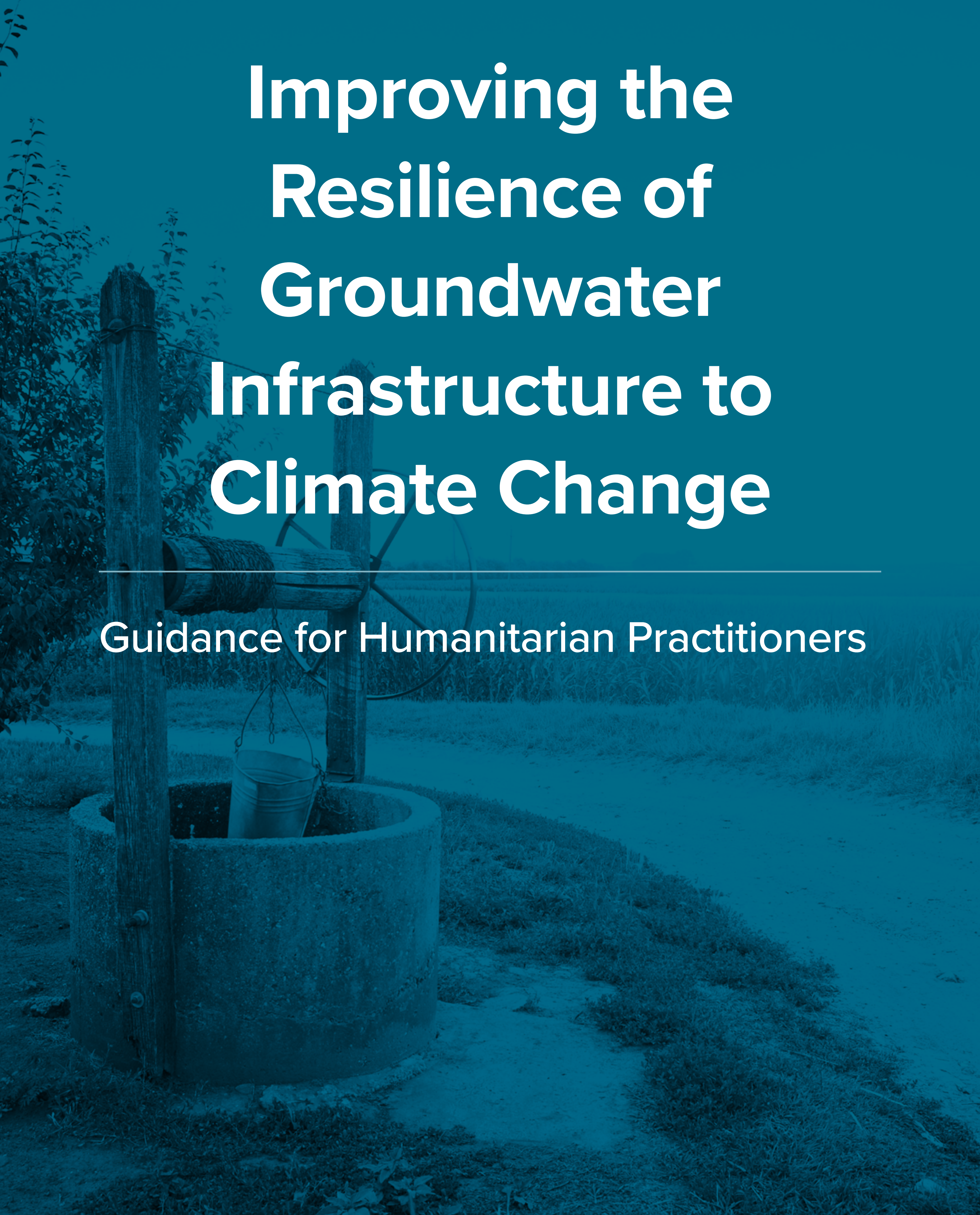
GUIDANCE NOTE 5

Improving the Resilience of Groundwater Infrastructure to Climate Change

Guidance for Humanitarian Practitioners



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Abbreviations

ACF	Action Contre la Faim
ASAL	Arid and Semi-Arid Land
DWL	Dynamic Water Level
EC	Electrical Conductivity
EM	Electromagnetic Surveys
GRI	Global Resilience Index
IDP	Internally Displaced People
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resource Management
MAR	Managed Aquifer Recharge
NAP	National Adaptation Plan
NGOs	Non-Governmental Organisations
PWL	Pumping Water Level
RCP	Representative Concentration Pathway
SIDS	Small Island Developing States
SPI	Standardized Precipitation Index
SWL	Static Water Level
TDH	Total Dynamic Head
TDS	Total Dissolved Solids
WHO	World Health Organization
WRI	World Resources Institute

Citation

Rygus, M (2025). Improving the Resilience of Groundwater Infrastructure to Climate Change. Guidance for Humanitarian Practitioners. Oxfam. Oxford.

Acknowledgements

This report was funded by the German Federal Foreign office. It was written by Michelle Rygus at Groundwater Relief (GWR) with contributions from Hannah Ritchie (GWR member) and support from Nick Mannix and Geraint Burrows at GWR, and from Andy Bastable, Oxfam.

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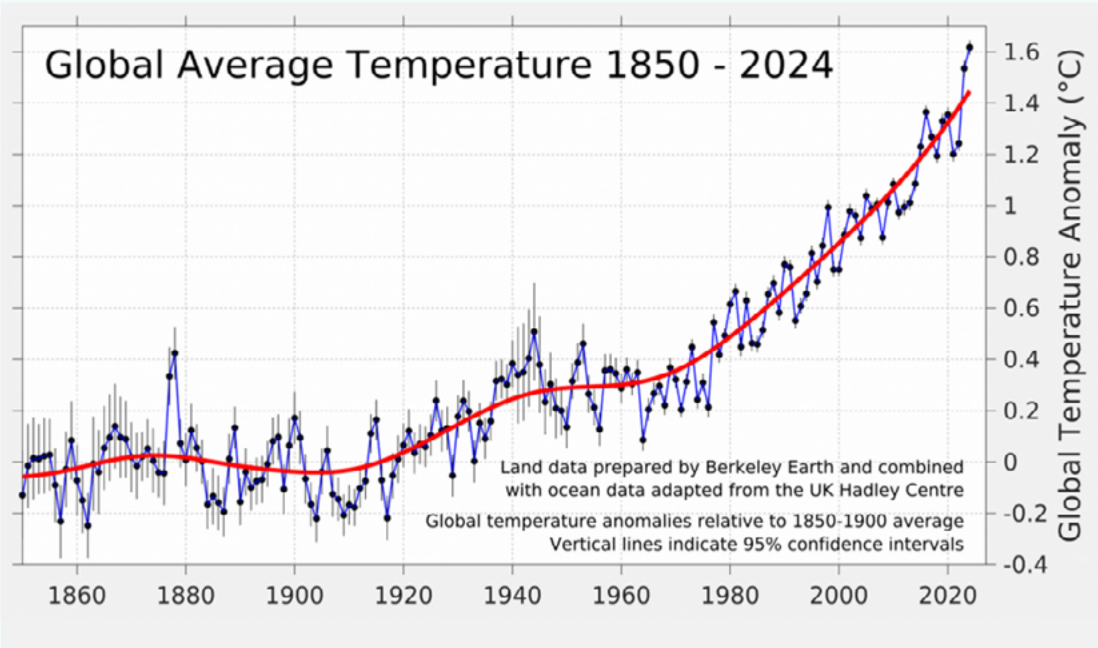
Cover Image: Creaturart Images | Shutterstock

Introduction

Why this guidance?

Our world is experiencing significant climatic shifts. Global temperatures have risen by approximately 1.5°C since pre-industrial times (World Meteorological Organization, 2024), leading to a chain of effects on our water systems.

Figure 1: Global annual temperature anomaly.



Source: Global Temperature Report for 2024 - Berkeley Earth[5]

We are witnessing melting sea ice, an average sea-level rise of about 3.6 mm per year over the period from 2006 to 2015 (Intergovernmental Panel on Climate Change (IPCC), 2022), and shrinking snowpacks that are melting earlier, reducing freshwater availability in many river basins. Rainfall patterns are becoming more erratic, with regions facing either too much rain or extended periods of drought. Furthermore, the frequency and severity of extreme events like storms, floods, and wildfires are on the rise.

In this context, groundwater is becoming an increasingly vital resource. Its vast natural underground storage capacity offers a critical buffer against the impacts of climate change on surface water supplies, supporting both direct water consumption and essential food production.

However, the infrastructure we build to access this groundwater is not immune to climatic challenges. Like any other investment, groundwater systems must be designed and constructed to withstand the growing threats of more frequent and severe floods and droughts, which are impacting vast areas across the globe.

This guidance provides practical, field-oriented strategies for new facilities and for retrofitting existing infrastructure to ensure that groundwater infrastructure is resilient and capable of continuing to provide water even during extreme climate events.

Who is this guidance for?

This document is designed for WASH practitioners involved in planning, designing, and constructing groundwater infrastructure, as well as government agencies, Non-Governmental Organisations (NGOs), and humanitarian organisations working to improve rural water supply in climate-vulnerable areas.

Figure 2: A WASH practitioner collecting water samples from a borehole for water quality analysis in Zimbabwe.

Photo: Njanike (2024). Image quality enhanced with Nano Banana Pro

Scope

This guidance is about the design and construction of climate-resilient groundwater infrastructure. The focus is mainly boreholes, but there is a consideration of dug wells and springs in flood or drought-prone areas, to ensure sustainable water access.

It is divided into four sections:

1. **Understanding the context: Climate Change and Groundwater:** this section provides the background for how climate change impacts groundwater resources, highlighting the need for resilient solutions.
2. **Siting Climate Resilient Groundwater Infrastructure:** pre-construction assessments are described to aid the selection of suitable locations for new groundwater infrastructure in flood or drought-prone areas.
3. **Design and Construction of Climate Resilient Groundwater Infrastructure:** this section offers practical strategies for developing new boreholes, dug wells, and springs as well as measures for rehabilitating existing infrastructure to become resilient to climate extremes.
4. **Sustainable Water Resource Management:** broader strategies for sustainably managing groundwater resources are covered (e.g., monitoring, allocation, protection) in areas significantly affected by climate change.

This guidance does not seek to replicate the many existing best-practice documents on groundwater development (e.g., borehole drilling techniques). Instead, it aims to enhance them by adding specific, climate-resilient measures for floods and droughts, while referencing key technical resources throughout.

1 Understanding the Context: Climate Change and Groundwater

1.1 Groundwater and Climate Change

Groundwater, accounting for approximately 99% of all liquid freshwater on Earth, provides social, economic and environmental benefits to society, including adaptation to climate change (UNESCO, 2020). Because aquifers store vast volumes of water accumulated over years, decades, or even millennia, they are comparatively more resilient to climate variability than surface water systems.

Climate change impacts groundwater by amplifying climate extremes such as droughts and floods. Often, these extremes occur in the same area (referred to as 'weather whiplash'), where there are rapid swings between extremes in weather. As a result, WASH practitioners implementing new or rehabilitating existing groundwater infrastructure may need to consider both the impact of droughts and floods within the same area.

Climate change impacts groundwater resources directly, by altering the water balance, and indirectly, through increased human demand (UNESCO, 2020).

Direct impacts:

Precipitation and Evapotranspiration: climate change is causing an intensification of precipitation, resulting in fewer light rainfall events and more frequent, heavy precipitation. Heavy rain events can enhance groundwater recharge, especially in drylands. However, rising temperatures also increase evapotranspiration, which can limit the amount of water available to replenish groundwater

Ice, Snow, and Permafrost: in colder regions, altered snowmelt patterns are reducing the duration and amount of seasonal recharge, worsening low summer flows. Thawing permafrost is also creating new groundwater pathways, increasing the connection between aquifers and surface water

Sea Level Rise and Salinisation: global sea-level rise causes saltwater intrusion into coastal aquifers and contaminates freshwater supplies, posing the greatest threat to low-lying deltas and Small Island Developing States (SIDS). The extent of saltwater intrusion is often accelerated by intensive groundwater pumping, which lowers water tables more significantly than sea-level rise alone

Groundwater Quality: climate extremes directly degrade groundwater quality. Intense rainfall can flush contaminants, like pathogens and nitrates, from the surface into aquifers, especially in areas with poor sanitation. In contrast, droughts can cause the concentration of solutes like arsenic and nitrate in shallow aquifers due to increased evaporation and reduced dilution from recharge.

Indirect Impacts:

An increased demand for water, particularly for irrigation, in response to rising temperatures and less reliable surface water, is often the greatest impact of climate change. The increased pumping can lead to groundwater depletion, threatening environmental flows and long-term water security

Understanding the impact of climate extremes (droughts and floods) is critical for designing and managing resilient groundwater infrastructure that can withstand periods of water scarcity while protecting water quality during extreme rainfall events.

1.2 Impact of Flooding on Groundwater

Flooding affects both the quantity and quality of groundwater resources.

Figure 3: A flooded borehole being used to wash clothes in Laguna district, Philippines, Oct 2009.

Photo: Geraint Burrows. Image quality enhanced with Nano Banana Pro

1.2.1 Groundwater Quantity

Flooding can significantly impact the availability of fresh water for affected populations by cutting off access, contaminating or putting existing water points out of action.

Flooding can also enhance groundwater recharge by increasing the rate of infiltration. The volume of additional recharge will depend on various factors, including the flood's duration, the soil's infiltration capacity, and the presence of impermeable surfaces.

In areas with permeable rocks, the rising water table may intercept subsurface infrastructure or even breach the ground surface - a phenomenon known as groundwater flooding. In contrast with transient surface floods, this type of flooding is often not tied to a specific rainfall event and can persist for weeks, or even months.

1.2.2 Groundwater Quality

Flood waters are often highly contaminated. Floodwater can enter unprotected or damaged wells and boreholes, directly transporting pollutants into the aquifer. Stagnant floodwater can persist as a long-term source of pollution.

In addition, heavy rainfall and increased surface flooding can enhance the downward flux of chemicals, suspended solids, and pathogens, while rapid infiltration through fractures or karst systems (for example, through pre-existing conduits and sinkholes found in soluble bedrock) can bypass natural filtration. Sediment mobilisation during floods may introduce geogenic contaminants (substances like arsenic and fluoride that are naturally found in local rocks and soil).

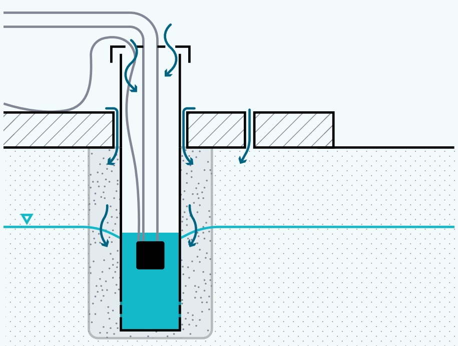
1.2.3 Vulnerability of Groundwater Infrastructure to Floods

Floods pose a significant threat to the safety and reliability of groundwater sources. The primary risk is microbiological contamination when floodwaters, often carrying pathogens and pollutants, infiltrate the water source (Rambags et al., 2011).

Floodwater typically enters boreholes or wells through two main pathways:

- **Direct short-circuiting:** water enters directly through openings in the wellhead (e.g., gaps around pumps, cables or measurement access points) or cracks in the apron/platform
- **Annular space infiltration:** water seeps down the outside of the casing through the gap between the casing and the borehole wall (the annulus), especially if the sanitary seal is inadequate, damaged, or non-existent. Cracks or faulty joints in the casing itself can also allow ingress

Figure 4: Vulnerable locations allowing the direct entry of flood water into wells without flood-protection measures.



- Non-watertight wellhead with openings for cable feedthrough and water-level measurements
- Cracks and fissures in the concrete structure
- Insufficient sealing of the annular space of the wellbore

Source: Adapted from Musche et al. (2018) by Ibex Ideas (2025)

1.3 Impact of Drought on Groundwater

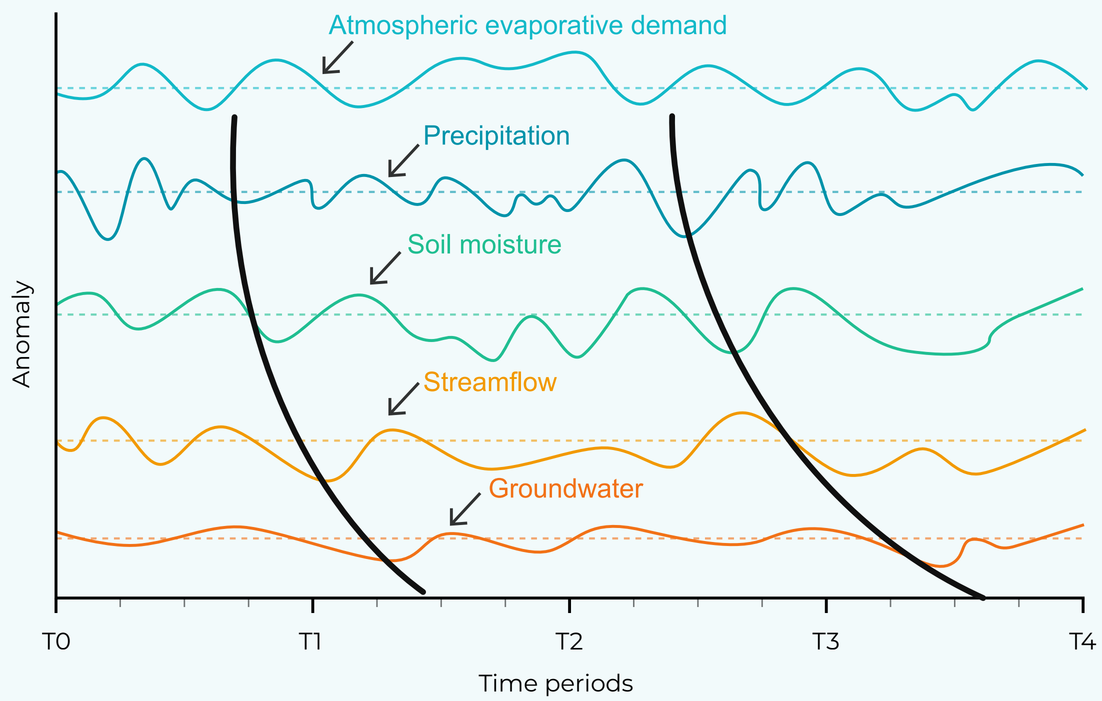
1.3.1 Groundwater Quantity

Climate change is intensifying aridity in many regions, leading to reduced infiltration and a consequent decline in groundwater recharge. Extended periods of drought result in a gradual decline in groundwater levels as diminished precipitation and reduced surface water contributions lower the recharge rates of aquifers.

Prolonged droughts can lead to declining water levels, reduced yields, increased stress on pumping systems, and potential water quality degradation. If the water table falls below the point of its intake, the water point will fail, leading to increased hardship for communities and greater pressure on remaining functional sources.

A critical component of groundwater behaviour during drought is the time lag between changes in precipitation and the subsequent response in groundwater levels (Figure 5) and well yields. Unlike surface water sources, which typically respond quickly to fluctuations in precipitation, groundwater systems exhibit delayed responses, often taking months or even years, to reflect altered recharge conditions.

Figure 5: Illustration of drought propagation from precipitation deficits (meteorological drought), which may be accompanied by increased atmospheric evaporative demand, to soil moisture deficits (agricultural drought), low streamflow, or groundwater level.



Source: Adapted from Zhang et al. (2022) by Ibex Ideas (2025)

The time lag between a meteorological drought (prolonged reduced rainfall) and its impact on groundwater sources depends on several factors (Robins et al., 1997), including:

- **The severity and duration of the drought:** longer periods of little or no recharge are more likely to reduce groundwater levels and affect well and borehole yields
- **The design and location of the groundwater extraction point:** shallow groundwater resources are more vulnerable to drought than deeper ones. Extraction points, such as shallow, hand-dug wells, are more sensitive to decreases in rainfall and recharge compared to deeper boreholes, which tap into more stable water reserves
- **The physical characteristics of the aquifer**, particularly its storage capacity, are important determinants. For instance, shallow, unconsolidated aquifers, such as the alluvial sediments often found in valley centres, are more directly connected to rainfall and surface water processes; this can make them more sensitive to short-term changes in surface conditions. In contrast, deeper basement aquifers store water in variable fractures and weathered zones; their weaker, slower connection to surface recharge makes them less immediately responsive to drought
- **Increased abstraction or demand:** during drought, other sources of water may be reduced, leading to increased reliance on groundwater. This surge in demand can result in over-pumping and exacerbate drought effects (Taylor et al., 2013), increasing competition for water resources and potentially sparking conflicts among different users. Fluctuations in demand may occur in the short term, such as when neighbouring wells dry up, or over the longer term, in response to factors like population growth and economic change

Moreover, declining groundwater levels due to drought can trigger cascading effects (one negative impact leads to another) - such as reduced streamflow undermining surface water availability and ecosystem health. Additionally, the extraction-induced lowering of water tables can contribute to land subsidence, which in turn may damage infrastructure and further disrupt water resources.

1.3.2 Groundwater Quality

Drought-induced reductions in groundwater recharge can lead to declining water quality, primarily through increased salinity.

In coastal regions, reduced recharge lowers freshwater levels, allowing seawater to intrude into aquifers (Dao et al., 2024).

In inland and semi-arid regions, increased irrigation and high evaporation rates can lead to soil salinisation and increasingly saline shallow groundwater.

Under drought conditions, less water is available to dilute contaminants, so more extreme droughts may lead to higher concentrations of contaminants in aquifers. This can result in increased contaminant concentrations at water points (Ascott et al., 2022).

1.3.3 Building in drought resilience to groundwater infrastructure

Ensuring water point resilience in drought-prone areas requires a proactive approach, focusing on careful site selection, appropriate design and construction, efficient water abstraction, and robust monitoring and maintenance strategies. Table 1 provides an overview of drought impacts on different types of groundwater infrastructure (i.e., boreholes, dug wells, and springs).

Table 1: Overview of drought impacts on different types of groundwater infrastructure.

Infrastructure Type: Boreholes	
Effects of drought	• Groundwater levels dropping • Subsidence & damage to infrastructure • Pumping systems need lots of maintenance = expensive = sometimes not repaired • Pumps & handpumps break down • Increased salinisation due to seawater intrusion • Environmental degradation around waterpoints due to livestock

Underlying causes of the effects	• Less recharge of aquifer due to reduced rainfall • Increasing population & water demand • Size of aquifers is limited • Unsustainable extraction of groundwater causing land subsidence • Over-pumping at congested water points (increased stress on individual sources as other sources run dry. Prolonged pumping throughout the day can also put considerable strain on the pump mechanism) • Lack of cash for community-level repairs • Communal system of maintenance & issue of spare parts
Overview of techniques to increase resilience	• Correct borehole siting (i.e., plan, install and test new borehole installations under the supervision of a suitably qualified and experienced hydrogeologist to ensure appropriate design for long-term sustainable abstraction for the local aquifer system) • Water level monitoring • Stop drilling in areas where saline groundwater is a problem • Drill deep enough at the start • Deepen existing boreholes • Reduce water demand and promote efficient water use • Find alternative water sources (e.g., pump water to a storage tank or reservoir when water availability is good to buffer peak demand/limited water availability) • Improve regional coordination between water providers • Link problem to Integrated Water Resource Management (IWRM) approaches

Infrastructure Type: Dug wells	
Effects of drought	• Can dry up • Groundwater levels dropping in perched aquifers
Underlying causes of the effects	• Less recharge of aquifer due to reduced rainfall • Increasing population & water demand • Size of aquifers is limited – e.g., perched aquifers will be used up faster • Wells not sunk deep enough into water table
Overview of techniques to increase resilience	• Avoid perched aquifers • Dig wells deeper – de-water well during caissoning within the water table • Allow for subsequent deepening by using a telescopic lining • Dig wells during the latter half of the dry season • Jet in the bottom of the well to provide a means of faster recharge • Pump water to storage tank / reservoir during times of good water availability to buffer peak demand / limited water availability) • Increase flow by use of porous concrete or perforated pointed steel pipes driven horizontally into the aquifer

Infrastructure Type: Springs	
Effects of drought	• Can dry up

Underlying causes of the effects	• Less recharge of aquifer due to reduced rainfall • Size of aquifers is limited • Increasing population & water demand
Overview of techniques to increase resilience	• Improve flow by excavating carefully at the spring eyes (natural exit point) • Construct a holding reservoir to bridge peak demand, or a lined pond to store larger quantities throughout the hours of flow • Design for dry season flow rates

2 Siting Climate-Resilient Groundwater Infrastructure

The success and long-term viability of an improved groundwater supply hinges on proper siting. As illustrated in Figure 6, proper siting of water points requires a detailed analysis of several interconnected factors:

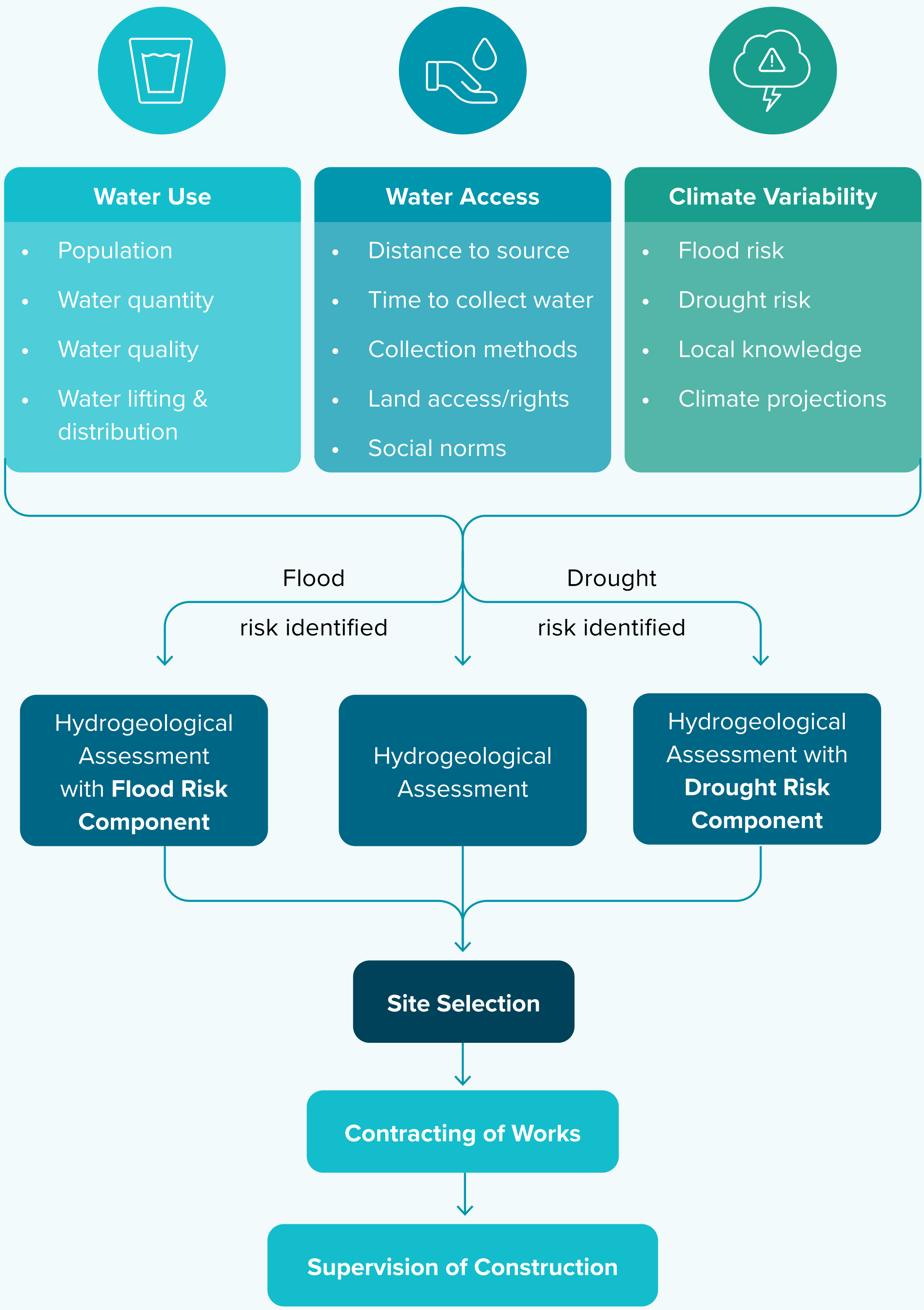
Water Use: the intended purpose of the well must be clearly defined, and both domestic and production needs must be considered. This includes understanding the target population, the required water quantity and quality, and the planned methods for water lifting and distribution

Water Access: the physical and social access of the community to the water point site is critical. It requires an assessment of the distance to the source, the time taken to collect water, existing collection methods, and local social norms. Practical considerations, like land ownership and access for construction equipment, must also be addressed

Climate Risks: to ensure the resilience of the water source over the long term, potential climate impacts must be assessed, including conducting flood and/or drought hazard assessments, incorporating local knowledge of past events, and considering scientific climate projections

Groundwater Availability: to determine the potential and reliability of groundwater resources, a hydrogeological assessment is necessary to establish a conceptual understanding of the local aquifer system. This involves defining the aquifer's physical characteristics, quantifying its capacity for groundwater storage, and understanding its dynamics, including groundwater flow paths, recharge (inflow), and discharge (outflow) zones. A clear understanding of these storage and flow components is fundamental to estimating how much water can be sustainably extracted. Combining this scientific approach with local knowledge provides a robust picture of resource availability

Figure 6: Components to consider when selecting a site for groundwater development.



Source: Adapted from author's figure by © Ibex Ideas (2025)

2.1 Water Access

A key component of siting new groundwater infrastructure is ensuring that the source is accessible to the community and its different households. Consider the following components to identify a suitable location:

Community Engagement and Land Rights	**Securing community buy-in and clear land rights is critical to avoid future conflicts** • Reach an agreement on a new water point location: this involves negotiating a compromise between technical limitations and community preferences • Prioritise the needs of women, who are often the primary water collectors • Consider land ownership and access issues before construction. Formal, written agreements may be necessary to guarantee public access to the water point and prevent disputes with landowners
Proximity to Users	**Whenever possible, locate the water point as close to the users as possible** • A closer water point minimises walking distances for those collecting water and reduces energy costs for electric or fuel-driven pumps and piped supplies • Conduct walkover surveys and interview households to understand the community layout and location preferences. Key questions related to water source/ accessibility are provided in Box 1 • Site water points away from potential sources of pollution (see Box 5)
Vehicle and Equipment Access	**The chosen site must be accessible for both construction and future repairs.** • Ensure there is a clear path for heavy machinery like drilling rigs, compressors, and support vehicles

Box 1: Key water source and accessibility questions

- What is the primary (preferred) source of drinking water for your household?
- What is your second choice source of drinking water if your first choice source is unavailable?
- When was the last time the primary source became unavailable and for what reason?
- How long (in minutes) does it take to go to the water source for drinking purposes, get water and come back (including wait time)?
- How many trips to collect water for drinking purposes are made per day in total?
- What containers do you use to collect the water?
- Have you experienced any of the following water problems in the last month? Bad taste, discolouration, objects in the water, water made me/my family sick
- Has your water access been affected by any of the following? Flood, drought, conflict, cost
- What is the primary way that your household treats your drinking water?

2.2 Water Use

Before selecting a groundwater supply site, determine who will use the water, how much they need, and how it will be delivered. The intended use directly affects the selection of the best location for new groundwater infrastructure. Considerations for different types of groundwater supply are provided below:

Rural Handpumps

- ✔ Ensure the location is physically accessible to everyone, including women, children, the elderly, and people with disabilities
- ✔ Use participatory community meetings to make siting decisions. This prevents influential individuals from locating the well for their private convenience. To actively support vulnerable populations, consider placing the well in a lower-income area

Motorised Pumps with Piped Systems

- Site the well near the majority of users to reduce piping and pumping expenses
- The location must be near a reliable power supply or be easily accessible for fuel deliveries and maintenance crews
- If the system includes public standposts, apply the same fairness and accessibility principles as for handpumps

Small Towns and Camps

- Towns: high water demand and the risk of urban contamination mean well fields should be located outside of town, where aquifers are higher-yielding and cleaner. Water is then piped to consumers
- Refugee or Internally Displaced People's (IDP) Camps: population density is high, but the daily water amounts allotted are typically lower. Wells can potentially be sited closer to users, due to the temporary nature of the settlements, but this increases the risk of contamination over time, requiring careful monitoring

Abstraction requirements also need to be assessed. These are often calculated using Sphere minimum standards (Sphere Handbook). Table 2 provides rough estimates of the daily water abstraction depending on the type of settlement to be served.

Table 2: Well or borehole yield and use (Carter, 2021).

Well or borehole yield (l/s)	Abstraction and use	Typical volume pumped (m^3/d)	Number of people served (domestic supply)
0.1–0.3	Communal handpump for domestic use	3–8	200–500*
1.0–5.0	Petrol, diesel, or solar pump for rural or small town supply	30 150	300–600** 1500***

5.0	Pumping solely for irrigation	150	Approx. 3 ha irrigated#

* Assuming per capita consumption of 15 litres per day

** Assuming per capita consumption of 50–100 litres per day

*** Assuming per capita consumption of 100 litres per day

Assuming crop water requirement of 5 mm per day

Note: Estimates assume eight hours of pumping per day.

2.3 Climate Variability

A preliminary analysis to guide fieldwork and planning can be carried out using free, online tools based on scientific models, which provide information about the flood and/or drought risk in the area of interest.

Access global flood/drought hazard mapping tools:

- Navigate to established global hazard mapping websites (refer to Table 3 for useful resources)

For Flood-Prone Areas:

- Identify flood type and hazard level: the tools will clearly state the risk level for ’Riverine flood’ and ’Coastal flood’, generating an immediate understanding of the primary threats
- Examine inundation depth and extent: assess the projected flood severity, extent, and inundation depth. For example, using the World Resources Institute (WRI) Aqueduct Global Flood Analyzer, the project’s flood magnitude and inundation depth can be viewed in different timeframes and climate scenarios. The projected inundation depth is important for deciding how high to raise the apron of a borehole or well, while the extent is important for deciding on borehole/well placement (refer to Flood-Resilient Boreholes)

For Drought-Prone Areas:

- Look at the overall drought risk score, which combines the likelihood of drought with the vulnerability of the population
- Examine historical drought indicators, such as the Standardized Precipitation Index (SPI). The SPI is widely used to assess the impact of meteorological droughts on water resources. A history of frequent or severe negative SPI values indicates recurring meteorological droughts that could affect groundwater recharge

Table 3: Useful resources to help identify climate hazards.

Resource	Description
World Bank's Climate Risk Country Profiles	Country-specific profiles summarising climate risks, vulnerabilities, and adaptation strategies.
IPCC Interactive Atlas	Interactive maps and data on climate change projections.
World Resources Institute Aqueduct Global Flood Analyzer	A tool to analyse flood risks globally and assess potential impacts of flooding on populations, economies, and infrastructure.
Global Resilience Index Risk Viewer	A range of indicators to assess the severity, frequency, and potential impacts of water scarcity (drought) and inundation maps, flood types, as well as climate scenarios.
Copernicus Emergency Management Service: Global Drought Observatory	A tool providing near-real-time drought monitoring and early warning information globally.
World Bank and ThinkHazard! Global Facility for Disaster Reduction and Recovery	A tool providing information on natural hazard risks (e.g., floods, droughts) in specific locations as well as recommendations for risk reduction.

2.4 Groundwater Availability

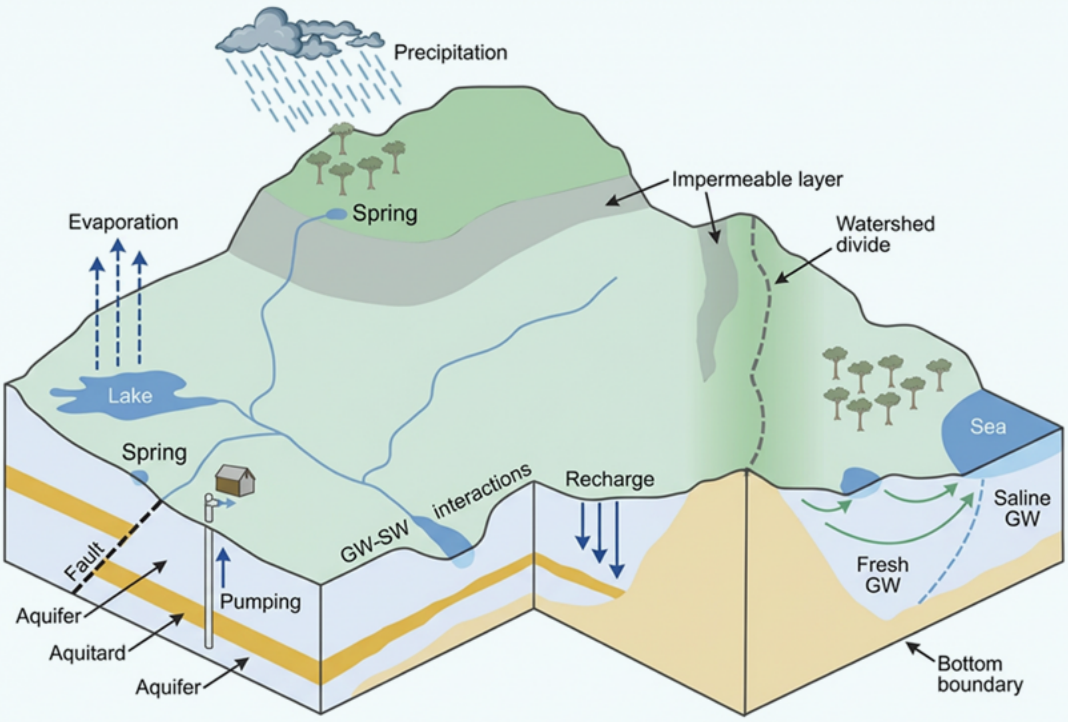
A **hydrogeological assessment** is essential for siting and designing any sustainable groundwater project. The assessment's primary goal is to develop a conceptual model of the local groundwater system. This model combines all available data to illustrate the understanding of groundwater conditions.

A vast body of technical guidance on how to conduct detailed hydrogeological assessments already exists, and this document does not seek to replicate it. Refer to the listed references in Box 3 for guidance or contract the work to a qualified hydrogeologist. The purpose of this section is solely to highlight the key components of a hydrogeological assessment and to emphasise its critical role in the overall process of developing groundwater infrastructure. The professional's central task is to build a conceptual model of the local groundwater system to identify the most suitable location and design of water supply boreholes within the system.

Developing a conceptual model (See Figure 7 for an example) is typically a two-phase process consisting of:

1. **Desk-Based Study:** gathering and reviewing existing data, including geological maps, drilling logs from previous projects, and hydrogeological reports to provide an initial understanding of the subsurface conditions
2. **Field Reconnaissance:** the desk study is validated through fieldwork, inventorying existing wells and springs (a 'hydrocensus'), examining geological outcrops, identifying potential contamination sources, and engaging with the community to understand historical groundwater dynamics and current needs

Figure 7: Schematic of a groundwater system.



Source: Modified from Enemark et al. (2019). Image quality enhanced with Nano Banana Pro

Table 4 outlines key factors for understanding groundwater availability:

Table 4: Key factors for understanding groundwater availability

Key Factor	Assessment Questions	Methods & Data Sources
Aquifer Extent & Boundaries	Have the productive water-bearing zones been identified? Is the aquifer's size (extent, depth, & layers) understood to estimate total storage?	• Geophysical Surveys: surface geophysical survey techniques (refer to Box 2) can help identify water-bearing formations • Existing Borehole Logs: data from previously drilled wells provides direct evidence of the depth, thickness, and type of geological layers • Test Drilling: in areas with limited data, drilling new exploratory boreholes may be necessary to confirm geophysical findings and collect direct samples
Sufficient Yield	Can the aquifer provide enough water to meet the intended demand (Section 2.2 Water Use)?	• Consult Geological Maps & Reports: provides existing data on expected aquifer yield • Conduct Pumping Tests: measures the performance and sustainable yield of a new or nearby borehole
Long-Term Sustainability	Is the aquifer regularly replenished by rainfall or river flow? Do historical water levels show a stable trend, or is there evidence of long-term depletion?	• Review Historical Water Level Data: analyse records from existing wells to understand the aquifer's response to seasonal changes and past droughts • Analyse Satellite Data: use tools like NASA's GRACE to assess long-term groundwater storage trends over large basins • Conduct Community Interviews: where no formal records exist, discuss historical water availability in local wells and springs

		• Investigate Recharge Sources: observe the local geology, slopes, soil, and vegetation to identify potential sources of regular replenishment for the aquifer by rain or rivers
Appropriate Water Quality	Is the water quality safe and suitable for its intended use (e.g., drinking, agriculture)?	• Domestic Use: water must be free of pathogens (from human or animal waste) and have low levels of harmful chemicals like arsenic or fluoride • Agricultural Use: water should be checked for high salinity levels, which can damage crops • Before commissioning the water point, the water must be tested. Its quality should be compared to national standards or, if unavailable, the WHO *Guidelines for Drinking-Water Quality* (WHO, 2006)

Box 2: An overview of surface geophysical survey methods (Davis and Lambert, 2002).

Surface geophysical surveys are indirect methods used to indicate where and how much groundwater there may be, increasing the success rate of drilling a borehole or digging a well. The most appropriate technique depends on the local hydrogeology.

Survey Methods:

- **Electromagnetic (EM) Surveys:** measure the electromagnetic conductivity of rock to quickly find water-bearing fractures and faults in otherwise impermeable rock
- **Electrical Resistivity Surveys:** apply an electric current to the ground through electrodes to measure variations in subsurface resistance, which can indicate water-bearing zones
- **Seismic Refraction Surveys:** create shock waves to determine the depth and layering of bedrock and identify potential water-holding fractures. They are more expensive, time-consuming, and complex than EM or resistivity methods

- **Magnetic Surveys:** use a hand-held magnetometer to detect the effect of certain minerals on the earth's magnetic field. They are useful in hard rock areas for locating geological formations, like metalliferous dykes, that can act as natural barriers to groundwater flow

Box 3: Key documentation for practical guidance on conducting hydrogeological assessments

For detailed information on undertaking a hydrogeological assessment refer to the following resources:

- Borehole Drilling – Planning, Contracting & Management: A UNICEF Toolkit - Dotun Adekile & Kerstin Danert, Skat Foundation, St Gallen, Switzerland; Jose Gesti Canuto, UNICEF, New York, USA; Djani Zadi, Peter Harvey, and Anne Cabrera-Clerget, 2018, Copenhagen, Denmar, UNICEF Publishing
- Developing Groundwater - Developing groundwater: a guide for rural water supply, MacDonald, Alan; Davies, Jeffrey; Calow, Roger; Chilton, John. 2005. Rugby, UK, ITDG Publishing
- Siting of Drilled Water Wells: A Guide for Project Managers - Siting of drilled water wells: a guide for project managers. Carter, R, Chilton, J, Danert, K, Olschewski, A. 2014. Rural Water supply Network (RWSN), SKAT Foundation.

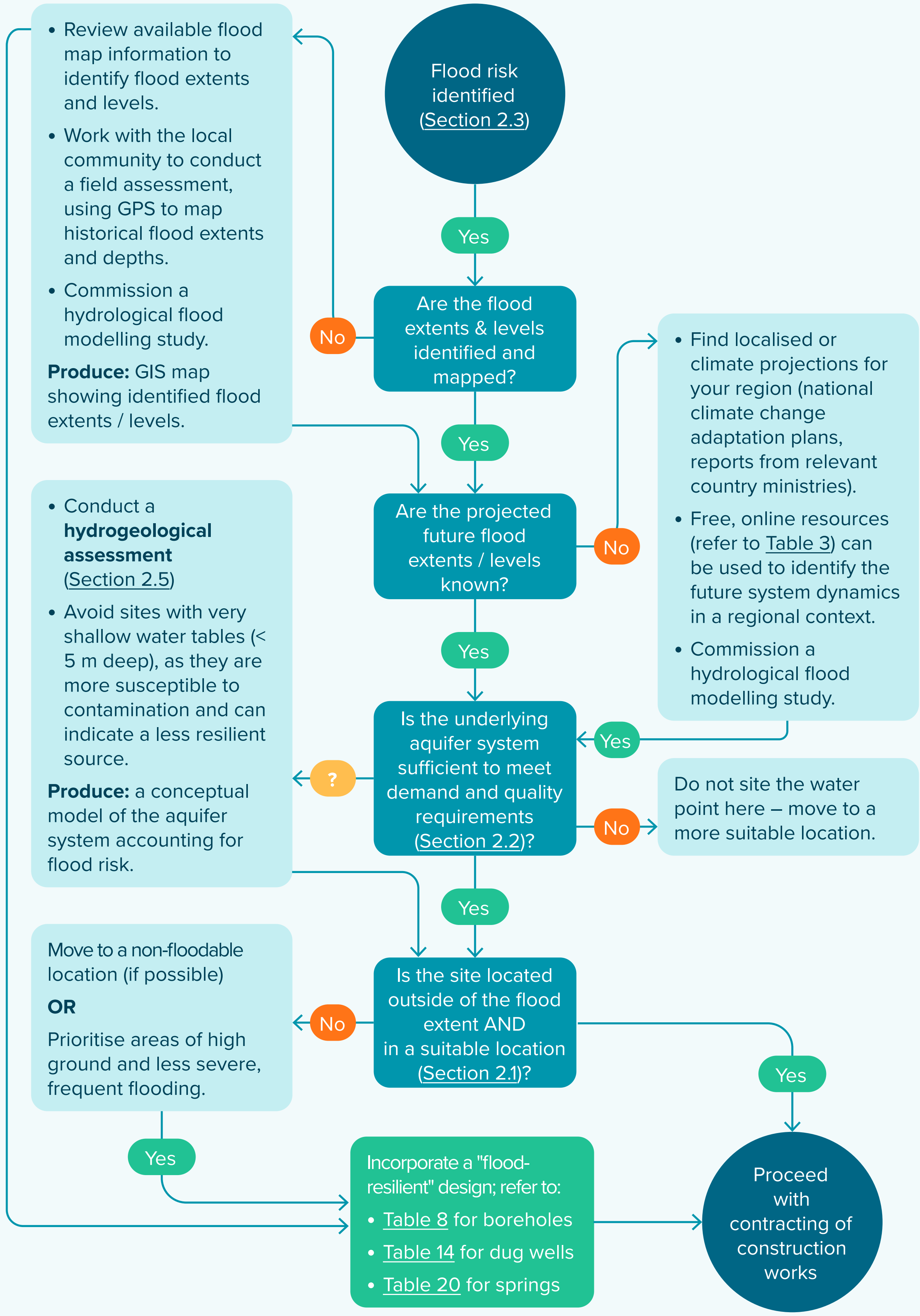
As climate variability intensifies, regions increasingly swing between the dual threats of drought and flooding. The following sections provide distinct assessment methods for flood-prone and drought-prone conditions; however, it is important to recognise that these scenarios are not mutually exclusive. Therefore, depending on your project's location and vulnerabilities, you may need to apply guidance from both flood and drought assessments to develop a comprehensive understanding of the potential impacts when developing groundwater infrastructure.

2.5 Assessment Methods in Flood Prone Areas

2.5.1 Flood Hazard Considerations

Where flood risk has been identified in the area (Section 2.3), the following information is required to mitigate risks such as floodwater intrusion, contamination, physical damage, and ensure new groundwater infrastructure is flood resilient.

Figure 8: Pre-construction assessment when working in a flood-prone area.



Source: Adapted from author's figure by © Ibex Ideas (2025)

A pre-construction assessment follows four steps:

1 Review of Available Flood Information

In the first step, existing flood information and fieldwork are reviewed to map historical flood extents and levels, gather local knowledge, and select the most suitable location for the water point. The following actions are required:

- ✔ **Collect and review all available information** from sources such as:
  - government offices (e.g., Ministry of Water Resources, National Disaster Management Agency)
  - NGOs and research institutes working in the region
  - flood hazard maps and existing hydrological studies
  - topographical maps and satellite imagery (e.g., Landsat, Sentinel)
- ✔ **Field Assessment**: the output of this step is a GIS map indicating historical flood extents and depths.
  - conduct transect walks to identify visible evidence of past floods, such as high-water marks on existing structures (buildings, trees, etc.). Measure the height of these marks from the ground to indicate the extent and level of the flood
  - analyse the local topography to identify natural drainage patterns and low-lying areas
- ✔ **Engage with the community** (e.g., conduct household surveys, focus group discussions, and/or key informant interviews) to understand the local flood context (i.e., flood frequency, severity, and impacts on water sources). Key questions about water source/accessibility are provided in Box 1, and the following can be useful for assessing flood impacts:
  - Does the water rise slowly from the river (riverine), or does it pool quickly when it rains hard (pluvial), or does it come from the direction of the sea during a storm (coastal)?
  - How high did the water rise during the largest flood you remember?
  - Which parts of the community were affected?
  - When did these floods occur (year, season)?
  - How long did the flooding last?
  - What were the impacts on water sources (wells, boreholes, springs) during these events?

Figure 9: Historical flood water marks identified on a building in Pibor (South Sudan).

Image quality enhanced with Nano Banana Pro

2 Use Climate Projections to Assess Future Flood Risk

With a better understanding of past floods, the next step is to analyse future flood risks to identify the most resilient zone for the new water point.

- **Use Existing Climate Projection Portals**: Search for data portals from national agencies (e.g., meteorological services, disaster management) or freely available tools based on global modelling (refer to Table 3)
- **Look for projected flood hazard maps under different climate change scenarios** (e.g., Representative Concentration Pathway (RCP) 4.5, RCP 8.5) to understand how flood extents and depths may change in the future
- **Alternatively**, if readily available data is insufficient or the project is particularly high-risk, **commission a specialised hydrological flood modelling study**. This provides the most accurate, site-specific projections of future flood levels and extents based on local surface water dynamics and climate variables
- **Synthesise the historical data** (step 1 of this assessment) with the future flood projections to identify a preliminary site that is safe from past floods and is also likely to remain safe given the projected future conditions

- If a truly low-risk zone cannot be identified, either:
  - recommend moving the project to a different, safer location entirely
  - prioritise the site with the lowest risk and acknowledge that a higher level of structural flood-proofing will be required in the design phase (refer to Table 8).

3 Hydrogeological Assessment with Flood Considerations

A Hydrogeological Assessment evaluates the potential contamination sources that might affect the water quality of the groundwater source.

To support the assessments, a sanitary survey may be conducted to identify and map all potential sources of contamination (latrines, septic systems, waste dumps, animal pens and agricultural fields) within a minimum safe distance of the proposed site (see Box 5), paying particular attention to the area upgradient.

The assessment should also consider how floodwaters can mobilise and transport contaminants from a wide area, delivering them directly to the water point location, increasing the risk of groundwater contamination.

4 Site Location Finalisation

This is the final step to consolidate findings and make a formal decision about the site before proceeding with construction contracts.

- Review the findings from all previous phases. Does the proposed site meet all the essential criteria (i.e., consider water access, water use, climate variability, groundwater availability)?
- Is the site conclusively located outside the combined historical and projected future flood extent?

If the answer to all verification questions is 'Yes', the site is formally approved. You can proceed with finalising the standard design and preparing for contracting.

If conditions are NOT met (especially if it is inside the current and/or projected flood extent), a compromise must be made:

- **First Choice:** relocate if possible. Re-examine the mapping from Step 1 to find an alternative site in a non-floodable location.
- **Second Choice:** accept the site with a flood-resilient design. If relocation is not feasible, a formal decision must be made to accept the higher-risk location, requiring the incorporation of a specific flood-resilient design (refer to Table 8 for details).

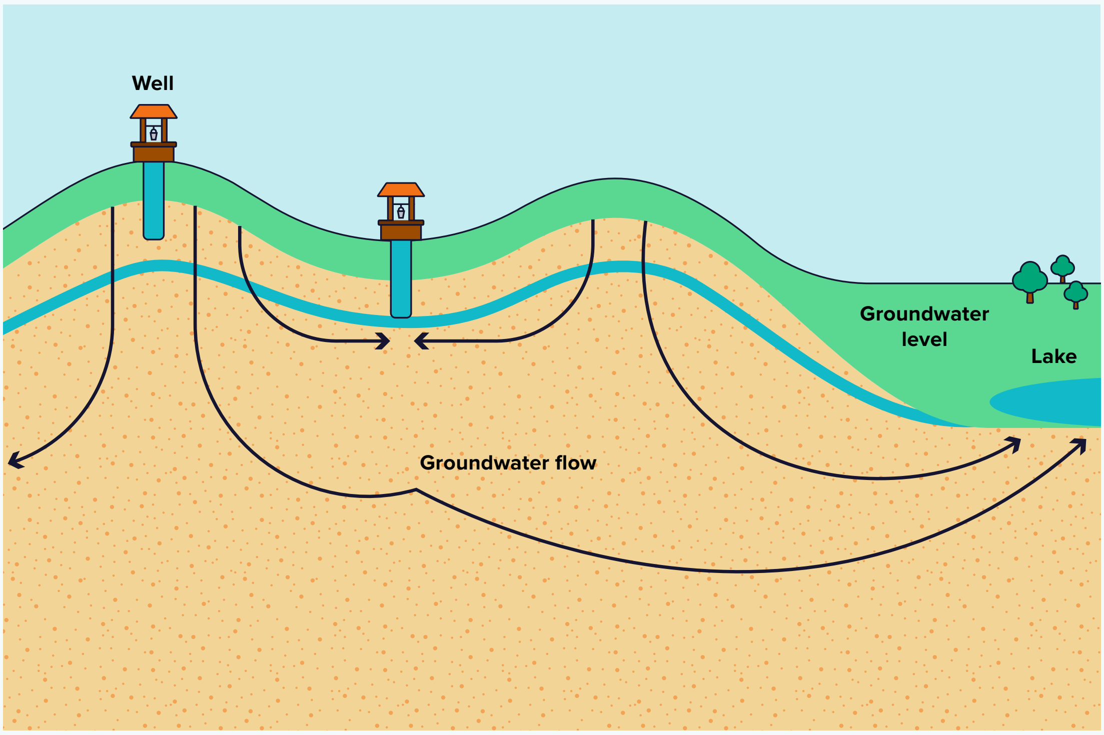
Box 4: Hydrogeological considerations for dug wells in flood-prone areas.

Low-lying areas are often more promising for well construction due to their proximity to the water table. Signs of shallow groundwater include:

- vegetation that thrives in high-water-table conditions (e.g., plants such as banana trees, bulrushes, sugar cane, and date palms)
- topographic depressions where groundwater tends to accumulate
- existing wells that yield plentiful, good-quality water

However, the area selected must not be prone to flooding that could inundate the well. Consider its proximity to rivers: floodplains might offer permeable alluvial deposits, but must be above the maximum flood level. Alluvial deposits of high permeability may be found at places formerly on the outside of a bend in an old river alignment, offering better conditions for groundwater extraction.

Figure 10: Schematic of groundwater flow for unconfined flow systems undisturbed by pumping where the water table often mirrors surface topography. Water tables are deeper at hilltops and steep slopes but shallower in valleys and depressions.



Source: Adapted from author's figure by © Ibex Ideas (2025)

Box 5: Determining Minimum Safe Distances (MSDs) for potentially polluting activities for water points (WHO, 2024).

An MSD for potential sources of contamination should be determined for the local context if resources allow, especially for faecal contamination. The MSD is based on an estimate of the time taken by contaminants to travel from their source to the water point.

1. Site-Specific Risk Assessment (Preferred Method)

Evaluate the following:

- **Hydrogeology & Soil Type:**
  - low Permeability (e.g., clays): MSD may be just a few metres, but beware of seasonal cracking, which increases permeability
  - medium Permeability (e.g., sands): MSD may increase to ≥100 metres
  - high Permeability (e.g., gravel, fissured rock): MSD may be several kilometres
- **Sanitation Technology:**
  - what type of containment is used (e.g., unlined pit, lined tank, septic system)?
  - what is the degree of pathogen removal of the technology?
  - what is the hydraulic load (volume of liquid) from the systems?
- **Groundwater & Catchment:**
  - what is the depth to the water table (at its highest)?
  - is the water source located upgradient from the contamination source?
  - are there other activities affecting the subsurface (e.g., quarrying, large-scale water extraction, seismic activity)?

If no data exists, conduct test drilling to log soil/rock types and perform infiltration tests to assess permeability. Assess infiltration when the water table is at its highest.

2. Baseline MSD (Fallback)

Use this approximate guide only when a site-specific assessment is not possible due to a lack of data or resources:

- **Horizontal Distance: at least 15 metres** between the water source and any permeable sanitation system (e.g., unlined pit, leach field)
- **Vertical Distance:** the bottom of any pit or leach field should be **at least 1.5 to 2.0 metres** above the highest anticipated groundwater table level
- **These are absolute minimums.** Increase these distances wherever possible, as they do not account for specific site risks

3. When MSD Cannot Be Achieved

If geographical or population density constraints prevent achieving a safe distance, implement risk-reduction measures:

- **Relocate:** move the water abstraction point or the sanitation facilities
- **Re-engineer Sanitation:** use alternative designs like raised pits or fully sealed, impermeable (e.g., concrete) containment
- **Implement Water Treatment:** ensure a final treatment barrier (e.g., chlorination, filtration) is in place for the water supply

For more information on conducting risk assessments for groundwater from polluting activities refer to Ahmed et al., 2016 and WHO, 2006.

Box 6: Key safe drinking-water quality indicators (Sphere Association, 2018).

- There are no more than 10 faecal coliforms per 100 ml at the point of delivery for undisinfected supplies
- For piped water supplies to populations over 10,000 people, or for all water supplies at times of risk or the presence of a diarrhoea epidemic, water is treated with a residual disinfectant to an acceptable standard (e.g., residual free chlorine at the tap is 0.2–0.5 mg per litre and turbidity is below 5 NTU)
- Total dissolved solids are no more than 1,000 mg per litre (approximately 2,000 µs/cm electrical conductivity for simple field measurement), and water is palatable to users

Box 7: The importance of triangulating community consultation.

Local communities hold vital knowledge about water sources and historical trends, but individual memories and perceptions of past events (like droughts or water level changes) can be inaccurate or vary widely. Therefore, always triangulate community information - cross-verifying what you hear from multiple sources and methods to build a more reliable picture:

- **Consult diverse groups:** engage separately with different community groups (e.g., women, elders, farmers, and pastoralists) as their experiences and knowledge often differ

- **Use multiple methods:** combine focus group discussions with individual interviews and participatory mapping to gather and cross-check information
- **Cross-reference with other data:**
  - compare community accounts with any available formal data (e.g., rainfall records, previous project reports, academic studies)
  - correlate with physical observations made during fieldwork (e.g., existing well water depths, flood marks)
- **Seek consistent themes:** look for common information or recurring themes across different groups and data sources, rather than relying on isolated statements

AVOID: Shallow Water Tables (if possible)

- Sites with very shallow water tables (e.g., < 5m below ground level) are more susceptible to surficial contamination. However, in many contexts shallow groundwater is the only option.

TARGET: Naturally Resilient Groundwater Systems (Vrba and Verhage, 2011)

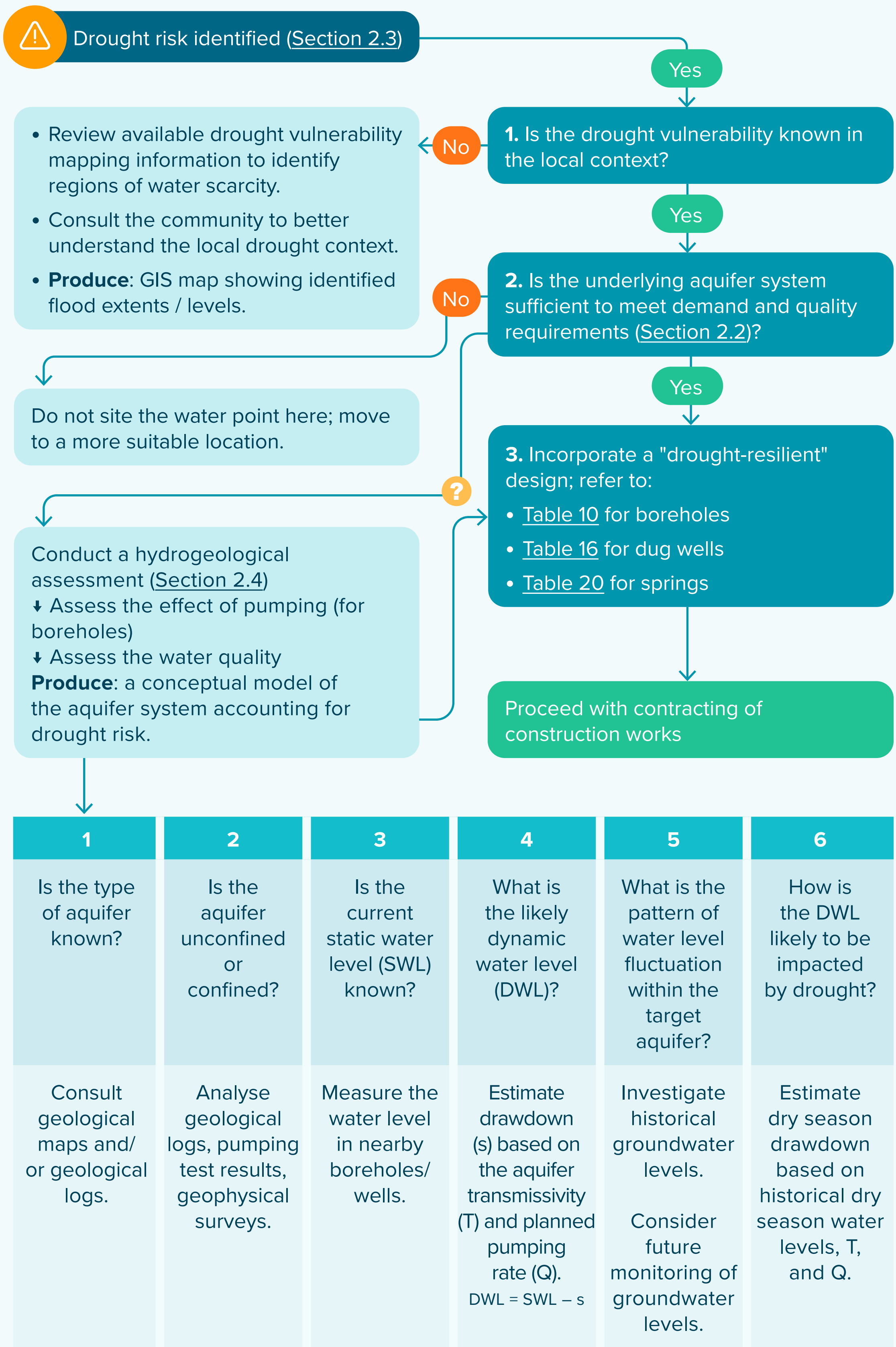
- **Confined (Artesian) Aquifers:** the overlying impermeable layer (confining layer) protects the aquifer from direct surface water intrusion. The pressure within the aquifer often prevents downward flow
- **Aquifers Protected by Low-Permeability Rock/Sediment:** thick layers of clay or unfractured rock significantly slow down or prevent surface water infiltration
- **Upward-Gradient Flow Systems:** in areas where groundwater naturally flows upwards (e.g., discharge zones), the hydraulic pressure resists surface water intrusion

2.6 Assessment Methods in Drought-Prone Areas

2.6.1 Drought Hazard Considerations

Where drought has been identified in the area of interest (Section 2.3), the process illustrated in Figure 11 outlines the information required to minimise the risks of groundwater infrastructure failure resulting from fluctuating or declining water levels.

Figure 11: Pre-construction assessment when working in a drought-prone area.



Source: Adapted from author's figure by © Ibex Ideas (2025)

Key considerations include:

1. The geology:

Different geological formations (e.g., unconsolidated sediments, sedimentary rock, crystalline basement, volcanic, karst) store and transmit water differently, which directly affects their resilience to drought. Table 5 provides an overview of drought impact considerations in different hydrogeological environments.

To determine the hydrogeological environment of your area of interest:

- Review national and regional geological maps from government surveys to identify the dominant rock type in your project area
- Examine drilling logs from nearby boreholes
- Perform field reconnaissance to observe surface rock outcrops and landforms, which provide clues to the underlying geology
- Consult local drillers who have practical, hands-on knowledge of the subsurface conditions in the area
- Potentially, conduct pumping tests on existing boreholes to understand the hydrogeological characteristics of the aquifer

2. The hydraulic condition of the target aquifer – is it confined or unconfined?

Unconfined aquifers, where the water table is open to the atmosphere, will present a changing transmissive zone as water levels fluctuate. During drought, when declines in water levels are greater than normal, this may result in dewatering the productive zone or significantly reducing the yield of the aquifer system.

Confined aquifers may also present a lower-than-normal piezometric pressure head during drought. However, as long as the water-bearing formation remains saturated, the aquifer will maintain the same productivity (although the pump will have to overcome a greater pressure head to remove water from the well). This characteristic makes confined systems more drought-resilient, though their recharge can be slow and occur at a distance from the water point.

To determine the hydraulic condition of the target aquifer system:

- **Analyse Borehole Logs:** look for the presence of a thick, continuous impermeable layer (clay, shale, dense rock) overlying the primary water-bearing zone. This is the clearest indicator of a confined aquifer
- **Check Static Water Level (SWL):** when a well is drilled into a confined aquifer, the water level will often rise significantly higher than the top of the aquifer layer it encountered. This is due to (artesian) pressure. In an unconfined aquifer, the SWL in the well simply corresponds to the water table
- **Review Pumping Test Data:** unconfined and confined aquifers show characteristically different drawdown patterns during a pumping test. Analyse existing test data if available

3. The seasonal water level fluctuation in the target aquifer

Understanding the historical seasonal high and low water levels is the best predictor of how the aquifer will behave during a severe drought.

- Investigate historical groundwater level data and rainfall data, if records are available (refer to Section 2.4)
- Consider implementing long-term monitoring of groundwater levels in the future to build a more robust understanding of seasonal and long-term trends
- Use a conceptual understanding of the groundwater system to understand recharge mechanisms and controls on the groundwater level

4. The Dynamic Water Level (DWL) based on water supply requirements

The DWL is determined by the aquifer transmissivity, storage, and the pumping rate. A less productive aquifer will result in a larger drawdown for a given pumping rate. To determine whether a borehole will be resilient to drought, estimate the lowest likely DWL during a drought. Refer to Borehole Rehabilitation for further information.

5. Potential interference effects

Existing or new boreholes can lower the water table over a wide area (‘cone of depression’, Figure 12). If this cone of depression intersects with other water points, it can cause interference, resulting in increased drawdowns. Furthermore, the ad-hoc development of many water points without a consideration of their cumulative impact can lead to long-term aquifer depletion or over-exploitation.

- ✓ **Inventory Existing Water Points:** conduct a reconnaissance survey to map all existing water points (boreholes, wells, and springs) in the vicinity to understand what could be affected. This inventory should cover a radius that could reasonably be influenced by the new borehole; this could be several hundred metres for extensive, productive aquifers
- ✓ **Analyse Data from Existing Boreholes:** analyse records, especially pumping test reports and lithological logs, from the inventoried boreholes. This data provides vital information on the aquifer's transmissivity
  - **High Transmissivity** (e.g., in sandy or gravelly aquifers) suggests the cone of depression will be wide and shallow, meaning a new well could impact other water points over a greater distance
  - **Low Transmissivity** (e.g., in mudstones or sparsely fractured rock) suggests the cone of depression will be deep and narrow, with a more localised but potentially severe impact on very close-by sources
- ✓ **Review the Legal Framework:** check for any national or local regulations regarding the required spacing between new and existing boreholes.

Table 5: Drought impact considerations in different hydrogeological environments.

Hydrogeological Environment:	Considerations
Unconsolidated Alluvial	**Favourable Characteristics** • Often shallow with high yields, making them relatively easy to develop.
	Drought Considerations • May experience seasonal water fluctuations making them more susceptible to droughts.

	• Vulnerable to over-extraction and contamination during droughts due to their shallow depth and connection to surface water. **Site Selection Requirements** • Prioritise sites with thicker saturated zones and assess potential for recharge. • Evaluate the distance to higher elevation areas that may contribute to recharge. • Assess contamination risk from surface sources and implement protective measures. **Specific Considerations** • Use pumping test data and hydrogeological conceptualisation to confirm sustainable yields. • Avoid overextraction in high-demand areas.
Sedimentary	**Favourable Characteristics** • Can have significant storage capacity and provide reliable yields. **Drought Considerations** • Recharge rates can vary depending on the type of sedimentary rock. Some may be slow to replenish during drought. **Site Selection Requirements** • Identify the type of sedimentary rock and its hydraulic properties (porosity, permeability) to assess drought resilience. • Evaluate the depth and thickness of the aquifer to ensure sufficient reserves. • Assess potential for connectivity to surface water and associated contamination risks. • Consider potential for saltwater intrusion in coastal areas.

	Specific Considerations • Sandstones and conglomerates have high potential for usable groundwater. • Clays and mudstones are poor aquifers and should generally be avoided. • If insufficient groundwater is found, consider alternative surface water systems.
Karst	**Favourable Characteristics** • Can provide large volumes of water due to high permeability and storage capacity.
	Drought Considerations • Highly sensitive to drought conditions due to rapid response to rainfall variations and reduced recharge during droughts. • Water levels may drop significantly during prolonged droughts. • Susceptible to contamination with quick travel times.
	Site Selection Requirements • Conduct detailed hydrogeological assessments to understand fracture networks and recharge potential. • Ensure proper well construction to minimise contamination risks.
	Specific Considerations • Karst aquifers can experience sudden depletion if recharge is insufficient. • Storage capacity depends on the extent of caverns and conduits. • Varying flow velocities and water storage capacities influenced by the degree of karstification and diverse hydrogeological conditions.

	• Boreholes drilled near springs, or in dry valleys, have the highest chance of success. However, any ground-water abstracted through boreholes will reduce the flow from the springs.
Basement	**Favourable Characteristics** • Can provide viable aquifers in weathered and fractured bedrock zones. **Drought Considerations** • Limited storage and slow recharge rates make them vulnerable to prolonged droughts. • Due to lower storage capacity, they are especially vulnerable to drought if they lack sufficient weathering or fracturing. **Site Selection Requirements** • Target vertical fractures and deep weathered zones for higher yields. • Conduct detailed geophysical surveys to locate productive areas. **Specific Considerations** • Highly variable yields depending on amount of weathering or fracture density. • High yields possible in weathered zone (commonly located in areas with overlying alluvial sediments). • If weathered zone alone can't provide adequate yield, fractures in the deeper bedrock may be tapped.
Volcanic	**Favourable Characteristics** • Can have high yields and good water quality depending on the type of volcanic rock.

Drought Considerations

- Recharge rates can vary significantly depending on the permeability of the volcanic rocks.

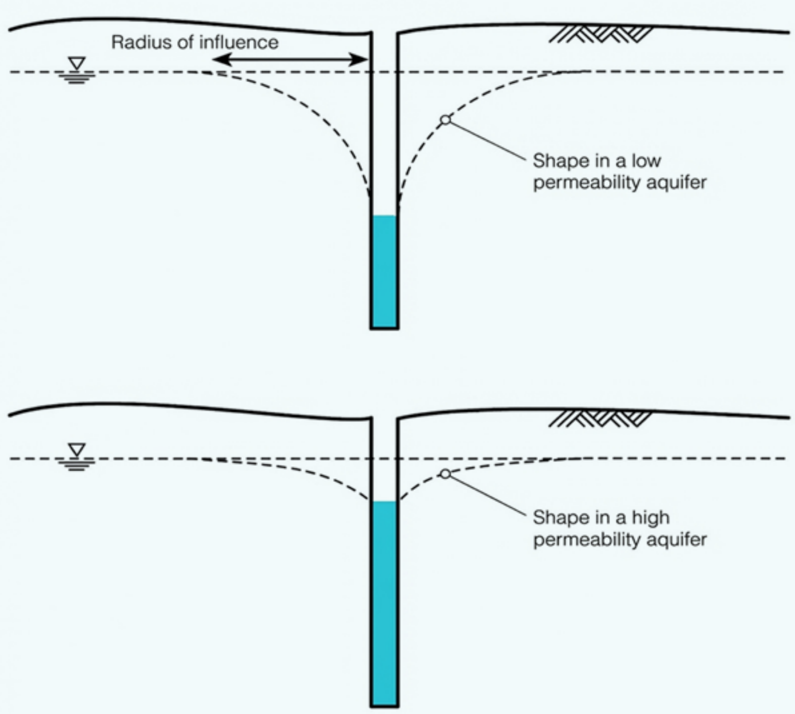
Site Selection Requirements

- Identify the type of volcanic rock and its hydraulic properties.
- Assess the depth and extent of the aquifer to understand its storage capacity.
- Evaluate potential for connectivity to surface water and associated risks.

Specific Considerations

- Volcanic rocks can have moderate porosity and sustain a range of yields.

Figure 12: Cone of depression in low vs. high permeability aquifers.



Source: WEDC (2019). Image quality enhanced with Nano Banana Pro

2.6.2 Undertaking a survey

The following actions are required:

Conduct a desk study to review all existing available information

Data may be obtained from sources such as:

- Existing groundwater drought vulnerability maps, if available (from government agencies, NGOs, research institutions)
- Hydrological surveys from local water ministries, meteorological agencies or disaster risk management agencies on water resources and climate impacts, and National Adaptation Plans
- Project reports from NGOs on groundwater resilience or on climate change adaptation
- Academic articles on climate impacts and water resources in the project's region. Contact local universities or research centres that may have conducted relevant studies

Engage with the community

The local community can provide a wealth of local information linked to drought impact on water sources. Conduct household surveys, focus group discussions, and/or key informant interviews to understand the local drought frequency, severity, and impact upon water sources. Key questions related to water source/accessibility are supplied in Box 1, and the following can be useful for assessing drought impact:

- Which water points dried up during past droughts?
- How long did they remain dry?
- How often do droughts occur?
- How low did the water level drop in wells/boreholes that didn't dry up completely?
- What alternative water sources did people use during droughts?

Collect field data

If there is insufficient available information to understand drought risk, field work may be required to obtain further information for the water supply design. This data would complement information from a standard hydrogeological assessment.

Field information that would be useful:

- water level data from existing water points
- groundwater-level monitoring points to record the fluctuation of water levels over time
- further investigate the drought-resilient boreholes identified during community consultations to understand why they are drought resilient. This would include understanding the depth of these boreholes, the location and aquifer system they are sourcing water from, the design and screen depth, and the potential recharge sources

2.6.3 Assessing water quality risks associated with drought

During a drought, lower groundwater levels and reduced recharge can cause the concentration of both naturally occurring and anthropogenic contaminants to increase, potentially making a previously safe water source toxic.

Analyse Geology for Mineral Contaminants: identify if the local rock types are known sources of mineral contamination (e.g., arsenic from certain sedimentary and volcanic rocks, or fluoride from granites). As water levels drop during a drought, there is less water to dilute these natural contaminants as they leach from the rocks, which can increase their concentrations.

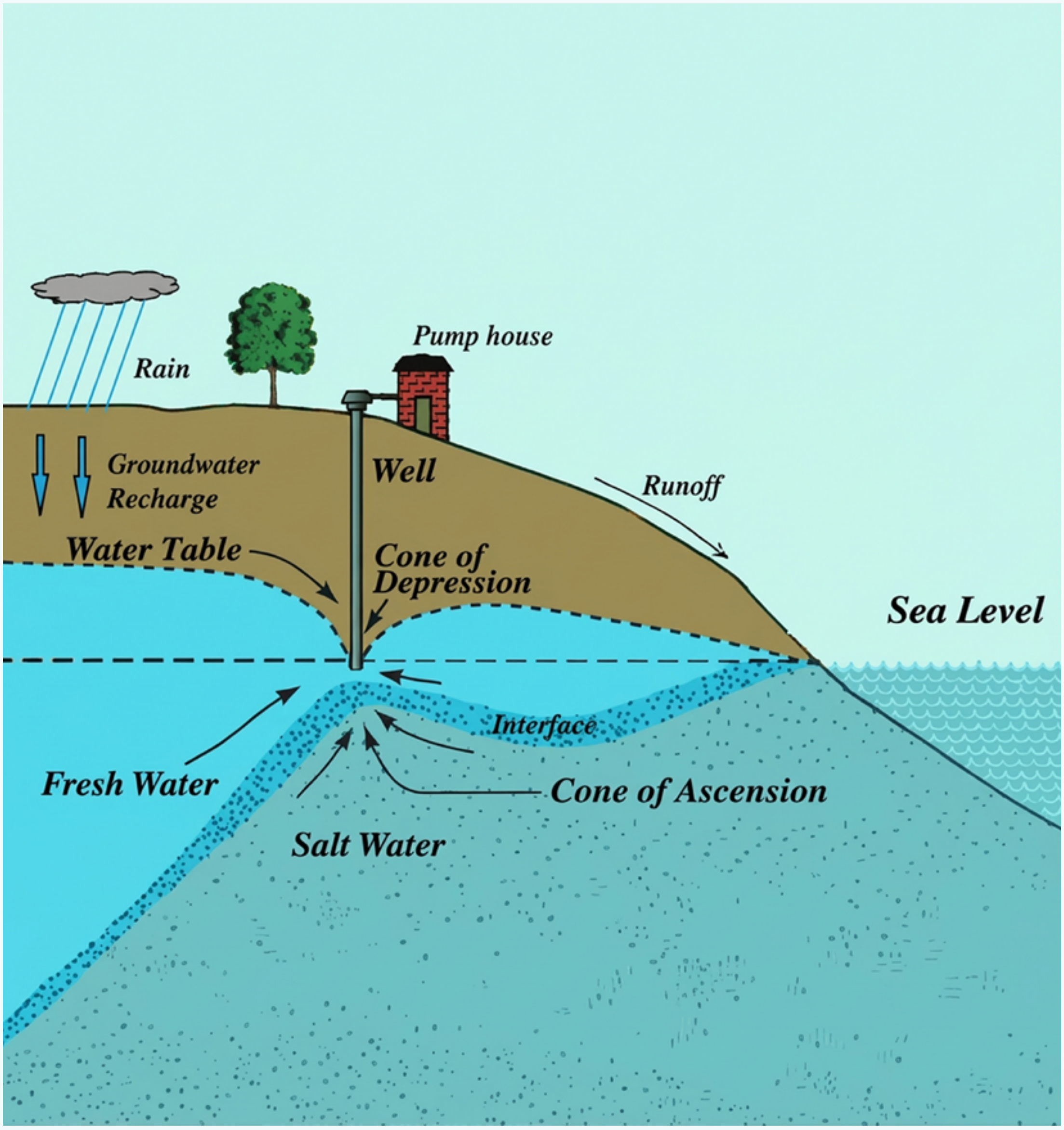
- conduct water quality sampling from a nearby, existing borehole that taps the target aquifer depth. Send the samples for comprehensive laboratory analysis

Assess Salinity Risks: it is important to evaluate potential sources of salinisation, as these risks are often amplified during a drought. Heavy pumping, which often increases during drought, can cause the 'upconing' (Figure 13) of deeper saline water, degrading the fresh water source.

- Salinisation can be a risk in various contexts:
  - in coastal areas, heavy pumping can draw in seawater, causing saline intrusion
  - in inland regions, heavy pumping can pull up deeper, naturally saline groundwater, which contaminates the freshwater supply
  - in arid climates, increased water demand for irrigation combined with high rates of evaporation can concentrate salts in the soil, which can lead to salinisation of shallow groundwater

- Use field metres to measure Total Dissolved Solids (TDS) or Electrical Conductivity (EC) from existing water points
- Use geophysical surveys, such as electromagnetic (EM) methods, to map the extent of fresh versus saline groundwater zones
- Avoid siting new infrastructure in areas identified with high salinity (TDS > 1000 mg/L) or areas showing increasing salinity trends, if possible. If a saline area is unavoidable, advanced treatment, like reverse osmosis or blending with fresher water sources, may be required

Figure 13: Upconing of saltwater by extensive pumping.



Source: Sreedharan and Pawels (2018). Image quality enhanced with Nano Banana Pro

AVOID: Shallow Aquifer Systems (if possible)

- ✕ Sites with shallow aquifer systems will be most impacted by drought. However, shallow groundwater may be the only option in many locations.

TARGET: Deeper Aquifer Systems

- ✓ Deeper aquifer systems, with thicker saturated thickness and therefore the storage potential is likely to be less affected by seasonal fluctuations.
- ✓ Confined aquifers are ideal targets as they are less affected by seasonal fluctuations.

3 Design and Construction of Climate-Resilient Groundwater Infrastructure

The findings from the hydrogeological assessment must directly inform the design of the new groundwater infrastructure.

- The borehole/well design must address the system's dynamics, particularly the anticipated water levels during drought conditions. This means accounting for the estimated dry season dynamic drawdown
- For best practices and guidelines for drought-resilient design and construction, refer to Table 10 for boreholes, Table 16 for hand-dug wells, and Table 20 for springs

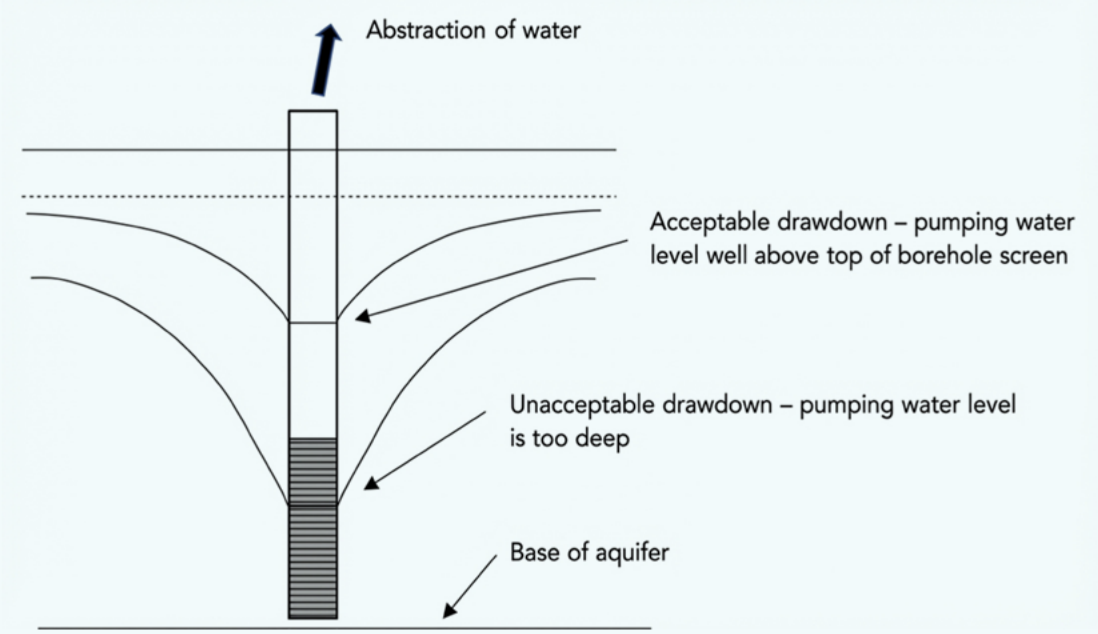
3.1 Boreholes

Boreholes are narrow-diameter wells drilled into the ground to access groundwater from shallow or deep aquifers. They are typically cased and screened to prevent collapse but enable water to flow freely into the well via slots in the screen. The method of drilling, such as hand-auger, rotary, or percussion techniques, depends on ground conditions and available resources. Due to their ability to access deeper, more stable groundwater reserves, boreholes play a critical role in enhancing water security and climate resilience, making them the primary focus of this guidance.

For a comprehensive resource on the construction of boreholes, and a comprehensive overview of drilling, refer to: Driscoll, F. G. (1986). *Groundwater and wells (2nd ed.).*

A critical consideration common to both flood and drought resilience is to position the screens appropriately. To determine the appropriate pump intake depth and a suitable pump to provide the design discharge, the drawdown and pumping water level needs to be estimated. Practically, there are limits to the drawdown that can be allowed, mainly depending on the thickness of the aquifer (Figure 14).

Figure 14: Practical limitation on groundwater abstraction rate in an unconfined aquifer.



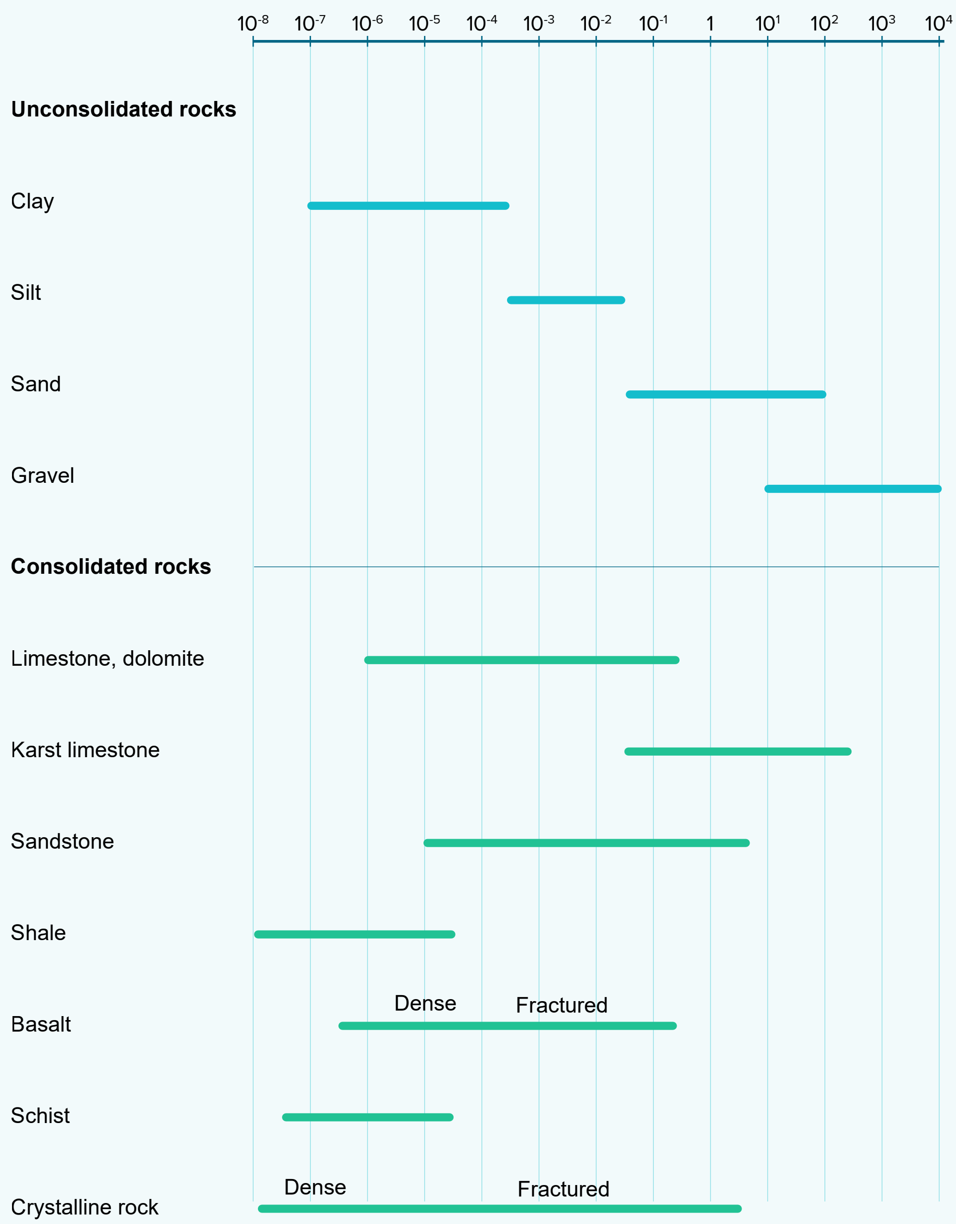
Source: Carter (2021). Image quality enhanced with Nano Banana Pro

1 To estimate likely dynamic water levels, use:

- **Existing Boreholes/Wells:** use the average specific capacity from nearby wells to estimate drawdown in a new borehole.
  - **Drawdown** = **Design Discharge / Average Specific Capacity**
- **Estimate aquifer transmissivity (T)** using Logan's Approximation, where: Drawdown = 1.22 x (Pumping Rate / Transmissivity)
  - **Transmissivity (T)** can be estimated if hydraulic conductivity (K) and saturated thickness (b) can be assumed:

  1. **Estimate K:** based on geological maps, geophysical surveys, or logs from nearby existing boreholes, determine the likely underground material at your proposed site. Use a reference table (an example is provided in Figure 15) to assign an estimated value for hydraulic conductivity (K).
  2. **Estimate b:** using the same data sources, estimate the depth of the static water level and the depth to the impermeable layer (the bottom of the aquifer). The difference between these two is the estimated saturated thickness (b).
  3. **Calculate transmissivity:** T = K x b

Figure 15: Hydraulic conductivity ranges of selected rock types in metres per day.



Source: Adapted from Carter (2021) by Ibex Ideas (2025)

2

Estimate pumping water level during the design phase:

- **Estimate Pumping Water Level (PWL)** by subtracting the estimated drawdown from the dry season static water level (SWL).
  - PWL = SWL - drawdown

3

Add a safety margin (e.g., 3 to 5 m+ below the lowest calculated PWL) to ensure the pump intake remains submerged throughout drought periods.

Borehole screens should be installed next to the water-producing horizons. In unconsolidated material, the screen slot size is critical and depends on the well design. Typical screen openings for different aquifer formations are provided in Table 6.

Table 6: Typical screen openings for different aquifer formations (Davis and Lambert, 2002).

Formation	Average size of screen slot (mm)
Fine sand	0.167
Medium sand	0.442
Coarse sand	0.813
Very coarse sand	1.580
Very fine gravel	2.850
Fine gravel	6.700

An appropriately designed screen and filter pack maximises the hydraulic efficiency of the borehole, allowing it to yield water more easily. It also prevents sand and fine particles from entering and damaging the pump, which helps to ensure the borehole remains reliable and operational during periods of drought.

To correctly select the screen slot size and the size of the gravel pack material, assess the aquifer's grain size by collecting representative samples of the aquifer sediments and performing a sieve analysis (Figures 16 and 17) to create a grain size distribution curve.

A practical field guide to determine slot size is to rub a sample of aquifer sediments against the screen slot – a perfect slot will allow some fine sand to pass and coarse grains to bridge (Ball, 2001).

Figure 16: Groundwater Relief sieve set and scales at Bentiu Protection of Civilians site in South Sudan August 2017.

Image quality enhanced with Nano Banana Pro

Figure 17: International Organization for Migration (IOM) staff using Groundwater Relief sieves to ensure the gravel pack was to specification before taking it to Bentiu Protection of Civilians site in South Sudan.

Image quality enhanced with Nano Banana Pro

Detailed design protocols for selecting screen slot sizes for both gravel-packed and naturally developed wells are provided in Davis and Lambert (2002), MacDonald et al. (2005) and Sterrett (2007).

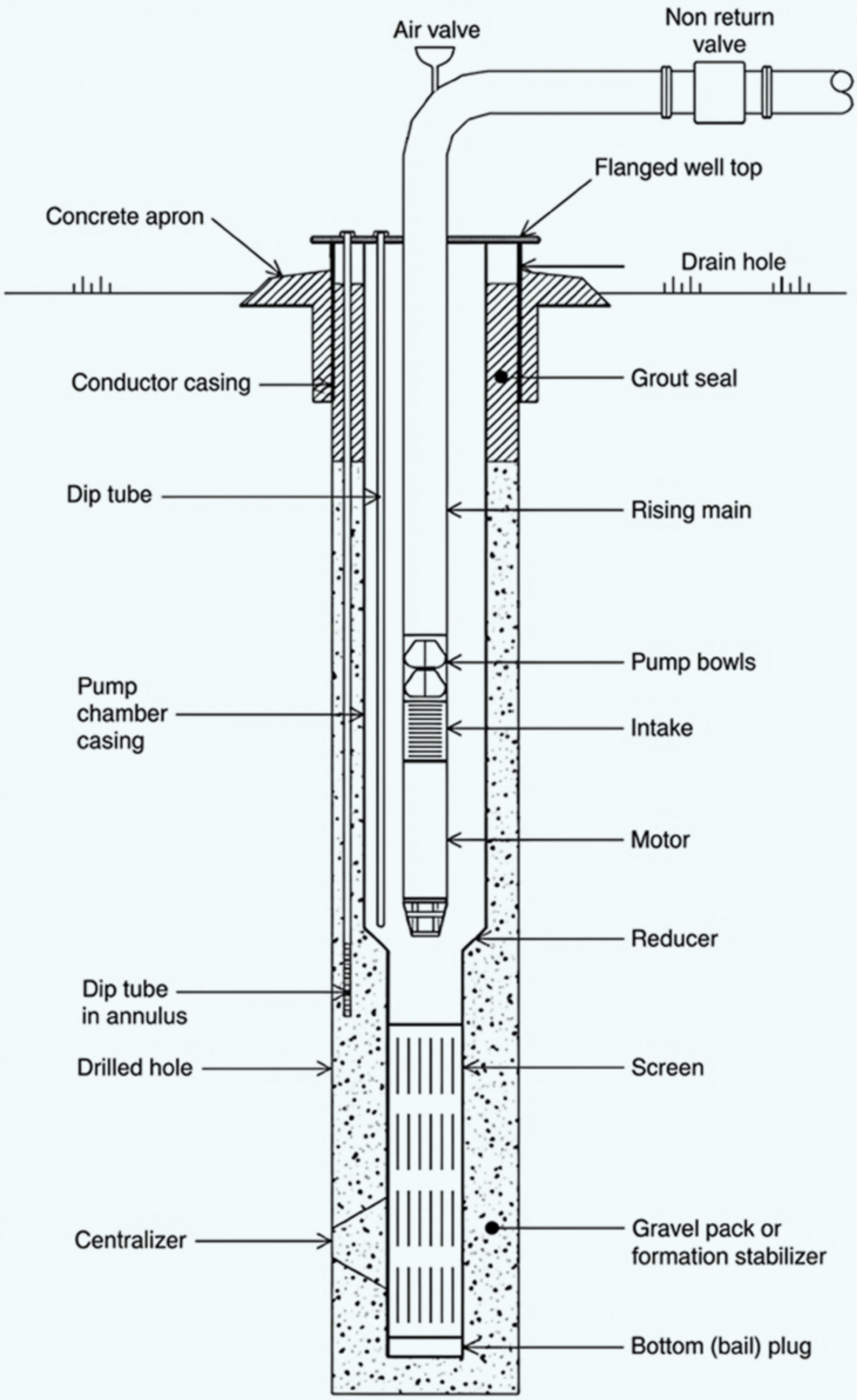
Table 7: Borehole characteristics

Category	Description
Advantages	• Accesses deeper, more reliable aquifers • Lower risk of contamination from surface sources (as a protected water point) • Generally provides a higher and more consistent water yield
Disadvantages	• High initial construction costs • Requires specialised drilling equipment and technical expertise • Maintenance and repairs, especially for submersible pumps, can be complex and costly
Climate Vulnerabilities	• **Flooding:** contaminated floodwaters can seep into poorly sealed boreholes. Above-ground pump structures can be damaged • **Drought:** reduced aquifer recharge can lower water levels, making pumping more difficult. Increased demand during dry spells can overburden pump systems

The type of pumping system installed in a borehole affects performance, operational costs, and vulnerability to climate impacts.

For further information, refer to: ***Chapters 5 and 6 of Rural Community Water Supply: Sustainable services for all*** (Carter, 2021) which provides an overview of handpump technologies for households and small communities and also examines the transition to piped water systems, including gravity-fed and mechanically pumped options (especially solar), highlighting their benefits, challenges (management, finance, storage), and the need for appropriate tariffs.

Figure 18: Components of a borehole.



Source: Misstear et al. (2017). Image quality enhanced with Nano Banana Pro

3.1.1 Flood-Resilient Boreholes

Ensuring the resilience of boreholes to flooding and contamination requires careful attention to design and construction. Key protective measures include installing a sanitary seal to prevent contamination and constructing an elevated borehole platform to mitigate flood risks. Implementation of flood protection measures (Table 8) should take place after the construction and development of the borehole, once the formation stabiliser or filter pack has settled.

Table 8: Flood protection measures for boreholes

Type of Measure	Details
Elevate Borehole Casing and Platform	Raise the borehole casing at least 0.3 m above ground level and the platform at least **0.4 m above the 100-year flood level or the highest recorded flood level**.
Surface Sealing (Sanitary Seal)	Place a **bentonite clay or cement grout seal** (minimum 3 m thick) in the annular **space between the borehole wall and casing** to prevent contaminated surface water from travelling down the annulus of the borehole around the casing.
Deeper Intake Depth	If water quality is a concern (e.g., potential sources of pollution are located nearby), consider deeper screen placement, as vertical travel through aquifer materials often provides better filtration than lateral distances (Lawrence et al., 2001).
Sealed Top Plate/ Headworks	The top plate/headworks for the borehole should be completely sealed and water-tight around the rising main, cables, and any other pipework, to prevent surface water from directly entering the borehole.
Positioning of Electrical/ Mechanical Components	In some cases, electrical or mechanical components could be located away from the flood-prone area to provide greater protection.
Drainage and Landscaping	The apron is sound with no cracks and **slopes away from** the borehole to a soakaway, **perimeter drainage trench or a French drain** to carry away floodwater.

3.1.1.1 Elevate Borehole Casing and Platform

Elevating the casing and constructing a raised platform are fundamental measures to protect a borehole from contamination by floodwater. A properly designed wellhead prevents contaminated surface water from overtopping the casing, ensuring the water remains safe to drink during and after a flood.

The first and most critical step is to determine the maximum local flood level experienced.

The second step, if possible, would be to account for changing climate conditions to determine what the future maximum flood levels and extents might be. One common practice is to estimate the **100-year flood level** (i.e., a flood event that has 1% probability of occurrence per year). This calculation would require the expertise of a hydrologist.

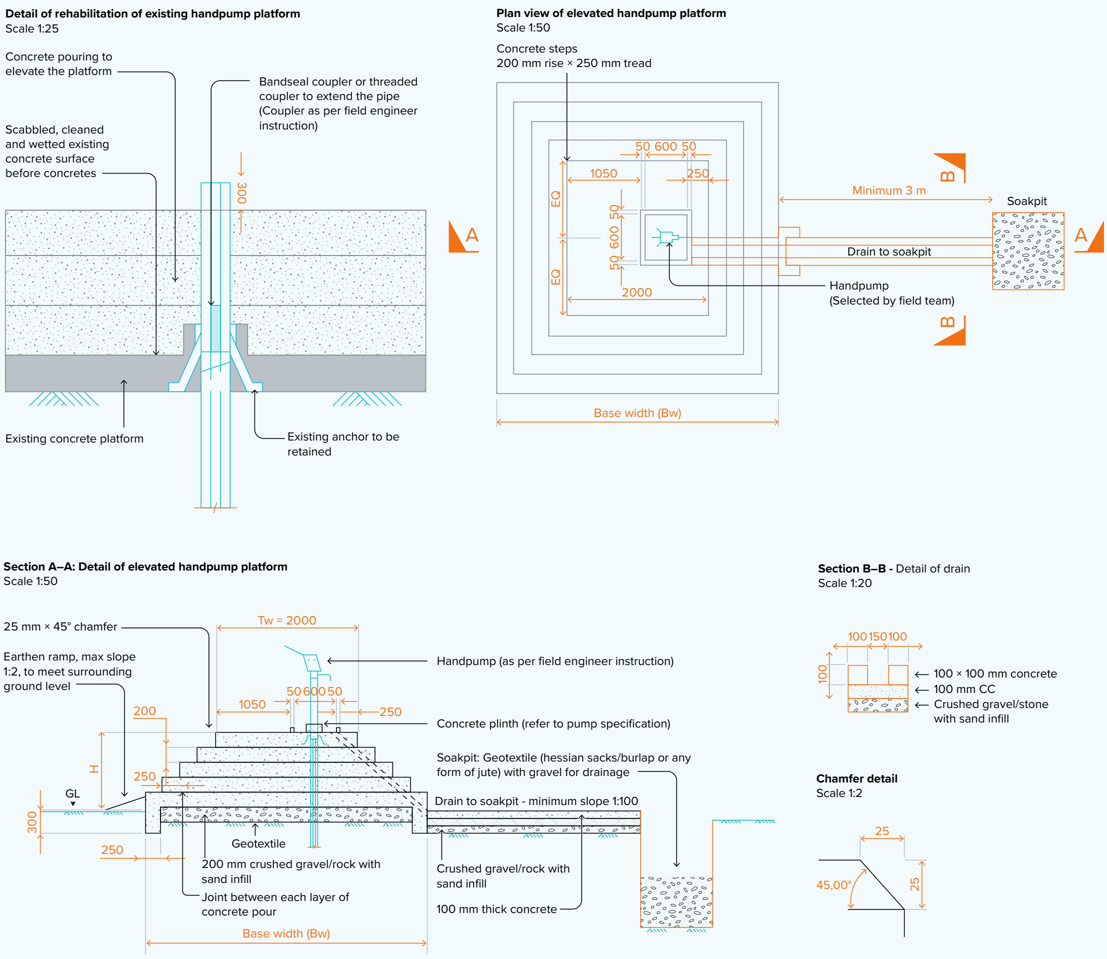
Figure 19: Examples of raised flood-resilient borehole platforms in South Sudan.

Source: left photo from UNICEF (2022), right photo from Groundwater Relief's work carried out during the International Organization for Migration ECRP-II project. Image quality enhanced with Nano Banana Pro

Once the maximum local flood level and extent are established, design according to these conditions. Construct a robust, slope-drained concrete or masonry platform around the borehole, following the detailed instructions in the design drawing Figure 20. The platform should extend at least 1.5 m from the casing and about 15–30 cm should be excavated for a sub-base to ensure stability. It is critical that the join between the platform and the casing is completely watertight.

The design drawing in Figure 20 includes two tables to guide construction: Table 1 provides the specific platform dimensions based on the determined flood level, and Table 2 provides a corresponding list of required material quantities.

Figure 20: Flood-resilient borehole platform design.



Rehabilitation of existing handpump platform for flood resilience (refer to note 6)

1. Determine platform height (H) based on maximum flood level based on formula given below.
2. Dismantle the existing pump and install coupler to elevate the riser pipe.
3. Scabble, clean and wet the existing platform surface.
4. Follow procedure to complete platform installation as per dimensions in Table A or formulae provided.

Calculation of platform dimensions

1. Estimation of platform final height

   H = flood depth + 400 mm
2. Number of steps, N = H / 200, rounded down to the nearest whole number
3. Height of ramp = H − N × 200
4. Top width, Tw = 2000
5. Base width, Bw = Tw + 2 × 250 × (N − 1)

Notes

General:

1. All dimensions are in millimetres unless noted otherwise.
2. Dimensions and material quantities are provided for a square platform. For alternative shapes, the dimensions and materials shall be estimated at field. It is estimated that a circular platform will yield a 20% saving in material usage.
3. Schematic plan view of hexagonal platform and alternative circular platform is presented in drawing number XXXX-XX-XX-DR-A-000.
4. Mould oil (or locally available alternatives such as vegetable or mineral oil or polythene sheet) shall be provided inside the formwork before concrete pouring.
5. This design is only applicable for platforms up to a flood height of 2 m.
6. Extension of existing borehole riser should consider if the existing pump can deliver the increased lift height.

Concrete pour notes:

7. Formwork shall be kept in place for a minimum of 48 hours.
8. Maximum concrete pouring height shall be 1.5 m.
9. Concrete shall be compacted by rodding, tamping and ramming. During rodding, the rod shall be inserted vertically to ensure effective vibration.
10. Adequate curing shall be provided after concrete pouring (minimum 48 hours for each layer and 7 days upon completion of the platform).
11. Loading shall be avoided within 48 hours of concrete pouring.

Source: Adapted from Mott MacDonald by Ibex Ideas (2025)

Table A. Platform dimensions for different flood depths																
Maximum flood depth (mm)	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
Platform height (H) (mm)	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Number of steps (N)	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10
Ramp height (Hramp) (mm)	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0
Top width (Tw) (mm)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Bottom width (Bw) (mm)	2500	3000	3000	3500	3500	4000	4000	4500	4500	5000	5000	5500	5500	6000	6000	6500

Estimation of material volumes:
Concrete works - concrete mix ratio is 1:3:6 (cement : sand : gravel). Refer notes on concreting.

Table B. Estimate material volumes (for square platform)																
Maximum flood depth (mm)	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
Platform height (H) (mm)	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Concrete volume (cubic metre)	4	5	6	8	9	11	13	15	17	20	23	27	30	34	38	43
Cement (cubic metre)	0,4	0,5	0,6	0,8	0,9	1,1	1,3	1,5	1,7	2	2,3	2,7	3	3,4	3,8	4,3
Sand (cubic metre)	1,2	1,5	1,8	2,4	2,7	3,3	3,9	4,5	5,1	6	6,9	8,1	9	10,2	11,4	12,9
Gravel (cubic metre)	2,4	3	3,6	4,8	5,4	6,6	7,8	9	10,2	12	13,8	16,2	18	20,4	22,8	25,8

Source: Adapted from Mott MacDonald by Ibex Ideas (2025)

3.1.1.2 Surface Sealing (Sanitary Seal)

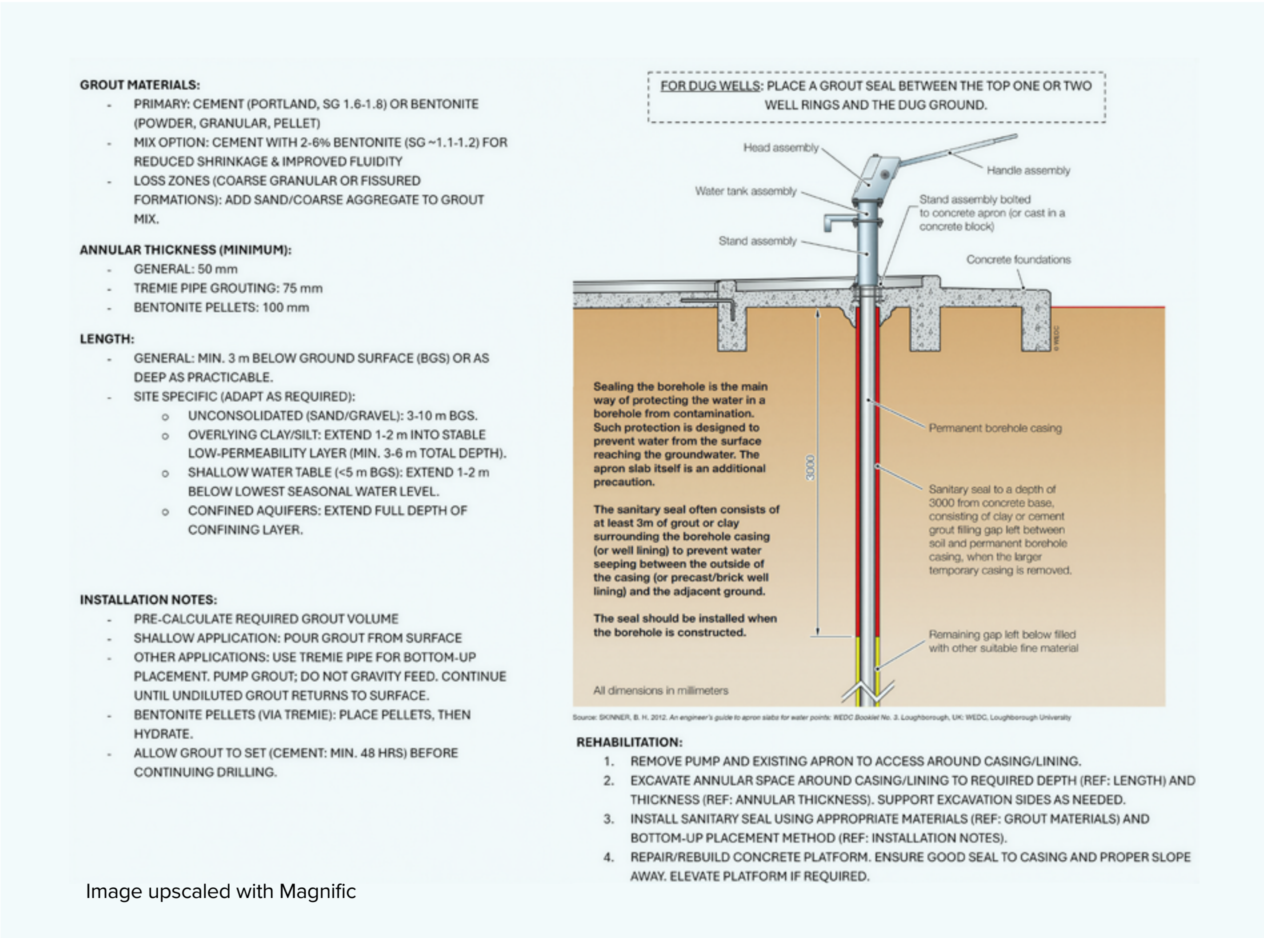
A subsurface sanitary seal is a critical flood resilience measure that works in tandem with an elevated platform. During a flood, when the ground is saturated, contaminated water can seep down the outside of the borehole casing. The seal's purpose is to block this pathway by creating an impermeable barrier in the annular space (the gap between the casing and the borehole wall). By preventing this seepage, a properly installed sanitary seal stops pathogens and pollutants from reaching the aquifer, ensuring the water source remains safe.

All borehole designs should include a sanitary seal in the upper section, typically extending from just below the surface down to a depth of at least 3 metres or, ideally, to the first impermeable geological formation.

Figure 21 illustrates the key components and installation guidance for a sanitary seal.

A properly installed sanitary seal with an elevated, well-drained platform creates a robust, multi-layered protection that significantly improves a borehole's resilience to flood contamination.

Figure 21: Components of a borehole sanitary seal for flood protection.



3.1.1.3 Deeper Intake Depth

In flood-prone areas where shallow groundwater is vulnerable to surface contamination, it is preferable to position the borehole screens at a greater depth. This increases the vertical travel of surface water through aquifer materials, providing more time for the water to be naturally filtered and treated before it enters the well through the screened sections. Deeper aquifer systems will be better protected from surface water contamination than shallow aquifer systems.

For practical guidance on assessing the risk of microbiological contamination of groundwater supplies, refer to existing guidance such as *Guidelines for assessing the risk to groundwater from on-site sanitation* (Ahmed et al., 2016).

3.1.1.4 Drainage and Landscaping

In addition to an elevated platform and a sanitary seal, proper landscaping and the construction of surface drainage features are effective measures for protecting a borehole from floodwater contamination. These measures actively intercept and divert contaminated surface runoff before it can reach and pool around the wellhead, minimising the risk of infiltration into the aquifer or inundation of the casing.

Concrete Apron and Drainage:

A sound, crack-free concrete platform, or apron, should be constructed to prevent contaminated water from seeping under the plinth. The apron should have a raised edge, or collar, to capture water spillage and surface runoff, directing it toward the drainage channel. It must slope away from the borehole casing and towards an outlet channel ('drainage channel') that carries the water to a soakaway located a safe distance downhill from the borehole.

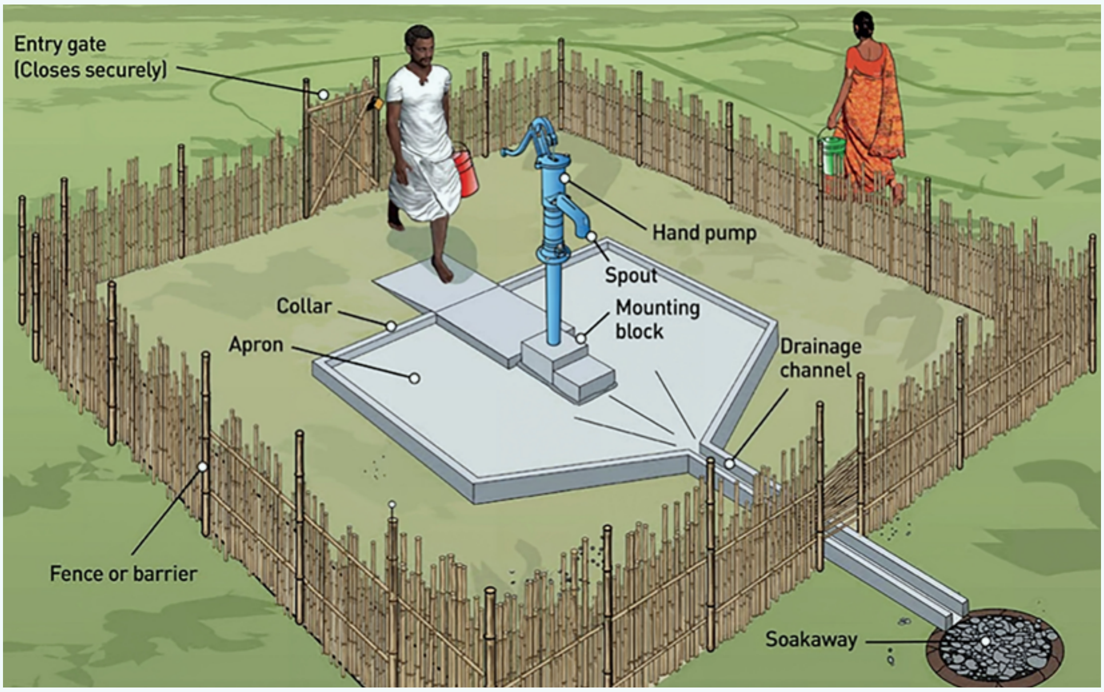
Construction of a Diversion Ditch:

A diversion or 'cut-off' drain can intercept and channel surface runoff from the wider catchment area safely around and away from the borehole site. The diversion ditch should be excavated on the ground upslope from the borehole, be deep and wide enough to handle the expected volume of floodwater, and have a continuous, gentle slope to carry water away without overflowing.

Fencing:

A fence or barrier should be constructed around the wellhead to prevent animals from contaminating the borehole area or damaging the components. It may also prevent unauthorised access by people. The fence should have an entry point, such as a gate, that can be closed tightly and latched shut or locked. Where practical, the fence or barrier should, ideally, be constructed at least 15 metres from the borehole.

Figure 22: A common borehole with a hand pump in a sanitary condition.



Source: WHO (2024). Image upscaled with Magnific

3.1.1.5 Borehole Rehabilitation in Flood-Prone Areas

Borehole rehabilitation is a critical intervention for upgrading existing water points in flood-prone areas, making them more resilient to contamination. It involves assessing the borehole's condition and upgrading its protective features, particularly the well head platform and sanitary seal, to prevent the ingress of contaminated floodwater.

Before starting any physical work, a thorough assessment of the borehole's condition is essential – refer to the assessment checklist in Appendix 1. The assessment should include a sanitary inspection to identify risks, such as a cracked apron, poor drainage, proximity to pollution sources, or changes in the water quality following flooding.

Once priority risk factors have been identified, the appropriate mitigating rehabilitation measure(s) (Table 9) can be implemented.

Table 9: Rehabilitation measures for boreholes in flood-prone areas.

Measure	Details
Repair or Reconstruct the Apron	Cracked, broken, or improperly sloped concrete aprons must be repaired or completely reconstructed. The new platform must be sound, impermeable, and sloped to direct all water to a drainage channel that leads several metres away from the well.
Elevate the Borehole Casing and Platform	If the existing borehole casing becomes inundated with floodwater, the casing and surrounding platform should be extended to a minimum of 0.4m above the flood level to prevent floodwater from overtopping it.
Repair or install sanitary seal	A faulty or non-existent subsurface sanitary seal is a major vulnerability. Repairing a seal may require removing part of the existing apron/platform, excavating around the top of the casing, and placing new bentonite or grout material in the annulus to create an impermeable barrier before reconstructing the platform.

Borehole Cleaning and Disinfection	After any physical rehabilitation, and especially after a flood, the borehole must be thoroughly cleaned to remove any siltation, mud, sand, or other debris that may have been deposited by floodwaters or accumulated over time. This is typically done through borehole development techniques such as airlifting or surging. Following cleaning, the borehole must be disinfected to kill pathogens and bacteria potentially introduced from floodwater, by adding a chlorine solution to the well, surging the water to ensure the entire column is treated, and then pumping the well to waste until the water is clean and the chlorine taste is gone. Refer to Box 8.

Box 8: Recommissioning and rehabilitation of boreholes and wells following flooding (adapted from McCluskey, 2021).

After a flood, boreholes and well water sources must be considered contaminated. The following three steps provide a practical guide to bringing them back into service safely:

1. **Structural Inspection & Rehabilitation:**

   Visually inspect the infrastructure's condition (wellhead, well exterior and interior), conduct the necessary repair or rehabilitation works (refer to Table 9), and restore protection of the water point (fences, vegetation).

2. **Physical Cleaning (For Damaged or Open Sources):**

   For partially protected water supplies like hand-dug wells, physical cleaning is a critical first step before any disinfection can be effective.

   The well must be de-watered and de-sludged to remove contaminated sediments and debris. This process is essential to improve the effectiveness of the subsequent chlorination and to restore the original yield of the well.

   Field-friendly de-watering and de-sludging kits can be used for this purpose, often by non-skilled personnel.

3. **Disinfection (Super-Chlorination)**

No water supply should be released for consumption until it has been properly disinfected.

Disinfect every potentially contaminated water supply (boreholes, wells, springs) using super-chlorination (shock chlorination) rates. This high dose is necessary to overcome the increased contamination load from potential leaks, system breakages, and proximity to damaged sewerage and drainage systems. Refer to Godfrey and Reed (2013) for guidance on using chlorination to disinfect a borehole (or well).

3.1.2 Drought-Resilient Boreholes

Drilling and designing boreholes in drought-prone areas requires careful planning to ensure long-term water security. This section describes key implementation measures to enhance borehole resilience to droughts.

Table 10: Drought resilience measures for boreholes.

Measure	Details
Overdrilling	Extending a borehole deeper than the primary water-producing zone can create a vital buffer that keeps the pump submerged and the borehole operational even when regional water levels decline during a drought.
Install Pump at Lowest Acceptable Depth	Install the pump at the lowest acceptable depth so that it can take in water from as much of the vertical depth of the borehole as possible.
Install Low Level Probe	Install a low-level probe in every borehole for dry-run protection, preventing pump damage from overheating if water levels drop too low.

Install Dip Tube for Water Level Monitoring	All motorised boreholes need a dip tube to measure the groundwater level.
Performance Assessment	Perform pumping tests following borehole development, and at regular intervals thereafter, to assess and monitor the performance of the borehole.
Install Storage Tanks/Reservoir	Install storage tanks or a reservoir to store water abstracted in periods of water surplus to buffer the water demand in periods of low availability (i.e., droughts).

3.1.2.1 Overdrilling

Overdrilling - drilling a borehole deeper than the main water-producing zone - can enhance a borehole's resilience to drought. As groundwater levels can naturally decline during droughts, creating extra depth provides a buffer, ensuring the borehole can continue to supply water when shallower sources fail.

Determine the Target Depth: drill deep enough to accommodate both pumping drawdown and the anticipated seasonal or drought-related decline in the regional water table.

- **Drill Past the First Water Strike:** do not stop drilling immediately after encountering a good water strike. Continue drilling to create sufficient depth below this zone
- **Account for Water Level Decline:** the final depth should be based on an assessment of the hydrogeology, including historical data on water level fluctuations, if available. Deeper boreholes can tap groundwater that is less affected by seasonal variations

Incorporate a Sump: a sump is a blank-cased section at the bottom of the borehole (at least 1 m below the lowest screen) (Figure 23) and provides a space for any sand or fine material to settle without clogging the screen or being drawn into the pump.

Figure 23: Example of borehole design in unconsolidated sediments.

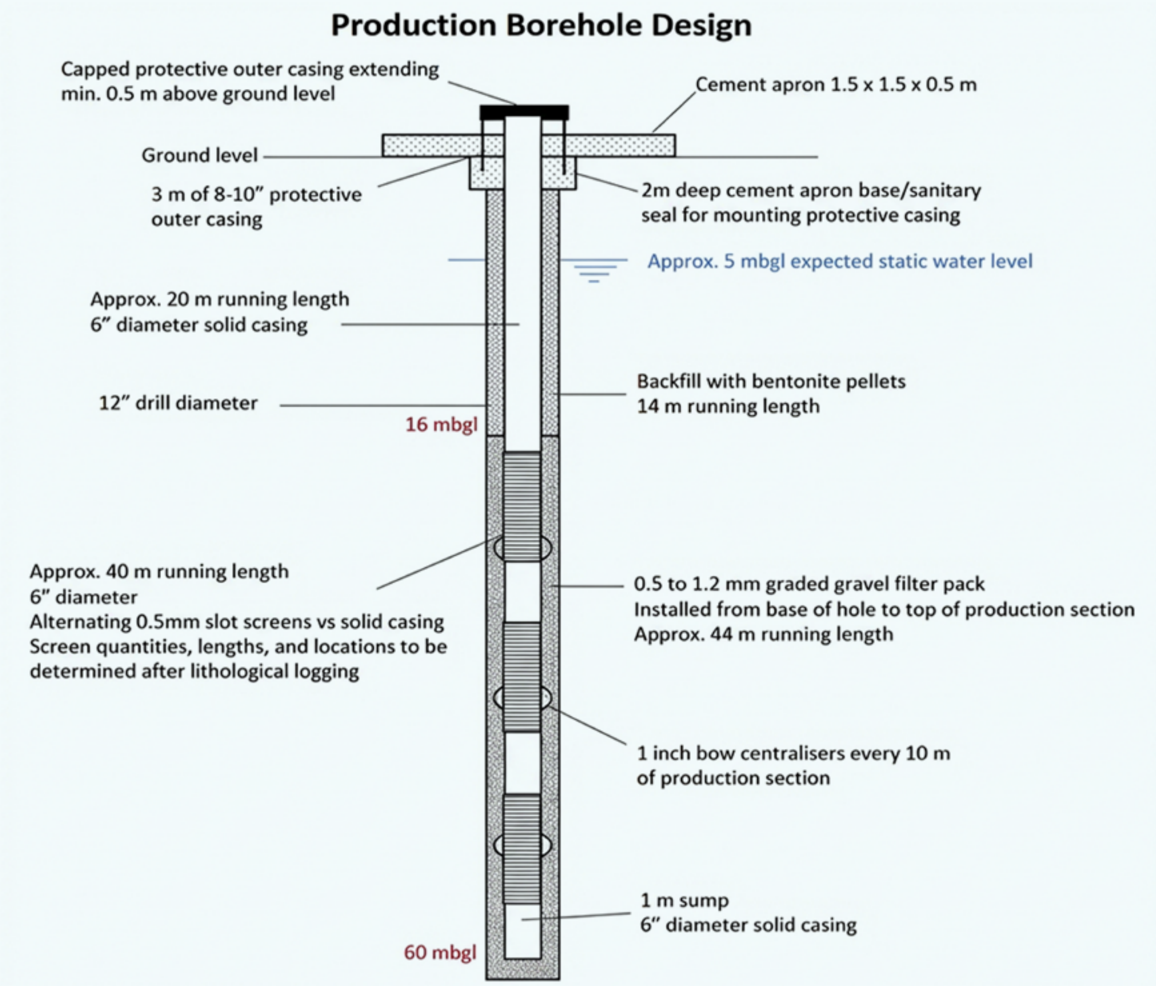


Image quality enhanced with Nano Banana Pro

3.1.2.2 Install Pump at Lowest Acceptable Depth

Positioning the pump deeper in the water column maximises the available drawdown - the vertical distance the water level can fall before it reaches the pump's intake. This creates a buffer, ensuring the pump remains submerged and operational for a longer period as water levels recede during a drought.

Technical Considerations:

Placement: the pump should not be placed at the very bottom of the borehole. It must be set at a safe distance above the borehole screen or intake zone (at least 1 m in height) to prevent clogging from sediment and to ensure unrestricted water flow into the pump.

Performance: a deeper pump setting increases the total dynamic head (TDH, the total pressure the pump must overcome), which will affect flow rate and energy consumption. The pump's specifications must enable it to perform efficiently at this greater depth. The final setting should be determined by the borehole's construction, its tested yield, and data on historical water level fluctuations in the area.

3.1.2.3 Install Low-Level Probe

Install a low-level probe within each borehole to protect the pump from declining groundwater levels during a drought. The probe can be secured to the raising main above the pump intake via cable ties (Figure 24). When the water level in the well drops below the level of the well probe, the probe will stop the pump, protecting it from running dry.

Figure 24: A low-level probe secured to a raising main.

Source: Lorentz (https://www.lorentz.de/s/help/1630/function-and-use-of-dry-run-protection/). Image quality enhanced with Nano Banana Pro.

3.1.2.4 Install a Dip Tube

Monitoring groundwater levels is the best way to understand the long-term sustainability of a water source and its resilience to seasonal changes and drought. To assess the drought resilience of a borehole, monitor the water level (refer to Groundwater Level Monitoring for guidance). The most practical monitoring tool is a water level recorder (dip metre) to take manual measurements of the water level.

Dip Tube Installation

- A dip tube provides clear, permanent access for manually measuring the water level in a borehole without interference from the pump's rising main
- A small diameter 1.25”-1.5” (inch) PVC/HDPE pipe is attached to the pump’s rising main using cable ties (Figure 25), strong string, or clips available in-country, and installed inside the casing
- Drill holes at the bottom of the pipe to allow water to enter
- The bottom of the dip tube should be placed sufficiently below the water table to accommodate future changes in water level (pumping and natural)
- An access port should be integrated into the design of the wellhead and concrete apron and positioned directly over the dip tube to allow a dip metre to be lowered without obstruction (Figure 26)

Figure 25: A PVC pipe with a bottom cap and some holes drilled acting as a dip tube for a borehole in South Sudan.

Image quality enhanced with Nano Banana Pro

Figure 26: (Left) A secure cap for the dip tube opening to prevent contamination and rainfall entering; (Middle) 2" diameter opening of dip tube; (Right) Measuring water level from the top of the dip tube using a dip metre.

Image quality enhanced with Nano Banana Pro

3.1.2.5 Performance Assessment (Post-Development)

Performing pumping tests following construction and development is important for understanding a borehole's efficiency and yield and establishing a baseline for its long-term sustainability.

Pumping Tests: the primary method for gathering performance data. Different tests provide different information about the borehole and aquifer.

- **Step Test:** this is the best measure of borehole efficiency. It is performed by pumping at several different increasing flow rates and recording the drawdown at each step to see how the borehole itself performs under increasing stress
- **Constant-Rate Test:** this is used to estimate the aquifer's properties (like transmissivity) and to estimate a long-term sustainable yield. The borehole is pumped at a single, controlled, constant rate for an extended period (e.g., 24-72 hours) to observe the aquifer's response over time
- **Recovery Test:** this is performed following a pumping test and often provides the most reliable data. It involves measuring the water level as it rises back to its rest level immediately after the pump is switched off

Specific Capacity: calculate the specific capacity of the borehole using the constant rate pumping test data, which is a useful measure of the borehole's performance.

- Specific capacity is the amount of water that can be pumped from the borehole per unit of drawdown. It indicates how 'stressed' the borehole is to achieve a certain yield
- Specific Capacity = Pumping Rate / Drawdown
- A high specific capacity indicates an efficient borehole that yields water easily. A low specific capacity suggests the borehole must work harder (i.e., has greater drawdown) to produce the same amount of water, making it less efficient and more vulnerable

- The specific capacity measured immediately after construction and development provides a vital baseline performance indicator for that specific borehole
- The baseline can be compared against periodic re-testing in the future. A significant decline in specific capacity over time is a clear indicator of a problem, such as borehole or screen clogging, or a decline in the aquifer's potential

3.1.2.6 Borehole Rehabilitation in Drought-Prone Areas

When an existing borehole underperforms in a drought-prone area, a series of rehabilitation measures can be implemented to improve its yield, efficiency, and resilience.

Before beginning any rehabilitation, a thorough assessment of the borehole is essential (refer to the assessment checklist in Appendix 1). The assessment may include a pumping test to determine the current yield and drawdown, a water level measurement (static and pumping), a downhole camera inspection (CCTV) to check the condition of the casing and screen and to identify priority risk factors in existing drought-affected boreholes. Implement the appropriate rehabilitation measure(s) (Table 11) to address them.

Table 11: Rehabilitation measures for boreholes in drought-prone areas.

Measure	Details
Borehole Redevelopment and Cleaning	Borehole redevelopment and/or cleaning can help to improve the borehole efficiency and increase the yield.
Borehole Deepening	Deepening an existing borehole can allow for access to deeper groundwater. However, this may not be suitable for all types of settings or conditions.
Pump System Modification	If the water table has dropped beyond the pump intake, the pump can be lowered to access the deeper water table, if there is room to do so. This may only function as a temporary measure.
Install Low-Water Level Sensor)	Install a dry-run protection sensor that automatically shuts off the pump if the water level drops below the pump intake, preventing damage to the pump.

Borehole Redevelopment and Cleaning

Borehole cleaning helps to remove fine material from the aquifer to improve permeability in the immediate vicinity of the well screen.

The following techniques can be used to physically or chemically clean/re-develop the borehole:

Mechanical Methods:

- **Airlifting:** inject compressed air deep into the borehole to create an air-water mixture that lifts sediment and loose material out. Effective for removing sand/silt
- **Jetting:** direct high-pressure water jets at the screen surface to dislodge incrustation and fine particles. Can be combined with brushing
- **Surging:** create rapid back-and-forth water movement through the screen (using a surge block or compressed air) to loosen fine particles and break down bridging
- **Brushing:** mechanical wire brushes scrape incrustation and biofouling from the casing and screen surfaces. Often used with jetting or airlifting (see Borehole Redevelopment and Cleaning)

Chemical Treatment:

Specific chemicals (e.g., acids for carbonate scale, polyphosphates for iron bacteria, chlorine for general biofouling) are used to dissolve or break down clogging agents.

Refer to *Misstear et al. (2017)* for further borehole cleaning and development guidance.

Borehole Deepening

Deepening an existing borehole that fails in a drought-prone area due to declining water levels can be a viable resilience measure. However, this approach carries risks and requires a thorough technical and financial assessment before proceeding.

Initial Feasibility Assessment:

- **Confirm Deeper Aquifers:** first, an assessment must confirm that a productive aquifer of suitable quality exists at a greater depth. Prospecting for deeper water-bearing zones can be done by drilling a small-diameter exploratory hole from the bottom of the existing well

- **Assess Existing Infrastructure:** conduct a borehole camera survey to assess the state of the existing casing and screen. This will reveal if it is intact and strong enough to support the stresses of further drilling
- **Evaluate Risks vs. Benefits:** there are risks associated with borehole deepening, such as damaging the existing casing and/or screen during the drilling process. These risks must be weighed against the potential benefits of accessing a deeper, more reliable water source
- **Compare Costs:** compare the total cost of deepening the existing borehole (including assessment, risks, and mobilisation) against the cost of drilling a new borehole nearby

Deepening Open-Hole Boreholes (best candidate):

Open-hole boreholes are the best candidates for deepening because there is no casing or screen at the bottom to act as an obstruction.

- These boreholes are typically drilled into hard, consolidated rock (like granite) that does not collapse. Casing is only installed through the upper, loose soil layers, leaving the lower section in the rock as an uncased 'open hole'
- The drilling rig has direct access to the rock at the base of the borehole, allowing for a similarly sized or slightly smaller diameter bit to extend the hole to a new depth

Note that deepening may not always be technically possible, even in an open-hole borehole. A borehole drilling/engineering expert should be consulted to determine its feasibility.

Deepening Cased and Screened Boreholes (more complex):

These boreholes are constructed in unconsolidated formations (like sand or gravel) and are lined with casing and screen along their entire depth to prevent collapse. Deepening is more complex and may only be feasible if the original casing string can be removed before deepening, or if the original borehole diameter is large enough (e.g., 10-12 inches /25-30cm) to allow for 'telescopic' drilling through the existing casing string. Note that the final, narrower diameter of the deepened section must still be large enough to accommodate the intended pump.

Pump System Modification

Modifying the pumping system can be a simple borehole adaptation in response to falling water levels during droughts. By adjusting the pump's depth, type, and placement, the water point's reliability and sustainability can be enhanced.

Lowering the Existing Pump: the most direct response to a declining water table is to lower the pump's position.

- If the water table has dropped beyond the pump intake, the pump can be placed deeper in the borehole if there is sufficient room. However, this should be considered a potentially temporary solution if water levels continue to fall

Selecting a New Pump: a significant drop in water level may require a new pump due to the additional lifting capacity required.

- A new pump with a higher lifting capacity can accommodate the increased TDH that results from a decline in the water level

Strategic Pump Placement:

- The pump intake should be set 3 to 5 m below the expected lowest dry season dynamic (pumping) water level
- It should be placed more than 1 m above the top of the screen to reduce the risk of clogging. In a bedrock borehole, it can be set at or just above the uppermost major water-bearing fracture
- The pump intake should be more than 3 m above the bottom of the borehole to avoid drawing up sediment

3.1.3 Borehole Operation & Maintenance

Routine checks involve assessing pump operation, inspecting visible components, and ensuring the wellhead area is secure and functional. Scheduled servicing includes performance monitoring and preventative maintenance.

Climate Resilience Considerations:

Flood Prone Areas:

- focus on wellhead integrity, sanitary seals, drainage, and rapid post-flood procedures (disinfection, testing). Ensure the apron prevents floodwater ingress. Consider raising wellheads or installing flood-proof seals where feasible.

Drought Prone Areas:

- monitor water levels (static and dynamic) and pump performance closely. Adjust pumping regimes if necessary. Anticipate increased wear due to higher demand or lower water levels.

Table 12: O&M Schedule for boreholes.

Frequency / Type: Regular Checks (Weekly/Monthly)	
Task	
Field Inspection	**Details:** Assess general borehole condition, infrastructure integrity (apron, drainage, fencing).
	Flood Considerations: check for erosion around the apron, ensure drainage is clear before rainy season.
	Drought Considerations: note any signs of over-abstraction (e.g., ground subsidence - though rare).
Water Quality	**Details:** Carry out regular checks on basic water quality parameters such as electrical conductivity, turbidity, pH and temperature.
	Flood Considerations: note any changes in water quality that might suggest floodwater contamination of the borehole.
	Drought Considerations: note any changes in water quality shown by electrical conductivity that might be associated with higher mineralised or saline water induced into the aquifer as a result of over-abstraction.
Pump Operation	**Details:** Keep track of daily pumping rate. A reduction in rate might be a sign of a problem with the borehole efficiency or a drop in the water table. Check ease of pumping/starting, listen for unusual noises (grinding, knocking), note any reduction in water flow/pressure.
	Drought Considerations: reduced flow may indicate a falling water table or pump issue - investigate promptly.

Above-ground Components	**Details:** Inspect pump head, handle/lever/motor housing, spout, bolts, fasteners for looseness, wear & damage. Check security of locks/covers.
	Flood Considerations: check for corrosion or damage after inundation. Ensure electrical components (if motorised) are protected/sealed.
Wellhead Area & Sanitary Seal	**Details:** Check concrete apron/plinth for cracks, erosion & damage. Ensure drainage channels are clear & direct water away from the wellhead. Inspect the integrity of the sanitary seal between the casing and the apron.
	Flood Considerations: ensure seal is intact to prevent contaminant ingress during/after floods. Repair cracks immediately. After flooding: halt supply, clean/disinfect well thoroughly, test water quality (especially for pathogens), restart only when safe.
Fencing/ Protection	**Details:** Ensure protective fencing is intact and gates function to prevent animal access/contamination.
	Flood Considerations: repair any damage caused by floodwaters quickly.
Frequency / Type: Scheduled/Annual Servicing (Annually/Biannually or as needed by Technician)	
Task	
Step-Drawdown Test (Annual)	**Details:** Perform test to check borehole efficiency and compare with baseline/previous results to identify issues (e.g., screen blockage, aquifer depletion). Crucial for assessing rehabilitation effectiveness.
	Drought Considerations: essential for monitoring aquifer response and sustainable yield. Declining efficiency requires investigation.

Pump Performance	**Details:** Measure flow rate, pressure, water levels (static/ dynamic) & power consumption (motorised). Compare against specifications/history.
	Drought Considerations: track performance trends; efficiency drops can indicate required maintenance or abstraction adjustments.
Pump Mechanism (Handpump)	**Details:** Follow manufacturer's guidelines. Check/tighten rising main connections. Inspect cylinder seals/foot valve. Requires a trained mechanic; major repairs may need external support.
Pump Mechanism (Motorised)	**Details:** Requires specialised skills. Ensure regular lubrication, component inspections (bearings, seals) & efficiency tests. Check electrical connections, safety devices, pump performance curve; listen for motor noise.
	Flood Considerations: inspect electrical systems carefully post-flood for water damage/safety before restarting.
	Drought Considerations: lower water levels may require pump adjustment or will increase wear; monitor amperage/ power use.
Borehole Cleaning (as needed)	**Details:** If continuous turbidity, reduced yield, or biofouling occurs arrange for well cleaning (e.g., jetting, surging, chemical treatment if appropriate) by professionals. Requires pump removal.
	Flood Considerations: increased turbidity is common post-flood; cleaning may be needed if it persists after initial flushing/disinfection.
	Drought Considerations: reduced yield due to screen encrustation/clogging might necessitate cleaning.

Wellhead Seal & Structure	**Details:** Verify integrity of sanitary seal at surface. Repair any cracks in apron immediately.
	Flood Considerations: re-inspect and repair seal/apron after any flood event.
Record Keeping	**Details:** Maintain detailed logbook of all checks, water level measurements, maintenance, repairs, parts used, water quality data & user feedback.
	Considerations: Ensure **flood/drought** specific observations and actions are recorded.

3.2 Dug Wells

Dug wells are large diameter, manually excavated wells. They are often lined with stones or concrete to prevent collapse. Common designs include protected dug wells, riverbed wells, and infiltration wells.

Protected dug wells are commonly between 5 and 20 metres deep, although some traditional hand-dug wells can be deeper.

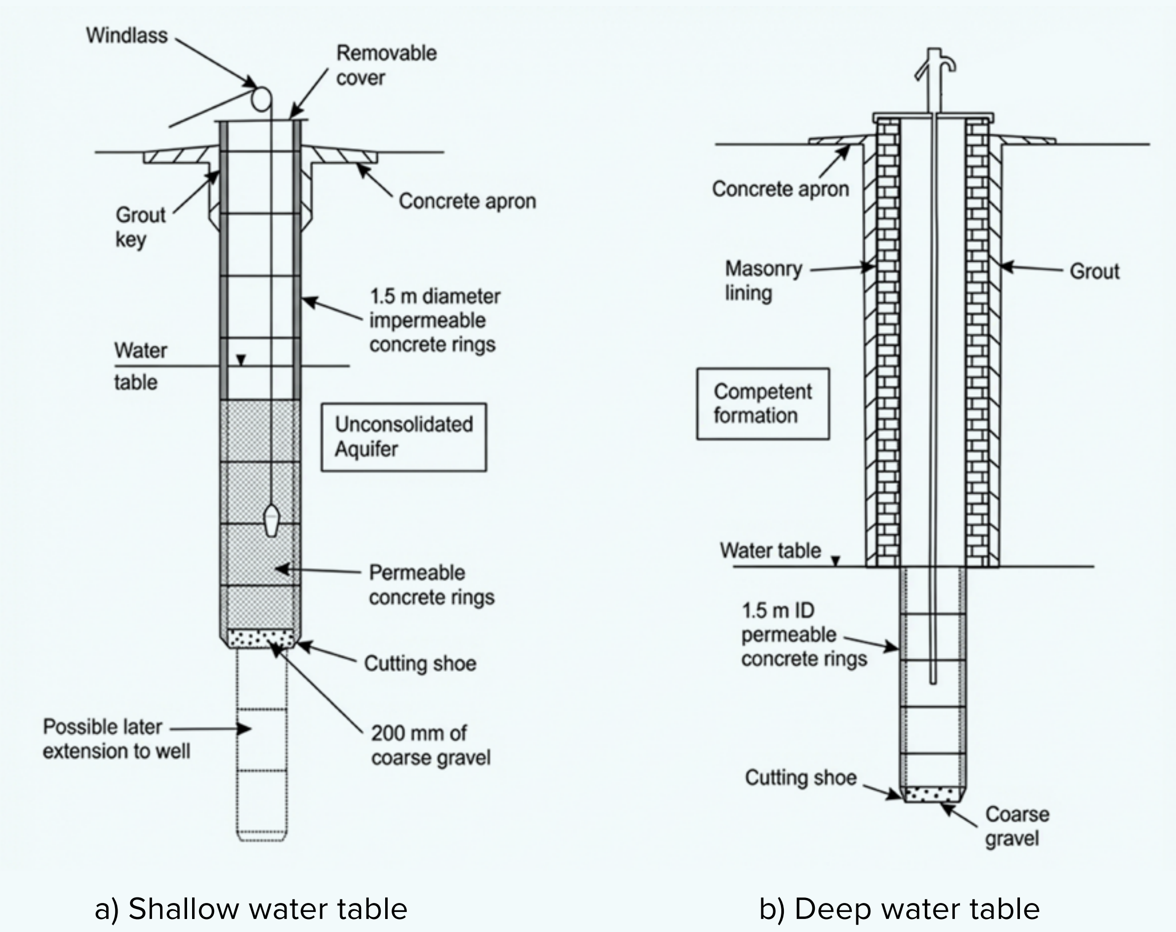
Table 13: Dug well characteristics.

Category	Description
Advantages	• Can be constructed using local materials and labour. • Relatively low cost. • Easily maintained.
Disadvantages	• High vulnerability to contamination. • Prone to drying out in drought conditions.

Climate Vulnerabilities

- **Flooding:** high contamination risk from surface runoff during floods.
- **Drought:** the well may dry out due to reduced shallow groundwater recharge.

Figure 27: Dug well designs for: a) shallow water table and b) deep water table.



Source: Misstear et al. (2017). Image quality enhanced with Nano Banana Pro

3.2.1 Flood-Resilient Dug Wells

Hand-dug wells tap into shallow groundwater sources. While often simpler and cheaper to construct than boreholes, their shallow nature and larger diameter make them **highly vulnerable to contamination**, especially during floods. Floodwaters can easily overtop the well, seep through inadequate linings or covers, or infiltrate through the surrounding ground if the sanitary protection is insufficient.

Therefore, constructing new hand-dug wells in flood-prone areas is generally **not recommended as a first choice**. Boreholes, if feasible, typically offer better protection. However, where shallow aquifers are the only viable or accessible water source, carefully designed and constructed hand-dug wells, incorporating specific flood-resilience measures, can provide a vital water supply.

Similar to boreholes, flood protection measures for dug wells (Table 14) create multiple barriers against contamination, such as an installation of a **sanitary seal** to prevent contaminated floodwater from infiltrating between the dug hole and the well lining, as well as the construction of an **elevated headwall** to prevent direct inundation of floodwaters into the well.

Table 14: Flood protection measures for dug wells.

Measure	Details
Elevate Well Lining and Platform	Raise the well lining at least **0.4 m above the 100-year flood level or the highest recorded flood level**. • For bucket extraction with low flood levels: build a raised headwall so that the height exceeds the flood level (>0.4m). • For handpumps or high flood levels: raise the headwall and platform above flood level (the borehole platform details found in Figure 20 can be adapted for dug wells).
Surface Sealing (Sanitary Seal)	Place a **bentonite clay or cement grout seal** in the **space between the dug hole and well lining** to prevent contaminated surface water from travelling down around the casing. This seal should be placed around the top one or two well rings. Refer to Surface Sealing for further instruction.
Deeper Intake Depth	If water quality is a concern (e.g., potential sources of pollution are located nearby), consider a deeper placement of the well intake, as vertical travel through aquifer materials often provides better filtration than lateral distances (Lawrence et al., 2001). Refer to Deeper Intake Depth.

Secure and Seal the Well Cover	Ensure the well has a solid, overlapping, and secure cover to properly seal the top of the well, preventing surface water, debris, and other contaminants from entering the hole directly.
Drainage and Landscaping	Ensure the apron is sound, with no cracks and **slopes away from** the borehole to a soakaway, **perimeter drainage trench or a French drain** to carry away floodwater. Refer to Surface Sealing.

3.2.1.1 Dug Well Rehabilitation in Flood-Prone Areas

Before rehabilitation, carry out a comprehensive assessment of the existing well. The checklist in Appendix 2 can be used to facilitate this.

Once priority risk factors have been identified, the appropriate rehabilitation measure(s) (see Table 15) can be implemented.

Table 15: Rehabilitation measures for dug wells in flood-prone areas.

Measure	Details
Repair the Headwall and Cover	**Repair the Existing Headwall** ✓ Repair cracks or holes in the upper, watertight section of the lining using watertight methods like patching with cement mortar. ✓ If the existing upper lining or headwall is severely damaged or structurally unsound, consider constructing a new, larger diameter lining around the outside of the existing well (see Figure 29 for an example). • it must extend high enough to form the new raised headwall (above the flood level) and deep enough (at least 1.5 metres below ground level or to the water table) to provide stability and cut off shallow lateral flow paths

	• the original well shaft and new lining should move independently (i.e., do not add concrete between the two) to allow future deepening of the well – in such a case, the original well shaft would move while the new exterior lining would act as the permanent lining **Install or Replace the Wellhead Cover** ✔ Construct or install a new, heavy, durable cover, typically from reinforced concrete (see Figure 30 for an example). ✔ The cover should be slightly domed or sloped to shed rainwater and overlap the headwall on all sides to prevent water ingress.
Extend the Headwall and Platform	If the well becomes inundated with floodwater, the headwall and surrounding platform should be extended to a minimum of 0.4 m above the flood level to prevent floodwater from overtopping it. • **For Bucket extraction with low flood levels:** build a raised headwall so that the height exceeds the flood level **(>0.4m).** • **For handpumps or high flood levels:** raise the headwall and platform above flood level (see Flood Resilient Boreholes above for platform details). Construct the apron with deeper foundations at the edge to resist floodwater erosion caused by running water that can undermine a concrete slab.
Repair or Install a Sanitary Seal	• A faulty or non-existent subsurface sanitary seal is a major vulnerability. • Repairing a seal may require removing part of the existing apron/platform, excavating around the top of the casing and placing new bentonite or grout material in the annulus to create an impermeable barrier before reconstructing the platform. See Flood Resilient Boreholes above.

Well Cleaning and Disinfection	After any physical rehabilitation, and especially after a flood, the well must be thoroughly cleaned to remove any siltation, mud, sand, or other debris that may have been introduced by floodwater or accumulated over time. After cleaning, the borehole must be disinfected to kill pathogens and bacteria potentially introduced from floodwater. Disinfect by adding a chlorine solution to the well, surging the water to ensure the entire column is treated, and then pumping the well to waste until the water is clean and the chlorine taste is gone. Refer to Box 8 for additional information.

Figure 28: Clay grout being added to provide a sanitary seal for a well in Madagascar.

Source: CARE Nederland (2016). Image quality enhanced with Nano Banana Pro

Figure 29: Flood-resilient well under construction in Madagascar.

Source: CARE Nederland (2016). Image quality enhanced with Nano Banana Pro

Figure 30: Cover slab rehabilitation being carried out on a well in Sierra Leone.

Source: Inter Aide (2015). Image quality enhanced with Nano Banana Pro

3.2.2 Drought-Resilient Dug Wells

Dug wells are highly vulnerable to drought because they are typically shallow and can only access groundwater near the surface, which fluctuates greatly with the seasons. Furthermore, they are frequently built in low-permeability materials that recharge slowly, causing them to dry up even during normal dry seasons.

In drought-prone regions, dug wells should only be considered when deeper boreholes or other more reliable options are not feasible due to:

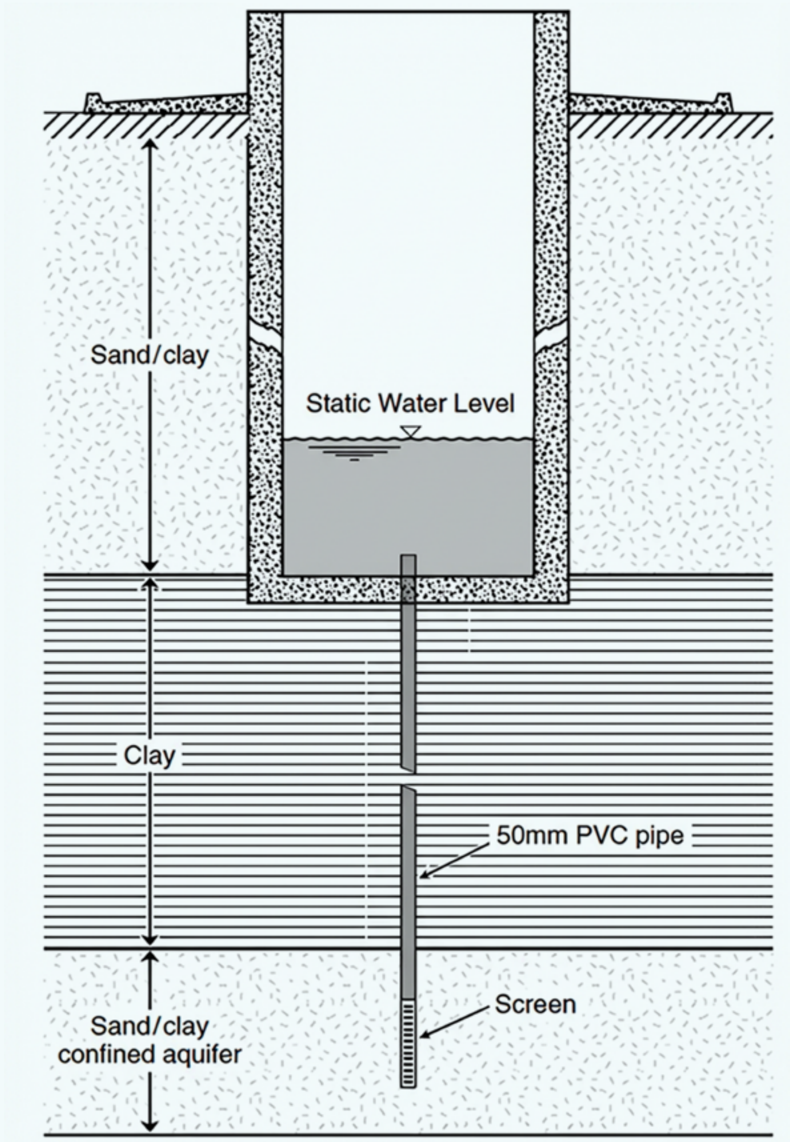
- Cost constraints
- Unfavourable geology for drilling (e.g., very hard rock at shallow depth)
- Specific community preferences or skills
- Situations where their storage capacity is advantageous

Table 16: Resilience measures for dug wells in drought-prone regions.

Measure	Details
Timing of Digging	Construct during the **latter half of the dry season** when groundwater levels are typically at their lowest.
Increased Well Depth	Excavate the well as deep as possible into the water table, ideally reaching more permeable layers or a stable base like bedrock. A dewatering pump can be used during excavation to allow digging below the static water table. Alternatively, a narrow diameter borehole can be drilled or jetted into the sediments at the base of the well Figure 31.
Wider Diameter for Storage & Access	Increase the diameter of the well to act as a natural reservoir, storing water that seeps in gradually, allowing it to meet peak water demands (e.g., morning and evening) at a higher rate than the aquifer's natural yield. The diameter must be sufficient to accommodate diggers and equipment for future deepening operations if the water table drops.

Well Performance & Yield Testing	Following construction and, ideally, at the peak of the dry season, test the well's performance. Conduct a simple recovery test by pumping the well, and then monitoring the rate at which the water level recovers, to assess its sustainable yield. A very slow recovery may indicate that the well cannot meet demand.

Figure 31: A dug well deepened via jetting to create a small diameter borehole.



Source: Davis and Lambert (2002). Image quality enhanced with Nano Banana Pro

3.2.2.1 Dug Well Rehabilitation in Drought-Prone Areas

Before rehabilitation, carry out a comprehensive assessment of the existing well to diagnose the issue(s). Refer to the checklist in Appendix 2.

Remediating dug wells in drought-prone regions primarily involves **expanding or deepening the existing structure** to reach additional water sources (Table 17).

Table 17: Rehabilitation measures for existing dug wells in drought-prone areas.

Measure	Details
Well Cleaning	Remove all debris, sediment, and stagnant water from the well to improve water quality and storage volume.
Well Deepening	If the well goes dry seasonally, deepening is the most effective measure for drought resilience. This should be done in the late dry season. **Techniques include:** • **Underlining:** manually dig deeper and line the new section from below with bricks or concrete blocks. • **Telescopic Lining:** sink smaller diameter, pre-cast concrete rings inside the existing well shaft to line the newly excavated depth. Refer to the SKAT manual *Hand-dug shallow wells* (Collins, 2000) for guidance. • **Jetting:** use a high-pressure stream of water to excavate softer materials like sand and silt from the bottom. This method is often used to sink a smaller diameter screened pipe deeper into the aquifer without requiring manual excavation inside the well. Refer to Davis and Lambert (2002) for further guidance. • **Drilling:** mobilise a drilling rig over the well to drill a narrow-diameter borehole from the bottom of the existing dug well. ◦ in consolidated rock, this borehole can remain an open hole

	• in unconsolidated sediments, this deeper hole will need to be cased (typically with PVC) and screened
Improve Water Inflow (Yield)	Improve the intake (to increase the rate of inflow) by replacing the lower sections of solid lining with perforated or slotted concrete rings during deepening or repair. A surrounding gravel pack should be installed around these new rings to filter out sand and silt.

3.2.3 Dug Well Operation and Maintenance

Dug wells require regular checks of the cover, lining, lifting device (windlass or pump), and platform.

Climate Resilience Considerations:

Flood Prone Areas:

- **Very vulnerable to contamination.** Focus on watertight covers, raised headwalls/ linings, secure aprons, and post-flood cleaning/disinfection

Drought Prone Areas:

- **Monitor water levels.** Yields can drop significantly. Consider well deepening or alternative sources during severe droughts. Prone to drying out completely

Table 18: Example of an O&M schedule for dug wells.

Frequency / Type: Regular Checks (Weekly/Monthly)	
Task	
Well Cover/Lid	**Details:** Ensure it is intact, fits properly, is kept closed & locks work (if fitted). Ensure it is watertight.
	Flood Considerations: ensure cover prevents floodwater entry. Check seal, if present.

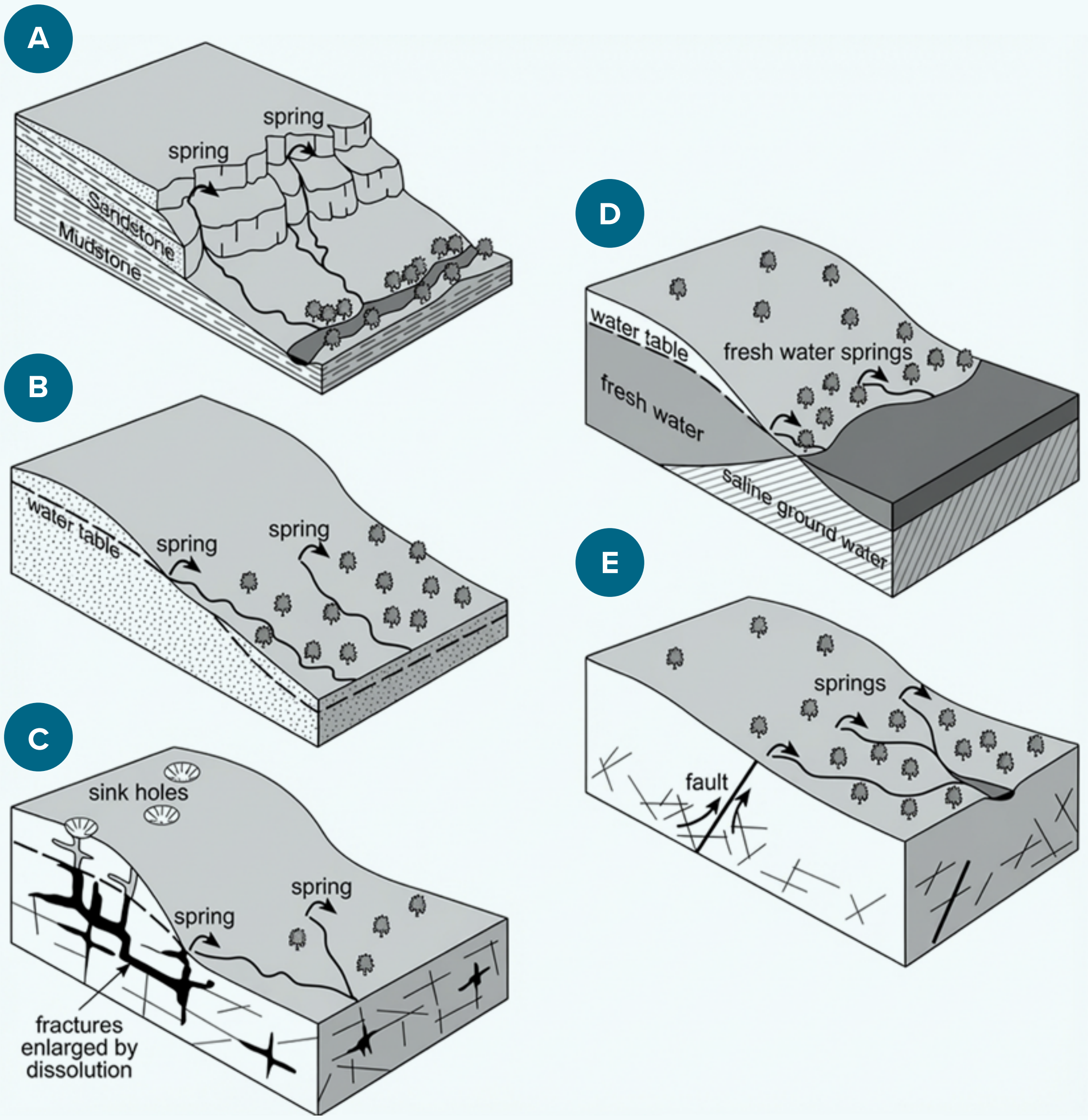
Yield Assessment	**Details:** Monitor yield. If declining significantly, consider deepening (if hydrogeology allows) or rehabilitation techniques.
	Drought Considerations: reduced flow may indicate falling water table or pump issue - investigate promptly.
Water Quality	**Details:** Carry out regular checks on basic water quality parameters such as electrical conductivity, turbidity, pH and temperature.
	Flood Considerations: note any changes in water quality that might suggest flood water contamination of the well.
Lining/Headwall	**Details:** Visually inspect upper lining and headwall for cracks, deterioration & potential contaminant entry points.
	Flood Considerations: inspect for structural damage post-flood. Ensure headwall is high enough to prevent overtopping if possible.
Lifting Device	Check rope/chain condition, bucket integrity, windlass handle/mechanism function. If pump fitted, check as per borehole guidance.
Platform/Apron & Drainage	**Details:** Check apron for cracks, erosion, damage. Ensure it slopes away from the well. Ensure drainage channels are clear and functional. Check surrounding area for erosion potential.
	Flood Considerations: ensure apron/drainage prevents ponding near well and resists erosion. Reinforce or elevate if necessary.
Fencing/ Protection	Ensure protective fencing is intact to prevent access to animals.

Frequency / Type: Scheduled/Annual Servicing (Annually or as needed)	
Task	
Cleaning	**Details:** Regularly remove floating debris. Periodically (annually or as needed) remove accumulated bottom silt/debris. Requires safety precautions and often emptying the well.
	Flood Considerations: essential cleaning required after any inundation event to remove silt and contaminants.
Structural Repair	**Details:** Repair cracks in lining, headwall, and apron promptly to prevent structural failure and contamination ingress. Address potential collapse issues.
	Flood Considerations: prioritise repairs after flood damage.
Lifting Device Maintenance	**Details:** Service windlass/pump as needed. Replace worn ropes. Inspect/maintain pump as per manufacturer's manual.
Sand Infiltration Control	**Details:** If sand/silt entry is persistent (especially after floods), consider installing bottom filters/slabs (requires emptying well).
	Flood Considerations: may be necessary if floodwaters introduce significant sediment.
Disinfection	**Details:** Shock chlorinate after major cleaning/repairs, or any suspected contamination event (e.g., post-flood inundation, a dead animal found). Test water quality afterwards.
	Flood Considerations: mandatory after any flood inundation, following thorough cleaning.
Record Keeping	**Details:** Maintain logbook detailing checks, cleaning, repairs, water levels, disinfection events & problems encountered.
	Considerations: Ensure **flood/drought** observations and actions are recorded.

3.3 Springs

Groundwater springs, where groundwater naturally emerges at the surface, can provide a high-quality water source, often requiring minimal treatment due to natural filtration. This makes them valuable assets for rural communities.

Figure 32: Different types of springs: a) at junction between different rock types; b) break of slope; c) karstic; d) fresh/saline interface; e) fault controlled.



Source: Adapted from MacDonald, A.M. (2005) Developing Ground Water: A Guide for Rural Water Supply. ITDG Publishing. p220. Image quality enhanced with Nano Banana Pro

The main hydrogeological types of springs include:

- **Contact Springs:** occur where permeable and impermeable rock layers meet, forcing groundwater to discharge at the surface. These springs are relatively stable but may experience reduced flow during droughts
- **Fracture-Controlled Springs:** form along faults, fractures, or joints in bedrock, where groundwater moves through cracks and emerges at the surface. These springs can provide high yields but may be prone to seasonal variation
- **Karst Springs:** found in limestone or carbonate rock formations, where water flows through dissolved channels and caves. These springs can have high, variable flows but are vulnerable to contamination due to rapid underground water movement
- **Valley or Slope Springs:** occur when the water table intersects the land surface on a slope or valley side. These springs are common in hilly and mountainous areas and can provide a consistent flow
- **Artesian Springs:** develop in confined aquifers, where water is under pressure and naturally flows to the surface through fractures or weak spots in the overlying rock. These springs often provide clean, steady water with minimal seasonal fluctuation
- **Coastal Springs:** found at the interface between fresh and saltwater in coastal areas, where freshwater from inland aquifers seeps out at beaches or underwater. These springs can be affected by tidal fluctuations and saltwater intrusion

A spring must be properly developed to obtain the full benefits of its flow, kept from the intrusion of animals and pollution, and protected from damage and possible diversion. They are usually protected by constructing a spring box or retaining wall around the outlet (the 'eye' of the spring), and may feed piped systems by gravity.

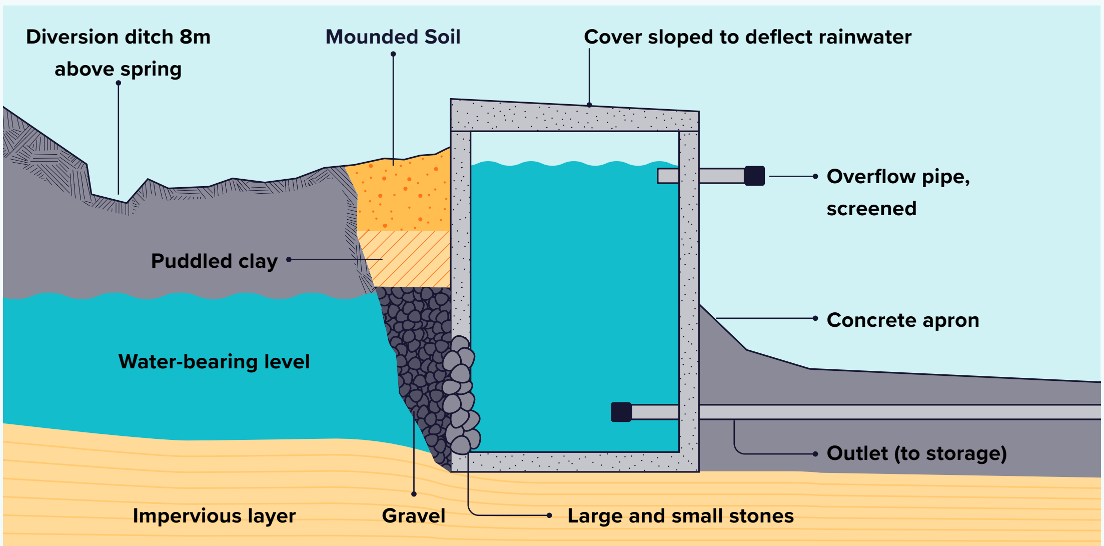
Table 19: Characteristics of groundwater springs.

Category	Description
Advantages	• Requires minimal infrastructure and no pumping, as it typically flows by gravity. • Often a reliable water source in mountainous or hilly regions. • Water is often of higher quality than surface water sources, having been naturally filtered through soil and rock.

Disadvantages	• Vulnerable to seasonal changes in flow, which may decrease or cease during dry periods. • The source can be easily contaminated if the outlet (the spring eye) and surrounding recharge area are not properly protected. • Location is fixed by local geology and cannot be chosen for convenience.
Climate Vulnerabilities	• **Flooding:** contaminated floodwaters can enter an unprotected spring outlet. In certain geological formations (like karst), contaminants can travel quickly from the surface to the spring with little filtration. • **Drought:** reduced rainfall reduces groundwater recharge, which can severely diminish or stop the spring's flow.

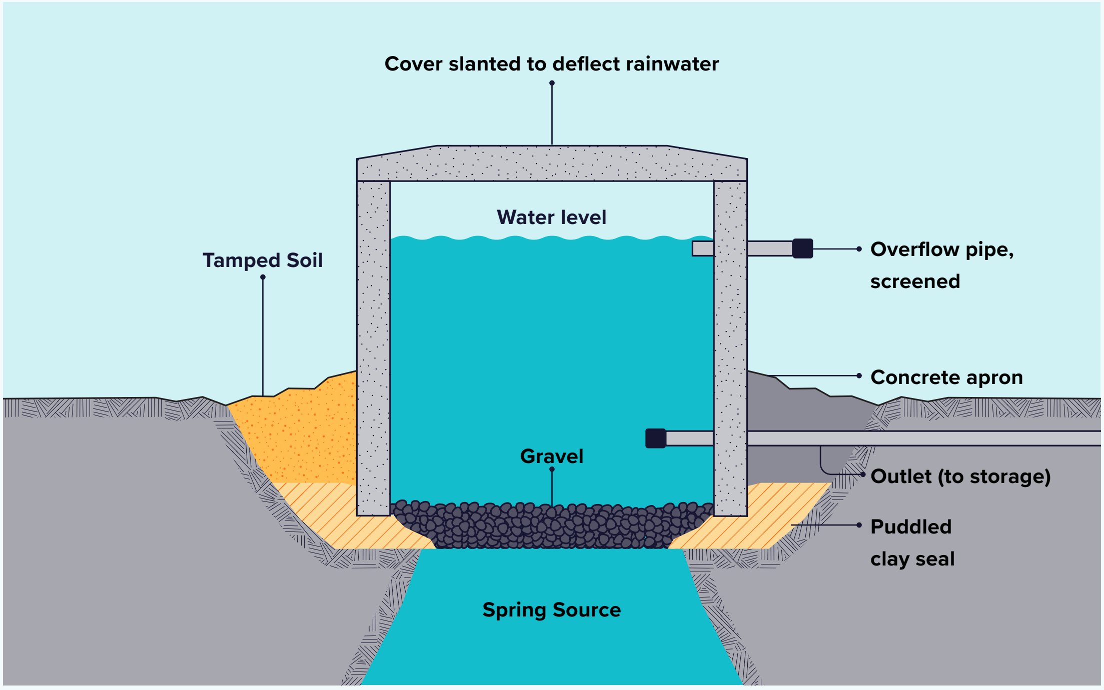
Two basic spring box designs can be modified to meet local conditions and requirements. The first design is a spring box with a single permeable side for hillside collection (Figure 33), and the second design has a permeable bottom for collecting water flowing from a single opening on level ground (Figure 34).

Figure 33: Spring box design with permeable side for hillside collection.



Source: Adapted from author's figure by © Ibex Ideas (2025)

Figure 34: Spring box design with permeable bottom for collecting spring water flowing from an opening on level ground.



Source: Adapted from author's figure by © Ibex Ideas (2025)

3.3.1 Assessing Climate-Resilient Springs

Before developing a spring, a thorough assessment is essential to understand its long-term behaviour and protect its water quality, ensuring the source is resilient to drought (yield failure) and floods (contamination).

3.3.1.1 Hydrogeological Context and Community Consultation

The first step is to assess the spring's long-term reliability by consulting the people who know it best. Detailed discussions with various community groups and key informants provide the most valuable information on sustainability. Key questions to ask include:

- How does the flow rate change between the wet season and peak of the dry season (e.g., the time taken to fill a bucket)?
- How long do people have to queue for water at different times of the year?
- Has the spring ever dried up, especially during past droughts?

If the flow is sufficient throughout the year, it can be considered a reliable source for the community. Assess whether a single spring is enough, or if a more resilient but distant spring needs to be developed as well.

3.3.1.2 Physical Site Assessment

Inspect the spring's location and characteristics.

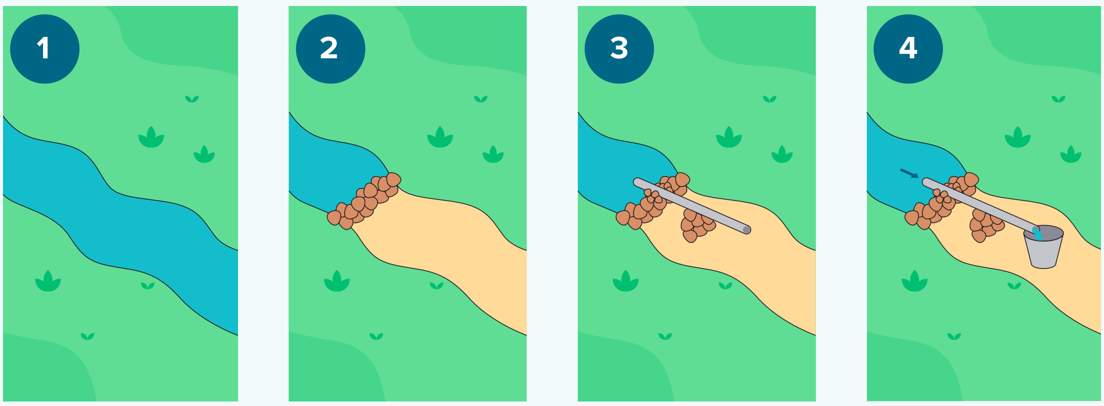
For Flood-Prone Areas:

- **Assess Elevation:** where possible, choose springs located above maximum historical flood levels.
- **Assess Spring Type:** prioritise 'ascending' spring types where water flows up under pressure, as they have better inherent natural protection against surface contamination.

For Drought-Prone Areas:

- **Assess Aquifer Source:** prioritise springs that appear to be fed by larger, deeper groundwater systems, as they are likely to be more resilient to drought. Typically, springs located at a lower elevation will flow longest in a dry period.
- **Observe Seasonal Shifts:** observe if the 'eye' of the spring (where water emerges) shifts its location seasonally, and identify the lowest emergence point, as this is the most reliable location for a potential intake.
- **Measure Yield:** directly measure the spring's flow rate. This can be done simply by channelling the flow through a pipe into a bucket of a known volume, and timing how long it takes to fill (Figure 35). Weirs are also commonly used to measure spring flows. Monthly measurements over a full year are ideal for assessing the minimum and maximum discharge, if time allows.

Figure 35: Steps for collecting spring flow measurements. Step 1: Find a suitable location along the spring where the ground has a natural gradient. Step 2: Build a dam wall using mud/soil/stones across the spring at a relative high point. Step 3: Embed the pipe. Step 4: Measure the flow rate.



Source: Adapted from author's figure by © Ibex Ideas (2025)

3.3.1.3 Catchment and Water Quality Risk Assessment

Assess the risk of the spring becoming contaminated, particularly during heavy rains and floods.

- **Survey the Catchment Area:** walk the catchment area upslope from the spring to identify potential sources of pollution, such as pit latrines, graveyards, waste disposal sites, or intensive agriculture. A minimum guideline is to have no pit latrines or waste disposal sites within 100 metres upslope of the spring intake.
- **Test Water Quality:** check the spring's water quality in both the wet and dry seasons. This is important because the quality can change as shallow, recent rainwater mixes with deeper groundwater, and pollutant concentrations can increase during low-flow periods.

3.3.2 Climate Resilience Measures for Springs

After a suitable spring site has been selected, specific measures can be taken during construction to protect the source from the impacts of floods (contamination) and droughts (low yield). Table 20 provides measures to take to help make springs more resilient to floods and droughts.

For comprehensive guidance on preparatory steps to be taken prior to any construction work, such as the tracing of springs, water testing, and spring flow measurement, refer to the manual *Spring Catchment: Manuals on Drinking Water Supply* published by SKAT (Meuli and Wehrle, 2001).

Table 20: Flood and drought protection measures for springs

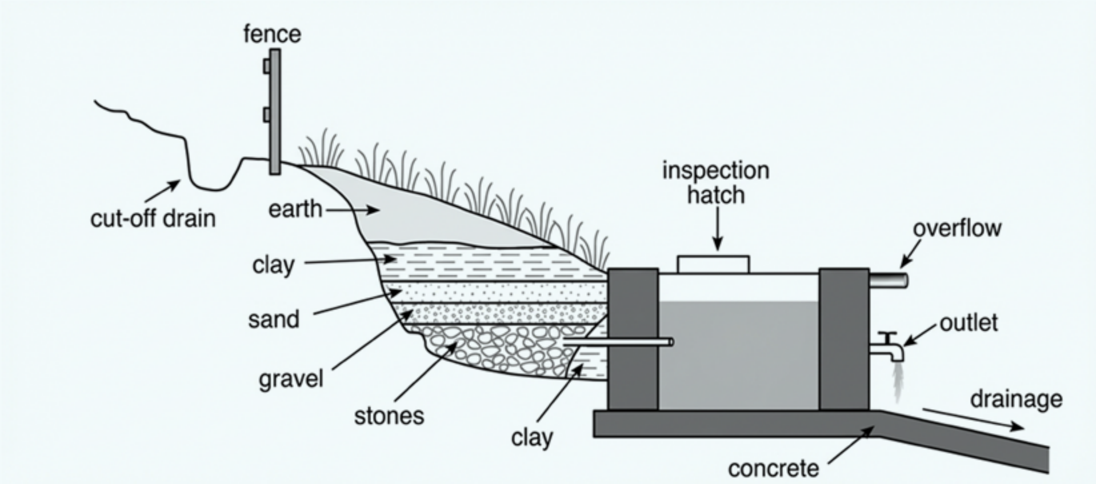
Climate Hazard: Flood	
Measure	**Details**
Erosion Control and Drainage	A ditch can be excavated on the slope above the spring to intercept surface runoff and divert it safely away from the collection area. Erosion control measures like gabions (wire cages with rocks) and deep-rooted vegetation can be used to stabilise the slopes around the spring and prevent them from being washed away.

Build a Secure Spring Box	A spring box is a covered, watertight collection chamber that protects the collected water from direct contamination. Due to the unique requirements of local settings and communities, no single spring box design fits all circumstances. It should have a secure inspection hatch, a screened overflow pipe, and a controlled outlet tap for water collection. The structure must be anchored firmly into the hillside or ground and have a raised access hatch with an overlapping, lockable cover that sits well above the **highest expected flood level.**
Protect the Intake Area	The eye of the spring should be excavated, and the intake pipe set within a filter area of layered stones and gravel (Figure 36). This intake area must then be capped with an impermeable layer of clay to prevent surface water from seeping down into the clean water source.
Sediment Management	If the spring carries high sediment loads during high flows, incorporate design features like filter layers or a sediment trap within the spring box to protect the pipes and maintain water quality.
Install a Protective Fence	A fence should be constructed around the entire protected spring area to keep animals and their waste away from the intake zone.

Climate Hazard: Drought

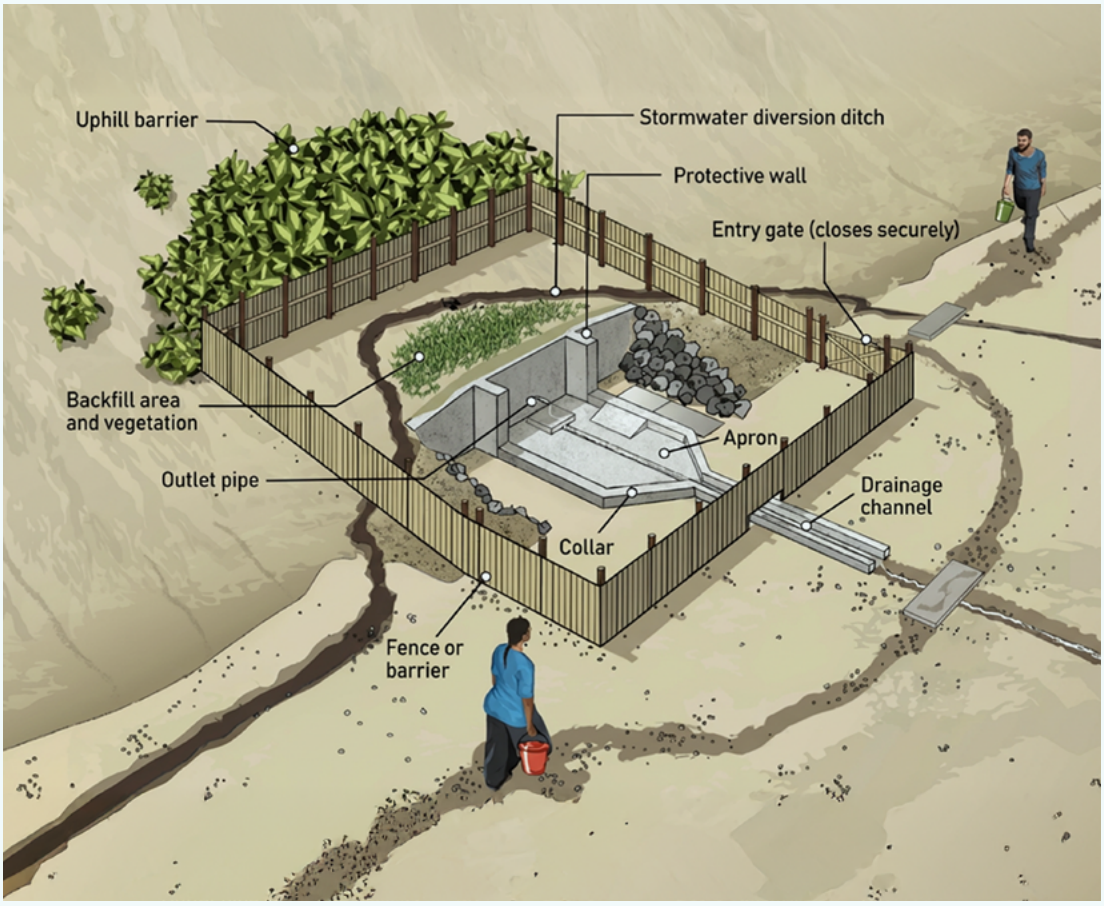
Measure	Details
Strategic Intake Placement	The intake pipe must be placed at the lowest known point where the spring emerges, especially if the eye of the spring shifts seasonally. This ensures that even the smallest flows during the peak of the dry season are captured.
Utilise the Spring Box for Storage	The spring box also functions as a small storage tank or reservoir. This is a critical drought resilience measure, as it allows a low-yielding spring to slowly accumulate water over time (e.g., overnight).

Figure 36: Protection measures for springs.



Source: Ahmed et al. (2016). Image quality enhanced with Nano Banana Pro

Figure 37: Key features of a well-protected spring source.



Source: WHO (2024). Image quality enhanced with Nano Banana Pro

3.3.3 Rehabilitating Existing Springs for Climate Resilience

Existing groundwater springs may be unprotected, damaged, underperforming (especially during droughts), or susceptible to flooding. This can compromise water quality and reliability. Rehabilitation aims to improve a spring source's reliability and safety.

Before commencing any rehabilitation work, conduct a comprehensive assessment of the existing spring source to diagnose issues and identify appropriate corrective actions. Refer to the detailed assessment checklist in Appendix 3.

If a spring ceases to flow during the dry season, it should generally be abandoned. However, if it maintains adequate flow, improvements are warranted. The assessment should:

- ✔ Confirm dry-season yield and water quality
- ✔ Inspect the integrity of the spring box, pipes, and tap stand
- ✔ Check if diversion ditches and fencing are functional

Box 9: Recommissioning and rehabilitation of spring sources following flooding (adapted from Swistock et al. 2022).

Rehabilitating a spring source after a flood is challenging because the constant water flow makes it difficult to meet the adequate contact time needed for chlorine to kill bacteria effectively. The following practical steps can be followed:

1. **Inspect and repair the structure:**

   - ✔ inspect the walls, floor, lid, and pipe inlets/outlets for any cracks, holes, or damage caused by the flood and perform any necessary structural repairs or rehabilitation (refer to Table 20).

2. **Clean the spring box: before attempting to disinfect the water, the physical structure must be cleaned.**

   - ✔ Prepare a cleaning solution by mixing approximately 120 mL of household bleach with 20 litres of water.
   - ✔ Use this solution to thoroughly scrub the interior walls of the spring box, removing any silt, slime, or debris.

3. **Shock chlorinate the system: to disinfect the spring box and the connected pipe network.**

   - ✔ Estimate the volume of water stored in the spring box in litres. (Note: Volume in cubic meters [m^3] x 1000 = volume in litres).

- For every 400 litres of water in the box, prepare a disinfection solution by mixing about 1.5 litres of household bleach with a few litres of water.
- Pour this solution into the spring box and allow the highly chlorinated water to flow through the entire system and out of every tap or faucet.

4. Flush the system and manage wastewater: the highly chlorinated water must be purged from the system before use.

- The following day, open all taps and flush the entire system until the strong chlorine odour is no longer detectable.
- Direct the initial, highly concentrated chlorine water to a safe disposal site – bare ground is best.

Table 21: Climate-resilient spring rehabilitation measures.

Measure	Details
Climate Hazard: Flood/Drought	
Measure	**Details**
Restore Protective Structures	Construct or repair all fundamental protective measures. This includes building a proper **spring box** or **retaining wall** if one is missing, repairing the tap stand **apron** and **drainage channel**, and ensuring the **diversion ditch** and **fence** are fully functional.
Climate Hazard: Drought	
Measure	**Details**
Enhance Spring Yield & Source Capture	For underperforming springs, the source can be re-excavated to clean out sediment and roots. To capture flow from multiple seeps, construct a long trench filled with gravel and install slotted pipes (e.g., in a Y-shape) to collect the water and direct it to a single collection point.
Increase Storage Capacity	Enlarging the existing spring box or installing an additional storage tank can buffer against low flows, allowing water to accumulate for use during peak demand.

3.3.4 Spring Operation and Maintenance

Spring O&M focuses on protecting the source area and maintaining the integrity of the collection and delivery system.

Climate Resilience Considerations:

For Flood-Prone Areas:

- Protect the spring box from inundation and physical damage. Ensure diversion ditches can handle heavy rainfall runoff. Monitor turbidity closely after heavy rain or flood events.

For Drought-Prone Areas:

- Monitor flow rates closely. Yields can decrease significantly or cease during droughts. Protect the catchment area to maximise infiltration.

Table 22 outlines an O&M schedule for protected springs.

Table 22: O&M schedule for protected springs.

Frequency / Type: Regular Checks (Weekly/Monthly)	
Task	
Protective Structures (i.e., spring box/ retaining wall, apron, drainage channel)	**Details:** Inspect for cracks, leaks & damage. If applicable, ensure overflow pipe is clear and functional.
	Flood Considerations: ensure box is protected from direct entry of floodwater/debris. Check structural integrity post-flood.
Water Quality	**Details:** Carry out regular checks on basic water quality parameters such as electrical conductivity, turbidity, pH & temperature.
	Flood Considerations: note any changes in water quality that might suggest flood water contamination of spring (this might be particularly relevant in karst areas).

Source Protection Area	**Details:** Ensure area uphill/around the spring is free from contamination sources (latrines, animals, waste). Check the effectiveness/capacity of surface water diversion ditches. Maintain protective fencing and appropriate vegetation cover (e.g., grass).
	Flood Considerations: ensure diversion ditches are well-maintained and adequately sized before heavy rains. Check for erosion damage post-flood. Reinforce upslope walls/vegetation if needed.
Water Collection & Flow	**Details:** Ensure all available spring water enters the collection system (no external seepage near the eye). Note significant changes in flow rate. Inspect intake pipe screens for clogging; clean/replace if necessary.
	Flood Considerations: check pipe screens frequently as debris load may increase.
	Drought Considerations: monitor flow rate closely; declining flow is a key drought indicator.
Delivery System (Pipes/Taps)	**Details:** Check pipes for leaks from source to tap(s). Inspect tapstand(s) for leaks, damage, and proper operation.
Drainage	**Details:** Ensure tapstand area is well-drained with no standing water. Check that soakaways or drainage channels are clear and functional.
	Flood Considerations: ensure drainage can handle runoff and prevent erosion around tapstand.
Frequency / Type: Scheduled/Annual Servicing	
Water Quality Testing	**Details:** Test annually (at minimum) - ideally before/after wet season) for faecal bacteria (e.g., *E. coli*), pH, turbidity, electrical conductivity & local contaminants. Test before initial use and after major repairs/ contamination events.

	Flood Considerations: test after heavy rainfall/flooding events, especially if turbidity increased.
	Drought Considerations: monitor water quality parameters as contaminant concentrations may increase as flow decreases.
Cleaning	**Details:** Clean sediment/debris from the spring box collection chamber annually or as needed. Clean tapstand area.
	Flood Considerations: may require more frequent cleaning if sedimentation increases.
Repairs	**Details:** Repair cracks in spring box structure, pipe leaks & malfunctioning taps promptly. Maintain/repair fencing and diversion ditches. Reinforce catchment protection measures (e.g., walls, vegetation) if erosion occurs.
	Flood Considerations: prioritise repairs of source protection and structural integrity post-flood.
Disinfection (if needed)	**Details:** If water quality tests show contamination or after major works/contamination ingress: drain system, clean & wash walls with chlorine solution, refill & add chlorine for disinfection; flush system.
	Flood Considerations: may be required if source protection was breached or testing shows contamination post-flood.
Record Keeping	**Details:** Maintain a logbook of checks, flow measurements, maintenance, repairs, water quality test results & rainfall observations.
	Considerations: Ensure **flood/drought** specific observations (flow rates, turbidity) and actions are recorded.

3.4 Alternative & Complementary Technologies for Drought-Prone Areas

In arid and semi-arid lands, conventional groundwater sources, such as boreholes and deep dug wells, are not always feasible, sustainable, or cost-effective due to challenging hydrogeology, deep water tables, or high costs. Furthermore, drought conditions exacerbate water scarcity, often leading to the failure of traditional sources.

This section provides an overview of alternative and complementary water harvesting and storage technologies suitable for drought-impacted regions. These technologies often focus on capturing and storing episodic rainfall and runoff, enhancing groundwater recharge, or accessing shallow subsurface water more reliably. Properly sited and designed, they can significantly improve water security and resilience for communities facing drought.

3.4.1 Sand Dams

Sand dams are reinforced concrete walls built across ephemeral (seasonal) sandy riverbeds. Their purpose is to trap sand and gravel carried by floods, creating an artificial aquifer upstream of the dam. Water is stored in the pore spaces of this accumulated sand.

Table 23 outlines the main components to consider when implementing sand dams.

Table 23: Sand dam characteristics

Feature	Description & Key Specifications
Function	A reinforced wall across a seasonal river that traps sand, creating an artificial underground aquifer to store floodwater.
Key Benefits	• Captures and stores episodic rainfall, providing a reliable water source in dry seasons. • Less evaporative water loss compared to open surface storage. • Natural filtration through the sand often enhances water quality.

Site Selection	• **River Type:** seasonal (ephemeral) sandy riverbeds with well-defined channels and stable banks. Needs distinct flood events that transport sand. • **Gradient:** gentle slopes (0.2% - 4%) to maximise sand deposition. • **Foundation:** impermeable layer (bedrock/clay) at <4-6 m depth below the riverbed. • **Sediment:** river must carry coarse to medium sand (target >60-70% sand, <10-15% silt/clay). Assess existing riverbed material and catchment geology – granite, quartzite, sandstone catchments are often good sources.
Core Construction	• **Materials:** typically rubble stone masonry with cement-sand mortar. • **Foundation:** must be 'keyed' into the impermeable layer. • **Wall:** often built in stages (0.5-1.0 m lifts per season). Base thickness typically 2/3rds of spillway height. • **Spillway(s):** central spillway for normal flows; higher flood spillways in wing walls. Must be level and perpendicular to flow. • **Apron:** concrete apron downstream of spillway to prevent undercutting (unless on solid bedrock).
Extraction Methods (typically upstream of dam)	• **Shallow Dug Wells:** excavated into the sand deposit; can be simple scoop holes or lined wells for better protection. • **Infiltration Galleries:** perforated pipes laid horizontally in the sand, conveying water to an intake well/sump for pumping. • **Direct Pipe Outlet:** a screened pipe through the dam wall allows direct gravity abstraction if sufficient head exists.

Figure 38: A hand-dug well adjacent to a sand dam with water seeping into the well through the caisson concrete ring walls.

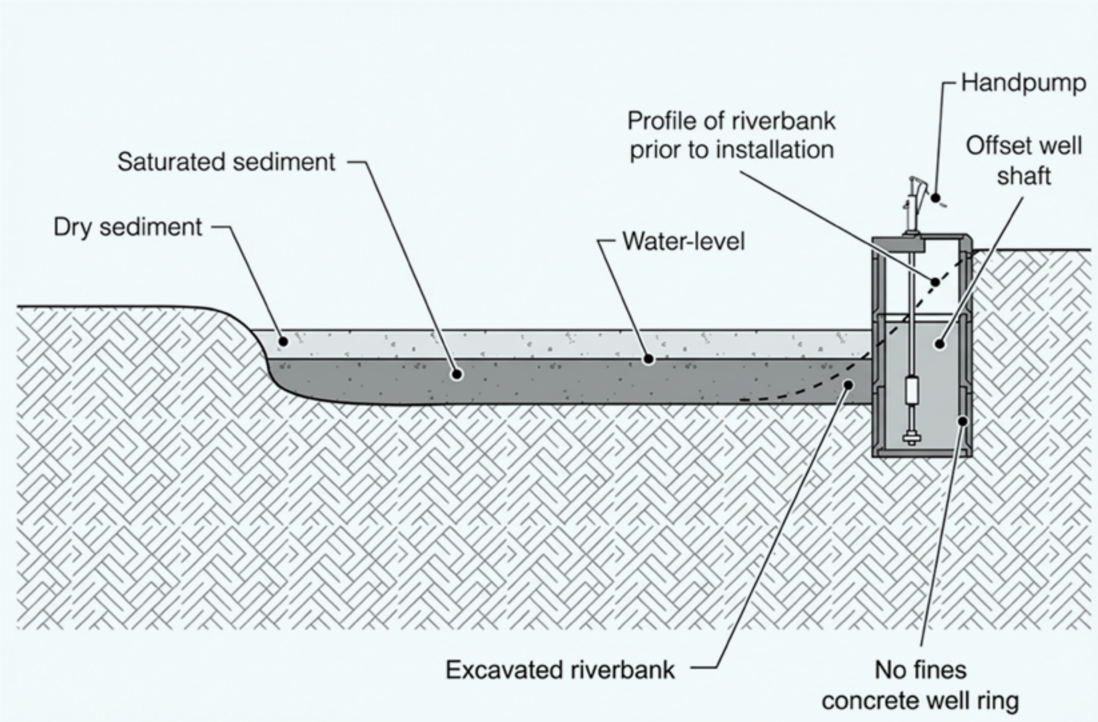


Image quality enhanced with Nano Banana Pro

Figure 39: Photos of two sand dams to illustrate the different sizes: a 200 cement-bag sand dam (top) and a 850 cement-bag sand dam (bottom).

Source: Maddrell (2018). Image quality enhanced with Nano Banana Pro

For comprehensive guidance on siting, designing, and constructing sand dams refer to *Sand Dams: A Practical & Technical Manual* (Maddrell, 2018).

3.4.2 Check Dams

Check dams are small, low barriers (typically less than 1.5-2 metres high) constructed across gullies or minor ephemeral streams using local materials like stone, gabions, earth, or concrete. Their main purpose is erosion control, achieved by slowing the runoff velocity and trapping sediment.

Although their direct water storage is minimal, check dams contribute indirectly to drought resilience by increasing the opportunity for water to infiltrate the soil. This enhanced infiltration can lead to localised shallow groundwater recharge and improved soil moisture, potentially benefiting nearby shallow wells and vegetation.

Table 24 outlines the main components to consider when implementing check dams.

Table 24: Check dam characteristics.

Feature	Description & Key Specifications
Function	A small dam built across a gully or channel primarily to reduce water velocity, control soil erosion, and trap sediment; it also enhances groundwater recharge.
Key Benefits	• **Erosion Control:** stabilises gullies and prevents them from deepening and widening. • **Groundwater Recharge:** slows runoff, increasing water infiltration into the soil. • **Sediment Trapping:** reduces downstream sedimentation and can improve water quality.
Site Selection	• **Landform:** small gullies/drainage channels with moderate gradients (<10%). Not for major rivers. Ensure gully stability. • **Soils:** underlying permeable soils are needed for significant infiltration benefits.

	Placement: often built in a series (closer together on steeper slopes). Position at stable, narrow sections in the gully.
Design & Construction	**Common Types:** • **Temporary:** brushwood/log dams (small gullies, low flow). • **Permeable/Flexible:** loose stone dams (small-medium gullies), woven-wire dams (finer sediment trapping), gabion dams (larger gullies, higher flows). • **Earthen:** earth plugs (small gullies, low gradients, non-humid areas). • **Permanent:** concrete/masonry dams (require more design). **Key Features:** • **Height:** keep low (<1.5-2 m) for stability. • **Foundation:** must be 'keyed' into the gully bed and banks (>0.5 m deep) to prevent undercutting. • **Spillway:** a central spillway is essential to safely allow overflow at peak flows. • **Apron:** often required downstream to prevent scour and undercutting.

Figure 40: Series of cascading simple stone rubble check dams constructed to control erosion and retain water within the surrounding soil.

Source: Oxfam GB, n.d. Image quality enhanced with Nano Banana Pro

For comprehensive detailed practical guidance on various check dam types, refer to *Geyik* (1986).

3.4.3 Infiltration Galleries with Stilling Wells

An infiltration gallery collects naturally filtered subsurface water from permeable sands and/or gravels near rivers or lakes. It consists of a horizontal perforated pipe ('gallery') buried in these sediments, connected to a vertical, lined well (stilling well) on the bank.

Table 25 outlines the main components to consider when implementing infiltration galleries.

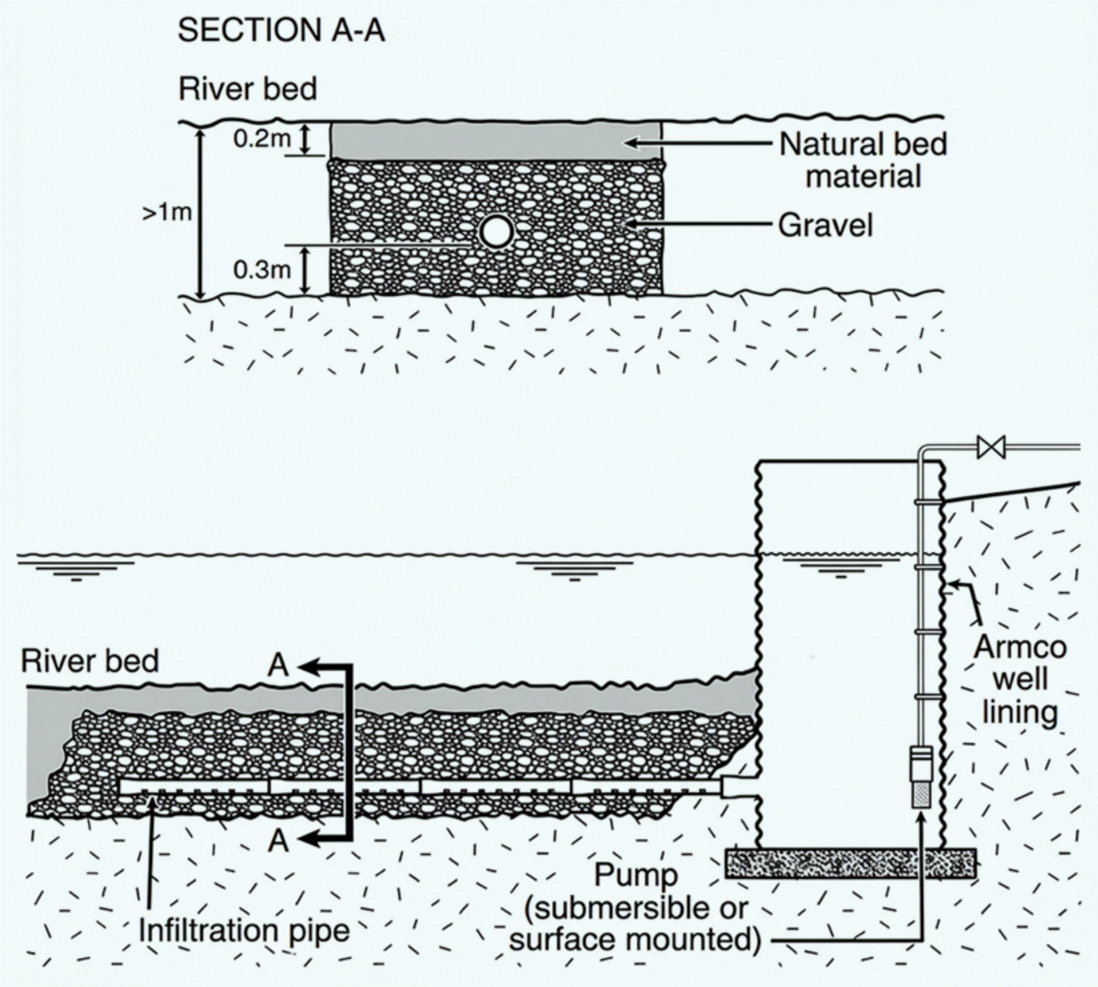
Table 25: Infiltration gallery characteristics.

Feature	Description & Key Specifications
Function	A horizontal, perforated pipe ('the gallery') buried in a riverbank collects naturally filtered water and channels it to a protected vertical 'stilling' well for pumping.
Key Benefits	• **Improved Water Quality:** natural filtration through sand/gravel removes contaminants. • **Protected Abstraction:** the stilling well can protect a submersible pump from flood damage. • **Drought Resilience:** accesses subsurface water that persists longer than surface flow and can aid in controlling excess surface water.
Site Selection	• **Landform:** banks of rivers/lakes with significant permeable sand/gravel beds extending below the dry season water level. Avoid highly erosive or shifting channel areas. • **Sediments:** must be investigated through test pits, augering, etc. Need sufficient depth (>1.5-2 m below dry season riverbed) and sufficient extent of permeable sand/gravel (ideally uniform medium-coarse sand; low silt/clay <10-15%).

	• **Hydrology/Hydrogeology:**
	  • the water table in the riverbank must seasonally submerge the gallery (ideally by >1 m at driest time)
	  • assess surface water quality (though filtration through sediments helps)

Design & Construction	**Gallery (Horizontal Pipe):** • **Material:** slotted/perforated uPVC, porous concrete, or well screens (non-corrosive, strong). • **Size:** min. 100-150 mm diameter. Length based on yield requirement and aquifer properties. • **Slots/Perforations:** sized to prevent sediment entry (based on filter pack). • **Filter Pack:** place clean gravel around the gallery pipe (100-200 mm thick) graded according to aquifer material. Use of a geotextile sock optional. • **Depth:** place gallery >1 m below the lowest seasonal water table to access persistent flow. • **Conveyance Pipe:** solid pipe from gallery to stilling well. **Stilling Well (Vertical Sump):** • **Material:** watertight (concrete rings, in-situ concrete, masonry). • **Size:** ~1-1.5 m internal diameter. Base >0.3 m below gallery invert. • **Cover:** heavy, lockable, raised >0.3 m above ground/flood level. • Construction method is similar to a hand dug well. **Extraction:** water is lifted from the stilling well with a handpump or motorised pump.

Figure 41: Design of a river bed infiltration gallery and stilling well.



Source: Davis and Lambert (2002). Image quality enhanced with Nano Banana Pro

For comprehensive guidance on siting, designing, and constructing infiltration galleries refer to ***Aqualinc*** (2014).

4 Sustainable Water Resource Management

4.1 Groundwater Resource Management

Sustainable water services depend on well-maintained physical infrastructure and also on the health and management of the groundwater resource. Sustainability requires users and practitioners to monitor, understand and protect these resources. Regulation, communication, and incentives to adapt practices based on changing conditions may be required.

When developing groundwater resources, practitioners must consider:

- What impact will their abstractions have on aquifers and existing water users, and
- How may seasonal or longer-term trends in groundwater levels or quality impact the infrastructure that is being developed?

In some locations, with strong water regulators, the aquifer systems are well regulated and significant information on the groundwater resources is available. In others, there may be no information at all.

In well-managed aquifers, new water sources are generally licensed, and permits are required to develop the resource. Local groundwater professionals can support you through the process of obtaining a licence.

In locations with weaker regulation, knowledge about the long-term availability of groundwater resources may be very limited. Good practice in such locations is to work with the local authorities to establish baseline monitoring during borehole/well construction or spring commissioning and maintain a simple monitoring programme once the source has been commissioned. This will support the operation and maintenance of the system and develop an understanding of longer-term changes in the resource.

In drought-prone areas, an understanding of long term trends is of greater importance as the risks of over abstraction are increased. Over abstraction can lead to both declining water levels and a deterioration in water quality. Monitoring should be focused on groundwater levels and quality at **critical water points**.

To identify which water points should be prioritised for monitoring, consider the following:

- **Population served:** prioritise sources supplying the largest number of people (e.g., the main village wells, school water sources, healthcare facility supplies).
- **Essential services:** identify water points crucial for essential services, such as hospitals, clinics, and schools.
- **Sole source dependency:** focus on communities or institutions with no alternative water sources.
- **Historically vulnerable points:** identify water points known to dry up first, or experience frequent pump failures during past droughts (through community consultation and past records).
- **Strategic importance:** consider water points vital for agricultural activities or local livelihoods.

Detailed guidance for the implementation or enhancement of groundwater monitoring networks is beyond the scope of this document. For relevant detailed technical guidance, reference can be made to existing guiding documents, such as:

- IGRAC's *Guideline on: Groundwater monitoring for general reference purposes* (revised 2008) (IGRAC, 2008)
- UNEP's *Technical Guidance Document for Water Quality Monitoring and Assessment of Groundwater* (United Nations Environment Programme, 2022)
- World Bank's *Practical Manual on Groundwater Quality Monitoring* (Ravenscroft and Lytton, 2022)
- Forthcoming Groundwater Relief & Action Contre la Faim (ACF) guidance document *Groundwater Monitoring in Humanitarian Contexts: A Practical Guide with Templates for Implementation*

4.1.1 Groundwater Level Monitoring

Measuring groundwater levels in boreholes or wells provides information on how water levels fluctuate within the aquifer.

Groundwater level measurements can be measured either manually, using a dip metre (Figure 42) or automatically, using a data logger (a pressure transducer). Automated loggers can also be fitted to surface telemetric systems, enabling data to be reported directly to a server or cloud-based database.

If using automated loggers, water levels should still occasionally be measured manually, to calibrate and check the automated logger data collected.

Dedicated small diameter monitoring wells or piezometers can be constructed with the sole purpose of supporting the collection of groundwater level data. However, information on water levels can be collected from water supply boreholes and/or wells in use, though the data is more difficult to interpret due to the impact of continual pumping on the water levels. A dip tube should be installed to facilitate the insertion and removal of monitoring equipment without snagging or entanglement within the rising main and power cables leading to the pump.

Figure 42: Example of a water level dip metre (will vary with manufacturer).

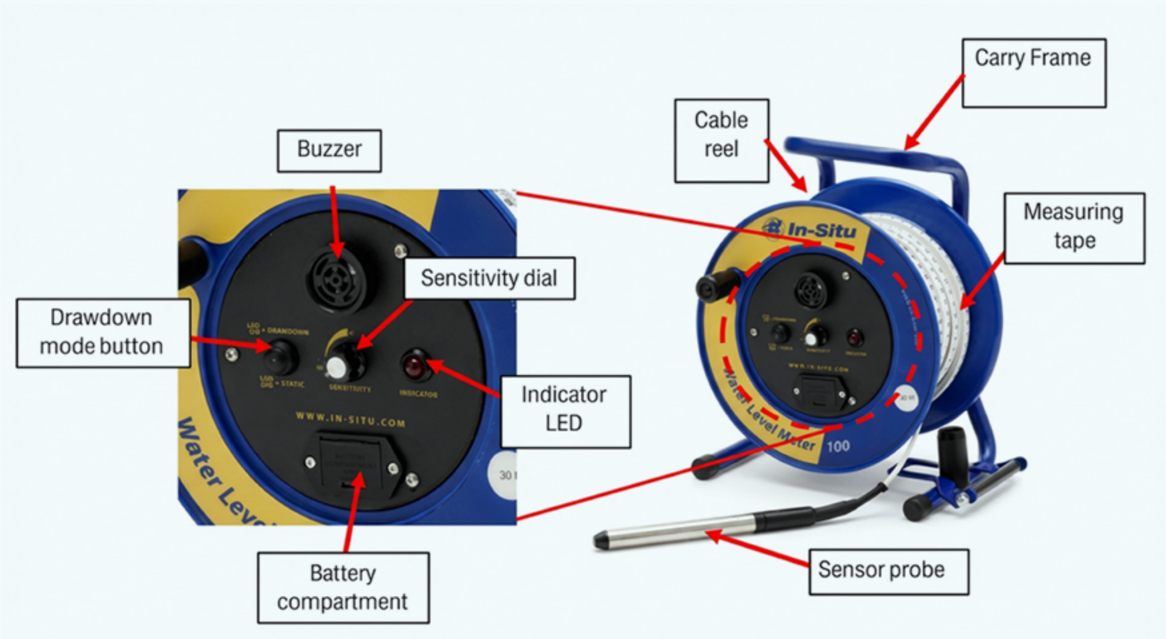


Image quality enhanced with Nano Banana Pro

4.1.1.1 Data Cleaning and Interpretation

Following collection, all data must be cleaned, checking data for any obvious errors and ensuring that borehole/well location information is recorded and accurate. Locations recorded in decimal degrees should be to 6 decimal places. All data should be recorded in metric units, and these units should be checked to ensure that the water level values are correct.

Cleaning data collected by automated data loggers is more complex. Logger data requires post-processing and validation against manual water levels for calibration purposes. Instrumental errors or anomalies in the data (e.g., those caused by a movement in the position of the logger during its deployment) may need to be removed in the final records. This ensures the data are representative of the water body being monitored, presentable, and understandable for interpretation and management purposes. The process is dependent on the integrity of the field and logger data collected and stored to date.

4.1.1.2 Interpreting and Using Monitoring Data

The most common way to present water level monitoring data visually is to generate a hydrograph by plotting water level elevation (or depth to water) against time for each monitoring location. An example of this is shown in Figure 43. Plotting rainfall data on the hydrograph may help visualise recharge responses and lags in groundwater response.

Figure 43: Example of a hydrograph showing high frequency water level measurements made with a data logger (in blue) along with manual measurements taken with a dip metre (in red).

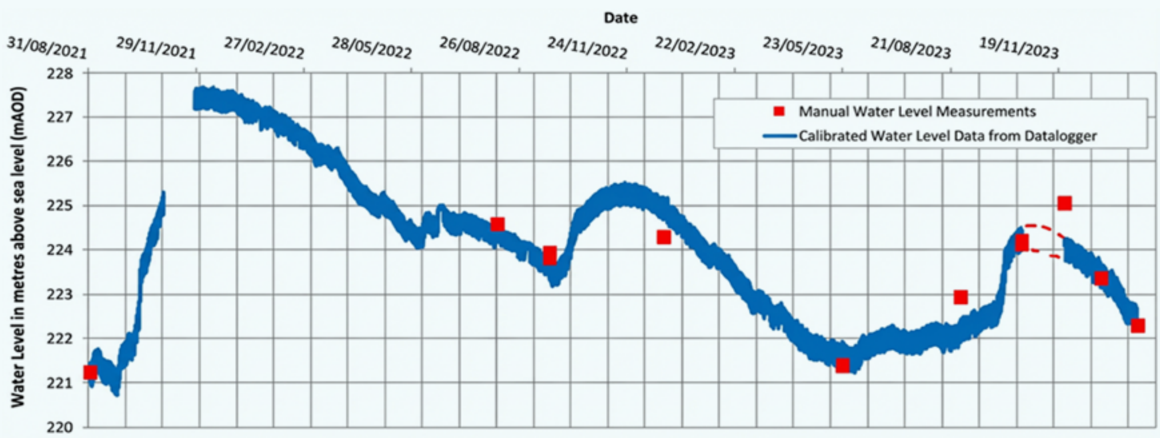


Image quality enhanced with Nano Banana Pro

Groundwater levels typically respond to annual climatic patterns: rising water levels during and after the wet season (indicating recharge) and declining levels throughout the dry season (due to natural recession and abstraction). A minimum of 12 months of continuous monitoring data is required to capture the full seasonal variation.

Groundwater level monitoring data can be used for:

Borehole design:

The depth that the pump is installed within a borehole should consider:

- The expected seasonal groundwater fluctuations, with pump intakes designed to account for the water table low points
- The expected dynamic drawdown associated with active pumping of water
- A safety factor

Diagnosing borehole problems:

If a borehole fails, water level data can be reviewed to identify any significant, rapid, or unexpected changes in water levels that fall outside typical seasonal patterns or known event responses.

If there is a rapid decline in water levels:

- *Conduct Immediate Well Inspection:* check the borehole for structural problems (e.g., collapsed casing, screen blockages, pump malfunction)
- *Investigate New Abstractions:* survey the vicinity for any new, nearby pumping activities that were previously unknown

If there is a rapid rise (not linked to major recharge events):

- *Inspect for Localised Flooding/Leakage:* check for surface flooding around the wellhead or leaks from nearby water infrastructure (supply lines, irrigation canals, wastewater systems) that might be directly recharging the well
- *Assess Well Seal Integrity:* confirm that the sanitary seal at the wellhead is intact, to prevent direct ingress of surface water (which could also introduce contaminants)
- *Assess Potential Contamination:* in some instances, a rapid change could indicate a pollution event affecting water density or flow pathways; if suspected, test for water quality promptly

Setting trigger levels:

During a drought, groundwater can decline further than its normal seasonal lows, significantly affecting water supplies if water levels drop below pump intakes or borehole/well depths. To provide a warning of potential problems, WASH practitioners can set trigger levels within key groundwater infrastructure. A trigger level is a pre-defined water depth that, when reached, activates a planned response. Setting one involves three key steps:

1. **Establish Baseline Conditions:**

   Understand the normal behaviour of the local groundwater source by monitoring key wells and boreholes over time to measure their typical seasonal fluctuation (the highest and lowest water levels in a normal year). This quantified range becomes the official baseline. Comparing future water levels against this baseline makes it easy to spot deviations caused by drought, over-extraction, or changes in aquifer recharge

2 Define the Trigger Level:

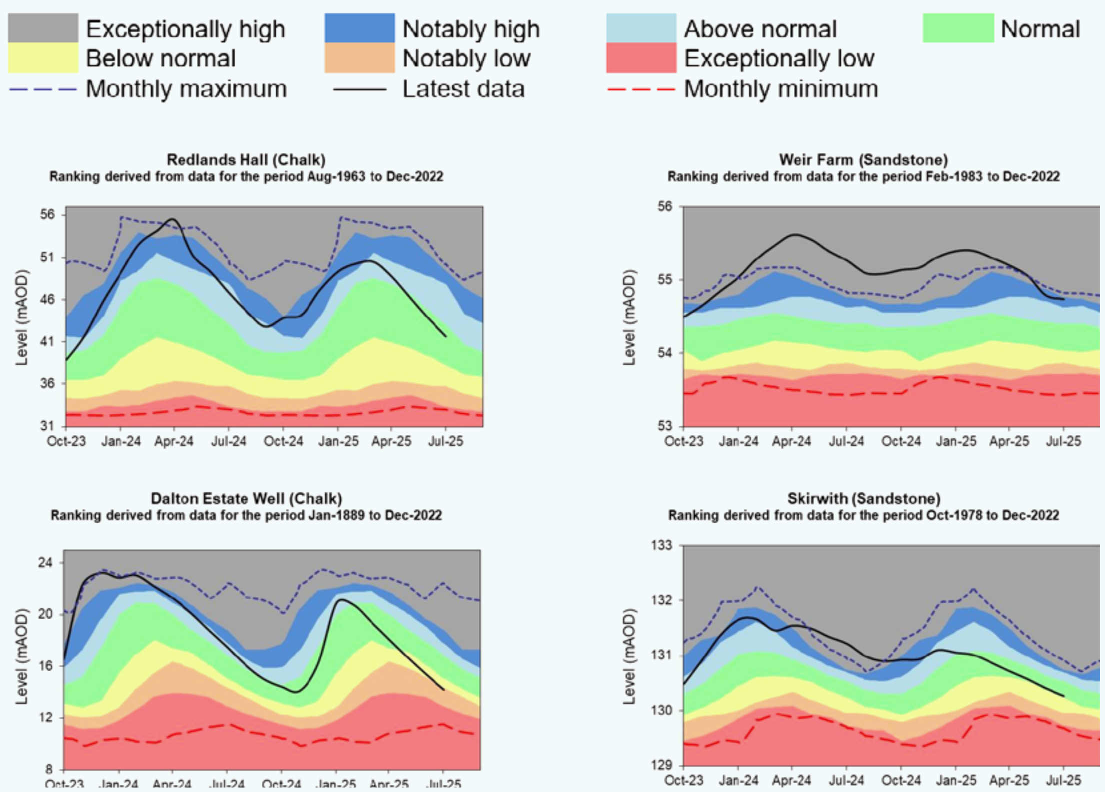
Set the trigger at a specific depth that is lower than the normal seasonal low, but safely above the critical point where infrastructure (like a pump intake) is located. When monitoring shows the water has fallen to the trigger level, an advance warning is provided of an escalating problem, before the water supply fails completely

3 Link Triggers to Pre-Planned Actions:

The purpose of a trigger is to prompt action. For each trigger level, a corresponding set of pre-planned, agreed-upon mitigation strategies should be ready for immediate implementation. Mitigation strategies might include:

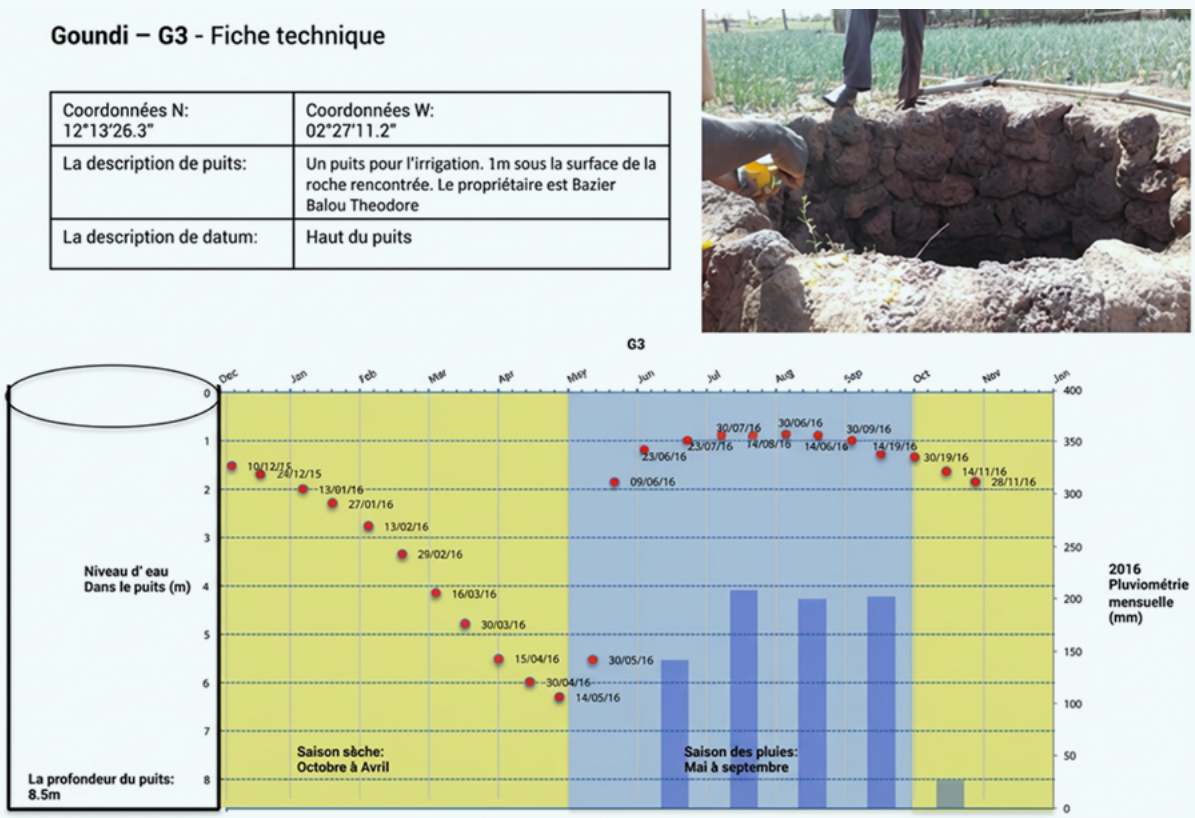
- Construction of new water points with improved design to ensure reliable year-round water access
- Implementation and enforcement of conservation measures to reduce overall water use during the dry period

Figure 44: Typical Monthly Situation report hydrograph.



Source: Environment Agency, UK. Image quality enhanced with Nano Banana Pro

Figure 45: Example of a hydrograph compared with well depth and rainfall data to support communication to farmers in Goundi, Burkina Faso.



Source: GWR (2016). Image quality enhanced with Nano Banana Pro

4.1.1.3 Analyses of Long-Term Trends (Multi-Year Data)

If possible, data should be collected over several years to identify consistent long-term trends in water levels.

If a consistent downward trend is observed: a consistent and significant drop below historical norms can be a strong early indicator of drought conditions developing and affecting groundwater resources.

1

Trigger Investigation:

Examine potential causes. Are current abstraction rates outpacing the rate of recharge, making them unsustainable? Have there been impactful land-use changes in the recharge zone (e.g., deforestation, urbanisation)? Are climate change effects (like reduced rainfall or higher evapotranspiration) resulting in reduced availability of groundwater?

2 **Review Abstraction Management:**

Implement or enhance water conservation measures, promote more efficient water use practices, and consider revising abstraction permits or local agreements

3 **Explore Alternatives & Augmentation:**

If the trend is severe, begin researching alternative water sources or investigate the feasibility of Managed Aquifer Recharge initiatives

4 **Adjust Future Plans:**

Incorporate the observed decline rate into future water supply plans and well designs; this may require drilling deeper, or selecting well sites in more resilient aquifer zones

If a consistent upward trend is observed:

1 **Investigate Causes:**

Determine the reasons. Is it due to increased rainfall, reduced local pumping, leakage from water supply or irrigation systems, or changes in land use?

2 **Assess Associated Risks:**

Evaluate the potential risks of waterlogging to groundwater infrastructure, sanitation infrastructure (like latrines), agricultural land, and building foundations

3 **Evaluate Resource Potential:**

If the rise is confirmed to be from increased sustainable recharge, assess whether abstraction rates can be carefully and sustainably increased to meet demand

Box 10: Monitoring the drought groundwater time lag.

Groundwater replenishment following rain can be delayed by months or years, due to local conditions, such as soil type and water table depth. This time lag means that drought impacts on groundwater are not immediately obvious; a long-term management perspective is needed.

Recharge time lags affect groundwater infrastructure planning, particularly in drought-prone areas, often leading to inaccurate water availability assessments. Groundwater levels might even continue to decline after rainfall due to the time lag. Relying solely on recent rainfall or current groundwater levels can lead to unsustainable extraction rates during droughts, risking over-pumping and resource depletion.

It is crucial to correlate long-term groundwater monitoring data with rainfall patterns to identify specific local recharge time lags and incorporate this understanding into operational planning. For instance, during prolonged droughts, even with some rainfall, water conservation and alternative source activation should be considered well in advance to account for the expected delay in aquifer replenishment.

Actionable Steps:

1. *Collect Historical Data:* obtain long-term rainfall records (from meteorological stations or community observations) and corresponding groundwater level data over the same time period.
2. *Correlate and Analyse:* plot rainfall data against groundwater level measurements over several years. Systematically compare these datasets to identify and quantify the typical delay in aquifer recharge, and understand any variability in this response due to rainfall intensity or differing aquifer conditions.

4.1.2 Monitoring Groundwater Quality

Collecting groundwater quality data can provide insights into whether changes are occurring within the groundwater environment because of increased abstractions, aquifer contamination or a changing climate. It is also essential for ensuring that the groundwater supply remains safe for human consumption. Water quality analysis can be undertaken directly in the field using field-specific monitoring equipment or, alternatively, samples can be taken and then analysed by a laboratory.

There are two main types of groundwater quality monitoring:

1. Strategic Monitoring is undertaken to develop a background understanding of water quality within an aquifer, to determine the general groundwater quality, potential contamination problems and monitor long-term changes in water quality
2. Defensive Monitoring is undertaken at ‘problem’ water points, to provide information about the impacts of suspected contamination sources (for example, when assessing groundwater salinity on coastal plains at risk of seawater intrusion induced by groundwater abstraction

The WHO *Guidelines for drinking-water quality: small water supplies* states that the focus of water quality testing should be on:

- **Microbial Safety:** the top priority.
  - Critical parameters to monitor: *E. coli* (or thermotolerant coliforms), free chlorine residual (if chlorinated), turbidity, pH (if chlorinated)
- **Priority Chemical Contaminants:** include those known or likely to be present locally at concerning levels of concentration.
  - Priority chemical parameters to monitor: arsenic, fluoride, lead, manganese, nitrate
- **Acceptability:** address parameters (like taste, odour, colour) that might lead users to choose potentially less safe water sources. Generally, acceptability parameters have no direct health effects, or concentration levels of concern to health are significantly higher than those that affect acceptability. Therefore, it is not usually necessary to monitor such substances (e.g. iron), particularly where resources for monitoring are limited.
- **Regular Review:** periodically update the list of parameters and their limits to reflect new information and drive continuous improvement.

To enhance flood resilience, testing should be carried out more frequently during and after floods, as well as disinfection of the well/borehole where needed. For drought resilience, changes in groundwater quality due to reduced recharge and dilution capacity should be monitored.

For further information on drinking-water quality monitoring parameters, including guideline or target values and minimum monitoring frequencies, refer to the WHO *Guidelines for drinking-water quality: small water supplies* (WHO, 2024).

4.1.2.1 Sample Collection

Samples should be collected in a clear plastic or glass container with a sealable lid. Ideally, talk with the laboratory staff who will be analysing the samples and obtain advice on which container to use (or use containers provided by the laboratory).

In general, a borehole or well should be thoroughly purged before sampling (unless using a grab sampler bag) to ensure that the sample is not 'stagnant water' that has been standing for a period in the well or casing. See Misstear et al. (2017) and Box 8 for several practical ways to assess when the well has been purged sufficiently.

Following collection, samples should not be exposed to prolonged sunlight during transportation or storage. Any samples collected for bacteriological analysis should be stored in a cool box laden with ice packs during transportation from the field to the office or laboratory. Samples should ideally be delivered to the laboratory as soon as possible, and no longer than 24 hours after sampling. The time period between sampling and delivery to the laboratory should be recorded on the sample records. Laboratories may have their own protocols for sample delivery, and it is important to have these in writing from the laboratory.

4.1.2.2 Data Interpretation

Understanding the results from basic water quality analysis is vital to ensure that populations have a clean and safe drinking water supply. Where parameter results for samples exceed WHO or country-specific guidelines, they should be highlighted and appropriate action implemented, i.e., appropriate water treatment, dilution with uncontaminated groundwater, decommissioning of the borehole, etc.

Identifying key trends in water quality can help predict and potentially minimise or prevent further contamination. Therefore, water quality data should be reviewed by a technical expert at least once annually. As water quality is likely to vary both seasonally and in the long-term, at least 12 continuous months of water quality data is required to fully capture seasonal variations.

A comprehensive chemical analysis should be performed annually at key boreholes. The data collected should be reviewed by a technical expert to identify key trends, increase the understanding of the aquifer systems and its interactions with host rock characteristics and support the identification of recharge.

4.2 Using Monitoring Data for Long-Term Planning and Resilience

When monitoring data on groundwater levels and quality has been routinely collected for over one year, it becomes an invaluable asset for strategic planning.

The data can be used by WASH practitioners to support informed decision making for future water resource development, improving the design and sustainability of water infrastructure and building long-term resilience to floods and droughts.

4.2.1 Strategic Planning Applications

The information gathered from monitoring can be used to:

- **Develop and Refine Conceptual Models:** data on geology, water strikes, and yields from every new borehole informs the continuous refinement of the area's conceptual model - the working understanding of how groundwater exists and moves in the local aquifers
- **Inform Future Siting and Design:** the growing database of knowledge should be used to guide all future siting and design decisions. If monitoring shows that shallow wells

in a certain geological formation consistently fail in the dry season, future interventions can target deeper, more resilient aquifers from the outset

- **Create Planning and Early Warning Tools:** at a regional or national level, hydrogeological data can be compiled to create powerful planning tools (such as regional groundwater models, water security and drought maps) or to set climate-hazard related actions (e.g., a low groundwater level detected during a drought could trigger water trucking). These tools help policy makers identify vulnerable areas, prioritise investment, and provide an early warning of water scarcity

4.2.2 Advanced Analysis for Sustainable Groundwater Management

As a groundwater resource becomes more developed or stressed, and long-term planning requires predictive insights, a transition to more sophisticated analytical tools becomes critical. Monitoring data provides the essential foundation for this work. The goal of advanced analysis is to build a deeper, quantitative understanding of the water resource to ensure its long-term protection and viability.

Engaging specialist support from government technical agencies, universities, or specialised consultants can be useful in the following scenarios:

- **Predicting Climate Change Impacts:** as problems of declining water levels are expected to become more extreme with the impact of climate change, the long-term sustainability of the aquifer in different future climate change scenarios can be assessed, particularly concerning changes in recharge patterns and drought frequency
- **Characterising Aquifer-Wide Trends:** a consistent, statistically significant trend (e.g., SWL decline >0.5 m/year, or a steady increase in salinity) is observed across multiple monitoring wells, necessitating a basin-scale water balance investigation
- **Investigating Water Quality Origins:** the source of persistent or emerging contamination (e.g., salinity, arsenic, nitrate) is unclear and requires solute transport modeling to identify pathways and forecast future migration
- **Evaluating Future Development Scenarios:** a new, large-scale water demand (e.g., irrigation, a new water supply network for an IDP camp, etc.) is planned, and its long-term impact on the aquifer and existing users must be quantitatively predicted
- **Optimising Infrastructure Placement & Design:** new, high-yield boreholes are needed. The data can be analysed to minimise interference with existing water points or to design flood protection measures based on numerical/probabilistic modelling rather than historical events alone
- **Resolving Water Allocation Conflicts:** objective, model-based evidence is required to mediate conflicting water uses between different communities or sectors and to establish equitable and sustainable abstraction limits

This deeper, quantitative understanding allows for optimised resource management, robust long-term planning, and the confident design of major infrastructure projects.

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Appendix 1: Borehole Assessment Checklist

1. General Information

Assessment Date: (DD/MM/YYYY)

Assessed By:

Borehole Location (Village/Town/Community):

Borehole ID / Name:

GPS Coordinates: Latitude Longitude

Year of Construction (if known):

Is water currently available from the borehole? Yes No

If No, describe why (e.g., faulty pump, low water level, etc.):

If Yes, what is the Static Water Level (SWL) (m below ground level):

If Yes, what is the Dynamic Water Level (DWL) (m below ground level):

Pumping rate: l/s

2. Data Review & Historical Information

Are the following records available for review?

Drilling Log (construction details, geology, yield): Yes No

Historical Pumping Test Data: Yes No

Historical Water Quality Reports: Yes No

Maintenance Records (pump repairs, cleaning, rehabilitation):	○ Yes	○ No
Historical Water Level Monitoring Data:	○ Yes	○ No

Is the borehole affected by seasonal drying or significant water level drops? ○ Unsure ○ Yes ○ No

If Yes, describe (e.g., when, how often, for how long, etc.):

3. Community Information & Water Usage

Estimated number of households using the borehole:

Is the borehole a primary or secondary source of drinking water?
○ Primary
○ Secondary

Are there alternative water sources available to the community? ○ Yes ○ No

If Yes, describe (type, reliability, quality concerns):

Does the borehole serve critical facilities (e.g., schools, health centres)? ○ Yes ○ No

If Yes, specify:

Have community members reported changes in yield or water availability (e.g., reduced flow, longer pumping times)? ○ Yes ○ No

If Yes, describe:

During dry seasons/droughts, have community members reported:

Reduced water availability or reliability?	○ Yes	○ No
Nearby boreholes drying up?	○ Yes	○ No

Increased time spent fetching water?	Yes	No
Water shortages or rationing?	Yes	No
Are there conflicts over water resources within the community related to this borehole?	Yes	No
Is the community aware of drought risks and water conservation measures?	Yes	No
Are there community-based water management plans or a water committee in place?	Yes	No

If Yes, briefly describe structure and effectiveness:

4. Wellhead, Surface Infrastructure & Sanitary Survey

Casing Height:

Is the top of the borehole casing at least 0.4 m above the highest known/estimated flood level?	Yes	No

Highest recorded/estimated flood level (m above ground):

Headworks Condition:

Is the pump/borehole headwork in poor condition or loose (e.g., cracked concrete, poor seals, missing cap/bolts)?	Yes	No

If Yes, describe:

Platform/Apron:

Is an apron present around the borehole?		Yes	No
If a hand pump is installed, is the platform/apron radius at least 1.5 m from the wellhead?		Yes	No

Actual radius (m) if less:

Is the apron in good condition (e.g., no gaps, deep cracks, erosion underneath)?	NA	Yes	No

Drainage:			
Is drainage inadequate, allowing water to accumulate/ stagnate around the wellhead or in the source area (e.g., drainage channel damaged/blocked, sloping towards the well)?		Yes	No
Casing Condition (Visible Portion):			
Is the visible casing corroded, damaged, or cracked?		Yes	No
If Yes, describe:			
Are there visible gaps around the borehole casing at ground level (suggesting sanitary seal issues)?		Yes	No
Sanitary Conditions & Protection:			
Is the area directly around the borehole seal/apron dirty (e.g., signs of pollution, animal faeces, stagnant water)?		Yes	No
Is a protective fence or barrier around the well/ source missing or inadequate (e.g., broken, gate not secure), allowing animal access?	NA	Yes	No
Potential Pollution Sources:			
Is there sanitation infrastructure (e.g., latrine, septic tank) within 100 metres of the borehole?		Yes	No
If Yes, approximate distance (m) and direction:			
Are there other sources of pollution within 50 metres (e.g., open defecation, animal pens, open drains, rubbish dumps, fuel storage)?		Yes	No
If Yes, describe type, distance (m), and direction:			
Is there any unprotected entry point to the aquifer within 100 metres (e.g., uncapped borehole, open dug well, abandoned well)?	NA	Yes	No

If Yes, describe:

5. Pump System & Downhole Condition

Pump System:

Are there visible signs of pump inefficiency or damage (e.g., unusual noises, leaks, corrosion)?		Yes	No

If Yes, describe:

Is the pump correctly sized for the borehole yield and community demand?	Unsure	Yes	No
Is the pump intake located at an optimal depth (considering Static Water Level (SWL), screen position, potential drawdown)?	Unsure	Yes	No

Downhole Inspection (if feasible/data available):

Has a CCTV survey been conducted previously or recently?		Yes	No

If Yes, Date:

Findings (casing/screen corrosion, cracks, blockages):

Is there known/suspected sediment accumulation inside the borehole?	Unsure	Yes	No
Has the current total borehole depth been measured and compared with the original drilling log?		Yes	No

Current measured depth (m):

Original depth (m):

6. Borehole Performance (if conducted during this assessment or recent data available):

Has a constant rate pumping test been conducted?	○ Yes ○ No
Date:	
SWL prior to test (m):	
Pumping Water Level (PWL) at end of test (m):	
at Pumping Rate (l/s or m^3/hr):	
for Duration (hrs):	
Drawdown (m) (SWL-PWL):	
Specific Capacity (m^3/hr/m or l/s/m):	
Calculated/Estimated Transmissivity (if available) (m^2/day):	
Has the well yield decreased compared to initial performance data or previous tests (compare the initial and current specific capacity)?	○ Unsure ○ Yes ○ No
Is the current sustainable yield sufficient to meet the community demand?	○ Unsure ○ Yes ○ No

7. Water Quality

Have changes in water taste, odour, or colour been reported by users?	○ Yes ○ No

If Yes, describe (seasonal changes, after rain/flood, etc.):

Is water treatment applied before use?	○ No Treatment ○ At Borehole ○ Downstream (Household)
If Yes, specify method(s) (e.g., Boiling, Chlorination, Filtration, Solar Disinfection, Other):	

Field Testing Results (if taken during the assessment):	
Turbidity (NTU):	
Electrical Conductivity (EC) (µS/cm):	
pH:	
Free Chlorine Residual (if applicable, mg/L):	
Temperature (°C):	
Other field tests:	
Sample taken?	○ Yes ○ No
If yes, sample ID:	

Laboratory Analysis Results:	
Parameter tested: *E. coli* or Thermotolerant (faecal) Coliforms (circle)	
Results	
Units	

Additional parameter (add additional parameters as needed)	
Results	
Units	

8. Assessment Summary & Recommendations

Immediate Concerns (requiring urgent attention):

Corrective Actions Needed (Tick all applicable and add details):

- [ ] Wellhead sealing (pump attachment, seal around casing):
- [ ] Drainage improvements around wellhead:
- [ ] Reconstruction/repair of apron:
- [ ] Cover replacement or repair (mounting block/apron elements):
- [ ] Elevate casing and platform (due to flood risk):
- [ ] Pump repair/replacement/adjustment:
- [ ] Borehole cleaning/redevelopment:
- [ ] Water quality treatment needed/improvement:
- [ ] Fencing/Protection improvement:
- [ ] Relocation/mitigation of nearby pollution sources:

- [ ] Further investigation (e.g., CCTV, detailed pumping test, geophysical survey):

- [ ] Community training on well operation & maintenance/hygiene:

- [ ] Water level monitoring programme implementation:

- [ ] Development of community water management/conservation plan:

Appendix 2: Dug Well Assessment Checklist

1. General Information

Assessment Date: (DD/MM/YYYY)

Assessed By:

Well Location (Village/Town/Community):

Well ID / Name:

GPS Coordinates: Latitude Longitude

Year of Construction (if known):

Total Depth (m):

Internal Diameter (m):

Is water currently available from the well? Yes No

If No, describe why (e.g., faulty pump, low water level, dry well):

If Yes, what is the Static Water Level (SWL) (m below ground level):

If Yes, what is the Dynamic Water Level (DWL) (m below ground level):

Pumping rate: l/s

2. Data Review & Historical Information

Are the following records available for review?

Historical water level records: Yes No

Records of previous well yield tests: ◯ Yes ◯ No

Previous water quality test reports: ◯ Yes ◯ No

Records of previous maintenance or rehabilitation: ◯ Yes ◯ No

If Yes:

Date:

Work done:

Reported Effectiveness

◯ Effective ◯ Partially Effective ◯ Not Effective ◯ Unknown

3. Community Information & Water Usage

Estimated number of households using the well:

Is the well a primary or secondary source of drinking water? ◯ Primary ◯ Secondary

Are there alternative water sources available to the community? ◯ Yes ◯ No

If Yes, describe (type, reliability, quality concerns):

Does the well serve critical facilities (e.g., schools, health centres)? ◯ Yes ◯ No

If Yes, specify:

Have community members reported changes in yield or water availability (e.g., reduced flow, longer pumping times, increased time spent fetching water, water shortages or rationing)?	○ Yes ○ No

If Yes, describe:

Peak collection times (Note: Collection at night may indicate scarcity):

4. Well Structure & Integrity

A. Wellhead & Cover:

Wellhead Height (above ground level) (m):

Is the top of the wellhead at least 0.4 m above the highest known/estimated flood level? ○ Yes ○ No

Highest recorded/estimated flood level (m above ground):

Wellhead Material:	Wellhead Condition:	Specific Damage (Describe: cracks, erosion, settlement):
○ Concrete	○ Good	
○ Brick	○ Fair	
○ Stone	○ Poor	
○ Other:	○ Failed	

Well Cover Present: ○ Yes ○ No

If Yes:

Material:	Condition:	Describe: cracks, gaps, rot, rust
○ Concrete	○ Good	
○ Metal	○ Fair	
○ Wood	○ Poor	
○ Plastic	○ Failed	
○ Other:		

Watertight Seal: ○ Partially ○ Yes ○ No

Secure Fitting (prevents easy removal/dislodging): ○ Yes ○ No

Inspection Hatch Present (if separate from main cover): ○ Yes ○ No

B. Well Lining (Shaft):

Wellhead Material:

○ Concrete Rings ○ Cast-in-situ Concrete ○ Brick ○ Stone

○ Unlined ○ Other:

Visible Lining Condition (from top, use light if possible):

○ Good ○ Fair ○ Poor ○ Failed

Observed Lining Defects (Describe location and severity):

Cracks:

○ None ○ Hairline ○ Minor (<5 mm) ○ Major (>5 mm)

Location:

Displacement / Misalignment of rings/bricks: ○ Yes ○ No

Location:

Signs of Infiltration through lining (e.g., jets of water, damp patches) ○ Yes ○ No

Location:

Partial or Total Collapse: ○ Yes ○ No

Describe depth/extent:

Is the well structurally sound for current use?	Yes	No
If minor damage exists, can it be repaired?	Yes	No
If unlined, could it benefit from lining (e.g., concrete rings)?	Yes	No

C. Apron & Drainage:

Apron Present:	Yes	No

If Yes:

Dimensions (Width x Length) (m): ____ x ____

Material:	Wellhead Condition:	Describe (cracks, gaps, erosion underneath):
Concrete	Good	
Brick	Fair	
Stone	Poor	
Other: ____	Failed	

Slope Adequate for Drainage (away from well, min 1:50):		Yes	No
Drainage Channel Present (to lead water away from apron):		Yes	No

If Yes, Condition:

Good (clear)	Fair (partially blocked)	Poor (blocked/ damaged)

Evidence of Water Pooling/Stagnation on or near apron/wellhead:		Yes	No
Soakaway Pit or Functional Discharge Point for drainage water:	NA	Yes	No

D. Protective Measures:

Protective Fence or Barrier around the well:	Partially	Yes	No

If Yes/Partially, Condition: ○ Good ○ Fair (needs repair) ○ Poor (inadequate)

5. Water Lifting System

Type of Lifting System:

○ Handpump ○ Motorised Pump ○ Rope & Bucket ○ Windlass

○ Other: ______

○ Fully Functional

○ Partially Functional

○ Non-Functional

If Partially Functional, specify issues:

If Handpump/Motorised Pump:

Brand/Model (if known):

Pump Condition/Attachment:

○ Good

○ Loose at attachment

○ Leaking

○ Corroded

Specific Issues Observed:

○ Excessive noise

○ Hard to operate

○ Low output

○ Other: ______

Is the pump/lifting system appropriate for the well's yield and depth? ○ Unsure ○ Yes ○ No

Estimated Repair Needs for Lifting System:

6. Hydrogeology, Water Availability & Yield

A. Water Availability & Seasonal Variation:

Is water currently available from the well? ○ Yes ○ No

If No, primary reason:

○ Dry Well ○ Faulty Pump Other:

○ Collapsed Lining ○ Contamination

Is the well affected by seasonal drying? ○ Yes ○ No

If Yes, describe (e.g., which months, how often, duration):

(Note: If dry only during particular months, rehabilitation, e.g., deepening, might provide year-round supply. If dry all year, rehabilitation is unlikely to be feasible; consider new well.)

Does groundwater level fluctuate significantly between seasons? (Community report or observation) ○ Unsure ○ Yes ○ No

Is there evidence of rapid infiltration/ recharge after rain? ○ Unsure ○ Yes ○ No

B. Well Yield:

Has the well yield reportedly declined recently or over time? ○ Unsure ○ Yes ○ No

If formal yield records are unavailable, consult the community:

Estimated buckets (specify size) (L):

Typically drawn per hour/day:

Wet Season: Dry Season:

Has a short pumping/bailing test been conducted recently to assess current yield? ○ Yes ○ No

If Yes, results (Yield L/min or L/hr, Drawdown m):

If No/Unsure, consider performing one if yield is a concern.

C. Drought-Prone Regions: Deepening Feasibility & Aquifer Characteristics

Was rock encountered during original excavation (if known)? ○ Unsure ○ Yes ○ No

If No, what is the nature of material above bedrock (e.g., sand, clay, gravel):

(Note: Deepening into low-permeability materials like silt or clay may not significantly increase yield.)

If Yes, can the well be deepened with specialised equipment (e.g., drilling, blasting – consider safety/cost)? ○ Yes ○ No

Has the lithology (soil/rock types) and stability of deeper formations been assessed (e.g., from nearby well logs, local knowledge)? ○ Yes ○ No

If No, consider investigating via nearby borehole/well logs, or geophysics. Or test drilling (if deepening is considered) to identify if additional water-bearing zones are likely to be present at greater depth, or if further deepening could encounter impermeable rock (hydrogeological basement)? (Note: Deepening dug wells can be less cost-effective than constructing a new well, especially in bedrock or unstable formations. Deepening an already unstable well is hazardous.)

D. Flood-Prone Areas: Flood Assessment

Has the well reportedly been submerged during past floods? ○ Yes ○ No

If Yes:

Maximum recorded/observed flood height at well location (m above ground):

Most recent significant flood (Month/Year):

Typical flood duration at well site (days):

Is the well accessible during typical floods?	○ Fully ○ Partially ○ Inaccessible
How long does water quality typically remain affected after flooding (days)?	

7. Contamination Risk Assessment

Distance to nearest latrine/sanitation facility (m):	
Type:	
Distance to nearest surface water body (river, pond, canal) (m):	
Is it a pollution source?	○ Yes ○ No
Other potential pollution sources within 50 m (e.g., animal enclosure/livestock area, agricultural land, fuel storage, cemeteries, industrial activity, open defecation areas):	
Is the well generally located upgradient or downgradient of most nearby potential contamination sources?	○ Upgradient ○ Downgradient ○ Unclear
Is the surrounding soil highly permeable (e.g., sandy, gravelly), increasing infiltration risk?	○ Unsure ○ Yes ○ No

Water Quality

Have changes in water taste, odour, or colour been reported by users?	○ Yes ○ No
If Yes, describe (seasonal changes, after rain/flood, etc.):	

Is water treatment applied before use?	No Treatment At Borehole Downstream (Household)
If Yes, specify method(s) (e.g., Boiling, Chlorination, Filtration, Solar Disinfection, Other):	
Field Testing Results (if taken during the assessment):	
Turbidity (NTU):	
Electrical Conductivity (EC) (µS/cm):	
pH:	
Free Chlorine Residual (if applicable, mg/L):	
Temperature (°C):	
Other field tests:	
Sample taken?	Yes No
If yes, Sample ID:	
Laboratory Analysis Results:	
Parameter tested: *E. coli* or Thermotolerant (faecal) Coliforms (circle)	
Results	
Units	

Additional parameter (add additional parameters as needed)	
Results	
Units	

8. Assessment Summary & Recommendations

A. Overall Well Condition:

- ○ Good (well-maintained, minor issues)
- ○ Fair (functional, needs some repairs)
- ○ Poor (significant problems, affecting use/safety)
- ○ Failed (unusable/unsafe)

B. Primary Issues Identified:

C. Rehabilitation Potential & Priority:

Is rehabilitation considered feasible? ○ Yes ○ No

Reason if no:

Rehabilitation Priority:
- ○ Urgent (critical for health/access)
- ○ High
- ○ Medium
- ○ Low

Estimated Rehabilitation Complexity:
- ○ Minor (simple repairs)
- ○ Moderate (skilled labour, some materials)
- ○ Major (significant reconstruction/equipment)

D. Recommended Corrective Actions (Tick all applicable and add details):

☐ Wellhead repair/reconstruction
- Material:
- Design:

☐ Cover replacement/repair
- Material:
- Watertight: ○ Yes ○ No
- Secure: ○ Yes ○ No

☐ Lining repair/reconstruction
- Type:
- Depth (m)
- Method:

Install new lining in unlined well	Type:	
	Depth (m)	
Apron construction/repair	Dimensions:	
	Slope:	Yes / No
	Material:	
Drainage improvement	Channel:	
	Soakaway:	Yes / No
Water lifting system repair/ replacement	Type:	
	Parts:	
Well cleaning/disinfection	Method:	
Deepening of well	Estimated Depth (m):	
	Method:	
Source protection measures	Relocate sources:	
	Improve barrier:	
Water quality treatment needed	At source:	
	At household:	
Further investigation needed (e.g., detailed pumping test, geophysical survey, comprehensive WQ analysis)		
Consider abandonment and construction of new water source (if rehabilitation not viable)		

Appendix 3: Spring Assessment Checklist

1. General Information

Spring ID / Name:

Location (Village/Area):

Assessment Date: (DD/MM/YYYY)

Assessed By:

GPS Coordinates: Latitude Longitude

Elevation (m above sea level):

Year of Construction/Protection (if known):

Approximate Number of Households Using Spring:

2. Spring Flow & Water Availability

A. Current Status & Flow

Is water currently available from the spring? Yes No

If No, describe why (e.g., blockage, dry, faulty component):

Current Flow Rate (L/s or L/min);

Method (e.g., Bucket method, V-notch weir):

Is the spring known to be seasonally dry or have significantly reduced flow? Unsure Yes No

Has spring flow reportedly declined recently or over time? ○ Unsure ○ Yes ○ No

B. Seasonal Variation & Reliability

Is the spring known to be seasonally dry or have significantly reduced flow? ○ Unsure ○ Yes ○ No

If Yes, describe evidence (e.g., which months, community reports):

Is this spring fed by a shallow aquifer or directly linked to rainfall (making it more vulnerable to drought)? ○ Unsure ○ Yes ○ No

Is the spring affected by flooding? ○ Unsure ○ Yes ○ No

If Yes, describe (e.g., submersion, water quality changes, frequency):

3. Protective Structure (Spring Box / Retaining Wall)

A. General Condition

Does the spring have a functioning protective structure (e.g., spring box, retaining wall)? ○ Yes ○ No

If No, describe any current protection:

Material of Structure:

○ Concrete ○ Brick ○ Stone ○ Plastic

○ Other:

B. Structural Integrity & Access

Are the walls, base, and cover free of visible cracks, leaks, or other damage?	Yes	No
Is there evidence of erosion or undermining of the foundation?	Yes	No
Is the inspection hatch lid present, in good condition, and does it fit securely?	Yes	No
Are there any signs of contaminants inside the spring box (e.g., animals, faeces, sediment, debris)?	Yes	No

If Yes, describe:

Is more storage volume required at the spring box (to manage peak demand or slow recharge)? Unsure Yes No

C. Intake, Outlet & Ventilation System

Are intake pipe(s) free of blockages from sediment or debris?	Yes	No
Is a functioning overflow pipe present and clear of obstructions?	Yes	No
Is the overflow outlet screened to prevent vermin entry?	Yes	No
Is the overflow discharge directed to a safe, erosion-resistant location?	Yes	No
Are air vents present and screened/protected to prevent contaminant entry?	Yes	No
Are all pipe penetrations into the spring box sealed and watertight?	Yes	No

4. Catchment Area & Source Protection

A. Contamination Source Survey

Distance to nearest latrine/sanitation facility (m):		
Is it upslope?	Yes	No
Other pollution sources visible within 30 metres (e.g., waste disposal, open defecation, animal grazing/ enclosure, agricultural land (pesticide/fertiliser use))?	Yes	No
If Yes, describe:		
Any unprotected entry points to the aquifer within 100 metres (e.g., unsealed well, quarry)?	Yes	No

B. Drainage & Fencing

Is a functional stormwater diversion ditch present above/ around the spring?	Yes	No
Does poor surface drainage cause water to pool around the spring box?	Yes	No
Is a protective fence or barrier present and adequate to prevent access by livestock/people?	Yes	No

C. Geological Setting

Observations on local geology (soil type, rock formations):			
Is the covering stratum (soil/rock layer above aquifer) believed to be sufficiently thick and of low-permeability (e.g., clay) to act as a natural filter?	Unsure	Yes	No

5. Water Quality

A. On-Site Assessment

User Perception: Any reported issues with taste, odour, or appearance?

Visual Appearance:	○ Clear	○ Slightly Turbid	○ Turbid
Visual Appearance:	○ None	○ Slight	○ Strong

If strong, describe:

Water Temperature (°C):

Is it stable? ○ Yes ○ No

B. Field Testing Results:

pH:	
Electrical Conductivity (EC) (µS/cm):	
Turbidity (NTU):	
Laboratory Sample Collected?	○ Yes ○ No
If yes, date:	
Microbiological (E. coli): Result	
Nitrates: Result	
Other results:	

C. Water Treatment

Is any water treatment currently applied? ☐ Yes ☐ No

If Yes, describe treatment at source or household level:

6. Overall Assessment & Recommendations

A. Summary of Key Issues

B. Recommended Corrective Actions

Protective Structure:

- ☐ Repair/Reconstruct spring box
- ☐ Repair/Replace inspection lid
- ☐ Clean interior of spring box

Intake/Outlet System:

- ☐ Clean/Unblock intake or overflow pipes
- ☐ Protect overflow outlet from vermin
- ☐ Improve overflow discharge point (erosion control)
- ☐ Reseal pipe penetrations

Catchment & Source Protection:

- [ ] Construct/Repair stormwater diversion ditch
- [ ] Construct/Repair protective fencing
- [ ] Address/Relocate nearby contamination sources

Water Quality & Management:

- [ ] Conduct further water quality monitoring
- [ ] Implement/Improve water treatment
- [ ] Implement regular flow monitoring
- [ ] Provide community training (O&M, hygiene)

GROUND WATER RELIEF

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