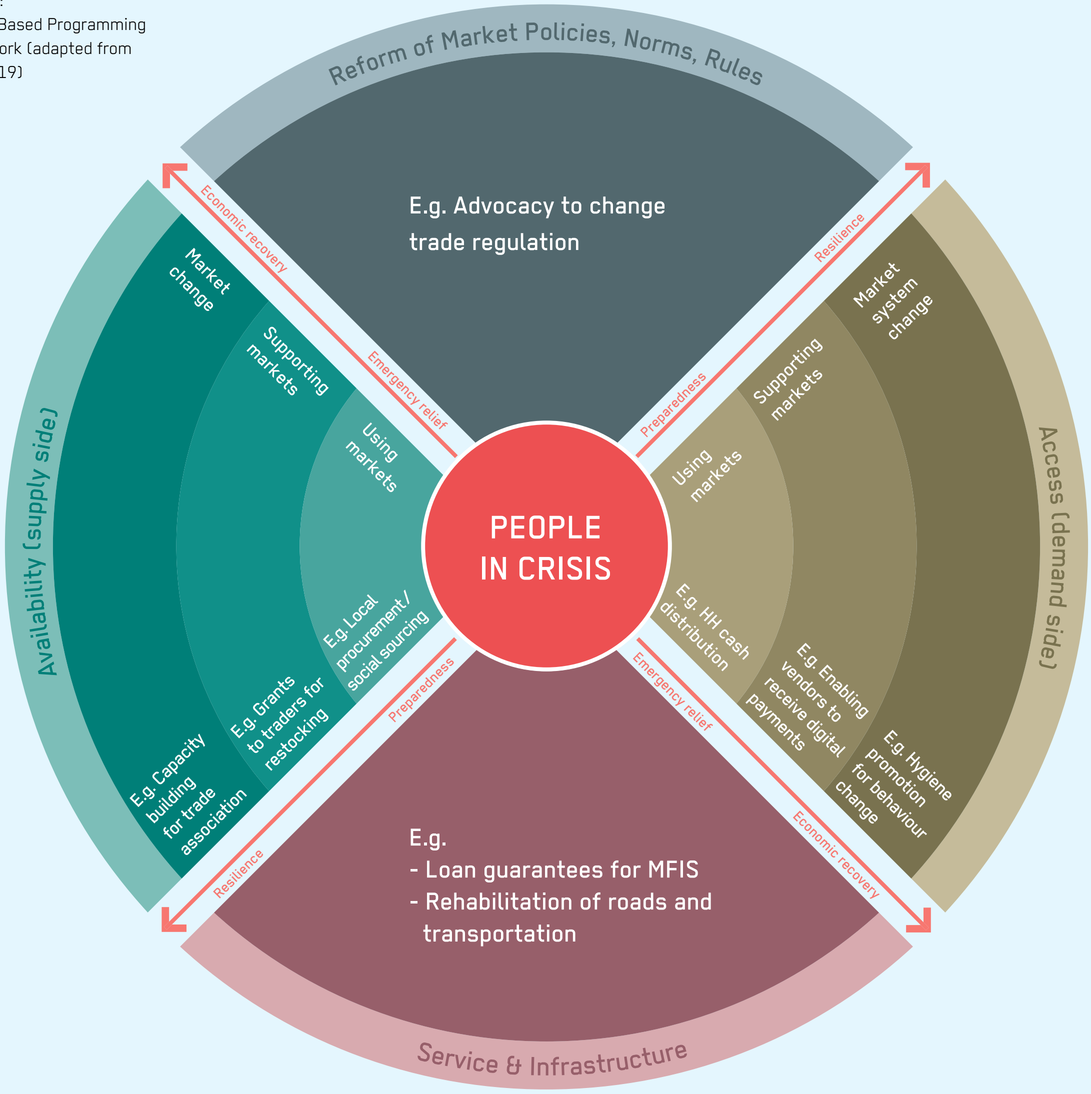
Assessments

Multisector Needs Assessments seek to identify different needs and capacities of a population affected by a crisis, including distinguishing who cannot meet these needs and why. Standard methodologies are available for this, including the Multisector Initial Rapid Assessment (MIRA) and Basic Needs Analysis (BNA). Most relevant to MBP is the BNA, as it defines the priority unmet basic needs of the population and the best modality to meet them. It includes the definition of a Minimum Expenditure Basket (MEB), including all items and services that households are likely to prioritise on a regular or seasonal basis and its average cost over time. By comparing the MEB with an estimated average current income of targeted households, agencies can calculate the current gap for households to meet their needs. Once this is defined, each sector and agency can try to fill that gap in the most coordinated and relevant way for the beneficiaries, either by using or supporting local markets, MBP modalities like cash/vouchers or in-kind assistance.

Emergency Market Assessments seek to understand the capacity of local markets to meet the needs of a crisis-affected population. They include an analysis of critical local markets (e.g. market prices, quantity/quality of goods and services available), household factors (e.g. purchasing behaviour, financial literacy) and the enabling environment (e.g. access to markets and financial services, infrastructure, regulatory frameworks, currency stability). Depending on context, time and available resources, market assessments can be in-depth analyses, such as those detailed in the Emergency Market Mapping Analysis (EMMA) toolkit or as simple as a few questions added to existing assessments. Market tools such as a Pre-Crisis Market Analysis (PCMA) can be used to understand critical markets and when they function normally and to identify their capacity to adapt to future shock events, especially in cyclical or protracted crises. This understanding can improve future responses or design preparedness programmes that strengthen local market actors so that they can continue to operate in a crisis to meet needs in a faster, more appropriate and efficient way than direct in-kind support.

Response Analysis is the link between assessments and programme design. It involves the selection of appropriate programme response options, target groups, modalities and delivery mechanisms. This selection should be informed by considering appropriateness and feasibility and should simultaneously address needs while analysing and minimising potential harmful side-effects. Modalities refer to the form of assistance (e.g. cash transfers, vouchers, in-kind distribution, technical support, community engagement, advocacy). Delivery mechanisms refer to the platform or service used to deliver the assistance to the beneficiaries, either in-kind or cash (e.g. in-kind water distribution via trucking operators or water vendors; direct cash distribution over the counter, via mobile money or bank transfer; voucher distribution via smart cards or prepaid cards).

Figure 6:
Market-Based Programming Framework (adapted from GWC 2019)



Implementation: Four Types of Market-Based Programming

WASH markets can be both affected by a crisis and used to respond to WASH needs. To enable a more effective, efficient and quality response, it is important to understand the whole spectrum of MBP programme types and the possible levels of engagement with the market **(see Figure 6)**.

1. Improving Market Demand and Access

Improving market demand for WASH goods and services can be strengthened by improving access to local markets. Barriers to access can be financial (lifted through Cash and Voucher Assistance (CVA)), physical (lifted by improving roads, organising fairs), or socio-cultural (changed through behavioural change strategies or social marketing).

Using markets through CVA: To generate demand for WASH services or products, cash grants can be provided. The use of the grant can be influenced by the design of the cash transfer. For instance, grants can be provided to individuals, households or communities. They can come at regular intervals, in tranches or as a lump sum. They can be conditional, requiring beneficiaries to fulfil conditions for either accessing the grant (e.g. cash for work) or using the grant (e.g. to connect to a piped water supply system), or unconditional if the grant is given to ensure beneficiaries can meet a range of basic needs. The latter is referred to as a Multipurpose Cash Transfer (MPC). Grants given in the form of vouchers can be restricted to specific commodities or services (e.g. water treatment products) or unrestricted value vouchers (up to a defined value for cash or commodities) redeemable with selected suppliers. CVA focuses exclusively on overcoming financial barriers faced by beneficiaries, without addressing other barriers to access.

Improve access to WASH market: Market actors may need temporary support so that users can adequately access goods, services or finances to meet needs in a crisis. A fair can promote innovation and create demand for goods and services. Vendors or service providers may need to be (pre-)qualified to meet the selection criteria (e.g. enabling vendors to receive digital payments) or standards (e.g. quality and format of accounting) of the CVA programme. Access to the market can also be improved by linking improvements in infrastructure (e.g. roads, bridges).

Improve demand through behavioural change strategies, including social marketing. While behavioural change strategies are routinely applied, social marketing is an emerging field in humanitarian WASH assistance. It aims to develop products and services that address user needs and to adopt marketing tools and promotional campaigns to influence users to, for instance, take up and use water purifiers. How behaviour is modified or adopted depends on the application of what is known as the marketing mix, which includes the product, place, price and promotion (4 Ps). Overall, a marketing intervention tries to steer the target population towards the intended outcomes, even if the total influence over each of the four Ps is limited. WASH marketing strategies also include behavioural change communication, which motivates the adoption of a particular behaviour (e.g. to boil water) or a complementary behaviour (e.g. handwashing with soap). 'Behavioural economics' is another field linked to social marketing; it studies the best way to improve the uptake of products, such as chlorine tabs, among the population (e.g. effects of free or subsidised distribution, direct or through voucher). These activities are challenging to implement in acute emergencies and may be more appropriate in the stabilisation and recovery phase, protracted emergencies or in disaster resilience building.

2. Improving Market Supply and Availability

Using, supporting and developing markets can strengthen the availability and capacity of the market system to deliver critical goods and services in an emergency.

Using markets starts with integrating existing local market structures to deliver immediate humanitarian assistance, which is usually based on the local procurement of WASH goods and services or the use of CVA. Understanding the market is crucial to decide if the market can be used, and the temporary support of suppliers or vendors might also be needed to ensure sufficient supply **(see below)**.

Supporting markets aims to restore market systems after a shock event, allowing humanitarian actors and beneficiaries to use the market as soon as possible. This can be done by providing grants to market vendors to recover stock; creating access to information on technology options, associated costs and contact details of suppliers of related goods and services; providing fuel vouchers or subsidies or spare parts to transport businesses (e.g. for water trucking operators); and supporting market traders to increase warehousing capacity (e.g. for water containers) and water utilities to restore or scale-up existing water treatment capacity (e.g. in host communities after refugee influx).

Market system change aims for long-term positive changes and strengthening the resilience of the WASH market system. This can be done through business model development (e.g. supporting private actors or community-based organisation to set up safe water kiosks), value chain development (e.g. determining if there is a market for point-of-use water filters), supply chain development (e.g. for construction materials to be available locally at a more affordable price), product design (e.g. designing affordable water filters) and improved access to financial services (e.g. offering micro-loans for water kiosk operators to set up their business). These activities are unlikely to be carried out during acute emergencies.

3. Reform of the Market Regulatory Framework

To help markets recover, humanitarian interventions can also include activities aimed at supporting the reform of the regulatory frameworks of relevant markets (national rules, norms, standards). This could be through advocacy for improved regulations (e.g. water quality assurance for safe water kiosks), a direct engagement in policy-making processes or by building the capacities of the actors involved (e.g. governments, regulators, utilities, etc.).

4. Strengthening of Market Services and Infrastructure

For critical WASH market systems to function, the broader market services and infrastructure may need to be supported, restored or developed. This could include loan guarantees for microfinance institutions, digital cash delivery technologies, support to improved market information as well as the rehabilitation of roads, transportation and telecommunication networks. These activities are often not directly related to WASH and can pose a challenge to WASH actors unless they are carried out through cross-sectoral interventions and/or with multidisciplinary teams.

Benefits of Market-Based Programming

MBP is increasingly heralded as having a critical place in the future of humanitarian programming. The proposed benefits of working through existing market systems include improvements in efficiency, effectiveness and scalability of programming and increased beneficiary dignity and choice. Where feasible, MBPs might promote a faster economic recovery due to economic multiplier effects, a better transition to development programming as well as higher levels of acceptance and sustainability. The introduction of water tariffs and payments increases the probability that water will be valued by the beneficiaries and that the revenue and working ratio of service providers can be sustained, even if the CVA is slowly phased out during the recovery phase. In general, MBP represents a way to address humanitarian WASH needs with a context-specific and systemic approach, helping to build the long-term resilience of population and WASH systems.

Risks and Challenges of Market-Based Programming

Water supply infrastructure is technically complex, subject to regulation, expensive (high capital expenditure) and dangerous if poorly implemented. Working through markets partly shifts the handling of quality and safety risks to local market actors and beneficiaries, but this can result in less control over construction quality in a cash-based re-construction programme. This can become problematic if beneficiaries, for example, use less skilled labour and fewer salvaged materials. Providing beneficiary choice does not negate the responsibility of humanitarian actors to ensure access to well-maintained facilities and services that are safely managed, inclusive and meet minimum humanitarian standards. Therefore, close and regular monitoring is crucial, and the design of MBP interventions should include risk-mitigation strategies (e.g. use of conditional or restricted cash transfers) as well as enabling activities such as technical support and capacity building. Where WASH programmes have identified risk factors related to knowledge, attitude and practice, these need to be addressed with appropriate complementary activities, such as community engagement, and hygiene and sanitation behavioural change **(see X.16)** or marketing that seeks to understand socio-cultural issues, build accountability and support healthy behaviour. WASH practitioners should always insist on a robust monitoring framework for MPC interventions that is informed by relevant WASH indicators and, if possible, epidemiological data, which can help anticipate disease outbreaks and sound an alarm on an outbreak as early as possible. This also implies a readiness to activate necessary additional and complementary action for containment.

→ **References and further reading material can be found on page 225**

Appendix

Glossary

A

Abstraction: Removal of water from a source.

Acidity: Higher concentration of positive hydrogen ions in the solution, resulting in a low pH value (below pH 7).

Adhesion: The tendency of molecules of liquids or gases clinging to the surface of a solid particle.

Adsorption: Adhesion of a thin film of liquid, vapour or dissolved ions to a solid substance without involving a chemical reaction.

Alkalinity: Capacity of water to resist or neutralise acids to maintain a fairly stable pH level.

Alluvial: Loose unconsolidated material (i.e., particles are not cemented together) that was previously deposited by ice or flowing water.

Aquifer: Geological formation capable of storing, transmitting (flow rate) and yielding exploitable quantities of water.

Artesian Aquifer: See Confined Aquifer.

B

Backfilling: Filling a hole using some of the material that was removed during the digging or drilling process.

Backwashing: Reversal of the flow of water to free a clogging material (e.g., sediments within a rapid sand filter or reverse osmosis filtration cartridges).

Basicity: Lower concentration of positive hydrogen ions in the solution, resulting in a high pH value (above pH 7).

Biological Contaminants: Organisms in water also referred to as microbes or microbiological contaminants (e.g. bacteria, viruses, protozoa). (Syn.: Microbial/Microbiological Contaminants)

Bone Char: Porous granular substance used for water filtration and decolouration; produced by charring animal bones.

Borehole: A narrow shaft bored or drilled from the surface to underground water sources for the extraction of water.

Brackish Water: Water with more salinity than fresh water but less than seawater (1,000-10,000 mg/L total dissolved solids). It is usually the result of seawater intrusion into groundwater bodies along coastal areas.

Brine: Water with high salinity (e.g. from aqueous sodium chloride used in electro-chlorination systems).

Buoyancy: Upward force exerted by water or fluids on objects that are wholly or partly immersed.

C

Canzee Pump: An inexpensive direct-action hand pump that consists of two PVC pipes inside of each other, each with a simple non-return valve made with a rubber flap. Maximal water lifting capacity is 12–15 metres.

Capital Costs: Costs related to the acquisition of a fixed asset or hardware.

Case Fatality Rate (CFR): A measure of the severity of a disease as defined by the proportion of deaths from a specified disease compared to the total number of people diagnosed with the disease within a specified period of time.

Catchment: A surface area that collects and drains rainwater and snow melt to a certain point (e.g. a small-scale roof catchment drains water that falls on the roof or a large-scale ground catchment drains water from surrounding land).

Check Valve: A valve that allows liquids or gas to flow through it only in one direction. Also known as a non-return valve.

Chemical Contaminants: Elements or compounds in water that may be naturally occurring (e.g. fluoride, arsenic, nitrate, toxins produced by bacteria) or man-made (e.g. pesticides, heavy metals).

Chemical Oxygen Demand (COD): Measure of the amount of oxygen required for the chemical oxidation of organic material in water by a strong chemical oxidant (expressed in mg/L). COD is an indirect measure of the amount of organic material present in water – the higher the organic content, the higher the oxygen requirement.

Chlorine Demand: The amount of chlorine added to water that is completely exhausted in the water disinfection process.

Coagulation: Process in which a chemical (e.g. aluminium sulphate or ferric chloride) is added to water to destabilise electrostatic charges of colloids, allowing these smaller particles to come together to form larger particles (through flocculation), which settle out faster or can be filtered due to their larger size.

Coliform Bacteria: Organism found in the digestive tracts and faeces of animals and humans that, when found in drinking water, may indicate the presence of pathogenic bacteria.

Colloids: Stable insoluble substances that are so small that the random motion of water molecules is sufficient to prevent them settling under gravity.

Commodity Valve: Low priced, widely available, manufactured valves used in water pumping and distribution networks.

Confined Aquifer: A saturated geological formation in which the water pressure at any point is greater than atmospheric pressure. (Syn.: Artesian Aquifer)

Contaminant: Physical, chemical, biological or radiological substance present in water that may be naturally occurring or man-made and that may affect public health if present in levels above water safety standards.

D

Desalination: The process of removing salts and minerals from water.

Desilting: The process of removing silt or deposits from a tank or reservoir.

Dewatering: The process of removing water (e.g. pumping water from an excavation).

Diffused Sources of Contamination: Contamination coming from unspecific pollution sources over a wide area (e.g. pollution from agriculture).

Discharge: The volume of water that passes a given point within a given period of time. It is an all-inclusive outflow term describing a variety of flows, such as from pipes or streams.

Disinfection: The elimination of pathogenic microorganisms by inactivation (e.g. using chemical agents, radiation or heat) or by physical separation processes (e.g. membranes).

Disinfection By-Products: Chemical, organic and inorganic substances that result from a reaction of a disinfectant (e.g. chlorine) with naturally occurring organic matter in water and that may be harmful.

Downstream: Further away from the source; the direction in which water is naturally flowing.

Duty Pump: The pump in use most of the time (i.e., not the standby pump).

E

Effluent: Outflow of water or another liquid from a pipe or treatment plant that is discharged to a stream or body of water.

Electrolysis: A technique using a direct electrical current to drive an otherwise nonspontaneous chemical reaction.

Embankment: A mound of earth or stone built to hold back water.

Erosion: The process by which soil and rock are worn way, loosened or dissolved and moved by natural forces such as rain, snow or wind.

Evaporation: The process by which water turns from its liquid phase into gas (vapour).

Evapotranspiration: The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

F

First Flush: The initial and often sediment- and contaminant-laden surface runoff in rainwater harvesting systems that is diverted away from the storage tank.

Flocculant: Clarifying agents used in water treatment to remove suspended solids from liquids by inducing flocculation.

Flocculation: A physical process wherein particles come together to form larger particles (flocs) following the introduction of floc-creating agents (flocculants) and slow agitation of the water.

Flux: Flow rate per area of membrane.

Flywheel: A mechanical device designed to efficiently store rotational kinetic energy, giving mechanical advantage to lifting water.

Friction Loss: Reduction in energy that occurs when water moves due to water molecules knocking into each other and against the pipe wall, which converts some of the total available energy into heat that dissipates into the environment. (Syn.: Head Loss)

G

Generator: A machine that uses fuel (e.g. diesel) to convert mechanical energy into electricity.

Gravity: The force that attracts an object or substance towards the centre of the earth or towards any other physical body having mass.

Greywater: Water generated from showers, bathtubs, washing clothes, handwashing and sinks.

Groundwater: Water that is held in pores and spaces within the geological formations of the earth's surface.

Groundwater Recharge: Process wherein groundwater is replenished. To be sustainable, this should be equal to or greater than what is abstracted.

Groundwater Table: The surface of the saturated water-bearing layer in the ground that is open to atmospheric pressure and that is not static but can vary over time due to lower recharge or higher usage.

H

Head Loss: See Friction Loss (Syn.)

Headwall: A wall of masonry or concrete built at the outlet of a pipe that functions to support the sides of an excavation as well as (together with the apron) to prevent erosion by water flow.

Heavy Metals: Metals with relatively high density that can enter water supply systems either through artificial sources (e.g. industrial or consumer waste) or natural sources (e.g. released from soils) and that can pose potential health risks.

Helical Rotor Pump: A positive displacement pump that works through the rotation of a helical rotor, which is shaped as a single helix that sits within a stationary double-helix rubber stator. Water occupies the cavity between the two, and when the rotor turns, this cavity moves upwards together with the water. (Syn.: Progressive Cavity Pump)

Hydraulic Cleaning: A set of techniques to clean pipes and sewer lines that includes the use of high-pressure and high-velocity water.

Hydraulic Conductivity: A property of soils and rocks that describes the ease with which a fluid (in this case water) can move through pore spaces or fractures.

Hydraulic Gradient: A measure of the decrease in total energy per unit length in the direction of flow when water is moving, which results from the phenomenon known as head loss.

Hydraulic/Pneumatic Power: Transmission of power by the controlled circulation of pressurised fluid to a motor that converts it into a mechanical output. For pneumatic power, pressurised gas is used.

Hydrogeological Survey: An investigation of geology, groundwater, geochemistry and contamination at a particular site, as well as climatic and recharge conditions, with a view to understanding the risk to groundwater or the usefulness for groundwater supply in a sustainable manner.

I

Impeller: A rotating component of a centrifugal pump that accelerates the fluid outwards from the centre of rotation.

Impulse pump: A pump using pressure created by air that pushes part of the liquid upwards.

In Situ: On site or in position.

Industrial Effluent: By-product of industrial or commercial activities, often with high physical and chemical contamination.

Infiltration: Process by which water on the ground surface enters into the soil.

Inflow: Flow of water into a specific technology.

Inlet: A part of a machine or structure through which liquid or gas enters.

Inorganic: Material derived from non-living sources (such as rock or minerals) and that does not contain carbon.

Intake: An opening through which fluid enters an enclosure (e.g. river intake) or a machine (e.g. pump intake, same as pump inlet).

Integrated Water Resources Management (IWRM): A process that promotes the co-ordinated development and management of water, land and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Ion Exchange: Process by which an ion in a mineral lattice is replaced by an ion from a contacting solution.

J

Jar Test: A laboratory procedure that simulates a chemical treatment process on smaller quantities of water using differing chemical doses.

K

Kinetic Energy: Form of energy that an object has due to its motion.

L

Log Removal Values (LRM): A logarithmic measure of the ability of a treatment process to remove pathogenic microorganisms. An LRM of 1 corresponds to a reduction of 90 %, an LRM of 2 corresponds to a reduction of 99 %, etc.

M

Managed Aquifer Recharge (MAR): The intentional recharge of water to suitable aquifers for subsequent recovery or to achieve environmental benefits, with added effects of reducing poverty, reducing risk and vulnerability and increasing agricultural yields.

Membrane: A thin, pliable sheet or layer of natural or synthetic (filter) material.

Membrane Fouling: Material retained on the surface of the membrane or within the pores that reduces the flow through the membrane.

Micro-Pollutants: A pollutant, usually from an artificial source, that is present in extremely low concentrations (e.g. trace organic compounds), yet above background levels.

Microbial/Microbiological Contaminants: See Biological Contaminants (Syn.)

Mitigation: The process or result of making something less severe, dangerous or damaging.

N

Nephelometric Turbidity Units (NTU): Measure of how much light shone through a water sample reaches a detector on the other side of the sample. Particles in the water reflect more light sideways, meaning more light arrives at the detector. A higher turbidity results in a higher reading.

O

Operation and Maintenance (O & M): Routine or periodic tasks required to keep a process or system functioning according to performance requirements and to prevent delays, repairs or downtime.

Operational Costs: The expenses associated with the operation, maintenance and administration of a specific technology or system.

Organic: Material containing carbon-based compounds coming from the remains of organisms such as plants and animals (and their waste products).

Outflow: Flow of water coming out of a specific technology.

Outlet: A part of a machine or structure through which liquid or gas exits.

Oxidation: The loss of electrons during a reaction by a molecule, atom or ion, e.g. when iron reacts with oxygen, it forms rust because it has been oxidised (the iron has lost electrons) while the oxygen has been reduced (the oxygen has gained electrons).

P

Pathogen: A disease-causing organism.

Permeability: The soil's hydraulic conductivity after the effect of fluid viscosity and density are removed (i.e., describes the innate properties of the soils and rocks themselves).

Permeate: To diffuse through; to pass through the pores or interstices of something.

Personal Protective Equipment (PPE): Protective equipment (e.g. clothing, helmets, goggles) designed to protect the wearer from injury or infection.

pH: Stands for power of hydrogen; a scale used to specify how acidic or basic (alkaline) a water-based solution is. A pH value below 7 indicates that a solution is acidic, and a pH value above 7 indicates that it is basic (alkaline).

Piston: The moving component of reciprocating pumps (among others) that is tightly contained within a cylinder.

Point of Collection/Abstraction: Location where water is collected by users (e.g. borehole, tapstand, river or lake).

Point of Use (POU): Location where the water is actually used and consumed (usually directly at household level).

Point Source of Contamination: Contamination coming from a specific pollution source that can be pinpointed.

Positive Displacement Pump: A pump that displaces a fixed amount of water per cycle.

Porosity: Ratio of the volume of interstices (intervening spaces) in a given sample of a porous medium to the gross volume of the sample, inclusive of voids.

Precipitation: Condensation of atmospheric water vapour that returns to the earth's surface as e.g. rain, snow, hail or fog.

Progressive Cavity Pump: See Helical Rotor Pump (Syn.)

Protected Spring: A spring that is modified to collect, transport and sometimes store spring water while preventing contamination.

Pump Discharge: The water coming out of a pump or the outlet port of a pump.

Pumping Test: A field test in which the performance of an aquifer is measured through the action of pumping a well to demonstrate well efficiency, possible yield and pump placement.

R

Rainwater: Water from liquid precipitation.

Recharge: Refers to water entering an underground aquifer through faults, fractures or direct absorption.

Recontamination: Process when something that had been cleaned again becomes contaminated (e.g. water that is treated gets contaminated again).

Rehabilitation: The restoration of something damaged or deteriorated to a prior good condition.

Reservoir: An impoundment of surface water in a natural depression that has been enhanced to hold the water by a man-made structure on one or more sides.

Residual Chlorine: The amount of active chlorine remaining in the water after a certain period of time (i.e., 30 minutes of contact time) after the initial chlorine demand has been met.

Residual Pressure: The extra pressure above a tap or outlet that is equal to either the static head (when no water flows) or to a point on the hydraulic gradient (when water flows).

Resuspension: The renewed suspension of a precipitated sediment (e.g. when stirring up mud that has settled at the bottom of a tank).

Rising Main: A pipe from a submerged part of a pump that rises to where water is delivered (e.g. pump head for a handpump or water tank for a submersible pump).

Riverbed: The bed or channel through which water flows, which is located at a lower point in a drainage system.

Run-Off: Water from precipitation that runs off the ground surface (rather than infiltrating), which then enters rivers, lakes or reservoirs.

Run-Off Coefficient: The percentage of water that runs off a surface and can be collected, wherein the remainder is lost (e.g. to splashing, evaporation or infiltration).

S

Saline/Salty Water: Water that has a high content of dissolved solids and is generally considered unsuitable for human consumption.

Saltwater Intrusion: The movement of saline water into fresh-water aquifers that can degrade groundwater quality (see also Brackish Water).

Salinity: The quality or degree of dissolved salt content.

Sand Trap: A plain section of casing under the screens at the bottom of a borehole that allows fine silt/sand particles to accumulate during the well development process and over time.

Saturation: When all the pores of a material or medium (e.g. soil) are filled with water.

Schmutzdecke: The most biologically active part of a slow sand filter, consisting of a dense population of microorganisms that develops over time and that is key to the disinfection properties of the filter.

Screen: A device used to prevent objects or particles from entering the water supply. Common examples of screens used in water supply operations include slotted pipes in boreholes or a set of bars used in raw water intakes (Syn.: Well Screen).

Sedimentation: The settling out of particles in a liquid by force of gravity.

Seepage: The slow escape of liquid (e.g. water from a diffuse spring).

Shock Chlorination: A process in which a large amount of chlorine is added to the water to adequately disinfect it, including all the solid particles in the water that would normally increase chlorine demand. After shock chlorination, the water is not safe to drink due to high chlorine levels and must be decanted.

Silt Trap: A device to prevent silt from entering a tank or water treatment system.

Siltation: The deposition of fine sediment in the bottom of a stream, lake or reservoir.

Skid-Mounted System: A set of equipment that is mounted in a frame(s) to ensure easy and secure transport and usage as a unit.

Solubilisation: Process by which a substance is made (more) soluble in water.

Strainer: A device with holes or made of crossed wires that is used to separate solid matter from a liquid – for surface water pumps, it is used at the end of the inlet pipe to prevent larger materials from entering the pipe.

Submersible Pump: A pump that is located underwater, from where it pushes water. It has a hermetically-sealed motor that is close-coupled to the pump body.

Suction Pump: A pump that is located above the water surface, from where it pulls water by suction into the pump housing.

Surface Water: Water that remains on the ground surface in large bodies (e.g. streams, lakes, wetlands) and that has not infiltrated into the ground.

Suspended Solids: Small solid particles that remain in suspension with water either as colloids or due to the motion of the water.

Sweet Water: Any naturally occurring water with less than 500 mg/L of dissolved salts.

Syphon: A tube used to convey liquid against gravity upwards from a reservoir and then down to a lower level of its own accord.

T

Tankering/Trucking: The bulk transport of water using a water tanker vehicle, which takes water from the source to a storage facility near a distribution point.

Tara Pump: A low cost and robust direct action hand pump with a buoyant pump rod that displaces water on both the up and down strokes. Maximal water lifting capacity is 15 metres.

Topography: The shape and features of land surfaces.

Totally Dissolved Solids (TDS): The quantity of minerals (salts) in solution in water, usually expressed in milligrams per litre (mg/L) or parts per million (ppm).

Turbidity: The measure of relative clarity of a liquid, usually expressed in Nephelometric Turbidity Units (NTU).

Turbine: A machine for producing continuous power in which a wheel or rotor, typically fitted with vanes, is made to revolve by a fast-moving flow of water, steam, gas, air or other fluid.

U

Ultraviolet (UV): Type of electromagnetic radiation that disinfects through the inactivation of pathogenic microorganisms.

Unconfined Aquifer: A saturated geological formation that is open to atmospheric pressure; its surface is known as the groundwater table.

Underdrain: A concealed drainage area/trench that allows water to pass while retaining material on top (e.g. a drainage area at the bottom of a rapid sand filter).

Unprotected Spring: A spring that is in its natural state and has not been modified to prevent contamination.

Upflow Filtration: Filtration process in which water flows from bottom to top.

Upstream: Nearer to the source; against the direction in which water is naturally flowing.

V

Velocity: Speed, or how far something travels over time.

W

Water Column: Conceptual column describing the vertical expanse of water between the surface and the bottom of a particular water body.

Water Hardness: A water quality parameter that indicates the amount of dissolved minerals, especially calcium and magnesium. Hard water has higher levels of these minerals.

Water Metering: The practice of measuring the amount/volume of water used.

Water Tariff: The price assigned to water supplied by a public utility (usually through a piped network) to its customers.

Well: Any artificial excavation constructed for the purposes of exploring and extracting groundwater or for injection, monitoring or dewatering purposes.

Well Efficiency: The ratio of aquifer loss (theoretical drawdown) to the total measured drawdown in a borehole/well, which shows the efficiency of the well as an engineering structure for water abstraction.

Well Screen: See Screen (Syn.)

Y

Yield: The amount of water that can be abstracted over time.

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All listed references are also available at and can be downloaded from the Compendium of Water Supply in Emergencies online platform and the Sustainable Sanitation Alliance (SuSanA) library.

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- Mazille, F., Spuhler, D. (undated): Desalination. Sustainable Sanitation and Water Management Toolbox (SSWM). URL: https://sswm.info/water-nutrient-cycle/water-sources/hardwares/surface-water-sources/desalination

S.5 Groundwater

Key in-depth reference on groundwater, borehole drilling and well design:

- Driscoll, F.G. (1986): Groundwater and Wells. Second Edition, Johnson Screens. St. Paul. USA

Detailed design guide for assessing groundwater contamination risk:

- Lawrence, A.R. et al. (2001): Guidelines for Assessing the Risk to Groundwater from On-Site Sanitation. British Geological Society. Keyworth. UK. URL: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/1926

Groundwater introduction:

- Price, M. (1996): Introducing Groundwater. Second Edition. Chapman and Hall. London. UK

Current guidelines on drinking water quality standards:

→ WHO (2017): Guidelines for Drinking-Water Quality. Fourth Edition Incorporating the First Addendum. WHO. Geneva. Switzerland. URL: https://www.who.int/publications/i/item/9789241549950

Practical guideline for test pumping:

→ ICRC (2020): Technical Review: Practical Guideline for Test Pumping in Water Wells. ICRC. Geneva. Switzerland. URL: https://www.icrc.org/en/publication/4033-technical-review-practical-guidelines-test-pumping-water-wells

Overview of groundwater in the context of the USA:

→ Alley, W. M., Reilly, T.E., Franke, O.L. (1999): Sustainability of Ground-Water Resources. U.S. Geological Survey Circular 1186. USGS, Denver. USA. URL: https://pubs.usgs.gov/circ/1999/circ1186/pdf/circ1186.pdf

S.6 Spring Water

Overview of origins of spring water and spring types:

→ Meuli, M., Wehrle, K. (2001): Spring Catchment. Series of Manuals on Drinking Water Supply (Volume 4). SKAT. Switzerland. URL: https://sswm.info/sites/default/files/reference_attachments/MEULI%20and%20WEHRLI%202001%20Spring%20Catchment.pdf

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

S.7 Gravity

Explanation of gravity flow systems and detailed worked example:

→ Arnalich, S. (2009): How to Design a Gravity Flow Water System Through Worked Exercises. Arnalich Water and Habitat. URL: https://www.scribd.com/doc/35189494/How-to-design-a-Gravity-Flow-Water-System

Overview of gravity systems:

→ Arnalich, S. (2010): Gravity Flow Water Supply: Conception, Design and Sizing for Cooperation Projects. Arnalich Water and Habitat. URL: https://www.scribd.com/doc/46026759/Gravity-Flow-Water-Supply

→ WaterAid (2013): Gravity-Fed Schemes. Technical Brief. URL: https://washmatters.wateraid.org/publications/gravity-fed-schemes-technical-brief-2013

Detailed design guide for gravity systems:

→ Jordan, T.D. (1980): A Handbook of Gravity-Flow Water Systems. IT. London. UK. URL: https://archive.org/details/fa_Handbook_of_Gravity-Flow_Water_Systems

S.8 Human-Powered Energy System

Overview of manually-operated pump types, lifting mechanisms and costs:

→ Baumann, E. (2000): Water Lifting. Series of Manuals on Drinking Water Supply, Volume 7. SKAT. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/220

→ Baumann, E. (2011): Low Cost Hand Pumps. Field Note No. 2011-3. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/307

Overview of power sources for pumping:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

S.9 Wind-Powered Energy System

Brief overview of mechanical wind-operated pumps and costs:

→ Baumann, E. (2000): Water Lifting. Series of Manuals on Drinking Water Supply. Volume 7. SKAT. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/220

Design considerations for using wind-electric systems:

→ Bergey, M.L.S. (1998): Wind-Electric Pumping Systems for Communities. International Symposium on Safe Drinking Water in Small Systems. Washington D.C. USA. URL: http://www.bergey.com/wind-school/wind-electric-pumping-systems-for-communities

Research showing efficiency of using wind to directly power AC pumps:

→ Lemmer, E.C. (2009): Wind-Electric Pump System Design. MSc thesis. Stellenbosch University. South Africa. URL: https://www.semanticscholar.org/paper/Wind-Electric-Pump-System-Design-Lemmer/6e6ec62468d698756f405b501118eace074a4616?p2df

Overview of power sources for pumping:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft, Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

Overview of using wind-electric systems:

→ US Department of Energy (undated): Small Wind Electric Systems. US Department of Energy. Washington D.C. USA. URL: https://www.energy.gov/energysaver/save-electricity-and-fuel/buying-and-making-electricity/small-wind-electric-systems

S.10 Solar-Powered Energy System

The Solar Pumping Toolkit:

→ Global Solar and Water Initiative (2018): The Solar Pumping Toolkit. Global WASH Cluster (GWC). Geneva. Switzerland. URL: https://washcluster.net/gwc-resources

Solar Powered Water System assessment carried out in four countries: Nigeria, Mauritania, Uganda and Myanmar:

→ Bamford, E., Zadi, D. (2016): Scaling Up Solar Powered Water Supply Systems: A Review of Experiences. UNICEF. New York. USA. URL: https://www.unicef.org/wash/files/UNICEF_Solar_Powered_Water_System_Assessment.pdf

Explanation on the basics of solar water pumping:

→ World Bank (2018): Solar Pumping: The Basics. World Bank. Washington D.C. USA. URL: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/880931517231654485/solar-pumping-the-basics

Solar water pumping knowledge base:

→ World Bank (2016): Solar Water Pumping Knowledge Base. World Bank. Washington D.C. USA. URL: https://www.worldbank.org/en/data/interactive/2016/12/08/solar-water-pumping-knowledge-base

Study to assess opportunities to use renewable energy for water pumping:

→ Shehadeh, N.H. (2015): Solar Powered Pumping in Lebanon. A Comprehensive Guide on Solar Water Pumping Solutions. UNDP/SDC. URL: https://www.lb.undp.org/content/lebanon/en/home/library/environment_energy/solar-powered-pumping-in-lebanon.html

Webinar Series: Sustainable Energy in Humanitarian Settings:

→ GIZ, FAO (2018): Toolbox on Solar Powered Irrigation Systems. URL: https://energypedia.info/wiki/Toolbox_on_SPIS

S.11 Electric-Powered Energy System

Brief overview of electric-operated pump systems and costs:

→ Baumann, E. (2000): Water Lifting. Series of Manuals on Drinking Water Supply. Volume 7. SKAT. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/220

Guidelines on electrical plant for non-specialists:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London. UK

S.12 Diesel- and Gasoline-Powered Energy System

Brief overview of diesel engine-driven pump systems and costs:

→ Baumann, E. (2000): Water Lifting. Series of Manuals on Drinking Water Supply. Volume 7. SKAT. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/220

Guidelines on mechanical plant for non-specialists, and installation of engine-driven pumps:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London. UK

I.1 Rainwater Harvesting: Raised Surface Collection

Rainwater harvesting overview:

→ Rain Foundation (2020): Rain Foundation Homepage. Amsterdam. The Netherlands. URL: http://www.rainfoundation.org

→ Persyn, R.A., Porter, D., Silvy, V. (2010): Rainwater Harvesting. Texas A&M AgriLife. USA. URL: https://rainwaterharvesting.tamu.edu/rainwater-basics

→ UNEP / SEI (2009): Rainwater harvesting. A Lifeline for Human Well-Being. UNEP & SEI. Nairobi. Kenya. URL: https://wedocs.unep.org/bitstream/handle/20.500.11822/7762/Rainwater%20Harvesting%20_%20a%20Lifeline%20for%20Human%20well-being-2009848.pdf?sequence=3&amp%3Bis

→ RAIN (2008): Rainwater Quality Guidelines. Rainwater Harvesting Implementation Network. Amsterdam. The Netherlands. URL: https://www.samsamwater.com/library/RAIN_Rainwater_Quality_Policy_and_Guidelines_2008_v1.pdf

Rainwater harvesting in rural areas:

→ Gur, E., Spuhler, D. (undated): Rainwater Harvesting (Rural). Sustainable Sanitation and Water Management Toolbox (SSWM). URL: https://sswm.info/water-nutrient-cycle/water-sources/hardwares/precipitation-harvesting/rainwater-harvesting-(rural)

Rainwater harvesting in urban areas:

→ Gur, E.; Spuhler, D. (undated): Rainwater Harvesting (Urban). Sustainable Sanitation and Water Management Toolbox (SSWM). Available at: https://sswm.info/water-nutrient-cycle/water-sources/hardwares/precipitation-harvesting/rainwater-harvesting-(urban)

Guidelines on rainwater harvesting and pond rehabilitation:

→ Bauer, R., Myint, S. (2009): Dry Season Water Strategies in Myanmar after Cyclone Nargis. 34th WEDC Conference Addis Ababa. Ethiopia. URL: https://wedc-knowledge.lboro.ac.uk/resources/conference/34/Bauer_R_-_337.pdf

WHO Sanitary inspection packages 2020:

→ WHO (2020): Sanitary Inspection Package (Drinking Water): Rainwater Collection and Storage. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/water-quality/safety-planning/rainwater-collection-and-storage/en

I.2 Rainwater Harvesting: Ground Surface Collection

Costs and O&M of rainwater ground collection systems:

→ Brikké, F., Bredero, M. (2003): Linking Technology Choice with O&M in the Context of Community Water Supply and Sanitation. WHO, IRC. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/hygiene/om/wsh9241562153.pdf

Literature review of ground catchment and storage systems:

→ Fewster, E. (2010): Desk Study. Resilient WASH Systems in Drought Prone Areas. CARE Nederland, Netherlands Red Cross. The Hague. The Netherlands. URL: https://www.preventionweb.net/files/47729_resilientwashindroughtproneareas.pdf

I.3 River and Lake Water Intake

Design information for different types of dam suitable for intake structures:

→ Jordan, T.D. (1980): A Handbook of Gravity-flow Water Systems. IT. London. UK.

Detailed design information for intakes and weirs:

→ FAO (undated): 7. Main Water Intake Structures. FAO. Rome. Italy. URL: http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/x6708e/x6708e07.htm

→ Lauterjung, H., Schmidt, G. (1989): Planning of Intake Structures. GTZ. Eschborn. Germany. URL: https://www.ircwash.org/sites/default/files/Lauterjung-1989-Planning.pdf

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

Overview of river intakes and design of submerged weir:

→ Smout, I., Shaw, R. (1991): Intakes from Rivers. The Worth of Water: Technical Briefs on Health, Water, Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technical-briefs/22.%20Intakes%20from-rivers.pdf

Information on costs and O & M:

→ Brikké, F., Bredero, M. (2003): Linking Technology Choice with O & M in the Context of Community Water Supply and Sanitation. WHO, IRC. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/hygiene/om/wsh9241562153.pdf

I.4 Protected Spring Intake

Overview of spring box construction:

→ Hart, W. (2003): Protective Structures For Springs Spring Box Design, Construction and Maintenance. Michigan Technological University. USA. URL: https://inspectapedia.com/water/Spring-Box-Design_HartW.pdf

Comprehensive design guide for gravity & artesian spring protections:

→ Meuli, M., Wehrle, K. (2001): Spring Catchment. Series of Manuals on Drinking Water Supply (Volume 4). SKAT. Switzerland. URL: http://www.sswm.info/sites/default/files/reference_attachments/MEULI%20and%20WEHRLI%202001%20Spring%20Catchment.pdf

Construction details for protecting springs without using a spring box:

→ Skinner, B., Shaw, R. (1999): Protecting Springs. An Alternative to Spring Boxes. In: Shaw, R. (Ed) Running Water: More Technical Briefs on Health, Water and Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/orgs/well/resources/technical-briefs/34-protecting-springs.pdf

Overview of gravity & artesian spring protections:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

I.5 Groundwater Dam

Key reference for groundwater dams:

→ Nilsson, Å. (1988): Groundwater Dams for Small-scale Water Supply. IT Publications. London. UK.

Practical experience from construction of subsurface and sand storage dams:

→ Nissen-Petersen, E. (2000): Water from Sand Rivers. Onsite Survey, Design, Construction and Maintenance of Seven Types of Water Structures in Riverbeds. RELMA/SIDA. Nairobi. Kenya. URL: http://www.worldagroforestry.org/downloads/Publications/PDFS/B16761.pdf

→ RAIN (2008): A Practical Guide to Sand Dam Implementation: Water Supply Through Local Structures as Adaptation to Climate Change. Rain Foundation. Amsterdam. The Netherlands. URL: http://www.rainfoundation.org/wp-content/uploads/2017/10/a-practical-guide-to-sand-dam-implementation.pdf

→ VSF (2006): Sub-Surface Dams. A Manual on Sub-Surface Dams Construction based on Experience of Vétérinaires Sans Frontières in Turkana District (Kenya). VSF-Belgium, Brussels, Belgium. URL: https://sswm.info/sites/default/files/reference_attachments/VSF%202006%20SubSurface%20Dams%20a%20simple%20safe%20and%20affordable%20Technology%20for%20Pastoralists%20Manual.pdf
→ Maddrell, S. (2018) Sand Dams. A Practical and Technical Manual. Excellent Development. London. UK. URL: https://www.researchgate.net/publication/325757526_Sand_Dams_A_Practical_Technical_Manual

I.6 Riverbank Filtration

Technical literature review of all ground catchment and storage systems (including infiltration galleries and Managed Aquifer Recharge):

→ Fewster, E. (2010): Desk Study. Resilient WASH Systems in Drought Prone Areas. CARE Nederland, Netherlands Red Cross. The Hague. The Netherlands. URL: https://www.preventionweb.net/files/47729_resilientwashindroughtproneareas.pdf

Information on water quality improvement through Riverbank Filtration:

→ Gutiérrez J.P., van Halem, D., Rietveld, L. (2017): Riverbank Filtration for the Treatment of Highly Turbid Colombian Rivers. In: Drinking Water Engineering and Science 10. URL: https://dwes.copernicus.org/articles/10/13/2017/dwes-10-13-2017.pdf

Reviews various types of natural and artificial means of Riverbank Filtration:

→ Oxfam (2000): Instruction Manual for Hand Dug Well Equipment. Covering Well Auger Survey, Well Digging, Dewatering and Desludging Kits. Oxfam. Oxford. UK. URL: https://www.humanitarianlibrary.org/sites/default/files/2014/02/Oxfam_WellEquipment.pdf
→ Shaw, R. (Ed) (1999): Improving Pond Water. Technical brief No.47. In: Running Water: More Technical Briefs on Health, Water and Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technicalbriefs/47%20-%20Improving%20pond%20water.pdf

Overview of infiltration galleries:

→ Smout, I., Shaw, R. (1991): Intakes from Rivers. The Worth of Water: Technical Briefs on Health, Water, Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technical-briefs/22.%20Intakes%20from-rivers.pdf

I.7 Protected Dug Well

Overview of hand-dug well methods:

→ Collins, S. (2000): Hand-Dug Shallow Wells. Vol. 5 of the Series of Manuals on Drinking Water Supply. SKAT/SDC. Switzerland. URL: http://www.sswm.info/sites/default/files/reference_attachments/COLLINS%202000%20Hand%20Dug%20Shallow%20Wells.pdf
→ WHO (2020) Sanitary Inspection Package (Drinking-Water): Dug Well with a Hand-pump. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/water-quality/safety-planning/dug-well-with-a-hand-pump/en/

Procedures for disinfection of hand-dug wells in emergencies:

→ Godfrey, S., Reed, B. (2013): Cleaning Hand-Dug Wells: Technical Notes on Drinking-Water, Sanitation and Hygiene in Emergencies. WHO/WEDC. Loughborough University. UK. URL: https://www.who.int/water_sanitation_health/emergencies/WHO_TN_01_Cleaning_and_disinfecting_wells.pdf?ua=1

Health and safety considerations:

→ Oxfam (2000): Instruction Manual for Hand Dug Well Equipment. Covering Well Auger Survey, Well Digging, Dewatering and Desludging Kits. Oxfam. Oxford. UK. URL: https://www.humanitarianlibrary.org/sites/default/files/2014/02/Oxfam_WellEquipment.pdf

Key reference for the in-situ and telescopic construction method:

→ Watt, S.B.; Wood, W.E. (1979): Hand Dug Wells and their Construction. IT. London, UK.

I.8 Protected Borehole

Short overview of drilling procedure and supervision tasks:

→ Adekile, D. (2012): Supervising Water Well Drilling. A Guide for Supervisors. Field Note No 2012-2. RWSN, St. Gallen, Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/392

Detailed practical guide on borehole drilling, well design and pumping tests:

→ Ball, P. (2001): Drilled Wells. Vol.6 of the Series of Manuals on Drinking Water Supply. SKAT/SDC, Switzerland. URL: http://www.sswm.info/sites/default/files/reference_attachments/BALL%202001%20Drilled%20Wells.pdf
→ ICRC (2010) Technical Review: Borehole Drilling and Rehabilitation under Field Conditions. ICRC. Geneva. Switzerland. URL: https://www.icrc.org/en/publication/0998-technical-review-borehole-drilling-and-rehabilitation-under-field-conditions
→ ICRC (2010) Technical Review: Practical Guidelines for Test Pumping in Water Wells. ICRC, Geneva. Switzerland. URL: https://www.icrc.org/en/publication/4033-technical-review-practical-guidelines-test-pumping-water-wells

Key in-depth reference for borehole drilling and well design:

→ Driscoll, F.G. (1986): Groundwater and Wells. Second Edition. Johnson Screens. St. Paul. USA.

I.9 Seawater Intake

Short overview of seawater intakes:

→ Pankratz, T. (undated): An Overview of Seawater Intake Facilities for Seawater Desalination. URL: http://texaswater.tamu.edu/readings/desal/seawaterdesal.pdf

Comprehensive overview of seawater intake construction options:

→ Water Research Foundation (2011): Assessing Seawater Intake Systems for Desalination Plants. Denver. USA. URL: https://www.waterrf.org/research/projects/assessing-seawater-intake-systems-desalination-plants

Details on design methods to reduce impingement and entrainment of marine organisms:

→ Water Reuse Association (2011): Desalination Plant Intakes: Impingement and Entrainment Impacts and Solutions. Alexandria. USA. URL: https://watereuse.org/wp-content/uploads/2015/10/IE_White_Paper.pdf

A.1 Hydraulic Ram (Impulse) Pump

General technical information:

→ Fraenkel, P.L. (1986): Water Lifting Devices. FAO irrigation and drainage paper 43. FAO. Rome, Italy. URL: http://www.fao.org/3/ah810e/ah810e00.htm
→ Allspeeds Ltd. (undated): Blake Hydram. Water Powered Pumps. Hydram Information Booklet. Allspeeds Ltd. Accrington. UK. URL: http://www.allspeeds.co.uk/wp-content/files_mf/hydrambooklet59.pdf
→ Jeffery, T., Thomas, T.H., Smith, A.V., Glover, P.B., Fountain, P.D. (1992): Hydraulic Ram Pumps. A Guide to Ram Pumps Water Supply Systems. Practical Action Publishing. UK
→ Watt, S.B. (1975): A Manual on the Hydraulic Ram for Pumping Water. Practical Action Publishing. UK
→ Hofkes, E.H., Visscher, J.T. (1986): Renewable Energy Sources for Rural Water Supply. IRC. The Hague. The Netherlands. URL: https://www.ircwash.org/sites/default/files/232.0-86RE-4903.pdf
→ Clemson University (undated): Home Made Hydraulic Ram Pumps. Clemson University. USA. URL: http://www.clemson.edu/irrig/Equip/ram.htm

A.2 Piston-Plunger Suction Pump

Overview of manually-operated pump types including costs and flow rates:

→ Baumann, E. (2011): Low Cost Hand Pumps. Field Note No. 2011-3. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/307

Overview of treadle and rower pumps:

→ Shaw, R. (Ed) (1999): 35. Low-Lift Irrigation Pumps. In: Running Water. More Technical Briefs on Health, Water and Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technicalbriefs/35%20-%20Low-lift%20irrigation%20pumps.pdf

Overview of pump types:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

A.3 Direct Action Pump

Overview of manually-operated pump types including costs and flow rates:

→ Baumann, E. (2011): Low Cost Hand Pumps. Field Note No. 2011-3. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/307

Evaluation of Canzee pump performance:

→ Erpf, K., Gomme, J. (2005): Mission Report on the Evaluation of Rapid Well Jetting and the Canzee Handpump Programme of MEDAIR in the Regions of Maroantsetra and Manantenina. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/fr/ressources/details/173

Information on Tara pumps:

→ Kjellerup, B., Journey, W.K., Minnatullah, K.M. (1989): The Tara Handpump: The Birth of a Star. UNDP/World Bank Discussion Paper Series. The World Bank. Washington D.C. USA. URL: https://www.rural-water-supply.net/en/resources/details/437

→ Shaw, R. (Ed) (1999): 41. VLOM pumps. In: Running Water: More Technical Briefs on Health, Water and Sanitation. Intermediate Technology. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technicalbriefs/41%20-%20VLOM%20pumps.pdf

A.4 Deep Well Piston Pump

Overview of Afridev pump:

→ Erpf, K. (2007): Installation and Maintenance Manual for the Afridev Handpump. Revision 2. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/_ressources/documents/default/286.pdf

Analysis of O&M of Blue Pump compared to India Mark, Afridev and Duba Tropic pumps:

→ Foster, T., McSorley, B. (2016): An Evaluation of the BluePump in Kenya and The Gambia. University of Technology. Sydney & Oxfam, UK. URL: https://www.uts.edu.au/sites/default/files/BluePump_Evaluation_Report_2016.pdf

Overview of deep well pumps and cylinder types:

→ Shaw, R. (Ed.) (1999): VLOM pumps. In: Running Water. More Technical Briefs on Health, Water, Sanitation. IT. London. UK. URL: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/research/wedc/pdfs/technicalbriefs/41%20-%20VLOM%20pumps.pdf

Overview of India Mark 2 pump:

→ SKAT/RWSN (2008): Installation & Maintenance Manual for the India Mark II Handpump. SKAT/RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/_ressources/documents/default/1-328-34-1384355371.pdf

A.5 Deep Well Progressive Cavity Pump

Short overview of progressive cavity pumps:

→ Baumann, E. (2000): Water Lifting. Series of Manuals on Drinking Water Supply. Volume 7. SKAT. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/220

Overview of positive displacement pumps including progressive cavity pumps with installation procedure:

→ Davis, J.; Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London. UK.

Overview of progressive cavity pumps and drive arrangements:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

A.6 Diaphragm Pump

Overview of different pumps and water lifting devices (incl. diaphragm pumps):

→ Fraenkel, P.L. (1986): Water Lifting Devices. FAO irrigation and drainage paper 43. FAO. Rome, Italy. URL: http://www.fao.org/3/ah810e/ah810e00.htm

Information on air operated diaphragm pumps:

→ Aro (undated): Air Operated Double Diaphragm Pumps. Aro. Ohio, USA. URL: https://www.arozone.com/en/products/diaphragm-pumps.html

Information on the Vergnet Hydro pump:

→ E4C (undated): Vergnet Hydro Pump. Engineering for Change. New York, USA. URL: www.engineeringforchange.org/solutions/product/vergnet-hydro-60-2000-pump

A.7 Rope Pump

Overview of manually-operated pump types including costs and flow rates:

→ Baumann, E. (2011): Low Cost Hand Pumps. Field Note No. 2011-3. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/307

Review of experiences with the rope pump in Latin America along with costs:

→ Brand, A.P. (2004): Meeting Demand for Access to Safe Drinking Water. Low-Cost Pump Alternatives for Rural Communities in Honduras. WSP. Lima. Peru. URL: https://www.rural-water-supply.net/en/resources/details/289

Information on manufacture and installation processes:

→ Van der Wal, A., Nederstigt, J. (2011): Rope Pump. Low-Cost Pump Series. Third Edition. Practica Foundation. Delft. The Netherlands. URL: https://practica.org/wp-content/uploads/2014/08/ropepump-manual-EN-full.pdf

Overview of rope pumps in different contexts, including maintenance costs:

→ WSP (2001): Developing Private Sector Supply Chains to Deliver Rural Water Technology. The Rope Pump: Private Sector Technology Transfer from Nicaragua to Ghana. World Bank. Washington D.C. USA. URL: https://www.ircwash.org/sites/default/files/WSP-2001-Ropepump.pdf

A.8 Radial Flow Pump

Overview of velocity pumps, system curves and pump design, with troubleshooting guide:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Description of pumping efficiency, system curves and pump curves:

→ Pedraza, A., Rosas, R. (2011): Evaluation of Water Pumping Systems. Energy Efficiency Assessment Manual, First Edition. Inter-American Development Bank. Washington D.C. USA. URL: https://publications.iadb.org/en/evaluation-water-pumping-systems-energy-efficiency-assessment-manual

Short overview of radial flow pumps:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

A.9 Axial Flow Pump

Pump standard details by technology:

→ Hydraulic Institute (undated): Standards and Guidelines for Pumps and Pump Stations. Hydraulic Institute. URL: http://pumps.org/Standards_and_Guidebooks.asp

Centrifugal and axial flow pumps; theory, design, and application of centrifugal and axial flow pumps:

→ Stepanoff, R. J. (1967): Centrifugal and Axial Flow Pumps. Wiley. New York. USA

A.10 Pumping Station

Overview on standards for pumps and pumping stations:

→ Hydraulic Institute (undated): Standards and Guidelines for Pumps and Pump Stations. Hydraulic Institute. URL: http://pumps.org/Standards_and_Guidebooks.asp

Information on standard packages for different pumping applications:

→ Oxfam (undated): Oxfam Supply Centre Equipment Catalogue. Oxfam. Oxford. UK. URL: https://supplycentre.oxfam.org.uk

T.1 Roughing Filtration

Brief overview of roughing filters in the emergency context:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Literature review of roughing filtration:

→ Nkwonta, O., Ochieng, G. (2009): Roughing Filter for Water Pre-Treatment Technology in Developing Countries. International Journal of Physical Sciences Vol. 4 (9). URL: https://www.researchgate.net/publication/237827490_Roughing_filter_for_water_pre-treatment_technology_in_developing_countries_A_review

Information about combination of roughing filters with slow sand filters:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

Thorough roughing filter design guide:

→ Wegelin, M. (1996): Surface Water Treatment by Roughing Filters: A Design, Construction and Operation Manual. SKAT. St. Gallen. Switzerland. URL: https://www.ircwash.org/sites/default/files/Wegelin-1996-Surface.pdf

Filter design for emergencies, using polystyrene beads instead of gravel as media:

→ Kapranis Y. (1999): Design of an Emergency Portable Roughing Filter using Polystyrene Beads as Media. WEDC. Loughborough. UK. URL: https://repository.lboro.ac.uk/articles/Design_of_an_emergency_portable_roughing_filter_using_polystyrene_beads_as_media/9457811

T.2 Rapid Sand Filtration

Brief overview of rapid sand filters in the emergency context:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London. UK

Detailed design information for rapid sand filters, including case studies:

→ Schulz, C.R., Okun, D.A. (1984): Surface Water Treatment for Communities in Developing Countries. IT. London, UK

Detailed overview of rapid sand filter design:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

General information on rapid sand filters:

→ Wegelin, M. (1996): Surface Water Treatment by Roughing Filters: A design, Construction and Operation Manual. SKAT. St. Gallen. Switzerland. URL: https://www.ircwash.org/sites/default/files/Wegelin-1996-Surface.pdf

T.3 Microfiltration (MF)

Overview on membrane filtration:

→ Allgeier, S. (2005): Membrane Filtration Guidance Manual. USEPA Office of Water. Cincinnati. USA. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/901V0500.PDF?Dockey=901V0500.PDF

Practical manual:

→ AWWA (2016): Manual of Practice M53. Microfiltration and Ultrafiltration Membranes for Drinking Water. Second Edition. AWWA. URL: https://www.awwa.org/Store/Product-Details/productId/37526929

→ AMTA (undated): AMTA homepage. American Membrane Technology Association (AMTA). USA. URL: https://www.amtaorg.com

Background of the MF/UF filtration technology:

→ Ahmed I., Balkhair K.S., Albeiruttye M. H., Shaiban, A. (2017): Importance and Significance of UF/MF Membrane Systems in Desalination Water Treatment. URL: https://www.intechopen.com/books/desalination/importance-and-significance-of-uf-mf-membrane-systems-in-desalination-water-treatment

T.4 (Assisted) Sedimentation

Overview of coagulation and sedimentation in the emergency context, including dosing methods:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Detailed design information for coagulant dosing, flocculation and sedimentation basins, along with costs:

→ Schulz, C.R., Okun, D.A. (1984): Surface Water Treatment for Communities in Developing Countries. IT. London, UK

Detailed overview of coagulant dosing, flocculation and sedimentation basins:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

Water treatment manual with protocols for jar tests in appendix:

→ Bourke, N., Carty, G., O'Leary, G., Crowe, M., Page, D. (2002): Water Treatment Manuals Coagulation, Flocculation & Clarification. Environmental Protection Agency, Ireland. URL: https://www.epa.ie/pubs/advice/drinkingwater/EPA_water_treatment_mgt_coag_flocc_clar2.pdf

T.5 Assisted Sedimentation with Filtration

Brief overview of rapid sand filters, coagulation and sedimentation in the emergency context:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Detailed design information for coagulant dosing, flocculation, sedimentation basins and rapid sand filters, incl. case studies and costs:

→ Schulz, C.R., Okun, D.A. (1984): Surface Water Treatment for Communities in Developing Countries. IT. London, UK

Detailed overview of coagulant dosing, flocculation, sedimentation basins and rapid sand filters:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

Overview of different coagulation kits for emergencies at various scales:

→ Dorea, C. (2009): Coagulant-based emergency water treatment Desalination. Volume 248. Issues 1–3, 15. Elsevier. URL: https://www.sciencedirect.com/science/article/pii/S0011916409005700?via%3Dihub

T.6 Chlorination

Effect of temperature and sanitary conditions on chlorine residual:

→ Ali, S.I., Ali, S.S., Fesselet, J.F. (2016): Evidence-Based FRC Targets. MSF OCA. Amsterdam. The Netherlands. URL: https://fieldresearch.msf.org/handle/10144/618835

Effect of pH on chlorine effectiveness:

→ Luff, R. (2001): Oxfam Guidelines for Water Treatment in Emergencies. Oxfam. UK. URL: https://oxfamilibrary.openrepository.com/bitstream/handle/10546/126732/water-treatment-guidelines-emergencies-250406-en.pdf;jsessionid=E4E9D80705B2101D8A53409FC973F592?sequence=1

Overview of chlorine products, jar test procedure and monitoring:

→ Noortgate, J., Maes, P. (Eds.) (2010): Public Health Engineering in Precarious Situations. Médecins Sans Frontières. Paris. France. URL: http://refbooks.msf.org/msf_docs/en/public_health/public_health_en.pdf

Overview of measuring and monitoring chlorine:

→ Reed, B. (2013): Measuring Chlorine Levels in Water Supplies. Technical Notes on Water, Sanitation and Hygiene in Emergencies. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/publications/2011/tn11_chlorine_levels_en.pdf

When to monitor chlorine:

→ WHO (1996): Chlorine Monitoring at Point Sources and in Piped Distribution Systems. WHO Fact Sheets on Environmental Sanitation. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/sanitation-waste/fs2_30.pdf?ua=1

T.7 Onsite Electro-Chlorination

Continuous on-site electro chlorite systems:

→ Casson, L., Bess, J. (2006): On-Site Sodium Hypochlorite Generation. Proceedings of the Water Environment Federation. URL: https://www.researchgate.net/publication/233710211_On-Site_Sodium_Hypochlorite_Generation

Manual for a specific continuous on-site system, describing the principle of operation and many O & M issues typical also for other systems:

→ Boges & Mahoney Inc. (undated): B1-150 OSEC® System. Manual. Wallace and Tiernan. Concord. USA. URL: http://www.borgesmahoney.com/Manuals/OSEC%20B1-150%2085.010AA%20UA%20OSEC.pdf

T.8 Ultraviolet (UV) Light

Technical manual on UV disinfection:

→ Schmelling, D. et al. (2006): Ultraviolet Disinfection Guidance Manual. USEPA Office of Water. Cincinnati. USA. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/600006T3.PDF?Dockey=600006T3.PDF

Overview of small scale UV system types:

→ Burch, J., Thomas, K.E. (1998): An Overview of Water Disinfection in Developing Countries and the Potential for Solar Thermal Water Pasteurization. NREL. Golden. USA. URL: http://www.nrel.gov/docs/legosti/fy98/23110.pdf

→ Gadgil et al. (1997): Field-Testing UV Disinfection of Drinking Water. 23rd WEDC Conference. Water and Sanitation for all. WEDC. Durban. South Africa. URL: https://wedc-knowledge.lboro.ac.uk/resources/conference/23/Gadgil.pdf

T.9 Slow Sand Filtration

Brief overview of slow sand filters in the emergency context:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Detailed information on all aspects of slow sand filtration:

→ Huisman, L, Wood, W.E. (1974): Slow Sand Filtration. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/publications/ssf9241540370.pdf

→ Schulz, C.R., Okun, D.A. (1984): Surface Water Treatment for Communities in Developing Countries. IT. London. UK

Information about combination of roughing filters with slow sand filters:

→ Smet, J., van Wijk, C. (Eds.) (2002): Small Community Water Supplies. Technology, People and Partnership. IRC Technical Papers Series 40. IRC. Delft. Netherlands. URL: https://www.ircwash.org/sites/default/files/Smet-2002-Small_TP40.pdf

T.10 Ultrafiltration (UF)

Overview on membrane filtration:

→ Allgeier, S. (2005): Membrane Filtration Guidance Manual. USEPA Office of Water. Cincinnati. USA. URL: https://nepis.epa.gov/Exe/ZyPDF.cgi/901V0500.PDF?Dockey=901V0500.PDF

Practical manual:

→ AWWA (2016): Manual of Practice M53. Microfiltration and Ultrafiltration Membranes for Drinking Water. Second Edition. AWWA. URL: https://www.awwa.org/Store/Product-Details/productId/37526929

→ AMTA (undated): AMTA homepage. American Membrane Technology Association (AMTA). USA. URL: https://www.amtaorg.com

Background of the MF/UF filtration technology:

→ Ahmed I., Balkhair K.S., Albeiruttye M. H., Shaiban, A. (2017): Importance and Significance of UF/MF Membrane Systems in Desalination Water Treatment. URL: https://www.intechopen.com/books/desalination/importance-and-significance-of-uf-mf-membrane-systems-in-desalination-water-treatment

T.11 Fluoride Removal Technologies

Comprehensive guide to fluoride and its removal:

→ Eawag (2015): Geogenic Contamination Handbook. Addressing Arsenic and Fluoride in Drinking Water. Eawag. Dübendorf. Switzerland. URL: http://www.eawag.ch/fileadmin/Domain1/Forschung/Menschen/Trinkwasser/Wrq/Handbook/geogenic-contamination-handbook.pdf

→ Fawell, J. et al. (2006): Fluoride in Drinking Water. WHO. Geneva. Switzerland. URL: http://www.who.int/water_sanitation_health/publications/fluoride_drinking_water_full.pdf

Comparison of fluoride removal techniques:

→ Feenstra, L., Vasak, L., Griffioen, J. (2007): Fluoride in Groundwater. Overview and Evaluation of Removal Methods. International Groundwater Resources Assessment Centre. Utrecht. The Netherlands. URL: https://www.un-igrac.org/resource/fluoride-groundwater-overview-and-evaluation-removal-methods

Interactive maps for fluoride:

→ Eawag (undated): Groundwater Assessment Platform. Eawag. Dübendorf. Switzerland. URL: https://www.gapmaps.org/Home/Public

T.12 Arsenic Removal Technologies

Comprehensive guide to arsenic and its removal:

→ WHO (2011): Arsenic in Drinking Water. Background Document for Development of WHO Guidelines for Drinking-Water Quality. WHO. Geneva. Switzerland. URL: http://www.who.int/water_sanitation_health/dwq/chemicals/arsenic.pdf

→ Eawag (2015): Geogenic Contamination Handbook. Addressing Arsenic and Fluoride in Drinking Water. Eawag. Dübendorf. Switzerland. URL: http://www.eawag.ch/fileadmin/Domain1/Forschung/Menschen/Trinkwasser/Wrq/Handbook/geogenic-contamination-handbook.pdf

Comparison of arsenic removal techniques:

→ Feenstra, L., Vasak, L., Griffioen, J. (2007): Fluoride in Groundwater. Overview and Evaluation of Removal Methods. International Groundwater Resources Assessment Centre. Utrecht. The Netherlands. URL: https://www.un-igrac.org/resource/fluoride-groundwater-overview-and-evaluation-removal-methods

Interactive maps for arsenic:

→ Eawag (undated): Groundwater Assessment Platform. Eawag. Dübendorf. Switzerland. URL: https://www.gapmaps.org/Home/Public

Overview of household treatment options, including costs for commercial treatment:

→ Mudgal, A. K. (2002): Draft Review of the Household Arsenic Removal Technology Options. RWSN. St. Gallen. Switzerland. URL: https://www.rural-water-supply.net/en/resources/details/298

T.13 Granular Activated Carbon (GAC)

Biological processes in GAC filters:

→ Velten, S. (2008): Adsorption Capacity and Biological Activity of Biological Activated Carbon Filters in Drinking Water Treatment. ETH Zürich. Switzerland. URL: https://doi.org/10.3929/ethz-a-005820821

Practical manual for O&M of GAC filter systems:

→ Siemens (2011): Operation and Maintenance Manual for GAC Adsorption System. Siemens Industry Inc. USA. URL: https://legacy.azdeq.gov/environ/waste/sps/download/Appendix_A_RID_Well_Site%2095.pdf

GAC operation:

→ Vahala, R. (2002): Two Step Granular Activated Carbon Filtration in Drinking Water Treatment. Helsinki University of Technology. Finland. URL: http://www.elaguapotable.com/Filtraci%C3%B3n%20por%20GAC%20en%20dos%20etapas%20%20.pdf

T.14 Ozonation

General information on ozonation:

→ Edtzwald, J. K. (Ed.) (2011): Water Quality and Treatment: A Handbook on Drinking Water, Sixth Edition. American Water Works Association. USA

→ Oram, B. (undated): Ozonation in Water Treatment. Water Research Center. URL: https://www.water-research.net/index.php/ozonation

→ LeChevallier, M.W., Au, K. (Eds.) (2004): Inactivation (Disinfection) Processes. In: WHO: Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. IWA Publishing. London. UK. URL: https://www.who.int/water_sanitation_health/water-quality/guidelines/en/watreatpath3.pdf

→ Mazille, F., Spuhler, D. (undated): Factsheet Ozonation. Sustainable Sanitation and Water Management Toolbox (SSWM). URL: https://sswm.info/sswm-university-course/module-6-disaster-situations-planning-and-preparedness/further-resources-0/ozonation

Fundamentals of ozonation and other advanced oxidation processes:

→ Stefan, M. (2018): Advanced Oxidation Processes for Water Treatment. Fundamentals and Applications. IWA Publishing

Overview of water disinfection processes:

→ LeChevallier, M.W., Au, K. (Eds.) (2004): Inactivation (Disinfection) Processes. In: WHO: Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water. IWA Publishing. London. UK. URL: https://www.who.int/water_sanitation_health/water-quality/guidelines/en/watreatpath3.pdf

T.15 Nanofiltration (NF) / Reverse Osmosis (RO)

Practical manual for operation of RO and NF systems:

→ American Water Works Association (2007): Reverse Osmosis and Nanofiltration. AWWA Manual M46. USA. URL: https://www.awwa.org/portals/0/files/publications/documents/m46lookinside.pdf

Overview of membrane desalination technologies:

→ AMTA (undated): Water Desalination Processes. American Membrane Technology Association (AMTA). USA. URL: https://www.amtaorg.com/Water_Desalination_Processes.html

Overview of RO and NF membranes:

→ Yang Z., et al (2019): A Review on Reverse Osmosis and Nanofiltration Membranes for Water Purification Polymers 11(8). ResearchGate. URL: https://www.researchgate.net/publication/334756274_A_Review_on_Reverse_Osmosis_and_Nanofiltration_Membranes_for_Water_Purification

D.1 Household Water Container

Review of household container types with suitability for transport and storage:

→ Sobsey, M.D. (2002): Managing Water in the Home: Accelerated Health Gains from Improved Water Supply. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/dwq/WSH02.07.pdf

Overview of household containers for transport and storage, including cleaning containers in emergencies:

→ Staveley, L. (2007): Household Water Treatment and Storage. Oxfam. Oxford. UK. URL: https://policy-practice.oxfam.org.uk/publications/household-water-treatment-and-storage-126715

D.2 Water Vendor Cart

General information on water vendors:

→ Kjellen, M, McGranahan, G. (2006): Informal Water Vendors and The Urban Poor. International Institute for Environment and Development. London. UK. URL: https://sswm.info/sites/default/files/reference_attachments/KJELLEN%20&%20MCGRANAHAN%202006%20Informal%20Water%20Vendors%20and%20the%20Urban%20Poor.pdf

→ World Bank (2017): Informal Water Markets in an Urbanising World. World Bank. Washington D.C. USA. URL: http://documents.worldbank.org/curated/en/358461549427540914/Informal-Water-Markets-in-an-Urbanising-World-Some-Unanswered-Questions.pdf

D.3 Water Trucking

Overview of organising trucking in an emergency, also how to assess roads and bridges:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Summary of tanker disinfection procedures:

→ Godfrey, S., Reed, B. (2013): Cleaning and Disinfecting Water Storage Tanks and Tankers. Technical Notes on Water, Sanitation and Hygiene in Emergencies. WEDC. Loughborough. UK. URL: https://www.who.int/water_sanitation_health/emergencies/WHO_TN_03_Cleaning_and_disinfecting_water_storage_tanks_and_tankers.pdf?ua=1

Comprehensive review of formal and informal water kiosks in African cities, including those that rely on trucking:

→ Keener, S., Luengo, M., Banerjee, S. (2010): Provision of Water to the Poor in Africa: Experience with Water Standposts and the Informal Water Sector. Policy Research Working Paper. World Bank. Washington D.C. USA. URL: http://documents.worldbank.org/curated/en/421921468191675047/pdf/wps5387.pdf

Key considerations for water trucking:

→ Reed, B. (2013): Delivering Safe Water by Tanker. Technical Notes on Water, Sanitation and Hygiene in Emergencies. WEDC. Loughborough. UK. URL: https://www.who.int/water_sanitation_health/emergencies/WHO_TN_12_Delivering_safe_water_by_tanker.pdf?ua=1

D.4 Water Kiosk

Overview of water vendors:

→ Kjellen, M, McGranahan, G. (2006): Informal Water Vendors and the Urban Poor. International Institute for Environment and Development. London. UK. URL: http://www.sswm.info/sites/default/files/reference_attachments/KJELLEN%20&%20MCGRANAHAN%202006%20Informal%20Water%20Vendors%20and%20the%20Urban%20Poor.pdf

Review of literature on water vendors including water quality and cost to the poor:

→ World Bank (2017): Informal Water Markets in an Urbanising World. World Bank. Washington D.C. USA. URL: http://documents.worldbank.org/curated/en/358461549427540914/Informal-Water-Markets.docx

Comprehensive review of formal and informal water kiosks in African cities:

→ Keener, S., Luengo, M., Banerjee, S. (2010): Provision of Water to the Poor in Africa: Experience with Water Standposts and the Informal Water Sector. Policy Research Working Paper. World Bank. Washington D.C. USA. URL: http://documents.worldbank.org/curated/en/421921468191675047/pdf/wps5387.pdf

Review of subsidised water kiosks for extending water provision in Zambian context:

→ GTZ (2009): Water Kiosks. How the Combination of Low-Cost Technology, Pro-Poor Financing and Regulation Leads to the Scaling Up of Water Supply Service Provision to the Poor. GTZ. Eschborn. Germany. URL: https://sswm.info/sites/default/files/reference_attachments/GTZ%202009%20CaseStudy_WaterKiosks.pdf

D.5 Water Kiosk

Explanation of reservoir sizing:

→ Arnalich, S. (2010): Gravity Flow Water Supply: Conception, Design and Sizing for Cooperation Projects. Scribd. URL: https://www.scribd.com/doc/46026759/Gravity-Flow-Water-Supply

Overview of tanks in emergency context, incl. design of elevated tanks to withstand wind pressure:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Overview of reservoir design:

→ World Bank (2012): Rural Water Supply Design Manual Volume 1. Water Partnership Program. World Bank. Philippines. URL: http://siteresources.worldbank.org/INTPHILIPPINES/Resources/RWS-VolIDesignManual.pdf

D.6 Water Storage Tank (Long-Term Locally Built)

Explanation of reservoir sizing:

→ Arnalich, S. (2010): Gravity Flow Water Supply: Conception, Design and Sizing for Cooperation Projects. Scribd. URL: https://www.scribd.com/doc/46026759/Gravity-Flow-Water-Supply

Overview of tanks in emergency context, incl. design of elevated tanks to withstand wind pressure:

→ Davis, J., Lambert, R. (2002): Engineering in Emergencies: A Practical Guide for Relief Workers. Second Edition. IT. London, UK

Overview of storage tank components and reservoir design:

→ Jordan, T.D. (1980): A Handbook of Gravity-Flow Water Systems. IT. London. UK. URL: https://archive.org/details/fa_Handbook_of_Gravity-Flow_Water_Systems

→ World Bank (2012): Rural Water Supply Design Manual Volume 1. Water Partnership Program. World Bank. Philippines. URL: http://siteresources.worldbank.org/INTPHILIPPINES/Resources/RWS-VolIDesignManual.pdf

D.7 Water Storage Tank (Long-Term Locally Built)

Explanation of gravity flow systems and detailed worked example:

→ Arnalich, S. (2009): How to design a Gravity Flow Water System through worked exercises. Scribd. URL: https://www.scribd.com/doc/35189494/How-to-design-a-Gravity-Flow-Water-System

Overview of gravity systems:

→ Arnalich, S. (2010): Gravity Flow Water Supply: Conception, Design and Sizing for Cooperation Projects. Scribd. URL: https://www.scribd.com/doc/46026759/Gravity-Flow-Water-Supply

→ WaterAid (2013): Gravity-Fed Schemes. Technical Brief. WaterAid. UK. URL: https://www.wateraid.org/uk/publications/gravity-fed-schemes-technical-brief

Detailed design guide for gravity systems:

→ Jordan, T.D. (1980): A Handbook of Gravity-flow Water Systems. IT. London. UK. URL: https://archive.org/details/fa_Handbook_of_Gravity-Flow_Water_Systems

Explanation of hydraulics, main components in distribution and pumping:

→ World Bank (2012): Rural Water Supply Design Manual Volume 1. Water Partnership Program. World Bank. Philippines. URL: http://siteresources.worldbank.org/INTPHILIPPINES/Resources/RWS-VolIDesignManual.pdf

D.8 Large-Scale Distribution System

Overview of gravity systems, including design of larger systems:

→ Arnalich, S. (2010): Gravity Flow Water Supply: Conception, Design and Sizing for Cooperation Projects. Scribd URL: https://www.scribd.com/doc/46026759/Gravity-Flow-Water-Supply

Detailed technical guide for design and analysis of larger-scale distribution systems:

→ Swamee, P.K., Sharma, A.K. (2008): Design of Water Supply Pipe Networks. John Wiley & Sons. New Jersey. USA. URL: http://de.slideshare.net/KimiaStore/design-of-water-supply-pipe-networks

Explanation of hydraulics, main components in distribution and pumping:

→ World Bank (2012): Rural Water Supply Design Manual Volume 1. Water Partnership Program. World Bank. Philippines. URL: http://siteresources.worldbank.org/INTPHILIPPINES/

→ WHO (undated): International Scheme to Evaluate Household Water Treatment Technologies. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/water-quality/household/scheme-household-water-treatment/en/

H.1 Safe Water Storage

WHO scheme to evaluate household water treatment technologies:

→ WHO (2016): Results of Round I of the WHO International Scheme to Evaluate Household Water Treatment Technologies. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/publications/hwt-scheme-round-1-report.pdf?ua=1

→ WHO (2019): Results of Round II of the WHO International Scheme to Evaluate Household Water Treatment Technologies. WHO. Geneva. Switzerland. URL: https://www.who.int/water_sanitation_health/publications/results-round-2-scheme-to-evaluate-houshold-water-treatment-tech/en/

Decision support on selecting HWTS:

→ Bivins, A., Beetsch, N., Majuru, B., Montgomery, M., Sumner, T., and Brown, J. (2019): Selecting Household Water Treatment Options on the Basis of WHO Performance Testing Protocols. Environmental Science and Technology. 53(9), 5043-5051.

Basic information on household water treatment and safe storage:

→ CAWST (2017): Introduction to Household Water Treatment and Safe Storage (HWTS). CAWST. Calgary. Canada URL: https://resources.cawst.org/technical_brief/1ba4f3fd/introduction-to-household-water-treatment-and-safe-storage-hwts

Illustrated field manual on water treatment and storage in emergencies:

→ IFRC (2008): Household Water Treatment and Safe Storage in Emergencies. IFRC. Geneva. Switzerland. URL: https://www.ifrc.org/Global/Publications/disasters/142100-hwt-en.pdf

Overview of household containers for transport and storage, including cleaning containers in emergencies:

→ Staveley, L. (2007): Household Water Treatment and Storage. Oxfam. Oxford. UK. URL: https://policy-practice.oxfam.org.uk/publications/household-water-treatment-and-storage-126715

Technical brief on household water treatment and storage:

→ Oxfam (n.d.): Household Water Treatment and Storage. Oxfam. Oxford. UK. URL: https://oxfam.app.box.com/s/bdib89mduefrdpj0umfh0uxrwtdq75y7

H.2 Handwashing Facility

Challenges and practices for handwashing in emergencies:

→ Ramos, M. et al. (2016): WASH in Emergencies: Problem Exploration Report Handwashing. Humanitarian Innovation Fund. London. UK. URL: https://globalhandwashing.org/wp-content/uploads/2019/03/Handwashing-WASH-Problem-Exploration-Report.pdf

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→ Reed, B., Bevan, J. (2014): Managing Hygiene Promotion in WASH Programmes. WEDC. Loughborough University. UK. URL: https://wedc-knowledge.lboro.ac.uk/resources/booklets/G013-Hygiene-promotion-booklet.pdf

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The Compendium of Water Supply Technologies in Emergencies offers a comprehensive and structured manual and planning guide on available water supply technology options in humanitarian settings. It disaggregates technologies into their functional components, clarifies terminology and provides guidance for identifying the most appropriate water supply technology solutions in a given context and for all relevant response phases of an emergency.
The document is primarily a capacity building tool and reference book that supports decision making when designing a water supply system. It offers concise information on key decision criteria for each technology and facilitates the combination of technologies to come up with full technical water supply system solutions. It also links the technologies to relevant cross-cutting issues and further resources.
The development of the compendium has been a collaborative effort of the German WASH Network and the University of Applied Science and Arts Northwestern Switzerland, together with Global WASH Cluster (GWC) partners and contributions from a multitude of international WASH experts and organisations.
It is the second volume of the 'Emergency WASH Compendium' series, following the already existing Compendium of Sanitation Technologies in Emergencies. A third volume focusing on Hygiene Promotion in Emergencies will follow.

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