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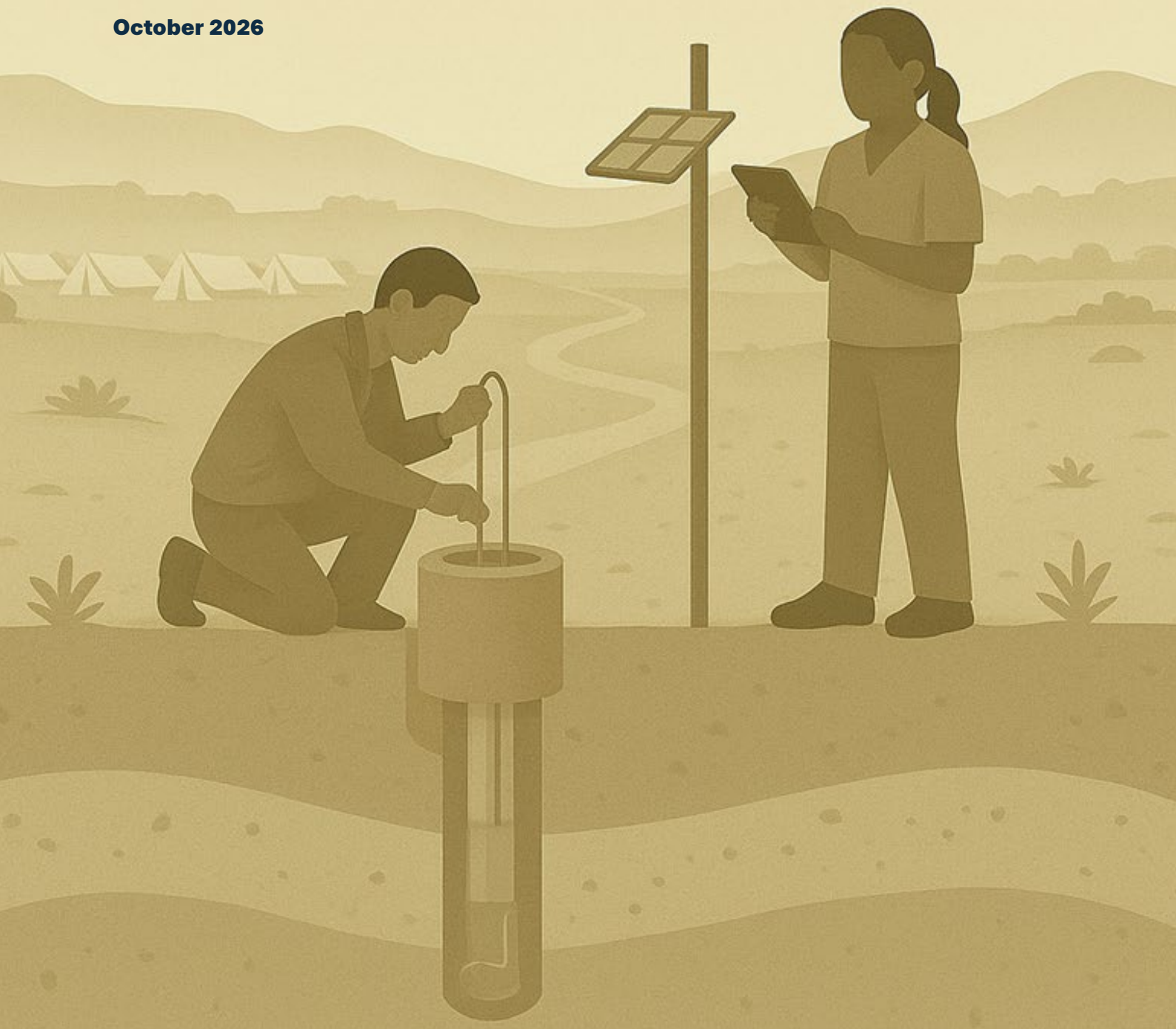
GROUNDWATER MONITORING IN HUMANITARIAN CONTEXTS

A Guide for Practitioners and Decision Makers

October 2026



EXECUTIVE SUMMARY

Groundwater monitoring is now recognised as a major gap in efforts to manage water sustainably. This gap is especially serious in humanitarian contexts, where most people rely on groundwater that is already under stress and largely "invisible", with little data available on its condition or how it is changing over time. Without this information, it is difficult to make informed decisions, anticipate and prevent system failures, or manage critical risks such as contamination, over-abstraction, and wider impacts on communities and ecosystems. Although awareness of its importance is growing and demand for groundwater monitoring programmes is increasing, projects in low-resource or crisis-affected settings still face major challenges and too often fail to deliver systems that are reliable, useful, and long-lasting.

This guide responds to that challenge. Drawing on recent research, practical case studies, expert interviews and field experience, it provides clear recommendations on how to design and implement groundwater monitoring in humanitarian and low-resource contexts. Readers are taken through the full monitoring timeline, from scoping and design through to piloting, operation, and long-term integration with national systems. Each step is illustrated with examples, common pitfalls to avoid, and practical templates for implementation in the document Annex. The guide is written for a broad audience, making groundwater monitoring more accessible for the actors most often tasked with managing and supporting these projects.

Beyond its explanation of best practices, the guide emphasises the importance of building systems that can integrate and communicate within local contexts and with local stakeholders. When done well, groundwater monitoring helps communities, local authorities and national actors understand the state of their groundwater, how it is changing over time, and how they can respond to competing demands for this extremely important resource.

The message is clear: effective groundwater monitoring is possible, even in extreme and challenging contexts, when it is realistic and appropriately designed with its beneficiaries. The benefits multiply as more actors get involved: NGOs, governments, communities, academics, industry, technical specialists, and financers all use groundwater data and can support these projects for both individual and collective benefit. A wider understanding, adoption and sharing of groundwater monitoring among actors can go a long way in protecting safe water access, both for today's emergencies and for future generations who need us to manage finite groundwater resources more sustainably.

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LIST OF ACRONYMS

ACF	Action contre la Faim
API	Application Programming Interface
BGS	British Geological Survey
BoQ	Bill of Quantities
BRAC	Bangladesh Rural Advancement Committee
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CSV	Comma-Separated Values
DO	Dissolved Oxygen
EC	Electrical Conductivity
EM	Electromagnetic
ERT	Electrical Resistivity Tomography
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GC-MS	Gas Chromatography – Mass Spectrometry
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GSM	Global System for Mobile Communications
GW	Groundwater
GWR	Groundwater Relief
HWISE	Household Water Insecurity Experiences Scale
IC-MS	Inductively Coupled Plasma Mass Spectrometry
ID	Identification
IDP	Internally Displaced Person
IGRAC	International Groundwater Resources Assessment Centre
IOM	International Organization for Migration
IRC	International Rescue Committee
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
mAOD	meters Above Ordnance Datum
M&E	Monitoring and Evaluation
MoU	Memorandum of Understanding
MSF	Médecins Sans Frontières
NGO	Non-Governmental Organisation

OPEX	Operating Expense
ORP	Oxidation–Reduction Potential
PH	Potential of hydrogen
POC	Protection of Civilians
QA	Quality Assurance
QPCR	Quantitative Polymerase Chain Reaction
RWSN	Rural Water Supply Network
SDG	Sustainable Development Goal
SIM	Subscriber Identity Module
SMS	Short Message Service
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
ToR	Terms of Reference
TWG	Technical Working Group
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
USB	Universal Serial Bus
USD	United States Dollar
USGS	United States Geological Survey
VES	Vertical Electrical Sounding
WASH	Water, Sanitation and Hygiene
WBMP	Water Basin Management Plan
WHO	World Health Organization
WQ	Water Quality
WV	World Vision

1. INTRODUCTION

Groundwater (GRW) is a vital part of the world's water supply, supplying roughly 50%[1] of all fresh water withdrawn for domestic use globally. It is a critical source for drinking water, sanitation, hygiene, and farming, especially in areas where surface water is limited, contaminated or unreliable. In many humanitarian settings, groundwater is the only realistic water source. Yet, it is often **under-monitored** and **poorly understood**, which leads to major challenges in managing it sustainably and providing reliable water supply.

Recent global initiatives such as the United Nations' Valuing Water[2] and Making the Invisible Visible[3] have highlighted how important it is to better monitor groundwater resources, asking the world, "how can we truly manage what we do not measure?" Despite these calls to action, **serious gaps** in groundwater data remain a challenge. This is especially true in humanitarian contexts, where urgent human needs and difficult working conditions often lead to monitoring being sidelined for other activities.

There is now strong momentum to improve this. **Advances** in methods, monitoring technologies, mobile data systems, digital tools and our understanding of how to implement monitoring have made groundwater monitoring more practical and affordable than ever before. Many governments, Non-Governmental Organisations (NGOs), UN agencies and development banks are looking for ways to include groundwater monitoring in both emergency response and long-term planning as a standard principle of good practice.

At the same time, there is a **growing need for field guidance**. Many previous documents assume a high level of technical knowledge that staff in humanitarian and development programmes may not have. This document is written to fill that gap. It gives **practical guidance** for setting up groundwater monitoring systems in low-resource and humanitarian contexts, where implementers may not be hydrogeologists but still need to design or manage monitoring programmes. The guidance in this document is based on field experience from multiple countries, expert interviews (conducted by Veness and Buytaert, 2025[4]), recent literature and real case studies.

We aim to **walk you through all key stages of a monitoring programme**, from initial scoping and design through to long-term handover. Sections include **practical tips**, links to **technical references**, and **practical templates** in the Annex to support implementation.

1 - https://www.unesco.org/reports/wwdr/en/2024/s
2 - https://www.unwater.org/publications/un-world-water-development-report-2021
3 - https://www.unesco.org/reports/wwdr/2022/en
4 - https://www.sciencedirect.com/science/article/pii/S1462901125000309?via%3Dihub

1.1 WHAT IS GROUNDWATER MONITORING?

Groundwater monitoring means collecting frequent (recurring) data to **understand the condition and use of groundwater**. This can include tracking water levels, water quality, and how much water is being used.

Monitoring can be done **manually** or with **automatic equipment**. It might happen over a short period or continue for years, depending on the objective. Aquifers are often composed of multiple hydrogeological layers, and monitoring programmes may focus on one or more of these individual aquifer units.

In humanitarian and development contexts, monitoring should match the **needs** and **limits** of the project. Organisations can choose different methods depending on what information they need, the information already available, and their capacity. Figure 1 shows the three main types of groundwater monitoring: **(1) water level, (2) abstraction, and (3) water quality**. The figure also illustrates two methods of groundwater assessment that can provide useful data to support continuous groundwater monitoring: **(4) geophysical subsurface surveys and (5) water user surveys.** Whilst all five methods may not be needed in some contexts, they each provide important information for decisions related to the use of groundwater.

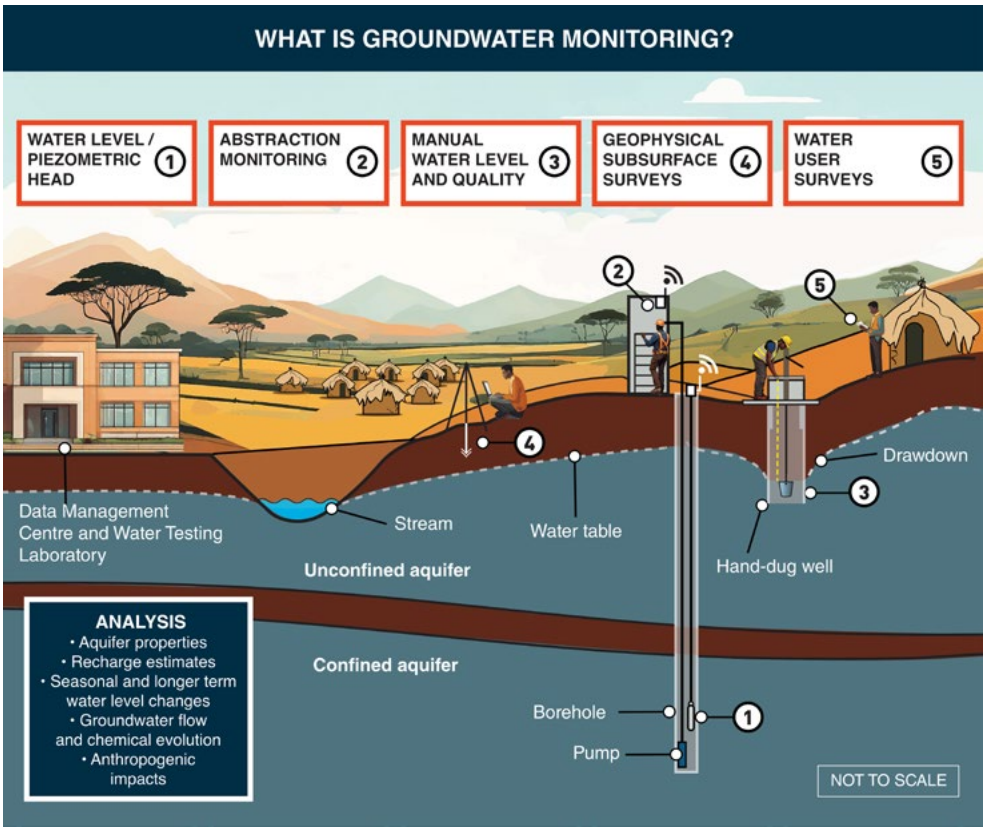

Figure 1: What is groundwater monitoring? (Rod Shaw)

No single method fits every situation. The right mix depends on the objective of the monitoring (why do we need the data?), who will use the data, what they need to know, what resources are available, and the local context. A mixed approach is often recommended.

CORE METHODS OF GROUNDWATER MONITORING

WATER LEVEL MONITORING

Sensors installed in boreholes or shallow wells can **automatically record changes** in groundwater level or pressure. This helps show how the aquifer responds to rainfall, pumping, or drought. Analysing trends in water level can help to anticipate water shortages and associated displacement, nutrition and health crises. Automatic monitoring is especially useful at key locations where regular access is difficult, or where long-term data is needed for tracking trends.

Manual monitoring remains a simple and **effective** option, especially in places with limited resources where water levels can be measured with tape (called dip meters).

ABSTRACTION MONITORING

Measuring **how much groundwater is being used** helps avoid over-abstraction and plan future water needs. Tools like flow meters or runtime sensors can track how much water is pumped each day or season. This data is important for spotting shortages, upgrading systems, improving water delivery efficiency and ensuring fair water distribution.

WATER QUALITY (WQ) MONITORING

Automatic water quality monitoring solutions, despite technological advances, remain **scarce** and too **expensive** for humanitarian contexts. But on the other hand, **manual water quality monitoring is a critical exercise**. Basic water quality tests (like pH, conductivity, turbidity, temperature) are done with handheld tools in-situ, and additional tests (such as E.Coli and heavy metals) are normally done by sending samples to a lab. Water quality monitoring is important for **spotting issues** like biological contamination, metal and chemical pollution, or salinity that could affect water safety.

COMMON METHODS TO SUPPORT GROUNDWATER MONITORING & ANALYSIS

GEOPHYSICAL SUBSURFACE SURVEYS

Though these are optional and usually conducted one-time, rather than being part of long-term monitoring, it is worth being aware of geophysical surveys and their capabilities. These surveys use surface tools like electrical resistivity or seismic techniques to **understand what's underground**, which can improve understanding of local hydrology and be used as a tool for freshwater exploration. They don't give real-time data but can be helpful at the start of a project when choosing where to drill new wells or in areas where the geology isn't well known. In cases where groundwater change is linked to ground subsidence, geophysical methods can also be used for investigations and periodic monitoring. Most geophysical investigation is indirect (e.g. seismic, electrical) and its interpretation requires a specialist.

WATER USER SURVEYS

Talking to communities and institutions can give valuable insights that technical monitoring alone may miss. Surveys can help understand how people use groundwater, what problems they face, and what changes they've noticed. This can reveal pressure points and build trust. Combining this local knowledge with monitoring data can give a clearer picture of how important each water point is to people's daily lives. For example, calculations of weekly abstraction volumes could combine with surveys of water use to estimate the amount of water being used for different activities.

ADDITIONAL HYDROLOGICAL MEASUREMENTS & OBSERVATION

To get the full picture when interpreting groundwater data, it is often necessary to monitor additional water parameters such as **rainfall**, **local river flow** or nearby **reservoir levels**. This provides helpful context such as where there may be backup water sources, how much water is replenishing the aquifer. It also allows hydrogeologists to model how groundwater availability is likely to change over the coming months.

1.2 WHY IS GROUNDWATER MONITORING NEEDED?

Without robust and continuous data, it's hard to see early warning signs when groundwater is under pressure. This can lead to water running out or becoming unsafe without warning. Problems like overuse, contamination, or drying of wells can be missed until it's too late. Even simple monitoring, like measuring water levels by hand or doing basic quality tests, can give important information that can trigger critical interventions. This helps water users, waterpoint committees and authorities manage resources better and avoid emergency situations linked to clean water shortages.

But monitoring is not just about averting problems. Done well, it **unlocks a wide range of benefits** for many actors across the water system and provides a basis for sustainable water management far beyond the duration of the humanitarian crisis. Figure 2 shows examples of how different groups use groundwater data in humanitarian settings, based on interviews with 42 expert stakeholders completed in the Horn of Africa (Veness and Buytaert; 2025)[5].

Figure 2: Summary of major groundwater monitoring data users and applications adapted from Veness and Buytaert (2025), who interviewed 42 stakeholders in the Horn of Africa. (Rod Shaw)

5 - https://www.sciencedirect.com/science/article/pii/S1462901125000309?via%3Dihub

Local and national **water authorities and utilities** are common users of groundwater monitoring data. These institutions are responsible for managing water resources and rely on monitoring to understand aquifer conditions, plan borehole drilling, and keep water systems working. If data is available, and if they have the capacity to use it, these actors can spot problems early and take action before peoples' water supplies are affected.

Non-governmental organisations (NGOs) and international organisations (such as United Nations agencies) play a key role in humanitarian settings, especially in the early stages of displacement or crisis response, in the management of displacement camps, and when anticipating health or nutrition crises. Groundwater monitoring helps these actors design and evaluate WASH (Water, Sanitation and Hygiene) programmes, justify infrastructure investments, and coordinate operations across sectors. For example, groundwater data can be used to site emergency water points in ways that minimise aquifer stress or contamination risks, or to monitor borehole performance across displacement camps.

Local communities and water committees may not always be formal institutions, but they often play an important role in managing water. Monitoring data, when shared in a clear and accessible way, can help these groups understand local water availability, plan how to share it fairly, and raise concerns when problems arise. This also helps build trust, local ownership and contributes positively to the overall governance of water systems.

Monitoring data also supports longer-term goals. Across **all core user groups**, having shared data improves communication, builds technical capacity, and supports stronger coordination and accountability.

Beyond these main users, many **other actors** are increasingly interested in groundwater data. For example:

- **Researchers** use it to study aquifers, water governance, or how well water projects are working.
- **Donors, development banks, and climate finance institutions** use the data to help decide which projects to fund, especially those focused on water security or resilience. When they see value in the data, these groups can also become active supporters or funders of the monitoring system.
- In some cases, **industries**, especially those with high water use, can also benefit from monitoring data. It helps them manage their operations more responsibly, comply with regulations, and work together with others on local water planning.
- **Journalists and policymakers** can use groundwater data when it is shared clearly and in formats they can understand. It can help them explain key issues to the public, draft better policies, or support specific water initiatives.

BOX 1 - CASE STUDY
GROUNDWATER MONITORING IN COX'S BAZAR, *BANGLADESH*

In response to **high water demand** from over 730,000 Rohingya refugees, Medecins Sans Frontieres Operational Centre Amsterdam (MSF-OCA) worked with Groundwater Relief to establish a groundwater monitoring programme within the Mega Camp in January 2018.

In 2019 the International Organization for Migration (IOM), with funding from the Government of Japan, worked with Groundwater Relief and Dhaka University to set up a **groundwater monitoring and modelling programme** in Cox's Bazar. The goal was to protect water supplies for both refugee and host communities by **improving how the aquifer was understood and managed.** The programme built a regional groundwater model, calibrated from over 1 year of monitoring data obtained from the MSF-OCA monitoring programme. The findings showed that water use from the Dupi Tila aquifer, about **49 million cubic metres per year,** was a sustainable water balance. However, the model also warned that parts of the aquifer risked large drawdowns in water level at high pumping rates (up to **20 metres**), which risked locally damaging camp infrastructure and affecting nearby community wells.

Installation of regional **groundwater monitoring network**

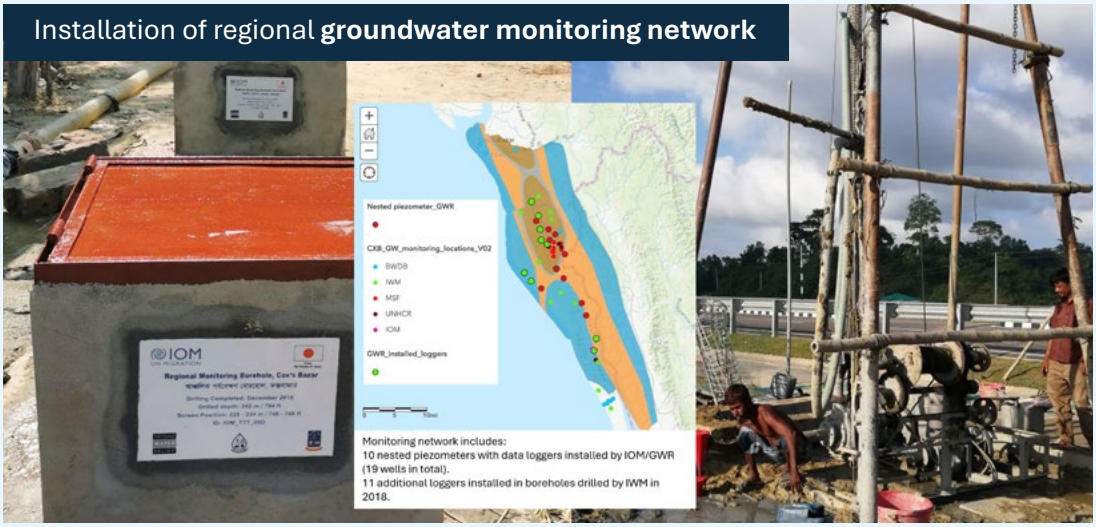

Figure 3: Groundwater monitoring by Groundwater Relief in Cox's Bazar, Bangladesh. (GWR)

The monitoring system provided clear further benefits to many different actors:

- **Multiple actors including IOM, the Department of Public Health Engineering (DPHE), United Nations High Commissioner for Refugees (UNHCR), United Nations Children's Fund (UNICEF), and Médecins sans Frontières (MSF)** used the data and model outputs to guide investment in water infrastructure, support the design of new boreholes and improve water supply operations at the refugee camps.
- **WASH Cluster coordination** improved as all partners had access to the same data and could make joint decisions based on shared understanding of the aquifer.
- **The model provided donors and climate finance organisations** more confidence in supporting a Water Supply Master Plan (WSMP), designed to upgrade the provision of water to camp refugees to a chlorinated, gravity-fed piped water supply system that would replace shallow tubewells that were considered vulnerable to contamination. The model is now managed by **Dhaka University**, is still being used as a shared tool for **long-term water security planning in 2026**.

→ *Read more about this case study in **Section 10 (page 119)**, which details the full process.*

1.3 WHEN IS IT YOUR RESPONSIBILITY TO MONITOR GROUNDWATER?

INTERNATIONAL ORGANISATIONS AND NON-GOVERNMENTAL ORGANISATIONS (NGOS)

Any groundwater-based supply system developed or supported by international or non-governmental organisations **should include a plan for at least essential monitoring**. This is both good practice and aligns with most organisations' principles on **sustainability, accountability and "do no harm"**. At its core, do no harm means that humanitarian action should avoid causing or exacerbating harm to the people or communities it aims to help.

In humanitarian settings, especially in high-density areas like refugee or Internally Displaced Person (IDP) camps, establishing groundwater monitoring will help organisations track how the aquifer is responding to their interventions. Most critically, organisations can use these data to set **thresholds or triggers**, where a monitoring indicator exceeding a threshold triggers proactive management interventions.

Where possible, in cases that are not part of urgent short-term humanitarian response, international organisation and NGO developed systems should be designed from the outset **with a long-term vision**, including eventual handover to local or national water authorities. Until then, data sharing and collaborative management with relevant institutions is important to build working relationships and capacity with those institutions, promote continuity, and avoid duplication.

WATER AUTHORITIES

Government water authorities are generally expected to **lead groundwater monitoring** where they have the institutional capacity and legal mandate to do so. In some contexts, responsibility for monitoring may be delegated to academic institutions, private organisations, or non-governmental organisations with the necessary technical expertise. National or regional authorities are often responsible for both monitoring and regulating groundwater resources, while implementation at the local level may be integrated into Water Basin Management Plans (WBMP) and supported through the engagement of local stakeholders.

Over time, it's best for most groundwater data, whether collected by government, NGOs, or private groups, to be **shared** through a central, government-managed system, only possible if appropriate to the project, context and existing data sharing agreements. This enables national-level analysis and supports better planning. In countries with limited government capacity, **temporary support** from **UN agencies, NGOs, or local authorities** is expected until institutional capacity has recovered.

WATER UTILITIES

Water utilities managing groundwater-based supply systems should **integrate routine monitoring** into their operations. This is important not only for technical reasons (like tracking water levels and quality to anticipate and prevent service issues) but also for financial sustainability. Transparent data improves trust with regulators, funders, and the public, and can support tariff setting, service expansion, and access to climate or development finance. In some countries, utilities may also have a legal duty to report groundwater data to national regulators.

WATER MANAGEMENT COMMITTEES AND LOCAL PRIVATE SUPPLIERS

Groundwater monitoring is rarely carried out by community committees or small private suppliers beyond occasional flow checks or during maintenance. However, even simple monitoring can deliver **valuable benefits**:

- Diagnosing well performance issues.
- Supporting fair water allocation.
- Triggering actions (such as rationing or using alternative supply) at alert thresholds.
- Increasing visibility and credibility with local authorities.

Public sector or NGO support can help these groups establish basic monitoring routines (e.g. using dip meters, simple water quality tests, a phone application to record data) and build capacity for data collection and interpretation.

BE CLEAR ON 'WHY' YOU ARE MONITORING

Beyond being a responsibility for many actors, groundwater monitoring projects often arise out of an already identified need for better groundwater information (e.g. a need to better anticipate borehole issues and finance repairs ahead of failure).

From the outset, it is good practice to maintain a list of the **key reasons** for, and **objectives** of, the monitoring program that you are planning. Central to this will be the development of a conceptual understanding of the groundwater system. Reasons and objectives may change during the scoping and setup phases as you become more aware of different environmental issues, stakeholders' monitoring needs and potential uses of the data.

1.4 PURPOSE OF THIS GUIDE

In many humanitarian contexts, groundwater monitoring is becoming an **expected part of project delivery**, especially from donors, who are increasingly aware that groundwater projects without proper monitoring and evaluation (M&E) plans have a high risk of failure. But the responsibility for monitoring often falls to people who are not hydrogeologists. Project managers, WASH coordinators, engineers, or general humanitarian staff are commonly asked to set up and manage monitoring systems, even if they have limited experience with groundwater.

One of the main goals of this document is to help those teams. It offers **practical, easy-to-follow guidance** for people who may not have a specialist background, but who are tasked with groundwater monitoring or overseeing others recruited to complete the monitoring function.

We use the term “humanitarian contexts” in a **broad** sense. This includes short-term emergencies, such as those caused by conflict, natural disasters, or mass displacement. But it also includes long-term or chronic situations, like areas with ongoing water or food insecurity, environmental stress, or unstable governance. In these places, humanitarian programming often overlaps with development, peacebuilding, and resilience work.

Whether groundwater monitoring starts during an emergency response or as part of a longer-term plan, the goal should always be to **keep it going** after the crisis ends. Long-term monitoring helps ensure that groundwater remains safe, reliable, and predictable throughout the recovery and development phases that follow.

1.5 DOCUMENT GUIDE

Chapters 2 describes a practical roadmap of how to set up, manage, and sustain a groundwater monitoring programme from initial scoping through to the eventual handover of an operational system. Then **Chapters 3 – 7** provide detailed guidance for each of these stages. In those chapters:

- **Case study boxes** illustrate real-world examples at each stage.
- Additional boxes highlight **common pitfalls** and how to avoid them.
- Key resources are **signposted** throughout.
- **Annexes** are attached with templates for practical use.

Chapter 8 introduces **"bigger picture"** issues related to groundwater monitoring that will be especially of interest to managers and stakeholders in higher-level decision roles, including:

- 8.1. The Challenge of Sustaining Monitoring Systems.
- 8.2. Decentralisation as a Pathway to Sustainability.
- 8.3. Future Directions to Improve Feasibility.

Chapter 9 provides **concluding reflections** - a summary of the guidance offered and next steps for those who want to implement or support groundwater monitoring.

Chapter 10 provides two detailed case studies showing the full monitoring process as completed in Cox's Bazar, Bangladesh and Northeast Syria.

2. MONITORING ROADMAP

Setting up a groundwater monitoring system follows a clear set of steps. These are similar to many other types of projects: you begin by understanding the situation and defining your objectives (scoping), then you design the system, prepare the resources, test the approach, and finally expand it into a working long-term programme.

Groundwater monitoring differs from many other projects because it is inherently a long-term intervention. The value of a monitoring programme increases the longer it continues, allowing trends, variability, and long-term changes in groundwater quantity and quality to be identified. Monitoring projects also need to be underpinned by data sharing mechanisms to ensure data collected is accessible to all relevant stakeholders. This means considering the long-term sustainability of a monitoring programme from the outset. Programme design should consider how monitoring activities can be integrated with the responsibilities of national water authorities or other designated government institutions with a mandate for managing and regulating water resources. Where possible, monitoring systems should be designed to strengthen existing national capacity and facilitate the long-term transfer of ownership and responsibility.

The process shown in **Figure 4** gives an overview of how a monitoring programme develops. It also matches the structure of the rest of this section of the guide, which explains detailed guidance for each step.

- **Chapter 3: SCOPING**
  Understand the need for monitoring: Why and where it is needed, what the groundwater risks are, what monitoring already exists, which partners may be involved, and whether the work is feasible with the available funding.
- **Chapter 4: DESIGN**
  Use what you learned during scoping to design a monitoring system that fits the context. Think about what data users need, the local hydrogeology, any challenges to operation, what resources are available, and how the system can work long-term.
- **Chapter 5: PREPARATION & PROCUREMENT**
  Once the design is agreed, get ready to implement it. This includes securing resources, making formal agreements, buying equipment, and setting up any digital systems.
- **Chapter 6: PILOT PHASE**
  Test the system in one area first. This stage is where monitoring begins, data is collected and analysed, and adjustments are made based on how the system works in practice.
- **Chapter 7: IMPROVEMENT, EXPANSION & HANDOVER**
  Use what you've learned from the pilot to improve the system. Then expand it to more areas while continuing to train people, gather feedback, and refine the design. At this stage, the system is operating and ready to be handed over. Responsibilities are transferred to local institutions, long-term financing is secured, and the system becomes part of regular water governance.

Although in **Figure 4** these steps are shown in order, they don't always happen one after another. In practice, many activities happen at the same time, especially from the pilot phase onward.

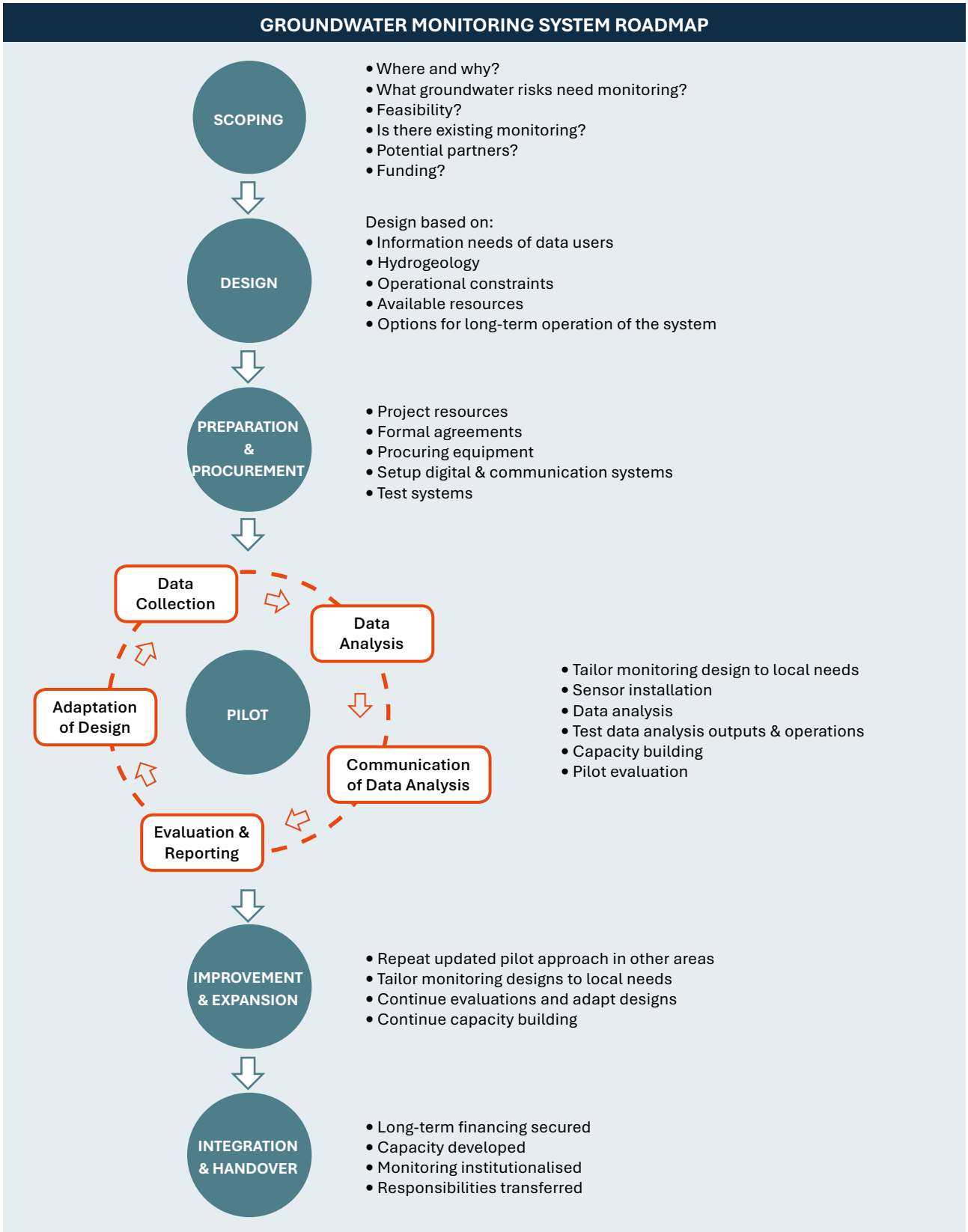

Figure 4: Roadmap to setting up a groundwater monitoring system.

BOX 2 - CASE STUDY

POORLY PLANNED MONITORING SYSTEM IN BENTIU CAMP, *SOUTH SUDAN*, AND THE IMPORTANCE OF SCOPING, DESIGN AND PILOTING

In urgent humanitarian emergencies, it is common for the early phases of groundwater monitoring such as **scoping, design, and piloting** to be shortened or rushed. However, skipping or rushing these steps often leads to problems down the line. Even during crises, many of the same challenges apply. Above all, there remains a need to design a system that meets the expectations and information requirements of the people operating the system and intending to use the data.

An example showcasing this pitfall is a **groundwater monitoring system** set up in **Bentiu Protection of Civilians (POC)**, South Sudan, by Groundwater Relief in 2016.

Figure 5: Queueing for water at the Bentiu Protection of Civilians (POC) site. (GWR)

In response to the urgent needs of displaced populations, **10 monitoring points** were quickly installed within a 3-week period at all the key production wells supplying the PoC. However, within a year, the system had largely collapsed with manual data collection discontinued, and automatic sensors going offline without repair. This initial failure was mainly due to setting up monitoring points quickly without investing in dip tubes or well head modification to protect monitoring equipment; limited capacities to manage the system; and **no clear plans** for how the system would be operated and maintained prior to its installation.

Despite the failure, the data obtained from the monitoring programme did provide clear evidence that the camp abstractions were not having a significant impact on the underlying aquifer system. This data supported arguments for continuing to invest in groundwater supply rather than a surface water supply scheme.

Initial failures resulted in many lessons learned and deeper discussions about monitoring system needs and responsibilities which enabled improvements and more sustainable monitoring to be set up at Wau POC the following year.

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BOX 3 - COMMON PITFALL
SKIPPING THE SCOPING AND DESIGN

Even in emergency situations, it's important to follow as many of these steps as possible. Sometimes it will be urgent to monitor key water points that are clear priorities quickly, but the rest of the system should still be designed in parallel. **Skipping key steps can lead to problems later** and may cause the system to fail. Typical causes of problems include:

- Failure to **properly designate monitoring responsibilities** to individuals
- Failure to design information outputs that are genuinely **useful** for intended users
- Failure to **setup communications** at the correct frequency and level of detail

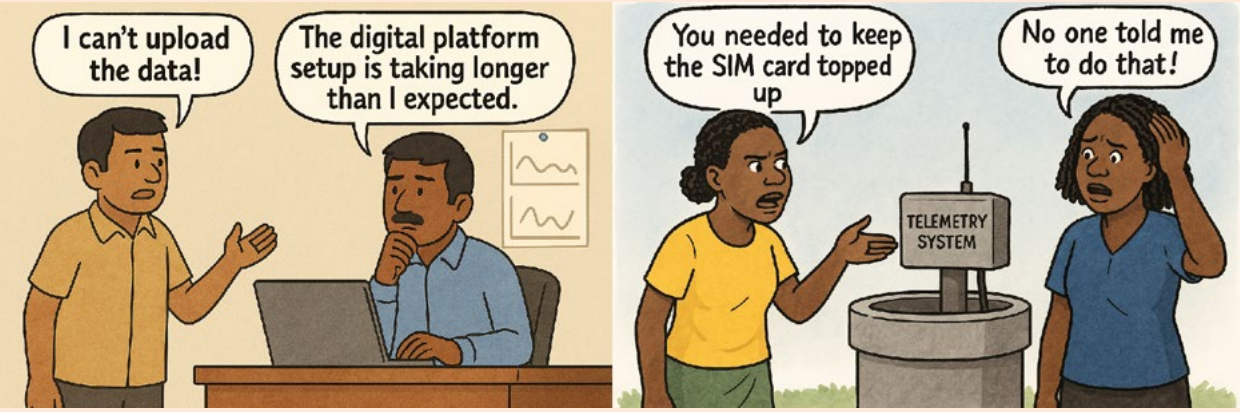

Figure 6: Rushing the scoping and design can lead to bigger problems later on. (ChatGPT+, 2025)

3. SCOPING

Before designing a groundwater monitoring system, it's important to assess whether monitoring is really needed, what it would involve, and whether it's likely to succeed. This early **scoping phase** helps you avoid wasted time, effort, and resources later on.

A good scoping study considers five key factors, shown in **Figure 7**. These considerations cover both the **evidence of monitoring needs** and **the constraints** that might limit the system's success.

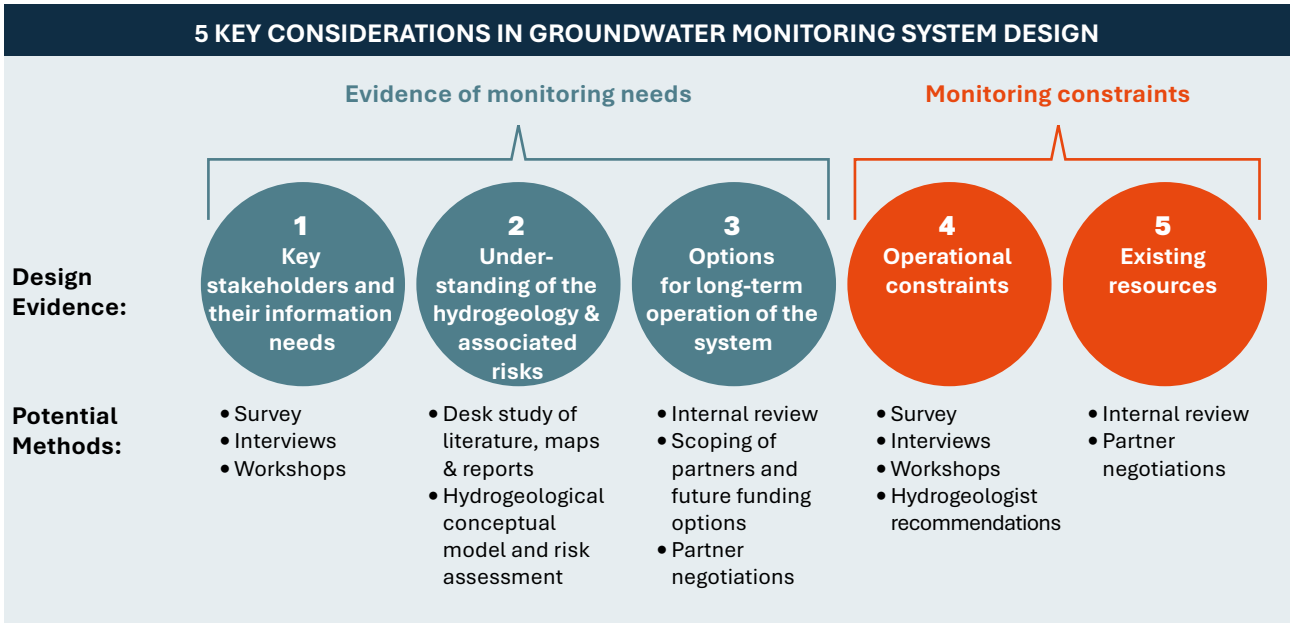

Figure 7: Five key factors to consider in the design of a groundwater monitoring system.

For each area, we recommend answering the following guiding questions to build a picture about the **reasons for monitoring** and its **feasibility in practice** (**Figure 8**), for which we provide a template for practical use in **ANNEX A1**.

ANNEX A1: GROUNDWATER MONITORING DESIGN SCOPING CHECKLIST

This checklist supports the scoping phase described in Section 3. It helps implementers document responses to key questions across five key areas. Example answers are included for reference but should be adapted to the local context and completed in more detail.

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SCOPING CHECKLIST FOR GROUNDWATER MONITORING

1 Key stakeholders and their information Needs

- Why is groundwater information needed in this context?
- Who will use the data? What decisions will it support?
- In humanitarian settings:
  - Could interventions affect the groundwater (e.g. drilling too many boreholes)?
  - Are there risks to existing users or the environment?
- What benefits could monitoring bring to different user groups?
- Are there other potential users who could benefit from the data (e.g. donors, regulators, researchers)?
- Are there possible co-benefits from monitoring, such as:
  - Local employment or technician roles?
  - Capacity building or training?
  - Partnerships across agencies or sectors?
- How can we ensure that monitoring data will be trusted, used, shared

2 Understanding of the hydrogeology & associated risks

- What groundwater risks are already known in the area?
  - Is supply reliable?
  - Are there known issues with water quality?
  - Do droughts or other events disrupt groundwater access?
- Will increased abstraction (e.g. from a large humanitarian response) put extra pressure on the aquifer?
- How well understood is the local hydrogeology?
  - Are there any major unknowns?
  - Would a basic hydrogeological study help clarify risks?
- Is additional monitoring (such as geophysical survey or water level monitoring at certain sites) needed to fill gaps in hydrogeological understanding?

3 Options for Long-Term Operation of the system

- If monitoring is eventually handed over, who is the most appropriate authority to manage it long-term?
  - What are their goals and responsibilities related to groundwater?
  - Do they currently need the kind of data your system would produce?
  - Are they interested in partnering on this project?
  - Will they have the budget, staff, and mandate to continue the work?
  - If they don't yet have the required capacity, could it be realistically built during the project?
- Do national policies, water laws, or government strategies support long-term monitoring?
- What funding options exist for ongoing monitoring after handover?
- What results would the monitoring system need to show to secure future support or funding?

4 Operational contraints

- Has groundwater monitoring been tried in this area before?
  - If yes, what worked and what didn't?
- Are there access constraints (e.g. roads, insecurity, remoteness)?
- Are there national or local laws, ethical approvals, or planning permissions needed?
- Will local authorities or communities support or resist groundwater monitoring?
- Is there enough capacity (people, time, technical skill) to manage the system in the long term?
- Can the required equipment and materials be purchased locally or imported?
- Will the costs (setup and ongoing) be manageable within the available budget?
- Is the expected value of the monitoring high enough to justify the costs (compared to other needs)?
- Are there any data security or privacy concerns that need managing?

5 Existing resources

- Is funding available for setup and ongoing operation? For how long?
- Are there opportunities to share costs or partner with other organisations?
- Is there existing infrastructure (e.g. boreholes, piezometers, labs) that can be used?
- What technical expertise exists in-country (government staff, universities, NGOs, private sector)?
- Can you find equipment and laboratory support locally?
- What digital systems or data platforms already exist, if any?
- Are there organisations or experts who may want to support or co-deliver the monitoring? Have they been consulted?

6 Deciding wether yo proceed

Once the scoping questions have been answered, you can decide wether to move forward with a full monitoring system design.

Generally, it makes sense to continue if:

- ✓ The expected **benefits** of monitoring clearly justify the costs.
- ✓ Monitoring appears **feasible**, given the operational and resource constraints.

If either of these conditions is not met, the project should be paused or redesigned.

Figure 8: Scoping questions to answer through desk study and initial conversations with actors who may use groundwater monitoring data and/or support the operation of the groundwater monitoring system.

4. DESIGN

Once the scoping process confirms that the envisaged groundwater monitoring is feasible and likely to deliver on its objectives and expected benefits, the next step is to design the system. Good monitoring design balances priorities with practical constraints. It should respond to user needs, match the hydrogeological risks, and remain achievable within the available resources and capacity.

This section sets out a five-step design process (**Figure 9**), which forms the structure for the rest of the Design Section. Although presented in sequence, some stages may be undertaken simultaneously.

- **STEP 1: GATHER DESIGN EVIDENCE**
  Use stakeholder engagement, hydrogeological assessment, and partner discussions to collect the information needed to guide the monitoring design.
- **STEP 2: SUMMARISE AND PRIORITISE RECOMMENDATIONS**
  Turn the evidence into a list of recommended monitoring actions and prioritise by balancing their importance (expected benefits) with expected costs and risks.
- **STEP 3: PREPARE DESIGN OPTION(S)**
  Package the recommendations into one or more practical monitoring system options that stay within budget and match local conditions.
- **STEP 4: DEVELOP A FINANCIAL MODEL**
  Break down the costs of the preferred option(s), including setup, operation, and any additional resources needed.
- **STEP 5: APPRAISAL AND DECISION TO CONTINUE**
  Present the full design and value proposition to internal or external decision-makers. If approved, the project can move forward to procurement.

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INITIAL DESIGN STAGES OF GROUNDWATER MONITORING SYSTEM

1 Gather Design Evidence

Understand context, constraints, and stakeholder needs

Design Evidence:

Evidence of monitoring needs

- **1** Key stake-holders and their information needs
- **2** Under-standing of the hydrogeology & associated risks
- **3** Options for long-term operation of the system

Monitoring constraints

- **4** Operational constraints
- **5** Existing resources

Complete a desk study and survey to:

- Map key data users, their relevant objectives and information needs.
- Identify local water supply concerns, groundwater risks, and hydrogeological unknowns.
- Assess institutional capacity, access challenges, and regulatory requirements.
- Identify available infrastructure, resources, and technical support.

Engage a hydrogeologist to:

- Develop an initial conceptual model of the hydrogeology based on currently available information.
- Assess groundwater risks and recommend monitoring priorities.

2 Summarise & Prioritise Recommendations

Summarise benefits, costs, risks, and feasibility of monitoring

- Summarise evidence into recommendations.
- Organise and prioritise based on:
  - Importance (anticipated benefits)
  - Expected costs
  - Risk of failure based on practical constraints

3 Develop Design Options

Build one or more viable monitoring system options

- Combine priority elements into design option(s).
- Ensure the system:
  - Stays within budget
  - Minimises risks
  - Aligns with user needs and partner incentives

4 Create Financial Plan

Build a basic cost model and identify funding needs

- Detail capital (setup) and recurring (operating) costs.
- List available finances among partners, including:
  - Expected payments or in-kind contributions
  - Additional resources needed or pledged by partners (staff, transport, equipment)

5 Appraise and Decide

Present design and decide wether to proceed

- Share the design with internal and external partners.
- Clearly communicate:
  - Benefits of monitoring relative the costs
  - Evidence of technical & operational feasibility
  - How identified risks will be adressed

YES?
Continue to preparation and procurement

NO?
Return to Step 3 and refine the design

Figure 9: Recommended 5 step process for monitoring system design.

4.1 STEP 1 GATHER DESIGN EVIDENCE

Before designing a groundwater monitoring system, it's important to collect detailed information across the five same key areas as explored in the scoping study (see **Figure 8**).

These five key areas are the foundation of the design process and can be addressed through a combination of desk study, survey and hydrogeological assessment:

- **4.1.1. DESK STUDY AND SURVEY** - Collect information on:
  - **A. Key Stakeholders and Their Information Needs.**
  - **B. Operational Constraints.**
  - **C. Existing Resources.**
  - **D. Options for Long-Term Operation of the monitoring system.**
- **4.1.2. UNDERSTANDING THE HYDROGEOLOGY AND ASSOCIATED RISKS** - Whilst it is recommended to work with a hydrogeologist throughout the design process if resources allow, here it is critical. Engage a hydrogeologist to review any available groundwater data, build a working conceptual model of the aquifer system, and assess groundwater risks to inform monitoring priorities.

4.1.1 DESK STUDY & SURVEY

A **desk study** and targeted survey are practical tools to gather information on current groundwater issues, information needs, operational constraints, existing resources and options for long-term operation of the groundwater monitoring system. This step can be completed through reviewing available reports and records, and by speaking with key stakeholders such as water authorities, WASH actors, borehole operators, and local community representatives. The remaining sub-sections (**4.1.1A to 4.1.1D**) explain how to carry out this process in more detail across each of the four key areas.

4.1.1A KEY STAKEHOLDERS AND THEIR INFORMATION NEEDS

To design a groundwater monitoring system that delivers value, it's essential to first understand who will use the data, what they need it for, and what support they might require. **ANNEX A2** provides an example-filled table for recording key users, their groundwater-relevant objectives and their information requirements to meet them.

BOX 4 - COMMON PITFALL
OVERLOOKING THE NUANCES OF INFORMATION NEEDS

One of the most common reasons groundwater monitoring systems go unused is a failure to understand the subtle, but essential, **differences in how various stakeholders interact with data.** Even when users are interested in groundwater issues, the format, timing, and communication style of the data can be just **as important as the data itself.**

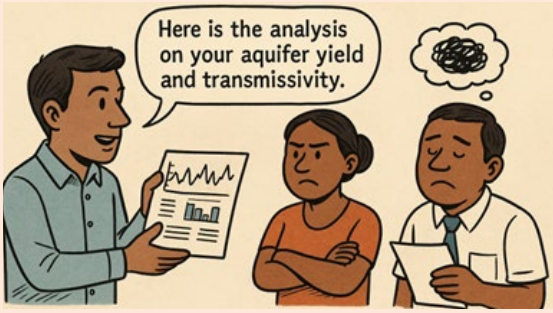

Figure 10: Different users have differing interests and levels of data literacy. (ChatGPT+, 2025)

As interviews informing this guidance by Veness and Buytaert (2025) show, data that is too technical, poorly timed, or mismatched with local workflows is often **ignored**, even by stakeholders who were meant to benefit from it. Information needs are rarely one-size-fits-all: some users may want summary charts, others need raw data; some prefer dashboards, others respond best to briefings or printed reports.

Without early engagement to understand these needs, assumptions can lead to systems and single format data communication platforms that technically "work," but **fail to support real decision-making**. Understanding data literacy levels, institutional routines, and communication preferences takes time, but is key to building systems that monitor relevant information to trigger real-world actions.

ANNEX A2: USER OBJECTIVES, INFORMATION NEEDS & BENEFITS OF GROUNDWATER DATA

This table captures the demand side of groundwater data and the requirements for each stakeholder:

- **Objectives & Activities Relevant to Groundwater**
  What is their role in groundwater management? Understanding this helps predict how they'll engage with the data.
- **Local Groundwater Concerns**
  What are the key risks or problems they face - e.g. falling water levels, salinity, maintenance, or non-technical issues such as communication, lack of evidence?
- **Groundwater Information Needs**
  What specific data would help them manage those risks and problems - seasonal levels, quality trends, flow rates?
- **Expected Uses of Groundwater Data**
  How would they apply this data - planning maintenance, requesting funding, warning users?
- **Expected Benefits of Data Use**
  What impact do they expect - more reliable services, better coordination, fewer breakdowns?
- **Data Format Requirements**
  In what format would they prefer to receive information - maps, graphs, alerts, dashboards?
- **Additional Support Needs**
  Would they need help understanding or applying the data - training, technical assistance, interpretation tools?

4.1.1B OPERATIONAL CONSTRAINTS

Humanitarian emergencies are especially **challenging environments for monitoring**. Even if groundwater data is in demand and funding is available, **practical barriers can limit where and how monitoring is possible**. These constraints should be identified early through a combination of desk study and discussions with local authorities, communities, and other actors during the survey process.

KEY AREAS TO EXPLORE INCLUDE:

- **Legal and Regulatory Compliance.**
  Speak with relevant authorities and community leaders to understand approval requirements and jurisdictional boundaries. Permissions may be needed from local governors, tribal leaders, district water offices, or national ethics committees. It's also important to understand any data-sharing laws or compliance procedures that might affect data storage, transmission, or publication. Guidance on this can be found in International Groundwater Resources Assessment Centre's[6] (IGRAC) (2008) guideline on groundwater monitoring for general reference purposes, particularly Chapter 5 and the DataCoM framework.

- **Access Constraints.**
  Identify areas where security issues, travel restrictions, or land ownership may limit physical access for installing or maintaining monitoring equipment. These challenges must be accounted for in system design, for example, by choosing alternative sites, using remote sensing, or engaging local partners to maintain access.

- **Technical and Capacity Barriers.**
  Survey respondents should be asked to identify potential technical or institutional risks that could disrupt monitoring. These may include:
  - Lack of staff or technical WASH skills
  - Limited capacity to manage or analyse data
  - Sensor maintenance needs or risk of vandalism
  - Unreliable data transmission or platform issues

- **Community Participation and Trust.**
  Social factors also matter. Conflicts of interest, low trust, or a lack of understanding about the purpose of monitoring can all hinder implementations. These should be raised during interviews, along with ideas for how to address them, such as through awareness workshops, hiring community technicians, or visibly marking and fencing installations.

- **Instability.**
  In many humanitarian contexts, the stability of institutions and of the communities themselves itself (which may move due to the crisis) are fragile. This can impact the definition of roles and responsibilities, the safety of monitoring participants, and the sustainability of the monitoring. Monitoring methods and scope should remain realistic when these are significant risks.

  Whatever constraints or challenges are identified: **co-design solutions wherever possible**. Early identification of barriers and suggestions for solutions during surveys and their recording in **ANNEX A3** can help shape those conversations and build support from the start. Many of these risks will require follow-up discussion and iterative design and testing with users during the pilot stage.

6 - https://un-igrac.org/data/resources/guideline-on-groundwater-monitoring-for-general-reference-purposes/

BOX 5 - CASE STUDY
BARRIERS TO MONITORING *IN THE HORN OF AFRICA*

Expert interviews in the Horn of Africa found that **common barriers to monitoring** included lack of staff, technical WASH capacity, financial constraints, weak data platforms, and issues with sensor reliability and security (**Figure 11**). Political and institutional barriers such as poor governance or lack of local buy-in were also frequently raised.

Whilst participants also made recommendations and solutions to address these barriers, which has contributed to the guidance throughout this document, some factors will remain challenges throughout the monitoring project **requiring a shared awareness and mitigating measures where possible.**

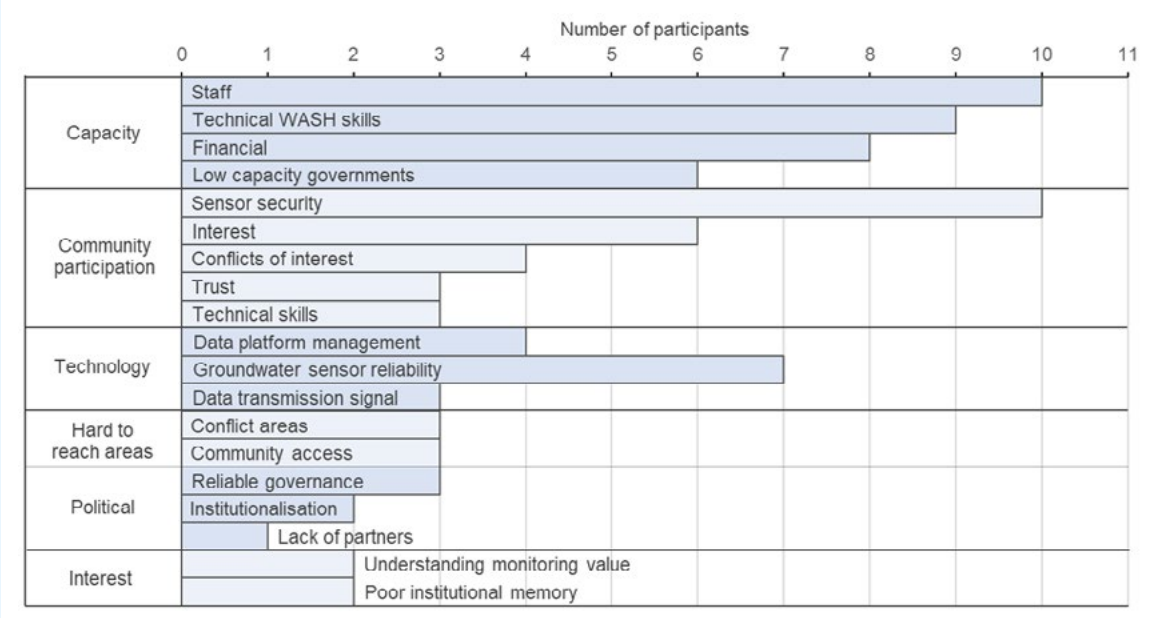

Figure 11: Summary of general barriers to groundwater monitoring in the Horn of Africa recorded during interview of 42 experts in 2022. (Veness and Buytaert, 2025)

ANNEX A3: OPERATIONAL CONSTRAINTS, RESOURCES & PARTNERSHIP OPPORTUNITIES

While Annex Table A2 looks at demand, Annex Table A3 focuses on feasibility. It helps assess whether the system is realistically deliverable, and how it might be supported. Key columns include:

- **Expected Challenges, Risks or Constraints**
  What barriers might affect monitoring - e.g. security, permissions, lack of staff or skills?
- **Solutions to Each Challenge**
  Can practical steps be taken - like hiring a local technician, building awareness, or adjusting equipment choice?
- **Interest in Supporting Monitoring**
  Are stakeholders willing to help or partner? If so, how - through staffing, coordination, funding, advocacy? Which stakeholder (e.g. national water authority) is best placed to take over the long-term operation of the monitoring system – are they interested?

- **Resources They Could Provide**
  What support is available - vehicles, equipment, office space, data?
- **Existing and Additional Incentives**
  What would motivate them to stay engaged - data access, training, formal roles?
- **Capacity Building Requirements**
  What skills or support would they need to participate effectively in monitoring activities?
- **Known Funding Opportunities**
  Are there grants or budget lines that could support monitoring now or in future?

This table feeds directly into planning the long-term operation and sustainability of the monitoring system, as well as shaping partnerships and exit strategies for humanitarian stakeholders from the outset.

4.1.1C EXISTING RESOURCES

A realistic monitoring system design should consider what's already available financially, technically and above all, institutionally. Early identification (ID) of existing resources can help reduce duplication, improve value for money, and open opportunities for co-financing or integration with ongoing work.

BOX 6 - COMMON PITFALL
OVERLOOKING THE NUANCES OF INFORMATION NEEDS

In humanitarian contexts, several actors may be planning or operating groundwater monitoring projects **at the same time**. Without coordination, efforts can be duplicated, opportunities for synergies can be missed, and in some cases, confusion among monitoring participants can undermine the sustainability of the projects. Working in isolation also risks collapse of the system if key individuals leave the organisation, as **the institutional memory for the project gets lost.**

Before launching a new monitoring initiative, **map and engage any existing or planned groundwater monitoring projects.** Establish how the design can link with or complement their work, and how you can jointly work towards a handover over your systems to the relevant national authority (as in **Box 8**).

Figure 12: Failure to share leads to duplication and redundancy in monitoring efforts. (ChatGPT+, 2025)

KEY RESOURCE CONSIDERATIONS DURING THE DESIGN PHASE:

- **Internal and Partner Funding.**
  Determine what funding is available across partner institutions. In humanitarian settings, many groundwater monitoring programmes are funded collaboratively between NGOs, UN agencies, and host governments.
- **External Opportunities.**
  During crises or recovery phases, large-scale funding windows may briefly open that are often linked to resilience building, post-disaster reconstruction, or climate adaptation programming. These should be explored early. UN agencies, bilateral donors, and pooled humanitarian funds (e.g. the United Nations Central Emergency Response Fund, WASH Cluster allocations) are all examples of potential sources.
- **Co-Financing and Collaboration.**
  Reach out to other organisations involved in groundwater management, explore co-financing, resource sharing, or joint implementation. This may include training exchanges, shared data platforms, or logistical support.
- **Existing Infrastructure and Programmes.**
  Map what water points, boreholes, piezometers, or telemetry systems are already in place. In many cases, existing boreholes can be adapted into cost-effective monitoring points. Also assess whether other monitoring programmes are already active (e.g. by NGOs, water authorities, academic institutions), and identify opportunities to align or integrate efforts and share equipment or facilities.
- **Industrial Actors.**
  There may be nearby industrial actors (mines, power stations, factories, water utilities) responsible for the majority of groundwater abstraction. Although cautious of what it means to them, they will often be supportive of groundwater monitoring and may contribute resources and their existing datasets.
- **Stakeholder Incentives.**
  Identify what motivates different actors to participate. Communities may want feedback on data; borehole operators might seek visibility or access to performance reports; water authorities may benefit from shared analysis or support to meet regulatory mandates; technicians may want a salary, transport, phone credit and certification. These incentives should be acknowledged and built into the design.

BOX 7 - COMMON PITFALL
OVERLOOKING PARTNER INCENTIVES

Implementation partners, whether community groups, borehole operators, government technicians or utilities, are essential to long-term success. But they **will not stay engaged without clear reasons to do so.**

Failing to identify and address their motivations is a regular cause of system failure. When roles become thankless or unrewarded, local partners often disengage - leaving sensors unmaintained, logs incomplete, and data unused.

Figure 13: Fulfilling partner incentives is critical to sustaining long-term monitoring. (ChatGPT+, 2025)

Designing-in small, context-appropriate incentives can significantly improve commitment and follow-through. The list below summarises common incentives for different partner groups:

- **National and Local Water Authorities, Regulators and Basin Authorities.**
  - Access to reliable data for reporting, planning, or regulation
  - Improved visibility and credibility with funders and ministries
  - Formalised role in data platforms or dashboards
  - Capacity-building through joint analysis or co-leadership in fieldwork
  - Alignment with sector performance indicators or climate reporting mandates
  - Real-time data to support compliance checks or abstraction tracking
  - Tools for setting evidence-based policy or tariff structures
  - Integration into legal or national monitoring frameworks
- **Community Water Committees or Village Leaders.**
  - Data summaries that help inform local water use decisions
  - Visual recognition (e.g. posters, briefings, community updates)
  - Involvement in decision-making or site selection
  - Opportunities to participate in training or governance structures
- **Field Technicians and Borehole Operators.**
  - Small stipends or performance-based incentives
  - Access to feedback (e.g. “your data helped trigger a repair”)
  - Mobile-based tools or simplified forms to reduce effort
  - Formal recognition or certification
  - Participation in regular coordination meetings
- **NGOs and Humanitarian Partners.**
  - Shared access to monitoring outputs for programme design
  - Inclusion in joint reports or learning briefs
  - Alignment with donor reporting and resilience goals
  - Opportunities for co-funding or visibility in joint platforms
- **Researchers and Academic Institutions.**
  - Access to high-quality field data for studies
  - Co-authorship opportunities or student project support
  - Collaboration in analysis, modelling, or tool development
  - Long-term relationships for capacity-building and knowledge transfer
- **Donors and Development Banks.**
  - Compliance with their mandates
  - Demonstrated value for money (cost-per-use or action-triggered metrics)
  - Visibility through dashboards, case studies, or reports
  - Contributions toward resilience, WASH, or climate outcomes
  - Options to co-invest in maintenance or scale-up
- **Private Sector and Water Companies.**
  - Shared access to monitoring outputs for operational decision making

4.1.1D OPTIONS FOR LONG-TERM OPERATION OF THE SYSTEM

In most humanitarian settings, groundwater monitoring is initially led by international or non-governmental organisations. However, these actors are typically not the long-term custodians of water systems. A key part of monitoring system design is identifying who will eventually take over operations and designing with that in mind from the very beginning.

Long-term operation in developing contexts can be supported through early coordination, shared ownership, institutional incentives, and a realistic financial pathway.

START THIS PROCESS DURING THE SCOPING AND SURVEY PHASE BY:

- **Mapping the relevant actors, such as:**
  - National and local water authorities
  - Public utilities or rural water service departments
  - River basin organisations
  - Regional governance frameworks or trans-boundary aquifer organisations
  - Academics
  - Any active public-private partnerships or donor-funded programmes with a water monitoring component
- **Initiating early discussions during interviews or site visits. Explain your intent to establish a monitoring system and eventually transfer responsibility. Gauge their:**
  - Interest in short- and long-term engagement
  - Current capacity (both technical and financial), roles, and constraints
  - Willingness to co-design or influence the system's format, reporting, or data-sharing mechanisms
- **Documenting findings and preferences, such as (see ANNEX A2):**
  - Institutional strategies relevant to groundwater
  - Incentives to support or participate in monitoring
  - Financial or capacity support they would need to take ownership
  - Any design preferences or institutional limitations that must be considered during system setup
- **Exploring funding pathways that could be activated once the system is operational, such as:**
  - National budgets or decentralised government transfers
  - Climate adaptation or water sector grants
  - Continued donor financing or transitions to debt financing
  - Partnerships with universities or water boards to institutionalise key functions
  - Integration into larger programs coordinated by international organisations

Early planning for ownership and funding strengthens the chance that a monitoring system will continue beyond the lifespan of the initial project.

BOX 8 - CASE STUDY

BUILDING OWNERSHIP THROUGH CO-IMPLEMENTATION *IN NIGERIA*

In North East Nigeria, ACF worked closely with the Nigerian Hydrological Services Agency (NIHSA) to establish **a groundwater monitoring system** designed for long-term government ownership. From the outset, ACF ensured that NIHSA was not just a future recipient, but an **active partner in implementation**.

SIM cards for telemetry were procured by NIHSA and registered in their name, giving the agency direct responsibility over data flow and system management. Installations were conducted jointly - starting with one led by ACF, followed by others led by NIHSA staff with ACF in a support role.

Figure 14: Automatic water level logger installed Degubi Health Clinic in Yobe, Nigeria. Together with a local WASH team, water authorities and the ACF Technical team. (ACF)

This collaborative process helped build both **technical capacity and institutional commitment**, creating the conditions for sustained system operation beyond the project period.

4.1.2 UNDERSTANDING THE HYDROGEOLOGY AND ASSOCIATED RISKS

Understanding the hydrogeological setting of an area is a foundational step in any groundwater project. A well-informed hydrogeological assessment is critical to the design and targeting of monitoring programmes, and is necessary to fully identify existing and potential risks to groundwater availability and quality. A professional hydrogeologist should be involved throughout this process.

This section is divided into four practical steps for implementers:

A. **Desk study:** to gather and review all available information.
B. **Water point survey:** to ground-truth existing data and fill critical gaps through field observations.
C. **Hydrogeological conceptual model:** to develop a clear, shared understanding of how groundwater behaves in the area.
D. **Groundwater risk assessment:** to identify and prioritise key risks to groundwater quantity and quality, and link these to your monitoring design.

Together, these steps provide the evidence base needed to design an effective, risk-informed groundwater monitoring programme.

4.1.2A DESK STUDY

The desk study does not replace field investigations, but it helps avoid duplication, anticipate technical or environmental challenges, and identify knowledge gaps early. It also provides an important reference point to validate or challenge field observations later on.

Information should be sourced widely. Government water departments, geological surveys, local universities, private sector actors (e.g. oil, mining, infrastructure firms), and community testimonies can provide useful leads.

KEY RESOURCES TO SEEK OUT INCLUDE:

- **Borehole and hydrogeological databases.**
  National or local inventories often contain drilling logs, construction details, historical pumping test data, and intended borehole uses (e.g. domestic, irrigation, industrial, other). These can indicate aquifer properties (such as transmissivity, storativity), groundwater demand, and existing pressure points in the network.

- **Geographical, geological and hydrogeological maps.**
  Even older or small-scale maps from national surveys can offer valuable insights. Look for aquifer boundaries, geological formations, recharge zones, faults or fracture systems, and connectivity with surface water. Hydrogeological maps, if available, can provide aquifer productivity ratings and areas of vulnerability.

- **Historical groundwater level monitoring data.**
  Water level time series from observation boreholes are especially valuable. These can help identify seasonal trends, long-term declines, and how aquifers respond to droughts, recharge events, or sustained abstraction. In many cases, monitoring gaps are filled with anecdotal reports, but interpreting these requires caution.

- **Meteorological and surface water data.**
  Rainfall, temperature, and evapotranspiration data can support basic recharge estimates and

help frame groundwater trends in the context of broader climate variability. Surface water catchments and hydrology should also be reviewed, as most aquifers interact closely with rivers, lakes, or wetlands in the same basin.

- **Water quality records.**
  National surveys, academic studies, or NGO assessments may provide groundwater quality data. Focus on key parameters such as conductivity, nitrates, arsenic, faecal coliforms as a biological proxy-indicator, heavy metals, and, where available, agricultural, industrial and emerging contaminants. Water quality trends often reflect changes in land use, abstraction intensity, or pollution sources.

- **Existing and planned water users.**
  Identify any large-scale water supply, abstraction, irrigation, industry, or infrastructure projects that may affect the groundwater system. These might include dams, piped water expansions, or irrigation schemes. Their impacts on recharge, abstraction, and water balance can be very large and should be noted.

- **Land use, population and water security data.**
  Agricultural expansion, deforestation, or urban development may influence recharge and water demand. Population density and growth trends are useful for estimating future pressure on water points. Information of water security within the population and changing water demand can also instruct areas for more intensive monitoring and additional groundwater resource development.

- **Previous assessments or consultancy reports.**
  Past hydrological or WASH assessments, even if informal or unpublished, can contain valuable observations.

- **Existing groundwater monitoring projects in the area.**
  Any new monitoring should ideally be complimentary and shareable with existing groundwater (and other hydrological) monitoring activities. Understanding what is already collected will avoid duplication.

4.1.2B WATER POINT SURVEY

To improve the information available for developing a hydrogeological conceptual model and risk assessment, implementers and hydrogeologist(s) should, where resources allow, conduct a **cross-sectional survey** of existing water points. The aim is to collect consistent baseline data on:

- **Static and dynamic water levels.**
- **Pumping rates and usage.**
- **Construction details (e.g. depth, screen interval, casing condition).**
- **Basic water quality.**
- **Spring location and flow.**
- **Anecdotal information about water points from local users.**

As well as pinpointing the **current status** of water in the aquifer(s), this **helps identify which boreholes are under pressure**, which are stable, and which might serve as **priority monitoring sites** based on volume, vulnerability, or importance to users.

The hydrogeologist can use these data to:

- **Identify risks, such as areas of intensive abstraction or water quality issues.**
- **Map the most appropriate waterpoints to be monitored.**

4.1.2C HYDROGEOLOGICAL CONCEPTUAL MODEL

Development of a hydrogeological conceptual model is **a critical activity** that starts during the desk study, and then grows and improves as new data is collected from fieldwork and monitoring over time. It is a way of pulling together what is known about the geology, aquifers, recharge and discharge, and the main risks to groundwater. Drawings, diagrams **and maps are part of the model itself**, helping to make the understanding clear to both technical specialists and non-specialists.

The hydrogeological conceptual model is an essential working tool that guides the design of the monitoring system. In many data-scarce regions, the first version of this model may be highly uncertain if there is little guiding data. In such cases, additional geological mapping, geophysical surveys and monitoring points may be recommended by the hydrogeologist alongside priority surveillance to **improve conceptual understanding** of the local aquifer(s). The conceptual model can be regularly updated as new information becomes available, and this should continue throughout the lifetime of the monitoring system.

A conceptual model provides a coherent picture of how water moves through the geological environment. It typically includes:

- **The different geological units.**
- **The location and type of aquifers.**
- **Key recharge pathways.**
- **Groundwater flow directions and gradients.**
- **Discharge points (e.g. springs, rivers, boreholes, lakes, coastal areas).**
- **Relationships between surface and groundwater systems.**

In humanitarian settings, conceptual modelling should follow a **cost-effective and context-appropriate approach**. Highly detailed geological or numerical models are rarely necessary unless geological complexity is directly limiting water access, infrastructure siting, or monitoring reliability. We strongly recommend engaging an experienced hydrogeologist to lead throughout this technical process. A sample **Terms of Reference (ToR)** for commissioning this work is provided in **ANNEX A4**.

ANNEX A4: HUMANITARIAN HYDROGEOLOGICAL CONCEPTUAL MODEL & RISK ASSESSMENT TERMS OF REFERENCE

A simple template Terms of Reference for commissioning a hydrogeology specialist to complete this work.

THE HYDROGEOLOGICAL CONCEPTUAL MODEL SHOULD AIM TO:

1. **Identify major groundwater risks** relevant to the monitoring design (e.g. salinisation, a high-volume abstractor such as a power station, falling water levels, arsenic or other chemical elements, exposure to biological contamination, etc.).
2. **Provide a visual understanding of the aquifer system** to support better site selection and data interpretation.
3. **Highlight critical unknowns** in hydrogeological understanding that could be addressed through targeted monitoring (e.g. installing data loggers in under-sampled zones).

This model should be used internally for system design, and externally to communicate risks and needs to stakeholders and donors. It can also serve as a basis for future evaluation of system performance.

In acute emergencies: If a hydrogeologist is not immediately available, attempt as far as possible to identify physical risks through desk study and conversations with those involved with local WASH programming. You can then move forward to the risk assessment. Even in this case, we strongly recommend resourcing a hydrogeologist as soon as possible to support with risk identification and the monitoring system's longer-term design before proceeding with the full procurement and setup steps. More practical advice on developing and refining qualitative conceptual models is available in **Chapter 4** of the IGRAC 2008 Guideline on Groundwater Monitoring[7].

BOX 9 - CASE STUDY

HYDROGEOLOGICAL CONCEPTUAL MODEL

(ADAPTED FROM A GWR STUDY IN CAMP OURANG, CHAD)

Figure 15 presents a simplified conceptual model of a typical groundwater system in a semi-arid, humanitarian setting, adapted from a previous Groundwater Relief project conceptualising the hydrogeology following field surveys at **Camp Ourang, Chad.**

It illustrates a **multi-layer aquifer system** influenced by seasonal rainfall, where flowing surface water features (wadis) focus recharge into sediments and deeper granite aquifers.

HYDROGEOLOGICAL CONCEPTUAL MODEL EXAMPLE

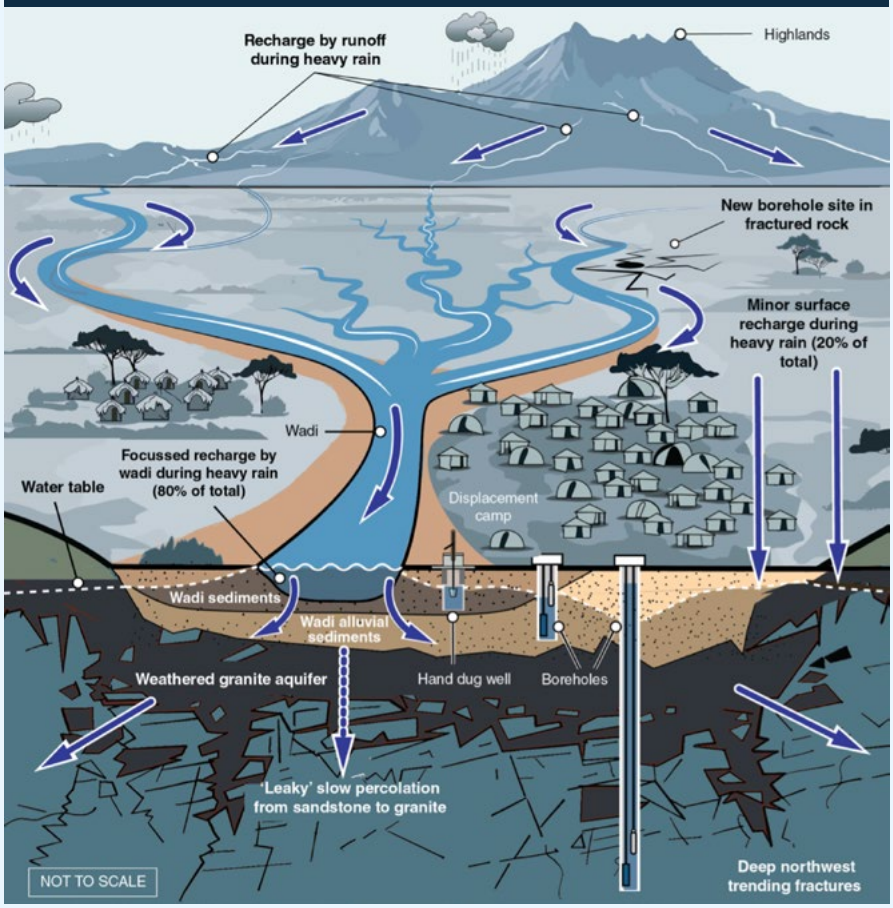

Figure 15: Example of a hydrogeological conceptual model describing the hydrogeology and flows of water through the system. Example adapted from a previous assessment by Groundwater Relief for Camp Ourang, Chad. (Rod Shaw)

7 - Redirecting you to https://communities.unep.org/download/attachments/38306048/IGRAC_WG1-7-Guideline-v12-03-08.pdf?api=v2

SURFACE SETTING AND RECHARGE DYNAMICS

The catchment includes highland areas where rainfall is concentrated. Surface runoff from these highlands flows into wadis - dry riverbeds that channel water during heavy rainfall events.

- **Focused recharge** occurs through the wadi, which is the dominant mechanism here (around 80% of total recharge). Water rapidly infiltrates through the permeable sediments that line the wadi base.
- **Diffuse recharge** (around 20%) takes place over broader surfaces, though it is less efficient due to vegetation cover, soil infiltration capacity, and evaporation.
- **A minor contribution** to recharge may also occur through fractures in exposed rock zones in the highlands.

This episodic recharge makes the system highly responsive to seasonal rainfall patterns, with groundwater levels rising rapidly after storm events and declining steadily during dry seasons.

GROUNDWATER FLOW AND CONNECTIVITY

- Groundwater flow follows the regional gradient from higher elevations toward the low-lying camp area.
- In the shallow system (wadi and sandstone), flow is lateral from the wadi to the displacement camp and responds quickly to recharge events.
- In the deeper system, flow is slower and occurs through fracture networks or weathered zones.
- There is **vertical leakage** from the sandstone into the granite, indicating interaction between aquifers, though this is limited.

The system is therefore vertically and laterally connected, but highly variable (heterogeneous). Local conditions such as fracture density or sediment thickness can vary groundwater behaviour significantly over short distances.

HYDROGEOLOGICAL STRUCTURE AND GROUNDWATER SYSTEMS

The subsurface is composed of different hydrogeological units:

- **Wadi Sediments:** Shallow, unconsolidated alluvial deposits with high permeability. These sediments form an unconfined aquifer that can provide short-term water supply but are vulnerable to seasonal drying and surface contamination.
- **Sandstone Layer:** A permeable unit that forms a clean and productive aquifer. It receives recharge from above (especially from the wadi) and slowly transmits water downward to deeper layers.
- **Weathered Granite Aquifer:** Deeper, low-permeability crystalline bedrock that can store water in its fractured zones. Recharge into this layer is limited and occurs through slow vertical percolation from overlying sandstone – labelled here as "leaky" recharge.
- **Fracture Zone:** On the right side of the diagram, this area contains deep, northwest-trending fractures in crystalline rock. These fractures may offer pathways for significant groundwater flow and storage in the basement rock. Boreholes drilled here target deep, discrete fracture zones, which can yield higher flows.

HUMAN INFRASTRUCTURE AND GROUNDWATER USE

The model shows a **displacement camp** situated near the wadi, where groundwater use is high. Three water supply technologies are illustrated:

- **Hand-dug wells:** Access shallow groundwater in the wadi sediments or upper sandstone. These are vulnerable to drying and contamination.
- **Intermediate-depth boreholes:** Tap into the sandstone aquifer, offering more reliable yields but still sensitive to seasonal declines.
- **Deep boreholes:** Target fractured crystalline rock to meet high demand. These are more expensive and technically complex but critical for large settlements.

The **location of the camp** in a wadi corridor with limited groundwater storage adds stress to the system. If abstraction exceeds recharge from the wadi, there is a risk of drawdown, well failure, or water quality deterioration.

4.1.2D GROUNDWATER RISK ASSESSMENT

Using the conceptual model, together with desk study findings, field data and stakeholder inputs, the hydrogeologist should carry out a **risk assessment** to identify and prioritise threats to groundwater. In most cases, the same hydrogeologist who developed the conceptual model will also lead this stage, updating and refining their model as new risks and uncertainties are identified.

In humanitarian and low-resource settings, a **qualitative risk assessment** is usually the most appropriate approach. This means using professional judgement, local knowledge and the available evidence to describe the main risks, how likely they are, and what their impacts might be.

TYPICAL RISKS INCLUDE:

- **Water quality degradation** from nitrate, arsenic, heavy metal, faecal or other biological contaminants.
- **Over-abstraction or unsustainable pumping**, especially from nearby industrial or agricultural users. This can reduce availability for drinking water, ecosystems, or small-scale farming.
- **Saline intrusion** in coastal or over-pumped areas.
- **Well interference or competition** between neighbouring boreholes.
- **Reduced recharge** due to land use change, deforestation, or climate variability.

For each risk identified, the assessment should point to **practical monitoring responses**, such as:

- Installing additional level sensors in high-risk areas.
- Increasing the frequency of water quality sampling.
- Tracking rainfall and river flow to link with recharge.
- Monitoring indicators of pollution (e.g., conductivity, chemical, biological).

Risks should also be checked against the **information needs of stakeholders** (see Section 4.1.1A). Often, the two will align; for example, a utility concerned with reliability may prioritise monitoring groundwater levels, while a health authority may focus on nitrate or faecal contamination.

In some cases, especially in areas where abundant data, resources, and demand for detailed analysis exist, a **quantitative risk assessment** may be considered. This typically involves numerical modelling, statistical analysis, or simulations of aquifer behaviour to evaluate risks more precisely. Such methods require significant technical expertise, reliable long-term datasets, and institutional capacity, which means they are rarely practical in the early stages of humanitarian projects.

Quantitative risk assessment is about **putting values on the components of risk**: the hazard (its probability, frequency and magnitude), the **vulnerability** of people and systems, and the **exposure** of communities or infrastructure. This framing is consistent with the Sendai Framework for Disaster Risk Reduction[8], which defines disaster risk as a function of hazard, exposure, and vulnerability. In groundwater contexts, this could mean estimating the probability of water levels falling below critical thresholds, modelling the likelihood and impact of saline intrusion, or quantifying how many people might be affected by contamination under different land-use scenarios.

Where such analysis is possible, it can help to compare the relative importance of different risks and support decisions about where to invest in protection, monitoring, or alternative supplies. For broader context, the United Nations Educational, Scientific and Cultural Organization (UNESCO) "Groundwater for Emergency Situations: Methodological Guide"[9] provides examples of risk assessments and lists typical risks for major hazards that contribute to humanitarian crises. In

8 - https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
9 - https://unesdoc.unesco.org/ark:/48223/pf0000192182

most humanitarian and resource-scarce settings, however, a **qualitative risk assessment**, built on the conceptual model, available data, and local knowledge, will remain the most practical and actionable approach, with quantitative methods reserved for contexts where data and capacities allow.

TYPICAL OUTPUTS OF THE RISK ASSESSMENT MIGHT INCLUDE:

- **A summary report** describing the main risks, uncertainties, and monitoring priorities.
- An **updated conceptual model** that shows how risks and monitoring needs fit into the groundwater system.
- A **proposed monitoring framework that is clearly linked to the risks** identified, and the **actions** that can be taken based on monitoring data.

ANNEX A4: HUMANITARIAN HYDROGEOLOGICAL CONCEPTUAL MODEL & RISK ASSESSMENT TERMS OF REFERENCE

A simple template Terms of Reference for commissioning a hydrogeology specialist to complete this work.

BOX 10 - CASE STUDY

CHAD RISK ASSESSMENT AND MONITORING IMPLICATIONS

Continuing from **Box 9**, with an example risk assessment based on the Chad conceptual model:

WATER QUALITY RISKS (MODERATE)

- Shallow aquifers (e.g. wadi sediments and upper sandstone) are vulnerable to faecal contamination, nitrates, and surface runoff, especially in areas near latrines, waste disposal, or livestock.
- Deeper aquifers may be affected by geogenic contaminants such as salinity, fluoride, or arsenic, particularly in crystalline or sedimentary formations.
- → **Monitoring actions:** Identify high-use boreholes for regular testing; prioritise faecal indicators, electrical conductivity (EC), and any known regional geochemical risks.

OVER-ABSTRACTION AND DRAWDOWN (HIGH)

- Multiple high-yield boreholes serving large populations (e.g. in or near displacement camps) may cause significant local drawdown, especially during the dry season.
- Vertical leakage between aquifers (e.g. from sandstone to granite) may delay visible signs of depletion at the surface.
- → **Monitoring actions:** Install water level sensors (automated or manual) in high-demand boreholes; monitor abstraction rates where flow meters are available.

RECHARGE VULNERABILITY (VERY HIGH)

- The system is heavily dependent on focused recharge via wadis. Any changes to land use, sedimentation, or rainfall patterns may reduce recharge efficiency.
- → **Monitoring actions:** Track rainfall (via rain gauge or meteorological data) and compare with groundwater level response; consider installing basic flow monitoring in wadis during recharge events.

FRACTURE SYSTEM UNCERTAINTY (LOW)

- Deep boreholes targeting fractured crystalline rock may perform well initially, but often depend on isolated, poorly connected fractures.
- These sources are difficult to predict and may fail without warning if over-abstracted.
- → **Monitoring actions:** Prioritise post-pumping recovery testing and step-drawdown measurements; interpret declines carefully to differentiate between natural variation and fracture depletion.

INSTITUTIONAL AND OPERATIONAL RISKS (VERY HIGH)

- Monitoring systems may fail if partners are unclear on roles, unsupported, or lose motivation.
- Community disinterest, equipment theft, or lack of data analysis capacity can result in partial or total monitoring collapse.
- → **Monitoring actions:** These risks should be addressed through a parallel operational strategy, including training, incentives, and clear handover planning.

DESIGNING THE MONITORING SYSTEM BASED ON THE HYDROGEOLOGY AND ASSESSED RISKS

Once the hydrogeology and risks have been assessed, the hydrogeologist and programme leads can review the evidence alongside recommendations from the user needs survey to define:

- **Which parameters to monitor** (e.g. water level, EC, nitrate, faecal, specific contaminants).
- **Where to monitor** (e.g. shallow wells near camps, deep boreholes in fractured zones).
- **How frequently to monitor** (e.g. continuous logging vs. monthly manual checks).
- **Which tools, methods and operational strategy to use.**

4.2 STEP 2 SUMMARISE & PRIORITISE RECOMMENDATIONS

By this stage, you will have gathered a lot of useful information from the **desk study**, the stakeholder survey, and the **hydrogeological assessment**. Each of these will have produced **ideas and suggestions** for what the groundwater monitoring system should include.

Some of these recommendations will come up more than once across those methods. This helps validate which parts of the monitoring system are the most important and likely to bring the greatest benefit. To keep things clear, it helps to summarise all the key **recommendations in a single table.** This makes it easier to:

- Decide what to include in the monitoring system.
- Understand the **benefits, costs and risks** of each action.
- Compare different options and decide what is realistic for your team and your budget.
- Communicate the plan to partners, funders or government authorities.

Table 1 is an example of what this table might look like (and the template for this table is included in (**ANNEX A5**).

ANNEX A5: MONITORING COMPONENT DESIGN CHECKLIST

This template corresponds to the table presented in Section 4.2, instructing how to summarise monitoring design recommendations.

This step doesn't need to be complicated. A **simple version like Table 1** can help your team make clearer decisions, and it helps others understand the thinking behind your design choices when you come to design it fully. Once the recommendations have been summarised, the next step is to organise them in rough order of priority (as completed in **Table 1**). The goal is to **decide which recommendations are most important, cost-effective and practically feasible** to include in the monitoring system design.

Prioritising in this way makes it easier to package the core actions together, and to spot which additions may be useful if more funding or capacity becomes available.

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RECOMMENDATION	EVIDENCE	EXPECTED BENEFITS	ADDITIONAL RESOURCES REQUIRED	RISKS & MITIGATION
1. AUTOMATIC GROUNDWATER LEVEL MONITORING in high-demand boreholes and dedicated monitoring boreholes(Camp, Town, Coastal site).	Hydrogeologist recommenda-tion; critical boreholes; stakeholder survey.	Within the abstraction boreholes, tracks drawdown and dynamic water level changes with regular hourly readings. In dedicated monitoring wells, records groundwater level changes and seasonal fluctuations. Enables comparison of current groundwater levels compared to same period in previous years.	Drilling of dedicated monitoring wells. Adaption of existing production wells. Technician time, data hosting, technical support with data cleaning, presenting and interpretation.	Sensor failure or data loss; mitigated by regular checks and regular calibration of sensors through manual measurements.
2. MANUAL GROUNDWATER LEVEL MONITORING (daily) in shallow hand-dug wells (Village, Camp, Riverbanks).	Community feedback; drought-prone area; shallow water reliance highlighted by hydrogeologist.	Tracks groundwater levels change and trends; community engagement; know the status of groundwater levels compared to same period in previous years.	Phone application to support recording of levels. Community-based staff or water committee.	Inconsistent data quality; mitigated by simplified forms and training.
3. MANUAL WATER QUALITY MONITORING (pH, EC, metals, E. coli, ammonia) near landfill, river, and over-pumped zones.	Landfill proximity; risk of microbial and chemical contamination.	Supports water safety, prevents health risks, informs infrastructure decisions, improves inter-agency trust, and provides evidence for health-related appeals or WASH upgrades.	Access to labs or mobile testing unit.	Missed parameters or lab delay; mitigated by SOPs and routine schedule.
4. WEEKLY SALINITY MONITORING (EC, chloride) at coastal and downstream wells (saline intrusion risk zone).	Aquifer salinisation risk.	Detects early onset of salinity problems, supports protective management, improves case for mitigation funding.	Salinity meters, refresher training.	Equipment calibration drift; mitigated by regular calibration and stock checks.
5. AUTOMATIC RIVER LEVEL MONITORING near town (pollution and flood risk).	Wadi flood history, past pollution events, recharge calculation from conversion to flow.	Improves early warning, supports modelling of water resources and flood risk.	Secure mounting, data integration platform, a river section of known area and velocity to calculate flow.	Equipment loss during flash floods; raise sensor and reinforce mount.
6. AUTOMATIC WEATHER STATION near camp (rainfall, temp, pressure).	Recharge modelling; rainwater harvesting schemes.	Supports recharge estimates, correlates with aquifer behaviour, used in predictive tools, helps frame data for non-technical users (seasonal briefings).	Secure siting, calibration checks.	Regular maintenance programme, spare parts available.
7. MONTHLY WATER USER SURVEYS (Camp southern blocks)	Reported local shortages; gaps in usage data.	Triangulates data with user behaviour, supports targeting of repairs or upgrades, improves local accountability.	Enumerator, basic training, tablet or paper forms.	Response fatigue; rotate locations and keep surveys short.

Table 1: Example-filled table for summarising the recommended components of a monitoring system, their benefits, costs, risks & mitigation. The table can be listed in ascending order of priority to help with packaging them into a monitoring system design.

4.3 STEP 3 DEVELOP DESIGN OPTIONS

Once priorities are clear, the next step is to bring everything together into a workable monitoring system design. This means turning your list of recommendations into one or more practical options that reflect the realities on the ground: what's needed, what's possible, and what will deliver the most value.

There are two major parts to this:

1. **The monitoring components** - What you will monitor, where, and how? (covered in Section 4.3.1)
2. **The monitoring operations** - Who will run the system, how often data is collected, how it is managed and shared? (covered in Section 4.3.2)

This step may involve preparing more than one design option, especially if you need to compare costs or present choices to funders or partners.

4.3.1 DESIGN MONITORING COMPONENTS

A good design will:

- ✓ Deliver the **most important recommendations.**
- ✓ Stay **within budget.**
- ✓ Choose options that **reduce operational risks.**
- ✓ Make sure each **implementation partner stays motivated** to stay involved (for example, by offering useful data, training, or small incentives).

What needs to be designed?

The three core elements of monitoring component design are:

- **Locations**
  Where will sensors, tests, or surveys take place? These should be linked to known risks (e.g. saline intrusion, contamination) or priority boreholes. A good design spreads monitoring points across both high-risk and baseline (control) sites.
- **Equipment**
  What kind of tools are needed for monitoring - manual dip meters, automatic loggers (with telemetry or not?), water quality test kits, rain gauges, mobile phones for surveys, any others? Choose the simplest tool that still meets the information need. Additionally, what equipment and tools are needed to build the monitoring installations?
- **Additional infrastructure**
  Will you need new piezometers, water level pressure sensors, solar panels, data management systems, storage units, electricity, or a laptop for data download? These supporting parts may make the difference between a functional and a neglected system.

  Will there be any satellite data inputs such as temperature and rainfall for modelling that require continuous download and a dedicated database for storage? Will there be an online dashboard for visualising the data that needs to be built by a technical team?

A checklist for designing these components is included in **ANNEX A5**.

ANNEX A5: MONITORING COMPONENT DESIGN CHECKLIST

This checklist supports the design of monitoring system components as described in Section 4.3.1. It can be used during team planning meetings, partner workshops, or budget planning sessions to ensure the system is well-targeted, operationally feasible, and meets local information needs.

BOX 11 - EXAMPLE
DESIGN OF MONITORING COMPONENTS

Figure 16 presents a simplified example of a monitoring system designed for a fictional displacement camp, based on the example design recommendations summarised in Table 1.

It includes a mix of manual and automatic monitoring tools, placed to address the most critical groundwater risks identified through conceptual modelling, stakeholder consultation, and site context.

Each component numbered in the diagram corresponds directly to a recommendation in **Table 1** and was selected based on its value for data collection, risk tracking, and stakeholder relevance.

Figure 16: Example monitoring design from a fictional example map of a refugee camp situated among multiple groundwater-related risks. (Rod Shaw)

① AUTOMATIC GROUNDWATER LEVEL MONITORING

Why it's included: These deep boreholes are often the primary sources of water supply for high-density areas. Monitoring static and dynamic water levels allows operators to:

- Detect over-abstraction.
- Adjust pumping schedules.
- Observe how water levels are changing seasonally and annually.

Related risks:

- Overpumping risk in the camp.
- Village supply drawdown.
- Aquifer depletion from insufficient recharge.

② MANUAL GROUNDWATER LEVEL MONITORING

Why it's included: Shallow hand-dug wells are often sensitive to short-term changes in recharge, often numerous, and easily accessible for manual monitoring. Deep boreholes also require manual measurements to calibrate sensors. Regular dip readings provide early signals of:

- Site-level performance of shallow sources & adjustment of pumping schedules.
- Detect over-abstraction.
- Observe how water levels are changing seasonally and annually.

Related risks:

- Overpumping risk in the camp.
- Village supply drawdown.
- Aquifer depletion from insufficient recharge.

③ MANUAL FULL WATER QUALITY TESTING

Why it's included: These tests cover multiple contaminants (pH, EC, metals, faecal indicators, etc.) at boreholes near known or suspected pollution risks. The focus is on early detection and safe water supply assurance.

Related risks:

- River pollution near town boreholes.
- Landfill leachate entering camp-area aquifer.
- Over-abstraction drawing contaminants into deeper zones.

④ MANUAL FULL WATER QUALITY TESTING

Why it's included: Monitoring electrical conductivity and chloride on a weekly basis helps detect saline intrusion, in case abstracting water draws sea water into the fresh aquifer.

Related risks:

- Saline intrusion from the coast into boreholes serving the southern part of the camp.
- Permanent degradation of water quality due to over-abstraction.

⑤ AUTOMATIC RIVER LEVEL MONITORING

Why it's included: The river is a possible source of recharge, but also a vector for pollution. Partnership with flood risk managers may justify regular automatic data. This level data helps:

- Correlate river stage with shallow aquifer recharge. (When channel area is known)
- Provide early warning for flash floods that may damage property & bring contaminants.
- Trigger water quality spot-checks in nearby boreholes.

Related risks:

- Sudden pollution from upstream settlements or waste.

⑥ AUTOMATIC WEATHER STATION

Why it's included: A basic weather station provides data on rainfall, temperature, and air pressure to provide important weather information and alerts, whilst supporting understanding of:

- Recharge timing and magnitude.
- Links between rainfall events and water level response.
- Seasonal water planning.

These data are also important for calibrating pressure-based water level sensors, and any hydrological models used in analysis.

Related risks:

- Misjudged recharge events or failure to detect them at all.
- Poor correlation between rainfall and water availability without supporting data.

⑦ MONTHLY WATER USER SURVEYS

Why it's included: These surveys gather data from users on:

- Perceived shortages.
- Access times and queueing.
- Water usage patterns.
- Pump functionality and satisfaction.

Related risks:

- Mismatch between abstraction and need.
- Operational issues not visible from sensor data.
- Poor uptake of monitoring findings without local voice.

HOW IT ALL COMES TOGETHER

This example system:

- Covers multiple aquifer depths and types.
- Responds to five major groundwater risks.
- Balances technical monitoring with community-level engagement.
- Keeps long-term operation feasible through partner contributions and realistic costing. (modelled fully in Step 4. Section 4.4)

4.3.2 DESIGN THE MONITORING OPERATIONS

Even the best-designed monitoring system will fail if it doesn't have well-managed day to day operations and ongoing maintenance. That's why designing **how the system operates** is just as important as choosing the equipment or locations.

Figure 17 shows what a healthy monitoring system might look like in practice. It includes all key stakeholders for a typical example, including water authorities, community partners, technicians, humanitarian agencies, and data users.

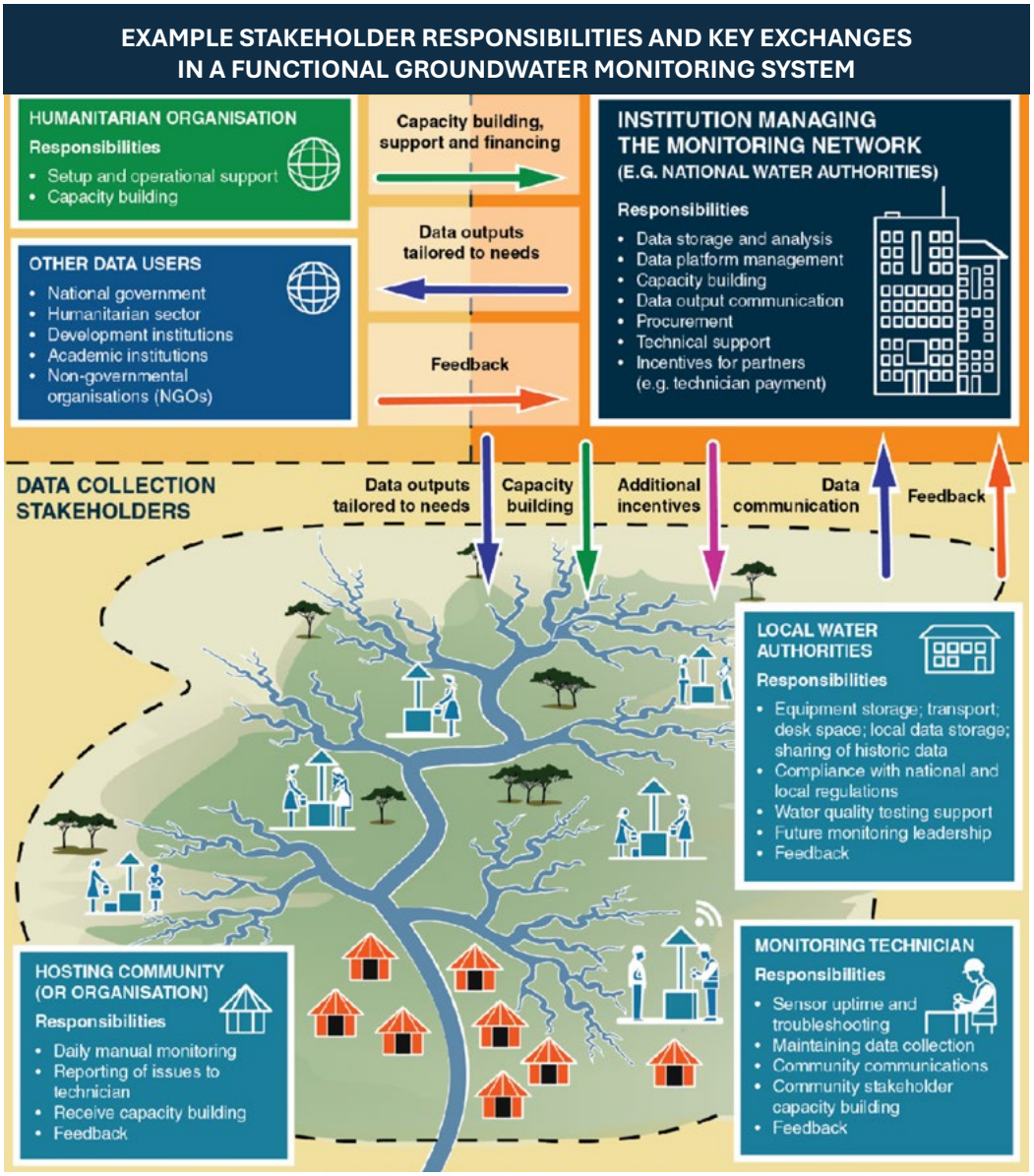

Figure 17: Example stakeholder responsibilities and key exchanges in a functional groundwater monitoring system. (Rod Shaw)

EACH ARROW REPRESENTS A **CRITICAL OPERATIONAL EXCHANGE** THAT NEEDS TO BE MAINTAINED:

- **Capacity building**
  Stakeholders like communities, technicians, and local authorities may need training, mentoring, or technical support to carry out their responsibilities confidently and consistently.
- **Data communication and outputs**
  The system must provide data in the right format, at the right time to those who need it - whether that's local authorities, NGOs, or regional water managers. This may include digital dashboards, SMS summaries, printed reports, or verbal briefings.
- **Incentives**
  Field technicians, water committees, and borehole operators often need modest, practical incentives, such as airtime, stipends, recognition, or equipment access, to keep them motivated and engaged.
- **Continuous feedback**
  Data collectors and frontline actors should receive feedback about how their work is used. This builds ownership, improves quality, and helps maintain motivation.
- **Support and coordination**
  Higher-level institutions (such as national water authorities or international partners) should offer ongoing support through funding, logistics, supervision, and data management.

A monitoring system will only work if each of the flows indicated by the arrows in **Figure 17** are maintained. **Break just one**, and systems typically begin to decline.

BOX 12 - COMMON PITFALL
IGNORING THE KEY 3 FOR SUSTAINABILITY

At the heart of a sustainable monitoring operation are **three key deliverables:**

1. The **information needs** of intended users are continuously met, and support is provided to help them understand and use the data.
2. The implementation partners (such as technicians, local authorities, and communities) are clear on their responsibilities and receive the **incentives** they need to stay involved.
3. **Enough resource and technical capacity** is built within partner institutions, so they can manage and support the monitoring system over time.

Figure 18: Three common concerns, frequently under-addressed by monitoring management. (ChatGPT+, 2025)

Whilst there are many other potential causes of monitoring system breakdown, failure to deliver one or more of these points is an extremely common cause of problems.

Agreeing Roles and Contributions

Because operations rely so much on collaboration, the design stage is the best stage to **explicitly assign and ensure full awareness of responsibilities**. As in **Figure 17**:

- Identify the **owner**: a local institutional body should be prioritised to secure the sustainability of the entire system.
- Identify who will do what (e.g. data entry, quality control, transport, communications)
- Understand what support each partner might need to succeed
- Begin negotiating **what each partner can contribute**, such as:
  - Transport for technicians
  - Lab access or data servers
  - Shared desk space
  - Staff time
  - Training, mentoring or capacity building
- Negotiate and define SMART (Specific, Measurable, Achievable and Timebound) **key performance indicators (KPIs)** and achievable targets for each responsibility, so the performance of each participating stakeholder can be measured, and potential weaknesses in the operational system can be identified and addressed.

Even small contributions from local partners will improve ownership, reduce costs, and expand what's possible within a limited budget. A template for assigning responsibilities is provided and partly filled with examples corresponding to **Figure 17** in **ANNEX A6**.

ANNEX A6: OPERATIONAL RESPONSIBILITIES AND ASSIGNMENTS

This annex provides a template and some examples of individual operational activities within the groundwater monitoring system. Each row corresponds to a specific task or function that must be assigned, with clarity on who is responsible, how often it must be done, who they report to, what support may be needed for them to carry it out, and the reportable key performance indicator (KPI) for the responsibility.

4.4 STEP 4 CREATE FINANCIAL PLAN

Once the monitoring components and operational responsibilities are agreed in principle, the next step is to **cost the system**. A complete monitoring system design must include a basic **financial model**. This is not just to get approval and funding, but also to ensure it can actually be delivered and maintained.

This means calculating:

- **What it will cost to set up** (equipment, infrastructure, training, initial staffing).
- **What it will cost to keep running** (technician time, data analysis, consumables, communications).
- **Who is paying for what**, and whether it's sustainable.
- And ideally, in addition – **what the benefits are**, and if they justify the investment and ongoing operational costs. Even if it's just a descriptive list, mapping expected project benefits can build the full picture for investors when you need to make the case for funding. Some expected benefits may be quantifiable too (e.g. reduced costs associated with borehole downtimes).

BOX 13 - COMMON PITFALL
THE FINANCIAL PLAN MATTERS

Monitoring systems often fail not because of bad design, but because their full cost wasn't considered. They may work well for a few months, then fall apart due to:

- **Unfunded repairs.**
- **No transport or paid working time** for technicians.
- Data that's collected but **never analysed** because there are no dedicated, paid staff for data analysis.
- **Burnout** of underpaid or unrewarded field staff.

Figure 19: Small but frequent operational costs can add-up unexpectedly. (ChatGPT+, 2025)

A simple but realistic financial model helps prevent this. It also helps:

- **Secure funding** from donors or partners.
- **Negotiate support** from implementing institutions.
- **Prioritise** which parts of the system to expand, or simplify if funding is limited.

ADDITIONAL INFRASTRUCTURE CONSIDERATIONS

Some systems may need **additional infrastructure** prior to installation to be costed in, depending on the design and what is already available:

- **Observation of existing, open wells:** Taking advantage of open, non-abstracting boreholes can give good insights on height of the static water level (the groundwater level when not drawn down by pumping) and produce robust calculations on changing water availability.
- **Adaptation of existing abstraction wells:** Pump mechanisms may need to be modified on existing wells to make installation of groundwater level sensors and manual measurements possible.
- **Water quality testing facilities**: May require mobile kits or access to a regional lab.
- **Data management hub**s: Small office space or shared desk with power, laptop, and storage can be essential for network coordination.
- **Satellite data:** Satellite measurements provide large-area information on rainfall, evapotranspiration, soil moisture, and groundwater storage change (e.g. from GRACE[10]: Gravity Recovery and Climate Experiment for large-scale storage changes). These data require no field infrastructure, but do require internet access, basic computing capacity, and staff time for processing. Satellite data is important for some analysis such as estimating groundwater recharge, understanding basin-scale trends, or building and validating groundwater models.

These should be discussed with the hydrogeologist and key partners during **Step 3**.

COSTING WORKSTREAMS AND ACTIVITIES

From your design, break the system down into **typical workstreams**. These are the areas of activity where costs will arise during setup and operation (**Table 2**).

WORKSTREAM	EXAMPLES OF COSTS
1. Setup & Procurement	Equipment, installation, site visits, logistics, training
2. Data collection	Technician time, transport, sampling tools, airtime
3. Data analysis	Staff time, software, laptops, hydrogeologist support
4. Data management	Dashboards, databases, server space, Information Technology (IT) staff
5. Data communication	Reporting tools, visualisation, feedback meetings
6. Community engagement	User surveys, meetings, posters or SMS updates
7. Capacity building	Training materials, workshops, citizen science projects
8. Technician support	Stipends, phone credit, uniforms, helpdesk
9. Maintenance	Tools, transport, paid overtime, replacement parts
10. Coordination and financing	Staff management, documentation, proposal writing

Table 2: Typical workstreams with activity(s) to be costed.

Then for each activity, build it into a financial model.

10 - https://grace.jpl.nasa.gov/

Your financial model doesn't need to be complex. A simple table, with setup and annual costs for each workstream and each activity within it, is enough. **Table 3** presents an example financial model for the example monitoring system presented in **Box 11**.

WORKSTREAM	ACTIVITY / LINE ITEM	SETUP COST (USD)	ANNUAL OPEX COSTS (USD)	COST NOTES / ASSUMPTIONS
1. Setup & Procurement	Purchase and install 3 groundwater loggers	12,000	0	Includes training, tools and materials for installation
	Purchase and transport 6 manual dip meters	3,000	0	For shallow wells across camp and village
	Procure test kits and water quality supplies	5,000	0	Starter kits for 12 testing points (T, Conductivity, pH, Arsenic III, Fluoride, E. coli, Nitrates, etc.)
	Install automatic weather station and river level sensor	6,500	0	Includes mounting and technical training
2. Data collection	Technician field time for monthly logger downloads and transport costs	0	12,000	12 trips @ $1000
	Manual water level and water quality checks	0	2,500	Rotation of 3 community-supported monitors
	Sample bottles, gloves, dip charts	0	600	Resupply over 12 months
3. Data analysis	Hydrogeologist support (3 days/month)	0	4,500	Part-time support @ $125/day
	Laptop and data software license	1,500	300	Basic Excel/GIS-based toolkit
4. Data management	Cloud dashboard hosting and backup	0	1,200	Includes website space and backup
	Server setup and data structuring	1,500	0	Initial structuring and design
5. Data communication	Quarterly reporting and dashboard summary	0	1,000	Templates and coordination time
	Community water point updates and posters	0	800	Camp zones + village
6. Community engagement	Monthly water user surveys	0	1,200	Enumerator + simple mobile tool
	Quarterly stakeholder dialogue sessions	0	1,200	Camp and village level
7. Capacity building	Initial technician training and follow-up workshop	2,000	500	Workshop + printed SOPs
	Community awareness and training briefings	1,000	400	2 local sessions/year
8. Technician support	Stipend (part-time role)	0	3,600	$300/month
	Uniform, mobile credit, tools	300	400	Phone, field kit, waterproof logs
9. Maintenance	Quarterly site visits for cleaning, battery swap	0	1,000	4 rounds/year @ $250 each
	Replacement parts and contingency fund	0	800	Batteries, lost test kits, calibration
10. Coordination and financing	Monitoring coordinator (shared staff)	0	6,000	50% role, includes grant reporting
	Documentation, proposal and learning	0	2,000	Mid-year and end-year reporting
Total		**32,800**	**40,000**	

Table 3: Simple example of a financial model for the small-scale groundwater monitoring system presented in Box 11.

It is then necessary to specify how the setup (capital) costs and annual operating (recurring) costs of the full monitoring system can be distributed across partners (**Table 4**). Contributions may be financial or in-kind (meaning delivered through goods and services, rather than contributions of money).

PARTNER TYPE	SETUP CONTRIBUTION (USD)	ONGOING ANNUAL CONTRIBUTION (USD)	CONTRIBUTION TYPE	KEY ROLES / NOTES
UN Agency (e.g. UNICEF)	15,000	5,000	Financial	Setup of equipment, dashboard, and initial training
Lead NGO Implementer	8,000	10,000	Mixed: financial + in-kind	Monitoring support, coordination, data communication
National Water Authority	2,500	7,500	In-kind	Office space, oversight staff time, national reporting link
District Water Office	1,000	4,000	In-kind	Field supervision, local engagement, data handover
WASH Cluster / Sector Platform	500	2,000	In-kind	Stakeholder engagement and information sharing
Donor / Climate Finance Window	20,000	5,000	Financial	Scale-up investments, technical consultancy, buffer funding
Research Partner or University	1,500	2,000	In-kind	Analytical support, field methods training
Community / Water User Committees	0	500	In-kind	Manual monitoring, feedback provision, hosting equipment

Table 4: Example of how the costs in Table 3 might be distributed across partners for the monitoring system design example in Box 11.

4.5 STEP 5 APPRAISE AND DECIDE

This step is where all the previous work comes together to make an informed decision: should we proceed with **implementing the groundwater monitoring system**?

Start by presenting the proposed monitoring system design to key decision-makers and partners. This may include internal programme leads, funders, government agencies, technical partners, and implementing organisations. The goal is to give them a clear, transparent picture of the proposed system and its expected impact.

At a minimum, your appraisal presentation should include:

- **The full design:** a summary of the selected monitoring components and how the operations will be delivered (see Sections 4.3.1 and 4.3.2).
- **Expected benefits:** including who the information will help, what decisions it will support, and any expected co-benefits (e.g. local jobs, capacity building, coordination improvements).
- **Costs:** setup and annual running costs, shown alongside the benefits for each major component. This makes the system's value proposition easy to understand.
- **Feasibility:** show that the design can be realistically delivered with the available budget, partners, skills, and resources. This includes:
  - Demonstrating how known operational risks will be reduced or managed
  - Evidence of interest and commitments from implementation partners
  - Plans for capacity building and partner incentives

If the monitoring design is **approved**, you can move to the next stage: **preparation and procurement**.

If the design **is not approved**, use the feedback received during the appraisal meeting to adjust your design. Often this means returning to **Step 3** (Design), refining one or more components to better match budget limits, reduce complexity, or strengthen local ownership.

REMEMBER: Monitoring systems only succeed when they are locally feasible, valued by end users, and delivered through strong partnerships. This final review stage ensures the system is not only well-designed, but has the support needed to succeed.

5. PREPARATION & PROCUREMENT

5.1 FORMAL AGREEMENTS

Before beginning procurement and system setup, it is important to formalise the partnerships and responsibilities based on the finalised monitoring design and financial plan. This helps ensure long-term collaboration and accountability, particularly when responsibilities are spread across different organisations or stakeholder groups.

5.1.1. PARTNER AGREEMENTS FOR MONITORING ROLES

All organisations with a role in the delivery of the monitoring system (see **Sections 4.3.2** and **4.4**) should agree on:

- **Their specific responsibilities** (e.g. data collection, equipment hosting, capacity building, monitoring operation, maintenance, security, data analysis, etc.).
- **The key performance indicator(s) (KPIs)** for their responsibilities (e.g. timeliness of reports, number of missing data points, number of users surveyed).
- **What support they will provide** (e.g. staff time, transport, technical help).
- **What they will receive in return** (e.g. data access, visibility, capacity support).

These agreements can take different forms depending on the context:

- **Legally binding contracts** may be required for partners contributing or handling funds, assets, or sensitive data (a generic template example is provided in **ANNEX A7**).
- **Memoranda of Understanding (MoUs)** are a common alternative when parties prefer a more flexible or symbolic agreement.
- In some cases, **informal letters of commitment** or joint implementation plans may be sufficient at the early stages.

The key point is that roles and expectations are clearly written down and agreed. This helps prevent confusion or disengagement later.

ANNEX A7: PARTNERSHIP CONTRACT TEMPLATE

Example partnership contract for a groundwater monitoring project. This template is intended as a starting point for development, rather than a legally robust solution. Any legal contract should be developed with lawyers and aim to comply with the laws and regulations of the country hosting the groundwater monitoring project.

5.1.2. DATA SHARING AGREEMENTS

Groundwater monitoring systems generate data that can be valuable, and **sensitive**. It is important to define:

- **Who owns the data?**
- **Who can access and use it?**
- **What it can be used for?**
- **Where and how it will be stored, visualised, and shared?**

The approach to data sharing must be context-specific and based on dialogue with those who own or manage the water sources, such as:

- Local water authorities.
- NGOs and UN agencies operating boreholes.
- Private contractors or service providers.
- Community water user committees.

Public data (e.g. from government-owned boreholes) is usually less sensitive and may be shared more widely. However, private or community-operated boreholes often involve **concerns about misuse, reputation, or regulation**. In these cases, monitoring partners should:

- Clearly explain the purpose and benefits of sharing the data.
- Offer to share **insights or analysis** back with water owners as part of the agreement.
- Tailor each agreement to what the infrastructure owner feels comfortable with, ensuring trust is built gradually.

In all cases, make sure data agreements are **transparent, respectful, and inclusive**. A generic template for developing this is provided in **ANNEX A8**.

ANNEX A8: DATA SHARING AGREEMENT TEMPLATE

Example data sharing agreement for a groundwater monitoring project.

5.2 PROCURE MONITORING EQUIPMENT

Once a monitoring system design has been agreed, procurement should begin for the equipment required to implement it. This includes sensors, installation tools, data platforms, and any related supplies needed for setup and long-term operation.

A few practical considerations are especially important in humanitarian contexts:

- **Test before scaling:** Start with a small pilot batch of equipment to check how well it performs in real field conditions. This helps identify problems early and adapt the design before investing in a larger system.
- **Choose the right level of complexity:** More advanced equipment can seem attractive but may require more stable power, security and specialised capacity to maintain. Choose solutions that match the available capacity and resources. When selecting a data logger brand and associated software, take care that language options include local & national language.
- **Favour durable, low-maintenance options:** Equipment that is easy to use, robust in the field, and require minimal calibration or upkeep is generally preferable. If you are unsure, consult an experienced hydrogeologist for their opinion.

- **Consider what monitoring equipment (if any) is in place:** There may already be existing monitoring systems in the area, as well as supporting infrastructure such as telemetry systems, staff or water quality testing facilities. Choosing complimentary technology and those that staff are already familiar with can be advantageous. Procurement may also be an opportunity to evaluate and replace existing technologies that are not working well.
- **Procure in bulk when possible:** If budget and planning allow, consider bulk purchasing for key items such as level loggers or field kits to reduce per-unit costs and simplify logistics. Coordinate with other agencies or clusters to explore joint procurement opportunities.
- **Buy from known and reputable suppliers:** Select equipment that is proven in similar contexts and for which spares and technical support are accessible. Use platforms such as WASH Cluster guidance, supplier catalogues (e.g. Oxfam Supply Centre, UN procurement), and previously field-tested equipment to shortlist options.
- **Build time into your schedule:** Procurement often takes longer than expected, especially when international suppliers, import procedures, or compliance checks are involved. Plan buffer time in your schedule to avoid delays to fieldwork.

BOX 14 - COMMON PITFALL
PROCUREMENT MISTAKES

Procurement is often rushed or handled without specialist input. This leads to common and costly errors:

- Purchasing unvented water level loggers **without a matching barometric sensor** to correct the data.
- Purchasing water level loggers with the **wrong pressure range or size.**
- Choosing manual dip meters of the **wrong cable length.**
- Buying water quality kits that require **reagents or calibration tools** that are unavailable locally.
- Selecting telemetry systems that **fail in poor mobile network conditions**, or require technical skills not present in the field team.
- Investing in high-end equipment when **simpler tools would have been more reliable and sustainable.**
- Overlooking the need for **local supplier support, spares, or warranties.**
- **Data logger software language** not spoken/ understood locally/nationally.

These issues can largely be avoided by involving an experienced **hydrogeologist or technical advisor** in the specification and procurement process. Their role is critical in ensuring the equipment fits the monitoring goals, environmental context, and available capacity.

Figure 20: Input from an expert can reduce costs and save time by averting later issues. (ChatGPT+, 2025)

Table 5 provides a starting point for reviewing the types of equipment commonly used in groundwater monitoring, with example models and rough indicative costs.

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TYPE OF MONITORING	EQUIPMENT NEEDED	MEASUREMENT FUNCTION	ANALYSIS OUTPUTS	ADDITIONAL NEEDS FOR USE
Manual groundwater (GW) level	Tape/dip meter of correct length with sound/light alarm	Static groundwater level (depth to water table); Continuous level time series	A hydrograph showing seasonal fluctuation and long-term groundwater level trends	Dip tube installation and potential well head modification to enable access to borehole/ well
Automated GW level suspended by non-stretch cord	Pressure transducer (non-telemetered), non-stretch kevlar or dyneema cord, dip meter for calibration	Static groundwater level (depth to water table); Continuous level time series. Some pressure transducers also record basic water quality data such as EC, DO, ORP, temperature	A hydrograph that could provide more detailed daily fluctuations in water level, including dynamic water level response to pumping	Dip tube installation and potential well head modification to enable access to borehole/ well. Barometric correction, suspension hanger
Automated GW level with direct read cable	Pressure transducer connected to surface via direct read cable, dip meter for calibration	Same as above	Same as above. Main advantage to direct read cable is that logger does not need to be removed from well to obtain the data	Same as above except some direct read cables are vented removing need for barometric correction
Telemetered GW level	Logger + direct read cable, GSM/satellite telemetry system, dip meter for calibration	Real-time data upload	Near-real-time status, early warnings, public platform integration, problem detection	Housing, power source, SIM card/data plan, telemetry tower for some types of telemetry
River level / flow	Staff gauge, radar or pressure level sensor, or manual flowmeter	River stage height and/ or flow	Flood alert systems, recharge correlation, hydrological modelling	Secure site, benchmark elevation survey, a 'rating curve' converting level to flow
In-situ water quality (WQ)	Field kits, handheld probes, Multi-parameter probes Dip meter with conductivity and temperature; Level temperature conductivity (LTC) loggers	EC, temperature, pH, DO, turbidity, , Arsenic III, Fluoride, Iron, Nitrate	Field-level water safety checklists, contamination detection	Calibration standards, consumables
Laboratory Analysis WQ	Spectrophotometry, Colorimetry, ICP-MS, Ion Chromatography, Titration, GC-MS, qPCR, membrane filtration	Physical properties, major and minor ions, inorganic and organic chemistry, microbiological and biological testing	Ionic balance, piper plots, comparison to water quality standards. Risk mapping, safety compliance, trend detection	Duplicate and blank sampling Cold chain (lab), preservation bottles
Abstraction monitoring	Electromagnetic or mechanical flow meters	Rate and volume of abstraction	Usage logs, overuse detection, maintenance flagging	Installation tools, borehole housing
Rainfall	Tipping bucket or weather station	Daily/hourly rainfall	Recharge correlation, climate hazard monitoring	Maintenance, calibration, open space install
Fixing & installation	Locks, enclosures, concrete, staff tools	Sensor protection, tamper resistance	Improves lifespan, reduces data gaps	Skilled labour, community coordination

Table 5: Monitoring equipment types, their expected data outputs, approximate costs, and key considerations for deployment. Hyperlinked examples are provided to guide procurement teams in evaluating appropriate models and suppliers.

Note: there are two main types of level logger: vented and absolute level loggers:

- **Vented level logger** includes a thin vent tube runs alongside the cable from the sensor to the surface, allowing the sensor to correct for atmospheric pressure directly. This means the pressure reading is automatically compensated for barometric fluctuations, and the output is a true water level above the sensor. The downside is that the vent tube requires a desiccant cartridge to prevent moisture ingress, which needs periodic field maintenance. Another important point is the need to know beforehand the depth of installation of the logger so the manufacturer can provide the exact length of the cable (protecting the vented tube).
- **Absolute level loggers** consist of a pressure transducer, which measures total (absolute) pressure. When submerged, the logger records both atmospheric pressure and water pressure above the level logger. Thus, a barometric logger is required to record atmospheric pressure continuously at the same time interval as the water level logger. In post-processing, the atmospheric pressure record is subtracted from the total pressure record: Water column pressure = Total pressure − Atmospheric pressure. What remains after subtraction is only the pressure due to the water column above the sensor. Converting that data to a water level in metres above the sensor, and knowing the sensor depth, allows calculation of the depth of the water table below the measuring point.

BOX 15 - CASE STUDY
REAL-TIME GROUNDWATER MONITORING *IN SOMALIA*

In Somalia, World Vision implemented a network of automated groundwater level monitoring stations equipped with telemetry systems on key piezometers. These sensors collect water level data and transmit it in real-time to a publicly accessible online dashboard, improving visibility of groundwater trends for humanitarian and government partners.

The success of this model highlights how telemetered systems can be effective, even in fragile and remote contexts. Explore the somalia dashboard and story[11].

Figure 21: World Vision's ArcGIS StoryMaps is also a good groundwater data communication tool. (WV)

11 - https://storymaps.arcgis.com/stories/4ec4d8c720c9446e9b06cce77cc07179

5.3 SETUP AND TEST THE DIGITAL AND COMMUNICATION INFRASTRUCTURE

A database is a structured system for storing, organising, and retrieving information. Unlike a spreadsheet (which is designed to be read by one person) a database is designed to be used by many people simultaneously, queried automatically, and connected to other tools (maps, charts, reports) that read the data and present it in useful formats.

A database system requires a server (a computer) that stores the data and keeps it accessible. That server can sit in three places:

- **On-premises:** a physical machine in an organisation or government office or ministry building.
- **On a managed cloud service:** a third-party company (Microsoft, Google, or a non-profit such as Kobo non-profit) runs the server on your behalf in their data centres.
- **On a cloud VPS (Virtual Private Server):** where you rent a server in a data centre (DigitalOcean, Hetzner, Amazon...), but you install and manage the software yourself.

Before field installation begins, it's important to establish and test the systems that will handle, analyse, and share the groundwater data. This includes:

A few practical considerations are especially important in humanitarian contexts:

- A **database** to store your data (offline or cloud-based).
- A **digital platform or dashboard,** if being used.
- The **communication channels** that will deliver outputs to different users.

This step ensures that the system is ready to receive and process incoming data, and that partners will see timely, meaningful outputs once monitoring begins.

Recommended Steps:

1. **Develop or configure the database and platform (if applicable)**
   - Ensure it aligns with the structure of your data (water level, quality, abstraction, etc.).
   - Apply user permissions and privacy settings in line with your data sharing agreements.
2. **Upload existing datasets for context and continuity**
   - Water point survey and borehole data.
   - Historic groundwater levels, quality, abstraction.
   - Digitised geological and hydrogeological maps.
   - Existing piped networks, drill reports, socio-economic data.
   - Weather station and surface water records.
   - Perceptual or conceptual hydrogeological model outputs.
3. **Design and test outputs in advance**
   - Use the uploaded data to produce sample dashboards, reports or visualisations.
   - Setup and test quality control (data cleaning for gaps and errors) processes.
   - Iterate based on feedback from intended users, especially where data literacy or internet access may be limited.
   - Prepare both high-level visuals and raw data outputs depending on user needs.

OPTION	DESCRIPTION	TYPICAL USES	ADVANTAGES	LIMITATIONS
Specialist water monitoring software (e.g. mWater)	Purpose-built platforms for water point mapping, monitoring, and surveys	Routine groundwater level and water quality monitoring; NGO programmes	Fast to deploy; designed for WASH and groundwater contexts; mobile data collection	Less flexible for bespoke analysis or modelling; subscription costs
Purpose-built platforms for water point mapping, monitoring, and surveys	Visualisation tools connected to an existing database	Internal reporting; partner dashboards; early-warning summaries	Widely used; low learning curve; strong visual outputs	Require a separate database; limited custom workflows
General dashboard builders (e.g. Google Looker, Microsoft Power BI)	Systems to store raw and processed data	Central data storage; feeding dashboards or analysis tools	Scalable; flexible; can support many downstream uses	Require data management skills; not user-facing on their own
Visualisation tools connected to an existing database	Bespoke digital platforms tailored to specific monitoring objectives	Complex networks; modelling workflows; early-warning systems	Highly flexible; can integrate sensors, satellites, models, and alerts	Higher cost; longer development time; requires maintenance
Databases / data storage (e.g. Supabase, Amazon Web Services, Google Drive)	Design, build, and maintenance handled by external specialists	Long-term programmes; national or basin-scale systems	Reduces internal technical burden; tailored to user needs	Higher financial cost; reliance on external partners
Cloud based file sharing management system	Data is stored and shared through cloud based filing system such as Sharepoint or Dropbox and users manage the data using software such as excel	Simple groundwater monitoring programmes	Low cost, common knowledge base	Manual entry, requires strict management processes

Table 6: Example options for digital platforms and data management systems.

BOX 16 - COMMON PITFALL
DELAYED OUTPUTS LOSE MOMENTUM

A frequent mistake is to install sensors first, before communication systems are ready. While the impulse to begin collecting long-term data is understandable, this often leads to months-long delays before users can access or interpret the results. Even a 3–6-month delay in seeing outputs can erode interest from water authorities, community technicians, or partners, and damage trust in the project.

Prioritise early testing of dashboards and communications. Seeing even a few pilot data points visualised in real-time can generate excitement and buy-in, while also allowing feedback before full deployment.

You should additionally seek to manage expectations regarding the outputs possible from early datasets. Some methods of analysis need multiple months of data to accumulate to start producing confident practical insights.

Figure 22: After the initial excitement of sensor installation, waiting for useful data outputs can be incredibly disappointing. (ChatGPT+, 2025)

BOX 17 - CASE STUDY
DIGITAL GROUNDWATER MONITORING WITH MWATER *IN NIGERIA*

In northeast Nigeria, **Action contre la Faim (ACF)** set up a groundwater monitoring platform using **mWater**, an open-access system for managing water-related field data. The platform supports a range of groundwater data types, including:

- **Water level measurements.**
- **Pumping test results.**
- **Borehole construction and geological data.**
- **Water quality parameters.**
- **Infrastructure condition surveys.**

These datasets are collected and uploaded via mobile forms, then visualised through **interactive dashboards** and downloadable tables. The platform's structure allows for detailed metadata such as GPS coordinates, aquifer descriptions, and date-stamped measurements, which helps ensure consistency and quality in the monitoring data.

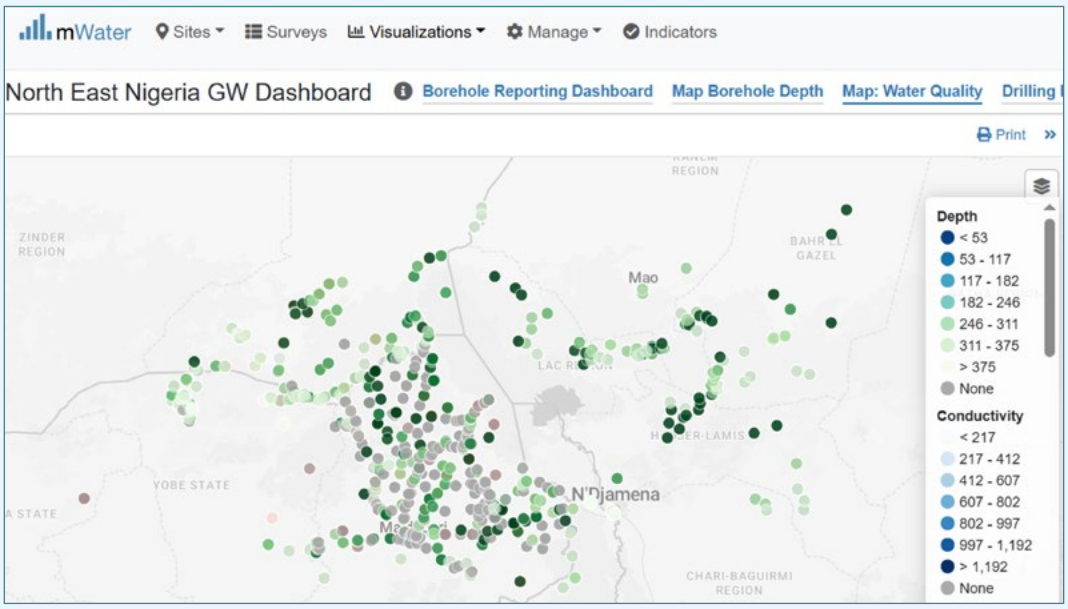

Figure 23: Digital platform presenting groundwater data in northeast Nigeria. (mWater)

The visual outputs are particularly suited to **technical users**, such as hydrogeologists, WASH engineers, and programme managers who are responsible for infrastructure planning and resource allocation. Time-series graphs, interactive maps, and filterable datasets help inform decisions about:

- Borehole rehabilitation or upgrades.
- Strategic placement of new supply infrastructure.
- Prioritisation of sites for manual or automatic monitoring.
- Diagnosing system failures or risks (e.g. drawdown, contamination).

The real-time data availability and structured format, developed by iterating feedback and adaptation of the visualisations with partners, mean they can make evidence-based decisions faster and use the platform to coordinate between teams.

5.4 ADDITIONAL INFRASTRUCTURE FOR DATA COLLECTION

Before field data collection begins, it's important to check whether any **infrastructure or facilitie**s are needed to support the monitoring system. If so, this is the time to build or install them: during the pilot, before full rollout.

Some common examples include:

- **A small data management centre** (e.g. a desk, laptop, and power supply at a local partner office).
- **A storage area** for equipment and spare parts.
- **Solar panels, fencing or locks** to protect equipment in the field.
- **Creation of a basic field laboratory** to support analysis of water quality samples using portable monitoring equipment such as colorimeter kit or bacteriological monitoring kit.

These items aren't always needed, but if they are part of your monitoring design, they should be in place before you begin collecting data. Installing infrastructure early can prevent delays later and helps build local trust and visibility for the monitoring programme.

6. PILOT PHASE

6.1 OVERVIEW

The pilot phase is where the groundwater monitoring system is put into practice for the first time. It provides a space to test the design, build partner confidence, and make sure the system delivers real value to users before rolling it out more widely.

This section follows the **five core elements** shown in **Figure 24**, which should be thought of as an iterative cycle. During the pilot, each of these elements (data collection, data analysis, communication of findings, evaluation and design adaptation) should be tested with users and refined. The pilot process allows for problems to be identified early, responsibilities to be clarified, and the system to be adapted for future expansion.

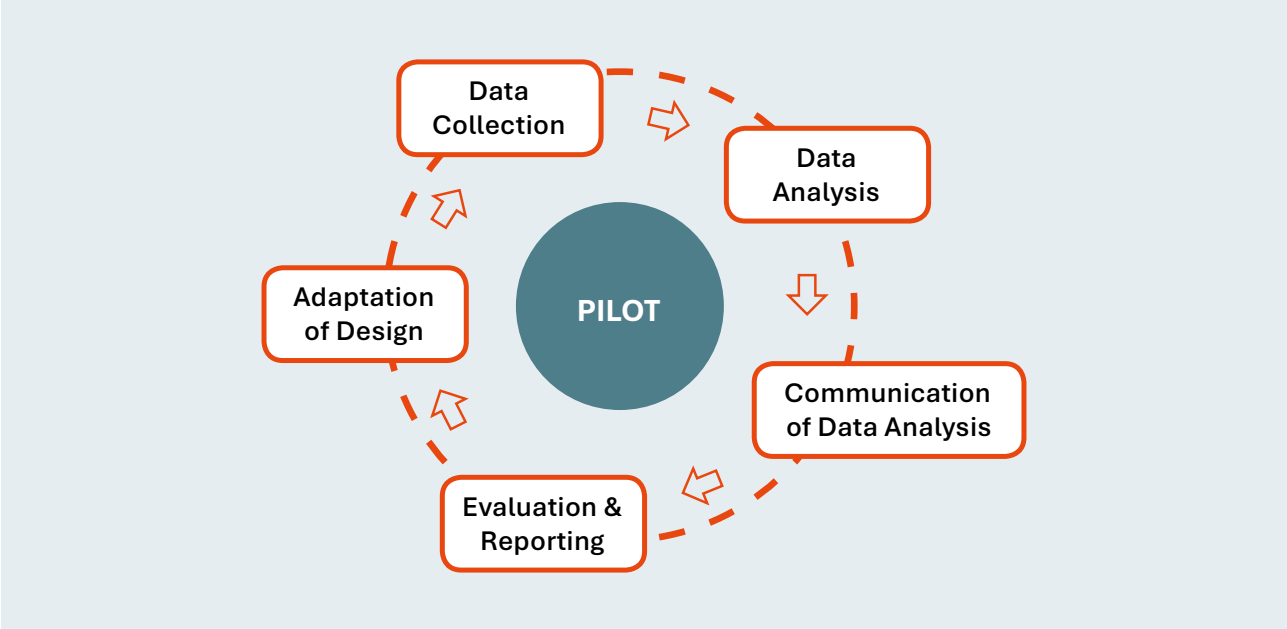

Figure 24: Core elements of a groundwater monitoring cycle, true for the pilot and the final scaled up system.

BOX 18 - COMMON PITFALL
TOO BROAD, TOO SOON

A frequent mistake is trying to monitor across a wide geographic area too early. E.g., collecting limited data from one or two boreholes per district across an entire region. This kind of sparse monitoring is rarely useful to local users, it is difficult for a small monitoring team to manage and it often fails to deliver clear value.

A better approach is to select a focused pilot area, such as a small catchment or a single displacement camp, where all components of the monitoring system can be properly tested. Once the pilot demonstrates success and clear benefits for local partners, then expansion can be considered.

Figure 25: It is best to get monitoring working locally before expanding its scale. (ChatGPT+, 2025)

In urgent humanitarian contexts, the pilot may be abbreviated, but even then, the system should still follow the key stages and early monitoring should focus on the most critical supply boreholes.

CAPACITY BUILDING AND COMMUNITY ENGAGEMENT DURING THE PILOT

In addition to testing the monitoring system's core technical components, the pilot is also the time to build the partnerships and skills needed for long-term success. Train the people who will be responsible for monitoring.

These could be infrastructure technicians, staff from a partner organisation, selected and traineed members or citizen scientist(s) within the local community. Their roles may include:

- Taking manual measurements.
- Downloading or checking sensor data.
- Charging or replacing batteries.
- Calibrating water quality sensors.
- Protecting sensors from damage or tampering.
- Raising awareness in their community.

Make sure these individuals understand their role, have the tools they need, and are properly supported. This may include training, regular communication, payment/other incentives, or receiving useful information back from the data they help collect. More details on capacity building can be found in **Section 6.7**.

ENGAGE AND PREPARE THE COMMUNITY

If any monitoring sites are located in or near communities, it's important to raise awareness early. This might involve a simple community meeting or a more formal workshop. The aim is to explain:

- Why the monitoring is happening?
- What equipment will be installed?
- What the community can expect (and how they can benefit) from the data collected?
- Who to speak to if there are any questions or problems?

BOX 19 - COMMON PITFALL
POOR COMMUNITY ENGAGEMENT AROUND SENSORS

Installing sensors in community-accessed wells without proper explanations and permissions can lead to misunderstandings, fear, or damage to the equipment. In Madagascar, ACF experienced theft of metal cables due to their high value.

A short community meeting before installation can build trust, improve protection of the equipment, and increase the chances of long-term monitoring success.

Figure 26: High-tech sensors can attract attention... and damage. (ChatGPT+, 2025)

6.2 DATA COLLECTION

The success of a groundwater monitoring system depends on the quality and consistency of the data collected. In this section, we focus on how to carry out the core groundwater **monitoring and survey methods** introduced earlier in **Figure 1**:

WATER LEVEL ①	ABSTRACTION MONITORING ②	WATER QUALITY ③	GEOPHYSICAL SUBSURFACE SURVEYS ④	WATER USERS SURVEYS ⑤

Each of these monitoring and survey methods will be covered in the subsections that follow **(Sections 6.2.1 – 6.2.5)**. For each, we describe how to plan and conduct data collection during the pilot, including practical tips, equipment considerations, typical challenges, and lessons from humanitarian contexts.

These core methods form the backbone of most groundwater monitoring systems in both emergency and long-term settings. Each method produces different insights, and together they provide a more complete understanding of groundwater use, availability, and risk.

Two further subsections are also included:

- **Complimentary water resource monitoring (Section 6.2.6)**: Describes complementary monitoring tools, such as rainfall gauges and river level recorders that can enhance interpretation and forecasting when used alongside the core methods.
- **Data Storage and Management (Section 6.2.7)**: Covers how to safely store and organise data collected in a way that supports long-term use, sharing, and analysis. This includes basic guidance on file structures, naming conventions, metadata, and preparing for integration into a shared platform.

Together, these sections provide practical guidance for setting up a complete and useful groundwater monitoring data collection system during the pilot phase.

SURVEYING LOCATIONS AND SETTING A MEASUREMENT DATUM

Before starting groundwater monitoring, it's essential to **accurately record the location** of all monitoring sites, including boreholes, wells, weather stations, river gauges, and data centres. Use a GPS device to record coordinates in decimal degrees to six decimal places (e.g., **13.456789°**) to ensure consistent records and make future visits or comparisons easier.

At each borehole or well, you must also set a **fixed measurement reference point**, called a **datum**. This is usually the **top of the borehole casing, dip tube, or well lining**. All water level readings, both manual and automatic, should be taken from this same reference point to make sure the measurements are comparable over time (**Figure 27**).

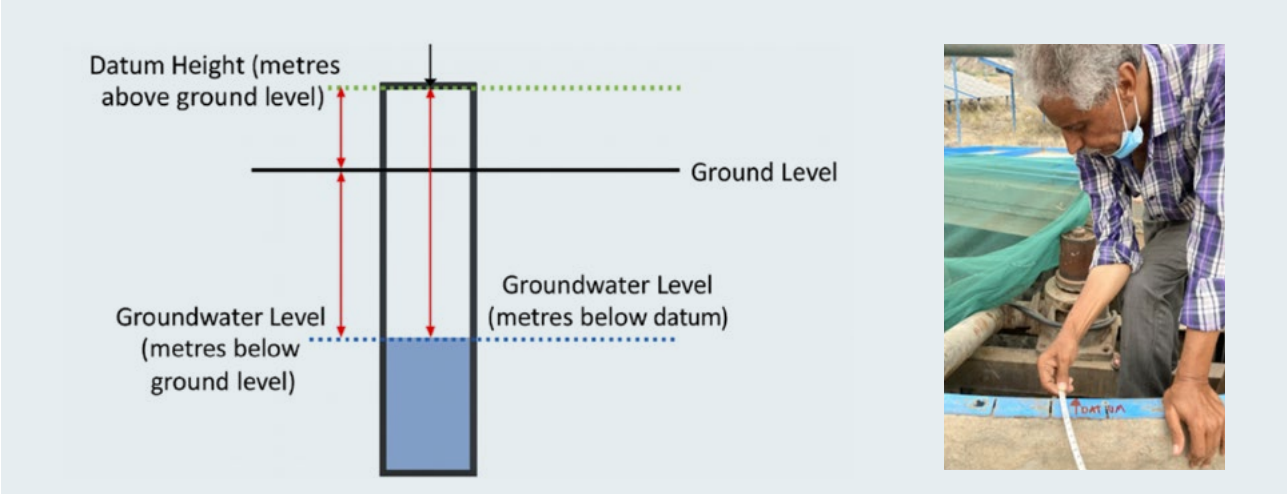

Figure 27: Marking the datum relative to ground and groundwater levels. In the photo, the employee from the National Water Resource Agency (NWRA) Yemen, working with a Groundwater Relief team, is taking a manual dip reading of the well's water level precisely at the height where the datum has been marked. (GWR)

6.2.1 WATER LEVEL DATA COLLECTION

6.2.1A MANUAL WATER LEVEL MONITORING

Manual water level readings are taken using a water level dip meter, a tool that is lowered into the well to detect the depth to groundwater from a fixed point (called a "datum"). These measurements should be taken at **regular intervals** depending on the monitoring objectives and available capacity.

Although manual methods require more staff time and field visits than automated systems, they remain a reliable and cost-effective option when well-planned and conducted by trained personnel. With proper technique, they can be highly accurate and are often a good fit for many humanitarian contexts. **ANNEX A9** describes standard operation procedures (SOPs) for manual monitoring in more detail, and **ANNEX A10** provides a form for recording measurements.

ANNEX A9: MANUAL WATER LEVEL MONITORING STANDARD OPERATING PRODEDURE (SOP)
Detailed instructions on how to monitor water levels using manual methods.

ANNEX A10: MANUAL WATER LEVEL MONITORING FORM
Use this form to record regular manual water level readings using a dip meter during the monitoring period.

BOX 20 - COMMON PITFALL
IN MANUAL WATER LEVEL MONITORING

- **Misreading the measuring tape** – Always double-check the depth before recording.
- **No dip tube installed** – This can cause the dip meter to get tangled in the pump, electrical cable, or safety rope.
- **Measuring from the wrong reference point (datum)** – Ensure the same fixed point is used every time.
- **Fuzzy or unclear buzzer signals** – Moisture on the well walls or falling water can trigger a weak signal. The correct water level produces a sharp, clear sound.
- **Sensitivity dial set too low** – If the dip meter doesn't beep when it should, check and adjust the sensitivity setting.
- **Use of low-quality dip meters** – Some cheaper models can stretch or degrade over time, leading to inaccurate measurements.
- **Measuring dynamic instead of static water levels** – For monitoring trends, water levels should be taken after the well has rested (e.g., overnight).
- **Data entry errors** – Mistakes when typing paper form data into spreadsheets can compromise the dataset. Cross-check digital entries against the original forms.

BOX 21 - CASE STUDY
CITIZEN-SCIENCE MANUAL MONITORING *IN BURKINA FASO*

In Burkina Faso, community members have been successfully trained to monitor groundwater levels and rainfall to support local water management. This **citizen science** approach was developed by the British Geological Survey (BGS) together with national and local partners.

Local volunteers were given simple tools:
- **Manual dip meters** for measuring water levels in boreholes.
- **Rain gauges** to track rainfall at village level.

Volunteers were trained to record and share measurements each month. The data was then sent to local water managers and the national water authority, helping to build a clearer picture of groundwater recharge and use across rural areas.

Figure 28: Community data collection and interpretation in Burkina Faso. (MediaWiki)[12]

KEY LESSONS:
- **Simple methods work:** Basic, low-cost tools and clear training make it possible for non-experts to collect useful groundwater data.
- **Local trust is critical:** Community members feel ownership and are more likely to protect and maintain boreholes when they are involved in monitoring.
- **Sustained support is needed:** Volunteers need regular feedback, recognition, and small incentives to keep the system running long-term.

This approach shows how, even in low-resource settings, community monitoring can help fill critical data gaps and support better decision-making for water security.

12 -https://earthwise.bgs.ac.uk/index.php/Case_Study_Community_Monitoring_Burkina_Faso

6.2.1B AUTOMATIC WATER LEVEL MONITORING

Automatic water level monitoring enables more frequent measurements of groundwater levels to be taken, providing more accurate information on how groundwater levels change over time. It uses small devices called **data loggers** (also known as **pressure transducers, or piezometers**) that are placed inside boreholes or wells. These loggers measure the pressure of water above them and convert that into a water level reading.

The logger is programmed to take regular readings (for example, every 30 minutes or every hour). It stores this data on its internal memory, or if it has a **telemetry system**, it can send the data remotely to a server or dashboard.

Automatic monitoring is helpful because it gives a detailed picture of how the groundwater behaves during the day, over seasons, or in response to heavy pumping. This is very useful for water supply planning and for spotting early warning signs of problems. Detailed instructions on how to monitor water levels using automatic pressure transducers are provided in **ANNEX A11.**

ANNEX A11: AUTOMATIC WATER LEVEL MONITORING STANDARD OPERATING PROCEDURE (SOP)

*The instructions for automatic water level monitoring in **ANNEX A11** are structured as follows:*

a. Pre-installation Preparations
b. Logger Programming and Installation
c. Calibration and Manual Water Level Checks
d. Logger Retrieval and Data Download
e. Logger Data Handling
f. Barometric Compensation
g. Logger Data Cleaning

The instructions also point to additional Annexes for practical use:

ANNEX A12: DATA LOGGER INSTALLATION FORM

This form should be completed during the installation of each groundwater level data logger to ensure accurate and traceable setup.

ANNEX A13: FIELD FORM

Use this form whenever a data logger is removed, downloaded, or reinstalled to maintain a record of calibration and data collection.

BOX 22 - COMMON PITFALL
UNRELIABLE DATA FROM MISSING CALIBRATION OR CORRECTION

Automatic groundwater monitoring often fails when key setup steps are skipped. Two of the most common issues are:

- **No manual calibration:**
  Manual water level readings are needed at the time of installation, removal, and reprogramming to check and correct the logger data. Without these checks, it's hard to trust the accuracy of the results.
- **No barometric correction:**
  Air pressure changes affect the readings from pressure loggers. If a barologger (or weather station measuring air pressure) is not installed nearby, water level data may be significantly wrong. One barologger can correct loggers within 30 km or 300 m elevation; beyond that, the correction won't be accurate.

Figure 29: Sense-checking the data for measurements that "sound wrong" often flags issues with sensor management. (ChatGPT+, 2025)

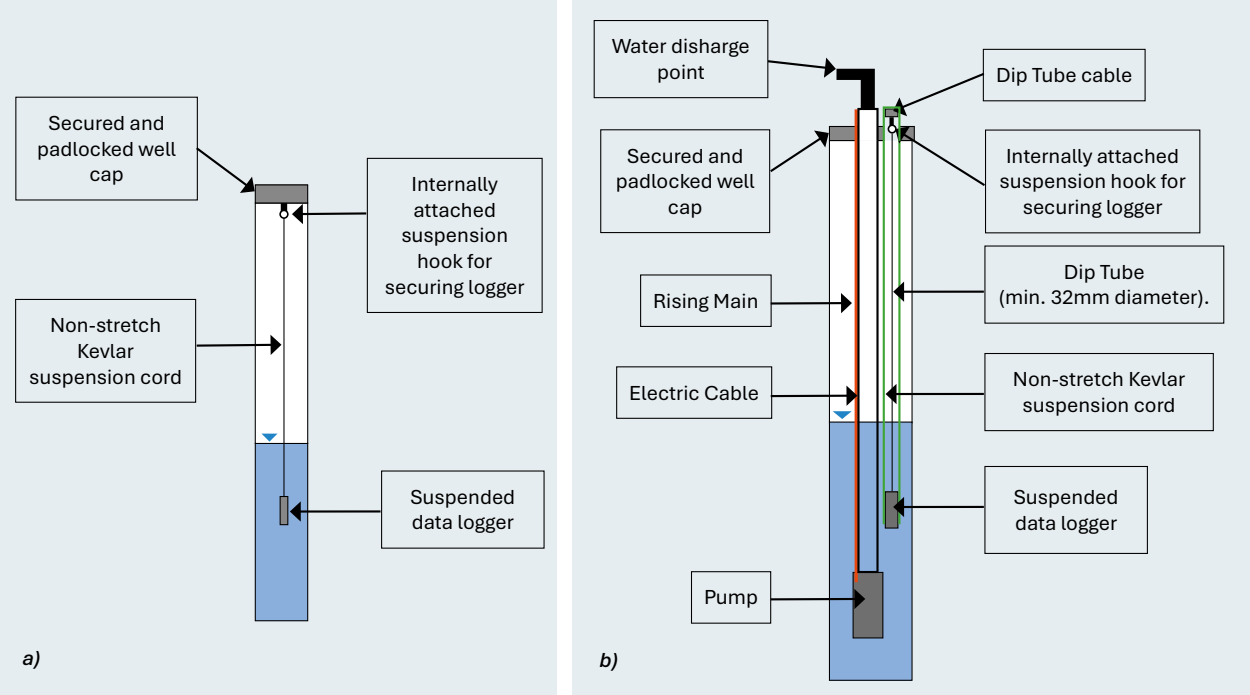

Figure 30: a) Schematic diagram of data logger installation in an observation well (no pump); b) Schematic diagram showing a data logger installed within a production borehole containing a pump and dip tube. (GWR)

BOX 23 - CASE STUDY

DIP TUBES: RETROFITTING MONITORING INFRASTRUCTURE IN AL MOKHA WELL FIELD, *YEMEN*

In humanitarian contexts, budgets often do not allow for the construction of dedicated observation wells. A more cost-effective and practical approach is to adapt existing production boreholes for monitoring purposes. This approach was successfully implemented in the Al Mokha well field in Yemen by Groundwater Relief.

At this site, pumps were temporarily removed and dip tubes were installed to allow safe and consistent access for both manual dip meters and automated pressure transducers. Dip tubes are narrow PVC or MDPE pipes (typically 1.5" diameter), capped at the bottom and perforated near the base. The example below shows a flexible MDPE dip tube being lowered into a borehole.

Figure 31: Dip tube installation in Al Mokha well field, Yemen. (GWR)

TELEMETERED LOGGER SYSTEMS AND ALTERNATIVE SENSORS

Where a telemetry system is used, the data logger is installed on a direct-read cable, which provides both the communication link and, where required, power connection between the logger and the surface-mounted telemetry unit. This enables groundwater level data to be transmitted remotely without the need to retrieve the logger from the borehole. Data are transmitted via a telemetry transponder to a central data platform (e.g. via a SIM and Mobile Network).

- Data is sent automatically to a central platform (e.g. via a SIM and mobile network).
- Use **the manufacturer's software or dashboard** to access the data.
- Always follow the manufacturer's user manual for setup, access, and troubleshooting.
- Be aware that in some countries, **built-in SIM cards** may raise **security** or regulatory concerns. SIMs can also unexpectedly go offline if standard user-agreements are not met. It's important to check national policies and consult local partners when setting up telemetered systems.

Newer non-contact water level sensors such as **sonic/ultrasonic meters** are becoming more available. These devices, like the **Solinst Sonic Water Level Meter**, use sound waves to estimate water depth **without needing to enter the well**. Low-cost, Arduino-based versions are also being trialled in some settings.

These tools may offer an alternative to loggers. However, they are still in development and face several limitations: well's diameter, presence of obstructions, air temperature or ambient noise can limit the accuracy or even the use of such devices.

FURTHER INFORMATION ON AUTOMATIC LOGGERS

Automatic data loggers are typically installed in boreholes either by suspending them on non-stretch Kevlar or Dyneema cord, stainless steel wire, or by using a direct-read cable.

When installed on a direct-read cable, data can be downloaded at the surface without removing the logger from the borehole, reducing the time required for data collection and minimising disturbance to the installation. In contrast, loggers suspended on cord or wire must be retrieved from the borehole each time data are downloaded, unless they are equipped with wireless communication capabilities.

To ensure that groundwater levels are recorded throughout the full range of expected fluctuations, the logger should be installed below the anticipated lowest dynamic water level. However, the installation depth must not exceed the logger's maximum pressure rating, as doing so may damage the instrument or result in inaccurate measurements. The selected installation depth should therefore provide an appropriate balance between capturing the full range of water-level variations and operating within the manufacturer's specified limits.

BOX 22 - COMMON PITFALL
COMMON PITFALLS IN AUTOMATIC PRESSURE TRANSDUCER MONITORING

Many systems fail due to preventable mistakes. Here are common pitfalls to watch for:

EQUIPMENT & INSTALLATION

- **Dip tube too narrow:** Make sure the dip tube has a wide enough internal diameter (usually ≥32 mm) for the logger to move freely.
- **Wrong suspension cord:** Regular ropes stretch, degrade, or snap. Always use non-stretch Kevlar cord to keep the logger at a stable depth.
- **Poor attachment at the wellhead:** Secure the cord or cable properly: exposed, loosely tied loggers can fall or get stolen.
- **Logger programmed incorrectly:** Common errors include:
  - Logger not turned on
  - Logging interval set too short or too long
  - Time zone or clock not synchronised
- **Barologger missing or not used correctly:** Without this, you cannot correct the logger's pressure data for air pressure changes.
- **No barometric correction possible:** The barologger should be installed within 30 km and ±300 m elevation of the water logger.
- **Faulty sensors:** In Madagascar 10% of ACF's commercially sourced sensors malfunctioned in the first years of monitoring. In humid climates it is very important to have desiccants and change it often.

FIELD SETUP & CALIBRATION

- **No manual calibration measurements taken:** At minimum, dip meter readings should be taken:
  - During installation
  - During removal
  - After any reprogramming
  - When loggers are moved (e.g. for pump maintenance)
- **Manual readings don't match logger timestamps**: To be useful for calibration, manual measurements must be taken at the exact same time.
- **Logger or barologger placed at different heights every time it is returned to the well:** If a logger is moved, it must be recorded and recalibrated.
- **Logger installed in wrong position:**
  - Too shallow: it may emerge from the water during dry periods
  - Too deep: it may hit the pump or get affected by turbulence
- **Water density not considered:** Fresh, brackish and saline waters exert different pressures. Select appropriate water type settings when configuring the logger.

6.2.2 ABSTRACTION MONITORING

Understanding how much groundwater is being used is just as important as knowing how much is available. Abstraction monitoring tracks how much water is pumped from each borehole or well. This helps manage supply, avoid overuse, plan infrastructure, and support fair water distribution.

Abstraction can be measured directly (e.g. using a flow meter) or estimated (e.g. based on pump run-time or user reports). The right method depends on your resources, equipment, and the willingness of water point operators to participate.

MANUAL MONITORING

Manual abstraction tracking is low-cost and practical where high-tech solutions are not possible. The most common approach is to work with the pump operator to record:

- When the pump was turned on/off.
- Estimated volume pumped (if known).
- Number of jerry cans or users served.
- Fuel or electricity use (if available).

This data is recorded daily on a simple pump operator data sheet. (see **ANNEX A14**).

ANNEX A14: PUMP OPERATOR ABSTRACTION LOG TEMPLATE

This sheet is to be completed daily by the pump operator or site technician to record groundwater abstraction from a borehole or well. The information helps monitor usage, plan supply, and ensure safe, sustainable management of groundwater resources.

It is most useful to take two daily readings directly before the pump is first turned on in the day (as the water level will have partly or fully recovered overnight), then after the pump is turned off for the day (likely representing its deepest drawdown or 'dynamic' water level).

Manual methods rely on trust and regular reporting, so building relationships and offering simple incentives (e.g. airtime credit, printed feedback summaries, public recognition) can help ensure consistency.

AUTOMATIC FLOW MONITORING

Where budgets allow, flow meters can provide more accurate and continuous abstraction data. There are several types (**Table 7**).

TYPE	HOW IT WORKS	ADVANTAGES	LIMITATIONS	EXAMPLE SUPPLIERS
Volumetric Flow Meters	Measure total volume of water passing through the meter.	Simple to install and read.	Can clog with debris; moving parts may degrade over time.	B Meters
Electromagnetic Flow Meters	Use a magnetic field to detect flow of conductive liquids.	High accuracy; no moving parts; suitable for high flow rates.	Expensive; needs a power source; only works with conductive fluids.	ABB, KROHNE
Ultrasonic Flow Meters	Use ultrasonic signals to calculate velocity and flow.	Non-intrusive; clamp-on versions available.	Sensitive to pipe material, bubbles, and installation conditions.	Siemens

Table 7: Summary of flow monitoring methods and suppliers.

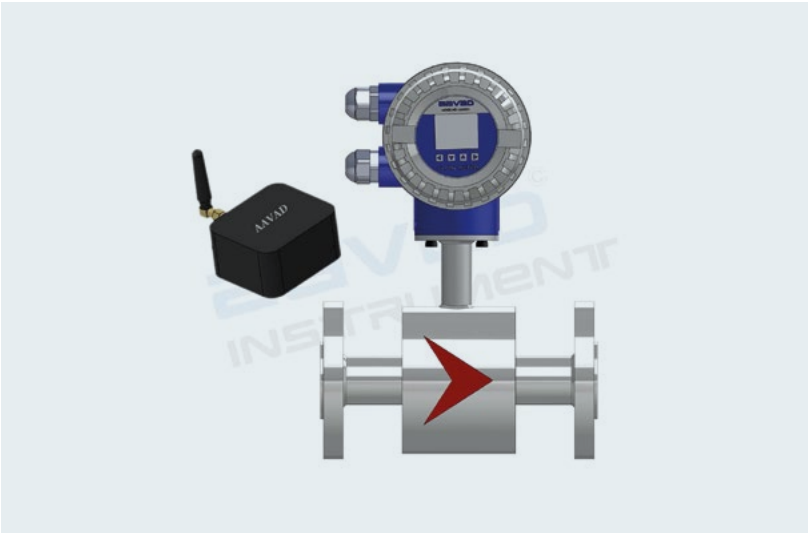

Figure 32: The Aavad Instrument Model AMAG-I integrates an electromagnetic flow meter with a complete telemetry ecosystem, allowing flow data to move securely from the meter to a cloud-based monitoring platform. (Aavad)[13]

PUMP RUNTIME MONITORING

An alternative way to estimate abstraction is by measuring how long the pump runs, then multiplying this by the known flow rate.

Pump runtime sensors can:

- Be mechanical (e.g. hour meters).
- Use electric current detection.
- Be digital and connect to **telemetry systems** for automatic uploads.

Example: *SweetSense sensors* – used in humanitarian WASH programmes to monitor pump activity remotely.

6.2.3 WATER QUALITY MONITORING

Water quality parameters can be collected during field visits using handheld meters or by sending samples to a laboratory. This approach allows for early detection of issues such as contamination or salinity. Automatic water quality monitoring remains rare in humanitarian contexts mainly due to equipment cost and complexity. **Table 8** provides examples of commonly used equipment for water quality monitoring, and **ANNEX A15** describes a Standard Operating Procedure (SOP) for manual water quality monitoring.

ANNEX A15: MANUAL WATER QUALITY MONITORING STANDARD OPERATING PROCEDURE (SOP)
*Detailed instructions on how to monitor water quality is provided in **ANNEX A15**. This references an additional **ANNEX A16**:* **MANUAL WATER QUALITY MONITORING FORM**.

13 - https://aavadinstrument.com/product/digital-water-flow-meter-with-latest-cgwa-guidelines/

APPLICATION	EXAMPLE KIT / EQUIPMENT	TYPICAL PARAMETERS MEASURED	EXAMPLE MANUFACTURERS / BRANDS	INDICATIVE COST (USD)
Field multiparameter testing (general)	Handheld multiparameter meter	pH, EC, DO, turbidity, temperature, salinity	Hanna, YSI, Horiba, Hach, Aquaread, Palintest	$100– $5,000 per unit
Microbiological testing (bacteriological quality)	Sterile sample bottles, Colilert® kits, membrane filtration kits	E. coli, total coliforms, faecal coliforms	waterscope.org, IDEXX, Millipore	$5 – $10 per test; $500+ for field kit
Heavy metals testing (field screening)	Portable colorimeters, field test strips	Lead, arsenic, iron, manganese	HACH field kits, ITS Quick Econo, Palintest	$300 – $1,500 per meter; strips ~$2/test
Heavy metals sampling (lab analysis)	Acid-washed bottles, field filters, acidification supplies	Full suite of trace metals	N/A (samples analysed in lab)	~$2–5 per bottle; lab fees $50–$200/sample
Nutrient sampling (lab analysis)	Pre-treated bottles, cool box, labels	Nitrates, phosphates, ammonia	N/A (lab analysis required)	~$2–5 per bottle; lab fees $20–$50/sample
Turbidity only (spot checks)	Portable turbidity meter, or manual turbidity tube	Turbidity (NTU)	Hach, Hanna, LaMotte	$500 – $1,500 per meter; $30 – 80 per tube
Micro-scale community testing	Simple test kits or strips	pH, chlorine residual, nitrate, iron	Wagtech, Palintest, Aquagenx	$1 – $5 per test
In-situ automatic continuous monitoring	Deployed probes, data loggers	pH, EC, temperature, turbidity, DO	In-Situ, OTT Hydromet, YSI/Xylem	$5,000 – $15,000+ per site
Sample storage & transport	Cool box, ice packs, labelling materials	Any requiring lab analysis	N/A	$50 – $200 depending on size

Table 8: Examples of commonly used water quality testing kits, including their typical measurement parameters, common brands and indicative cost.

Figure 33: Using two handheld water quality probes to take manual measurements in Cox's Baxar, Bangladesh (left). A field testing kit for E.Coli and coliform bacteria used by Groundwater Relief in Cox's Baxar, Bangladesh (right). (GWR)

6.2.4 GEOPHYSICAL SUBSURFACE SURVEYS

Geophysical surveys are non-invasive methods used to explore the subsurface and understand aquifer characteristics without drilling. These techniques are **particularly useful in the early stages of monitoring system design**, especially where the geology is poorly understood or where there is uncertainty about aquifer connectivity, extent, or vulnerability.

Whilst not normally a form of long-term monitoring in themselves, geophysical surveys provide valuable information that can guide where to place monitoring wells, what depth to monitor, and whether additional groundwater risks may exist. In areas affected by saline intrusion, geophysical techniques based on electrical resistivity or electromagnetic conductivity can be used to monitor the movement of saline water into freshwater aquifers and to track changes in the position of the freshwater–saltwater interface over time.

COMMON GEOPHYSICAL METHODS

METHOD	DESCRIPTION	WHAT IT SHOWS	COMMON USE CASES	LIMITATIONS
Electrical Resistivity Tomography (ERT)	Sends electrical currents into the ground and measures resistance	Identifies aquifer boundaries, clay layers, salinity, fractures	Mapping shallow aquifers or freshwater–saline interfaces	Requires training, not ideal in urban/metal-rich environments
Vertical Electrical Sounding (VES)	Measures ground resistance at increasing depths from a single point	Provides a vertical profile of resistivity vs. depth	Used to estimate depth to water or bedrock	Limited lateral information
Seismic Refraction	Uses sound waves to estimate subsurface layering	Identifies rock depth and layer continuity	Locating weathered zones or fractures	Less effective in saturated, unconsolidated soils
Electromagnetic Methods (EM)	Measures conductivity using EM fields	Rapid mapping of shallow conductivity	Identifying saline water zones, leachate	Affected by surface metal and power lines
Protonic Magnetic Resonance (PMR)	A sounding device measuring groundwater reserves	Identify aquifers & groundwater reserves	Use in complex areas: it is not influenced by salinity and fractures	Expensive and needs a specialist for data analysis

Table 9: Examples of main geophysical methods used to survey groundwater.

WHEN TO USE

Geophysical surveys are most helpful when:

- The geology is uncertain or inconsistent across the monitoring area.
- Drilling costs are high and need to be optimised.
- Monitoring networks require strategic placement of observation points.
- Aquifer salinity, recharge zones or geological risks (e.g. faults) are suspected.
- Groundwater changes are linked to ground subsidence that needs investigating.

PRACTICAL CONSIDERATIONS

- Surveys should be conducted or supervised by a geophysicist or hydrogeologist with relevant experience.
- Methods vary in complexity and cost. ERT and VES are relatively affordable and commonly used in humanitarian settings.
- Some surveys can be completed in a few hours; others require several days and larger teams.
- Results should feed directly into the design of the monitoring network.

EQUIPMENT AND PARTNERS

You may not need to buy this equipment. Organisations such as **NGOs**, **UNICEF**, and **national geological surveys** often maintain equipment and technical staff that can support humanitarian actors with surveys or training. In some countries, universities or the private sector may also be strong partners.

Figure 34: Groundwater relief supporting local technicians in setting up an electrical resistivity tomography (ERT) survey in Cox's Bazar, Bangladesh. (GWR)

BOX 25: COMMON PITFALL
MISINTERPRETATION OF GEOPHYSICAL DATA

Geophysical data can be difficult to interpret correctly without proper expertise. A common pitfall is misinterpreting resistivity data, e.g., assuming low resistivity means fresh water when it could also indicate saline or clay-rich layers. Always interpret geophysical data in conjunction with drilling logs and local hydrogeological knowledge.

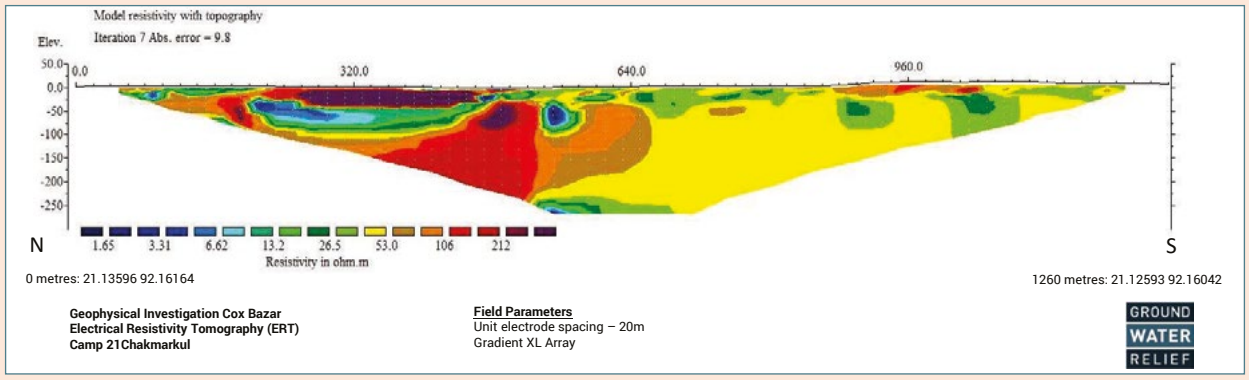

Figure 35: A Geoscientists Without Borders resistivity survey below displacement camps near Cox's Bazar, Bangladesh. (GWR)

6.2.5 WATER USER SURVEYS

Water User Surveys often will help compliment groundwater abstraction monitoring. Water user surveys help uncover how communities interact with groundwater points: how much they use, what they use it for, and whether their needs are being met. These surveys provide essential context for interpreting changes in water levels and quality and improve transparency and accountability in water management. Templates for conducting these surveys are included in **ANNEX A17**.

Water user surveys can also reveal who is being served by groundwater systems and how equitably water is being accessed across different groups. This information is particularly useful for identifying vulnerable or underserved populations and can support better design of water access and pricing policies.

6.2.5A HOUSEHOLD WATER USE SURVEYS

Household water user surveys provide valuable information on how groundwater resources are accessed, used and perceived by communities. They can be used to assess water sources, collection practices, quantities used, reliability of supply, water quality perceptions, seasonal variations, household expenditure, coping strategies during shortages, and user satisfaction with water services. When repeated over time, household surveys can help identify changes in water use and demand and provide important context for interpreting groundwater monitoring data.

The survey sample should be selected using a statistically robust sampling approach to ensure that the results are representative of the wider population. For most groundwater monitoring and water resource assessments, a confidence level of 95% with a ±5% margin of error is considered good practice. The required sample size depends on the total number of households within the study area. For large populations (typically greater than 20,000 households), a sample of approximately 380–385 households is generally sufficient to achieve a 90% confidence level with a ±10% margin of error. For smaller populations, the sample size can be reduced using a finite population correction. Households should be selected using an appropriate sampling method to minimise bias and ensure adequate representation of different communities, socioeconomic groups and water users. For research purposes only, use a 95% confidence level with a ±5% margin of error.

When interviewing households, ask simple and intuitive questions. Many households do not measure water in litres, so it is best to use the typical collection vessel as the unit of measurement (e.g. jerry can or bucket). Questions should focus on weekly water use (rather than daily), as this balances accuracy with memory recall. Please refer to **ANNEX A17**.

6.2.5B KEY INFORMANT INTERVIEWS (KII)

Gathering broader usage estimates from those managing the water source helps to assess total abstraction and who the groundwater is serving. Please refer to **ANNEX A17**.

Key informant interviews can provide contextual information that cannot be obtained from surveys of technical monitoring data alone. Interviews with well owners, water users, community representatives, local authorities, and other stakeholders can help identify changes in groundwater availability and quality, seasonal patterns of use, pumping practices, infrastructure performance, and emerging water-related issues. They can also provide insight into historical trends, local perceptions, and institutional arrangements, helping to interpret monitoring data and identify potential risks or management priorities. When undertaken using a structured questionnaire and consistent methodology, key informant interviews provide an important complement to hydrogeological monitoring and support more informed groundwater resource management.

KII questions can be open-ended and focussed on user groups experiences:

- Do you face any problems with your water access?
- What do you think causes these problems?
- What would be your suggested solutions?

These responses should be recorded and later reviewed using basic thematic analysis. This involves looking for patterns in the responses. For example, if multiple users mention "long queues" or "salty water," the number of times these arise can be counted and presented to water managers as key issues to address.

6.2.5C MONITORING WATER PRICES

In many contexts, water is not free. When households or institutions pay for water, prices become a powerful indicator of groundwater pressure and water security (**Figure 36**).

Track:

- The price per jerrycan or bucket at formal and informal sale points.
- Water truck delivery prices (especially in crisis or informal settings).
- Any seasonal changes in price.
- Who sets the price (committee, private supplier, etc.).

Water prices are often the most visible early signal of scarcity or inequity. If water becomes too expensive, it can signal emerging shortages, monopolies, or failure of formal supply systems.

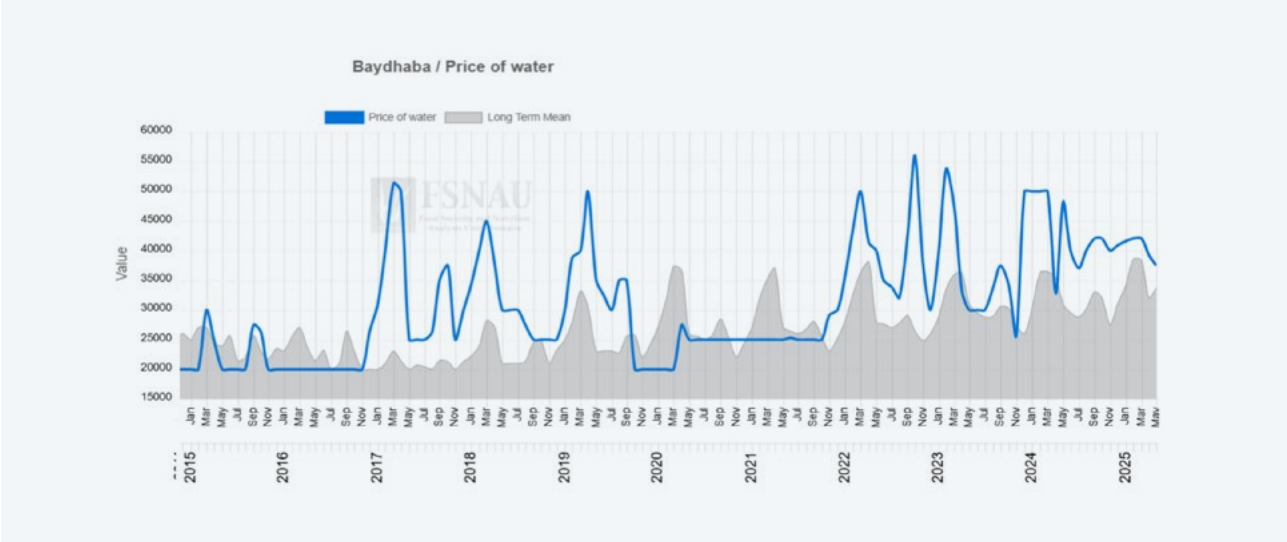

Figure 36: Water price mapping in Baydhaba (Bay), Somalia shows water price spikes during the 2017 and 2021-2024 droughts and local humanitarian crises. Minor price spikes can be seen during the two April and September short dry seasons most years. (Food Security and Nutrition Analysis Unit: FSNAU)

ANNEX A17: MANUAL WATER QUALITY MONITORING FORM

Please adapt and use for your water user surveys.

6.2.5D WATER SECURITY INDICATORS

For a more structured assessment, tools like the Household Water Insecurity Experiences (HWISE) Scale can be used. The HWISE scale is a validated survey tool that assesses whether households have experienced water-related problems in the past month such as going to bed thirsty, not having enough water for cooking, or needing to change plans due to water shortages.

The HWISE index allows for easy comparison across households, helping to identify groups most at risk of water insecurity. It is particularly useful in humanitarian settings where aid effectiveness and equity need to be closely monitored. Note: standard HWISE scales currently do not include water quality parameters, only focusing on water quantity and water access.

WASH Insecurity Analysis (WIA), promoted by WASH clusters and partners UNICEF, is also a promising tool with local, national and regional applications that is in development.

6.2.6 COMPLIMENTARY WATER RESOURCE MONITORING

In addition to direct groundwater monitoring, it is recommended to collect supporting environmental and hydrological data to help interpret groundwater trends, quantify recharge or water balance, and understand local water security. These data can help validate anomalies, support decision-making, and improve analysis outputs. Where possible, these complementary datasets should be integrated into the groundwater monitoring design from the start.

6.2.6A WEATHER (METEOROLOGICAL) STATIONS

Installing a local weather station provides high-quality rainfall, temperature, evapotranspiration and atmospheric pressure data. Rainfall data from local tipping-bucket rain gauges are often significantly more accurate than satellite rainfall products, particularly in arid zones or areas with high spatial rainfall variability.

- Rainfall & evapotranspiration are essential for estimating recharge, especially in simple models (at least 3 rain gauges are required upstream to estimate this).
- Temperature data supports evapotranspiration calculations.
- Barometric pressure can be used to compensate pressure transducer data in groundwater loggers (can replace the need for a separate barologger if the station is close to the wells).

Weather stations should be placed in a secure, open area and routinely maintained. Many can store and transmit data via SIM cards or LoRa systems.

6.2.6B SATELLITE RAINFALL DATA

If installing a weather station is not possible, freely available satellite rainfall datasets can be used as an alternative, although they tend to be less accurate. These include:

- CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data).
- GPM (Global Precipitation Measurement).
- TAMSAT (Tropical Applications of Meteorology using SATellite data).

These datasets are useful for tracking long-term trends or comparing with local records to understand rainfall variability.

6.2.6C SATELLITE VEGETATION DATA

Vegetation indices like NDVI (Normalised Difference Vegetation Index) and LAI (Leaf Area Index) are useful proxies for groundwater availability, especially in shallow aquifer systems used by plants. But care should be taken when drawing the link – sometimes vegetation can be irrigated or sustained by rainfall whilst groundwater is declining in the subsurface. These datasets can help to:

- Indicate areas of groundwater-dependent ecosystems.
- Track the impact of drought or excessive pumping on vegetation.
- Monitor land-use changes affecting recharge.
- Anticipate where food, health and nutrition crisis may occur (e.g. the HydroNut project in Southern Madagascar).

NDVI data is available through platforms like:

- Google Earth Engine.
- Copernicus Open Access Hub.
- NASA MODIS.

6.2.6D RIVER LEVEL DATA

Monitoring river levels can help understand:

- Recharge dynamics (e.g. during high flows or floods), when a 'rating curve' is available for the river to convert river level to flow.
- Contamination risks, especially where rivers recharge shallow aquifers.
- The interconnectivity between surface water and groundwater systems.

Water level loggers or non-contact sonar devices can be used in secure riverbank installations.

6.2.6E RIVER WATER QUALITY DATA

In areas where rivers influence shallow aquifers, monitoring surface water quality can provide early warning of contamination. Key parameters include:

- Turbidity.
- Faecal coliforms or E. coli.
- Conductivity and salinity.
- Chemical pollutants or runoff contaminants.

Data can be gathered manually or using sensors with automated samplers, where feasible.

6.2.6F RESERVOIR AND RAINWATER HARVESTING DATA

In some areas, artificial reservoirs or small-scale rainwater harvesting structures are key to water supply and recharge. Monitoring water levels in these systems can support:

- Water budgeting and resource planning.
- Understanding recharge contributions to nearby aquifers.
- Detecting system losses or leakage.

Manual measurements or low-cost pressure sensors can be installed for periodic tracking.

6.2.6G WATER TRUCKING DATA

In many humanitarian contexts, water trucking is a major component of local water supply, especially during emergencies. Gathering data on:

- Number and volume of trips.
- Source locations and delivery destinations.
- Costs and pricing trends.
- Water quality testing (if possible).

...can help create a complete picture of local supply and demand.

BOX 26: CASE STUDY

COMBINING GROUNDWATER, RAINFALL, AND TEMPERATURE DATA TO SIMULATE BOREHOLE PERFORMANCE *IN SOMALILAND*

In Somaliland, a **groundwater monitoring project** led by Imperial College London demonstrated how **simple modelling techniques** can extend the usefulness of short-term monitoring efforts. The project used a combination of:

- **Rainfall data** from the freely available TAMSAT database.
- **Actual evapotranspiration data** (derived from temperatures) downloaded from the African Flood and Drought Monitor.
- **Groundwater level data** from automatic pressure-based loggers.

These datasets were used to train a basic **groundwater model** that simulates water level fluctuations over time. After just a few months of data collection, the British Geological Survey designed model (Aquimod) was able to **closely reproduce observed borehole water level changes**, even when logger data was temporarily unavailable.

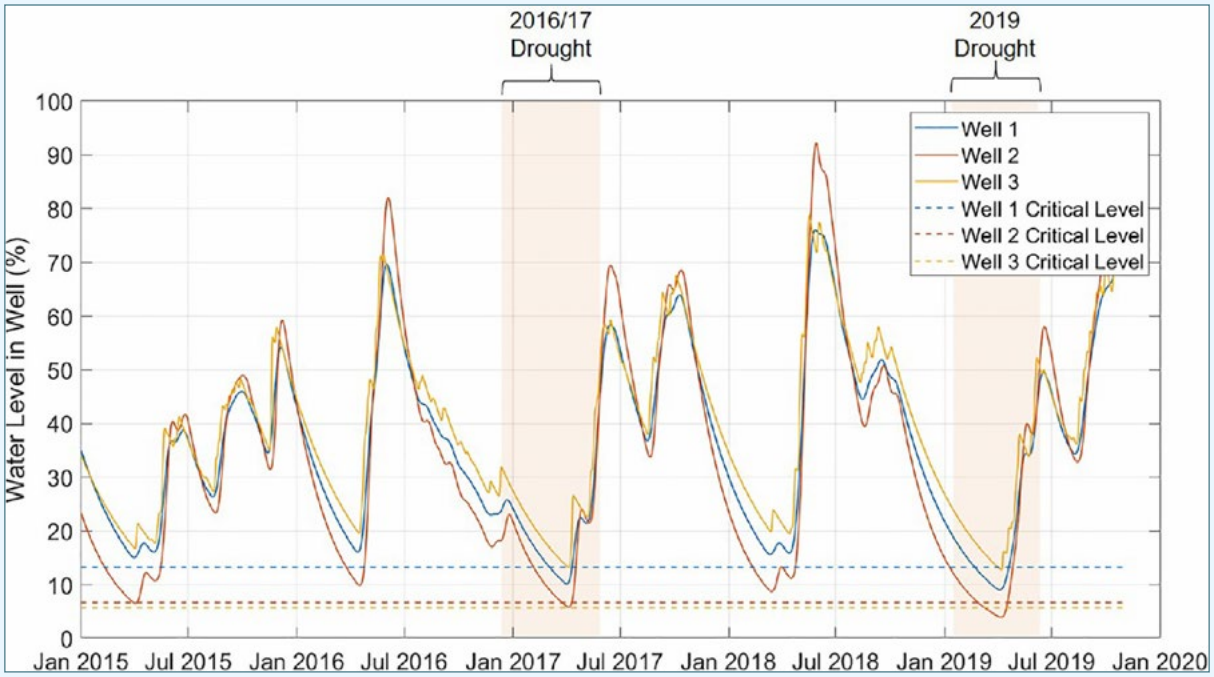

Figure 37: The British Geological Survey's Aquimod model was able to simulate the water levels of 3 wells under past and future rainfall conditions after just 7 weeks of groundwater data was used to 'calibrate' (train) the model. (Veness et *al.*, 2022)

This type of model doesn't replace monitoring, but it **adds resilience** to monitoring systems by making use of early data to simulate behaviour when sensors go offline. Once a model is setup, it also provides a way of forecasting how groundwater levels are likely to change in future weeks – months, based on different rainfall and temperature scenarios.

6.2.7 DATA STORAGE AND MANAGEMENT

Whether collected manually or automatically, all data must be recorded accurately, stored securely, and made easy to access and use by the right people.

In fragile or humanitarian contexts, systems should be designed to last beyond the involvement of a single organisation. This means keeping things simple, well-documented, and preparing for a smooth handover from the start.

KEY PRINCIPLES

- Start simple, plan for sustainability: Avoid complex digital systems unless they're truly needed and capacity exists. Clear file naming, regular backups, and a shared folder structure often go a long way.
- Engage key stakeholders: National and local water authorities should be involved early. Use data-sharing agreements or workshops to agree on roles and responsibilities.
- Assign responsibilities clearly.
- Plug in to existing digital systems, if any: explore partnerships to avoid repetition and improve the reach of the groundwater data. This may save you creating entire digital platforms from scratch.

STORAGE RECOMMENDATIONS

- Use both local and cloud storage:
  - Back up files on external drives or local servers
  - Also store them on shared cloud services (e.g. Google Drive, Dropbox, OneDrive, pCloud)
  - Ideally, folders should be owned or co-managed by relevant authorities to ensure future access
- Set up a clear, shared folder structure.
- Use consistent file names with dates in International Organization for Standardization (ISO) format (e.g. YYYY-MM-DD) and avoid special characters or spaces.
- Share folder links, not individual file links, so collaborators can always see updated content and avoid broken access paths.
- Metadata: Each dataset should be accompanied by:
  - Borehole ID and location
  - Measurement method and equipment used
  - Logger settings (if applicable)
  - Datum details
  - Contact person and date of collection

6.2.8 QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC)

Before groundwater data are analysed, shared, or used for decision-making, quality assurance and quality control (QA/QC) checks must be carried out. QA/QC does not need to be complex or highly technical, but it is a critical step that maintains the credibility and user trust in the entire programme.

QA/QC should be applied to all data types, including groundwater levels, abstraction, water quality, rainfall, and satellite-derived data.

THE PURPOSE OF QA/QC IS TO:

- identify and rectify any obvious errors or faulty readings.
- flag data that may be unreliable or need further checking.
- ensure consistency across time, locations, and data collectors.

RECOMMENDED QA/QC CHECKS

The following checks are recommended and can usually be done using simple tools (e.g. spreadsheets, automatic functions in dashboards, or basic scripts).

1. **Range checks**
   - Check that values are physically realistic (e.g. groundwater levels above ground surface, negative abstraction volumes, negative EC values).
   - Define simple acceptable minimum and maximum ranges for each variable.
2. **Unit checks**
   - Confirm that units are consistent and correctly recorded (e.g. metres vs centimetres; µS/cm vs mS/cm).
   - Correct unit errors before any analysis.
3. **Reference datum checks**
   - Confirm that groundwater levels are measured relative to a consistent reference point (e.g. top of casing, ground level).
   - Apparent step changes may be caused by changes in reference point rather than real groundwater change.
4. **Step-change checks**
   - Identify sudden jumps or drops that are unlikely to represent real change.
   - These may indicate sensor movement, damage, datum changes, or transcription errors.
5. **Missing and duplicate data checks**
   - Identify gaps in time series where data should exist.
   - Check for duplicate timestamps or repeated values, particularly in automated datasets.
6. **Manual–sensor cross-checks (where sensors are used)**
   - Take periodic manual groundwater level measurements at sensor sites.
   - Compare manual and sensor readings directly.
   - Where differences occur, trust the manual measurement to correct for sensor drift or movement.
   - Repeated corrections may indicate the need for sensor calibration, data correction, or replacement.
7. **Sensor diagnostics and system checks**
   - Review battery level, signal strength, and data transmission success.
   - Identify data drop-outs, irregular reporting, or internal sensor warning flags (where available).
8. **Spatial consistency checks**
   - Compare measurements with nearby boreholes or wells where possible.
   - Isolated outliers may indicate local errors or faulty sensors.
9. **Contextual consistency checks**
   - Compare groundwater data with related information such as abstraction records, pumping schedules, rainfall, or surface water levels.
   - Implausible timing or trends should be flagged for review.

WHEN QA/QC SHOULD BE CARRIED OUT

Incorrect or unchecked data can undermine confidence in the entire monitoring programme and lead to misinformed decisions with serious real-world consequences. To mitigate this risk, QA/QC should be carried out:

- When data are first received, particularly if downloaded or transmitted in batches.
- Automatically or periodically (manual review) for continuously received data.
- Again before analysis, reporting, modelling, or early-warning use.

Clear responsibility(s) for QA/QC should be assigned from the outset. Whatever the approach taken, when handling suspect data:

- Do not delete data by default.
- Flag suspect values clearly (e.g. “questionable”, “under review”).
- Record in a table or spreadsheet:
  - What was flagged?
  - Why it was flagged?
  - What action was taken (corrected, excluded, retained)?
- Where possible, retain raw (unmodified) data separately.

ANNEX A18: QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) CHECKLIST

A checklist of important QA/QC checks, typical issues identified and recommended actions. This can be setup in a spreadsheet alongside a log of changes made and why.

6.3 DATA ANALYSIS

Groundwater data analysis helps turn raw monitoring data into meaningful insights. But this work is often technically complex, especially when interpreting changes in water levels, abstraction rates, or water quality trends. In many humanitarian and low-resource settings, these skills may not be available locally. That’s why this section offers a basic orientation, links to further learning, and guidance for incorporating technical expertise into your project.

WHY GOOD ANALYSIS MATTERS

Without proper analysis, monitoring systems can fail to deliver impact or give misleading information. For example:

- Changes in water levels may be seasonal but could also signal over-abstraction.
- Salinity trends might reflect natural cycles or be an early warning of contamination.
- Pump runtimes may look normal but, when combined with falling water levels, may indicate supply stress.

By analysing these datasets together, WASH teams and water authorities can make better, evidence-based decisions. What this means in practice is having correct information at the right time, in a useable, easily interpretable format so it can **trigger a specific decision or action** by the responsible party.

WHO SHOULD DO THE ANALYSIS?

If your team includes a hydrogeologist or trained data analyst, they should take the lead on interpreting groundwater trends. If not, consider one of the following approaches:

- **Short-term external support:** Bring in a hydrogeologist or data expert during the pilot to set up analysis workflows and train staff.
- **Partner institution support:** Coordinate with national water authorities, universities, or NGOs who may already have analysis capacity. Specialised international actors such as IGRAC can also support national/local actors.
- **Online training or courses:** Options like the Rural Water Supply Network (RWSN) online courses or UNICEF/ International Rescue Committee (IRC) WASH systems academy may offer accessible learning to follow.
- **One-week intensive training:** A targeted capacity-building workshop led by a consultant may be more cost-effective than full-time hiring and support sustained institutional ownership.

If external support is used, always pair them with local technical staff to enable skills transfer and build longer-term capacity.

BOX 27: COMMON PITFALL
UNDERESTIMATING DATA ANALYSIS

It is a common pitfall to underestimate the technical expertise required for analysing groundwater monitoring data. Without sufficient in-house or partner capacity, valuable datasets may go unused or worse, misinterpreted, leading to poor decisions or missed opportunities.

Make sure that technical analysis needs are recognised early and addressed as part of the pilot.

WHAT ANALYSIS IS FEASIBLE?

While groundwater modelling may require advanced expertise, many of the most common and useful analyses can be done with:

- Microsoft Excel (or similar spreadsheet software).
- Visual plots of water level over time.
- Monthly abstraction totals by well.
- Comparisons between water level and rainfall.
- Simple anomaly detection or threshold warnings (e.g. groundwater falls below dry season average).

BOX 28: CASE STUDY

MADAGASCAR: HOW SIMPLE AND COMPLEX INSIGHTS ARE POSSIBLE FROM GROUNDWATER DATA

Figure 38 shows how groundwater level data can reveal both basic and advanced insights for water management. In this example from ACF's work in Madagascar, two monitoring wells were installed close to each other at similar elevation. Yet their water level responses are dramatically different because they tap into different aquifers separated by an impermeable layer - highlighting the importance of hydrogeological expertise in getting the full story.

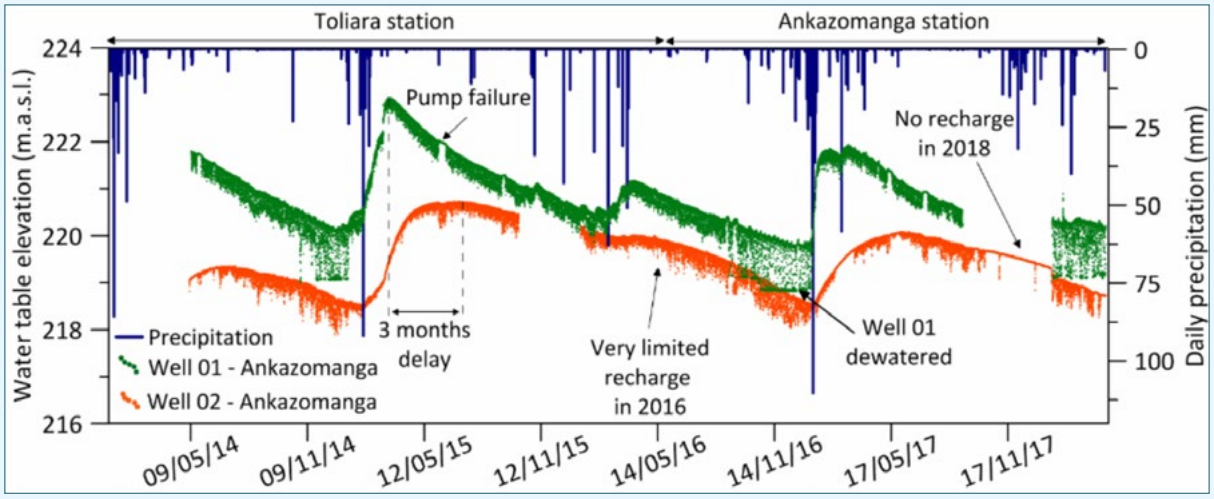

Figure 38: Two well hydrographs collected by pressure transducer in Madagascar. (ACF)

Simple insights:

Many WASH staff or local stakeholders could interpret key features in this plot:

- A clear ***pump failure*** in Well 01, causing the water level to rise.
- A ***three-month delay*** between rainfall and recharge in Well 02.
- Periods of ***very limited recharge*** (2016) or ***no recharge*** (2018).
- Dewatering of Well 01, signalling over-abstraction or aquifer stress.

More advanced analysis:

Specialist support (e.g., a hydrogeologist) can help teams use the same dataset for:

- **Understanding complex aquifer interactions** in fractured or karst systems.
- **Developing early warning triggers and abstraction limits** for drought or crisis response (e.g., low water levels could trigger water trucking).
  → **ACF** did this in Madagascar based on a trigger index equivalent to the popular Standardized Groundwater Index (SGI) – this raised alerts in bulletins if groundwater levels were unseasonably low
- **Calibrating groundwater models or water balances** to plan abstraction.
- **Creating piezometric maps** to visualise groundwater flow direction only if high precision (<10 cm) monitoring point elevation has been measured.

Basic plots like this are useful for everyone but some insights need solid geological review and technical guidance. Always check your data interpretation with the local context and, when possible, link to a partner with hydrogeological expertise.

The chosen methods of data analysis should be guided by the information needs defined during the scoping and design phases. Table 10 details key insights and their methods of analysis.

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
1) Water Level Monitoring Analysis				
Groundwater levels status (comparing current groundwater levels with historic values). **Two indicators commonly used: Groundwater level ranking and Standardised Groundwater Index (SGI)**	Statistical methods that use long-term groundwater level time series to assess the state of groundwater levels and identify emerging groundwater stress, providing early warning of groundwater drought or over-abstraction when levels are consistently below normal. **Ranking** categorizes groundwater levels (e.g. normal, below normal, above normal). **SGI** converts historical groundwater levels measurements into standards deviation.	Who uses it: Water resource managers, WASH planners, drought early warning systems, hydrogeologists. Applications: Early detection of groundwater stress or drought conditions; supporting seasonal preparedness; providing an objective threshold for triggering groundwater-related action in multi-hazard early warning systems.	Data needed: Groundwater level time series (ideally, 5-10+ years observed, or back-modelled such as by Veness et al., 2022 [14]). Result format: - Map of groundwater level ranking at monitoring stations. Aggregation can be done at aquifer level if sufficient representative monitoring points are available. - Hydrographs of time series of SGI values per well, typically monthly. Values below certain thresholds (e.g. –1.0, –1.5, – 2.0) indicate increasing severity of groundwater deficit. Hydrographs may be colour-coded to show severity bands.	Collect continuous or regular groundwater level data over multiple years (minimum 5–10 years for stable results). Use a statistical standardisation method such as SGI[15] to remove seasonal variation and show anomalies relative to long-term behaviour. Groundwater level ranking and SGI calculation can be done in Excel or automated on a platform (e.g. using Python or R). Methodological report and Python code for calculating the groundwater level ranking available at IGRAC[16] website and GitHub[17].
Borehole efficiency and optimal pumping rate for the well	The maximum safe pumping rate at which the well can operate without excessive drawdown or damage. It is determined by finding the point at which further increasing the discharge causes a disproportionate increase in drawdown.	Who: Water supply operators and engineers. Applications: Setting pump size and operation schedules; ensuring long-term well sustainability in community water systems.	Data needed: Step-drawdown test data – i.e. multiple pumping steps with recorded discharge rates and drawdowns at each step. Result format: Table/graph of drawdown vs. pumping rate, highlighting the optimal rate.	Conduct a step-drawdown test[18]: pump the well in increasing steps of flow and measure drawdown for each step. Plot drawdown against discharge to find the "inflection point" where drawdown begins rising non-linearly. That inflection indicates the optimal rate. (Guidance for analysis: use Jacob's method to separate well losses.)

14 - https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2022WR032165
15 - https://hess.copernicus.org/articles/17/4769/2013/hess-17-4769-2013.html
16 - https://un-igrac.org/wp-content/uploads/2024/12/CN_Reporting-methodology_GW-levels-2025_final-1.1.pdf
17 - https://github.com/UNIGRAC/Global-Reporting-Groundwater-Levels
18 - http://www.aqtesolv.com/pumping-tests/step-drawdown-tests.htm

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
Daily abstraction rate	The abstraction rate provides information on the current demand on the source and information on water usage patterns (peaks, averages).	Who Water scheme operators, utility managers, WASH program managers. Applications: Supporting water balance calculations; comparing supply against demand; licencing, charging and quotas.	Data needed: Flow rate measurements (via flow meter) and pump operating hours per day (or daily meter readings). Output: Recorded abstraction rate (e.g. in m^3/day). This can be tabulated by minute/ hour/day or plotted as a time series.	**Flow monitoring:** Install a water meter on the pump or use pump discharge ratings. Record the meter reading or calculate volume (flow rate × hours run) each day.
Comparison of rainfall data against seasonal aquifer response (water level variation between wet and dry seasons)	How the groundwater levels rise and fall in reaction to seasonal changes and precipitation. Understanding this helps in planning water infrastructure design and use by knowing how much the water table usually fluctuates throughout the course of the year.	Who: Water resource planners, rural water supply technicians, hydrogeologists. Applications: Anticipating seasonal water shortages (e.g. pre-dry-season planning); managing pump emplacement and pumping schedules; support recharge calculations.	Data needed: Continuous or frequent water level measurements and rainfall data. Output: Hydrographs (water level and precipitation vs. time) highlighting seasonal peaks and lows; summary statistics by season (e.g. average dry-season water level vs average wet-season level).	Time-series analysis: Plot groundwater level over time against daily or decadal rainfall data and mark seasons. This should be the 'static water level', not affected by nearby abstraction drawdown. Calculate seasonal means and ranges. For more rigour, apply time-series methods or groundwater hydrograph analysis techniques to quantify seasonal recharge and discharge cycles. (Open-source tools and USGS examples[19] analysing seasonal groundwater fluctuations are available for detailed methods.)
Long-term water level behaviour (trend over years)	The overall trend of the aquifer's water level over multiple years – e.g. is the groundwater level declining, stable, or rising? This shows the sustainability of the aquifer under current use and climate.	Who: Water authorities, environmental managers, hydrogeologists. Applications: Long-term resource planning and aquifer management (e.g. deciding if pumping must be reduced); detection of groundwater depletion or recovery; informing policy for groundwater protection and drought mitigation.	Data needed: Groundwater level records spanning years (from manual monitoring and/or logger data), ideally correlated with rainfall and abstraction records. Output: Long-term hydrograph (time series) over years/ decades; trend lines or statistical trend analysis (magnitude of change per year); reports indicating whether levels are dropping or stable.	**Trend analysis:** Plot multi-year water level data to visually assess the trend. Compute statistics or apply a trend test (e.g. linear regression, Sen's slope, Mann Kendall test for significance and/or a Change to Range CRI Index) to quantify the rate of change and its significance relative to historic patterns. Simple approaches involve comparing average levels year by year. There are dedicated groundwater data tools (some open-source) for trend analysis – for example, USGS's long-term monitoring techniques[20] as well as IGRAC[21, 22].

19 - https://pubs.usgs.gov/sir/2005/5168/pdf/sir2005-5168_6.pdf
20 - https://pubs.usgs.gov/circ/circ1217/pdf/circular1217.pdf
21 - https://github.com/UNIGRAC/Global-Reporting-Groundwater-Levels
22 - https://un-igrac.org/wp-content/uploads/2024/12/CN_Reporting-methodology_GW-levels-2025_final-1.1.pdf

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
Transmissivity of the aquifer	Transmissivity (T) indicates how much water can be transmitted horizontally through the aquifer (across a unit width) under a hydraulic gradient. A key measure of aquifer productivity (high T often implies high well yields).	Who: Hydrogeologists, groundwater consultants, water resource planners. Applications: Aquifer characterization); designing individual wells or larger well fields; input to groundwater models or contaminant models.	Data needed: Aquifer test (pumping test) data – usually a constant-rate pumping test with observation well(s) to capture drawdown over time at known distances. Output: A numeric value of transmissivity (units: e.g. m^2/day). Sometimes reported with hydraulic conductivity and aquifer thickness for more context.	**Aquifer test analysis:** Perform a controlled pumping test and apply aquifer formulas (analytical solutions). For example, use the Theis (1935) or Cooper-Jacob[23] method to match drawdown-time data from observation wells to type curves. Many open-access tools (spreadsheet templates, software like AQTESOLV) detail the procedure for calculating T.
Specific Capacity (SC) of the well	Specific capacity is a quick indicator of well performance, defined as the pumping discharge divided by the drawdown (Q/s, often in L/min per meter or gal/min per foot). Essentially, it tells how much water you get per unit of drawdown in that well. A higher SC means a more productive well.	Who: Well operators, drillers, hydrogeologists. Applications: Rapid assessment of well health immediately after drilling and during operation; comparing wells in an area; tracking well performance over time (a dropping SC can signal clogging or aging of the well and need for rehabilitation). It is also used in preliminary estimation of transmissivity and to help choose pump size.	Data needed: A stable pumping rate and corresponding drawdown measurement. Output: Specific capacity value (e.g. "5 m^3/hour per meter of drawdown"). Often documented right after drilling/test-pumping a well, and tracked periodically.	**Field measurement:** Pump the well at a constant rate for a set duration (e.g. 1 or 2 hours). Measure the drawdown (change in water level) in the well until it stabilises. Calculate SC = Q / s.]. **Usage in analysis:** SC can be used to estimate transmissivity roughly (empirical formulas, e.g. Logan's Method (1964) T=1.22×Q/s.
Aquifer storage (Storativity or specific yield)	The amount of water the aquifer stores and can release. In confined aquifers this is measured by storativity (S), a dimensionless fraction of water released per unit decline in head over a unit area. In unconfined aquifers, it is often given as specific yield (the drainable porosity).	Who: Groundwater modellers, hydrogeologists, water planners. Applications: Estimating the volume of groundwater available ("aquifer reserves"); predicting impacts of long-term pumping – e.g. how much the water table might drop if X volume is withdrawn; understanding resilience to drought.	Data needed: Typically derived from a **pumping test with observation wells.** One needs measurements of drawdown over time and distance. Output: A storativity value (dimensionless, e.g. 0.0005 for confined aquifer, or a specific yield percentage for unconfined). This might be reported in test analysis reports alongside transmissivity.	Aquifer test analysis[24]: Using the time-drawdown data from observation wells, apply methods like Theis curve matching or Cooper-Jacob straight-line method to solve for storativity.

23 - http://www.aqtesolv.com/cooper-jacob.htm
24 - http://www.aqtesolv.com/aquifer-tests/aquifer_properties.htm

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
Radius of influence, Cone of depression, Source Protection Zone	The radius of influence is the radial distance from the pumped well to the point where drawdown becomes negligible. It defines the size of the "cone of depression" around a pumping well. Understanding this helps assess the impact of a well on other water bodies or water users. It can also be used to determine Source Protection Zones to support regulation and protection of a public water supply.	Who: Hydrogeologists, wellfield designers, environmental regulators. Applications: Determining well spacing in a wellfield; assessing interference with nearby wells or springs; delineating protection zones and estimating area of influence for contamination risk (how far pollutants might be drawn in).	Data needed: Pumping test observations, ideally drawdown measured in one or more observation wells at various distances, or the time it takes for drawdown to stabilize. Alternatively, empirical formulas (requiring transmissivity, pumping duration, etc.). Output: A distance (in meters or kilometres) for the radius of influence. Sometimes a map showing the cone of depression footprint (circle) around the well.	Using aquifer parameters (T and S) from a pumping test, one can compute radius of influence. Empirical equations (e.g. Sichardt's formula) use parameters like transmissivity, storativity and pumping time to approximate the radius of influence. However, caution should be applied when estimating the radius of influence especially in large groundwater systems with long residence times.
Groundwater modelling	Groundwater models are developed from a conceptual understanding of the aquifer informed by field data, such as borehole records and geophysical surveys, and calibrated using observational data including groundwater levels, rainfall, and abstraction data to simulate aquifer behaviour under different conditions and assess future management scenarios.	Who: Water planners, hydrogeologists. Applications: Understanding long-term resource sustainability, testing scenarios (e.g. new wells, climate impacts), planning recharge or abstraction management.	Data needed: rainfall, land use soil type, geology, evapotranspiration, groundwater level data (minimum 1 year record, preferably 3 – 5 years), borehole records and pumping test data to provide aquifer property information. Output: Calibrated model files, simulated versus observed hydrographs, and groundwater water budget estimates.	Develop a conceptual model (flow directions, boundaries); input time-series data; run calibration to match observed water levels. Open-source tools like MODFLOW (via ModelMuse) or FEFLOW are commonly used. Intro: MODFLOW Guide[25]. Free IHE Delft online course "Introduction to Modflow and Model Muse"[26].
Groundwater contour maps	By measuring the static water levels in multiple wells across an area at one point in time, one can map out groundwater contours which will provide information on the slope of the water table, the direction groundwater is flowing.	Who: Hydrogeologists, environmental engineers, contamination specialists. Applications: Identifying which way a pollutant spill might travel in the groundwater; siting new wells up-gradient of potential contamination sources; understanding recharge and discharge areas; regional hydrogeological mapping for water resource assessments.	Data needed: Simultaneous (or near-simultaneous) water level measurements in a network of wells over the area of interest, along with coordinates and elevations (ideally, to a precision < 10 cm. Output: A **groundwater contour map** or potentiometric map (confined aquifer) –Often accompanied by arrows showing groundwater flow directions.	Collect static water level data from multiple wells (ideally on the same day to ensure comparability). Convert each measurement to elevation (e.g. meters above sea level) by subtracting depth-to-water from the well's known elevation. Plot these on a map and draw contour lines of equal head. The result is akin to a topographic map but for the water table.

25 - https://gw-project.org/books/getting-started-with-modflow/
26 - https://ocw.un-ihe.org/course/view.php?id=101

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
2) Water Quality Monitoring Analysis				
Water quality trends (temporal changes in groundwater quality)	How the groundwater's chemical quality changes over time. For example, are parameters like nitrate, pH, salinity, or contaminant concentrations increasing, decreasing, or stable? This helps identify gradual pollution, salinization, or improvements due to management. Trends can indicate whether an aquifer is getting contaminated or if interventions are effective.	Who: Water quality specialists, environmental health officers, resource managers. Applications: Tracking pollution plume movement or saltwater intrusion over time; adjusting water treatment needs (e.g. if salinity is creeping up); assessing the impact of land use changes on groundwater quality (e.g. agriculture, sanitation); regulatory compliance monitoring for drinking water sources.	Data needed: Periodic water quality sampling results from the well (for key parameters) over months or years. Output: Graphs of each parameter vs. time (e.g. concentration vs date); possibly a statistical analysis of trends (significant upward/ downward trends). Could include a summary table of parameter changes per year.	Compile time-series data for each water quality parameter. Plot them to visually inspect changes. Use statistical methods to confirm trends – e.g. linear regression for gradual changes or the Mann-Kendall test for monotonic trends. It is important to have enough data over a sufficient period (often 5–10+ years) to distinguish true trends from seasonal variability. Guidelines (e.g. EU Water Framework Directive guidance[27]) are available for conducting trend analysis on groundwater quality data, explaining how to account for seasonal effects and which statistical tests to use.
Water quality compliance (safe drinking water check	Comparison of groundwater quality monitoring data against drinking water standards or other relevant water quality guidelines. Essentially, this is an assessment of the water's fitness for use (potability for humans, or suitability for irrigation, etc.) by comparing measured parameters against health-based limits. It can reveal if the aquifer is affected by contaminants (e.g. arsenic, E. coli, nitrates) beyond acceptable levels.	Who: Public health officials, WASH program managers, water supply operators. Applications: Ensuring the water is safe for consumers – e.g. deciding if treatment or an alternative source is needed; routine surveillance of water points in humanitarian contexts; regulatory reporting to demonstrate compliance with national standards; identifying emerging contamination issues before they worsen.	Data needed: Water quality test results for relevant parameters (chemical, microbial) and the standard or guideline values for those parameters (e.g. WHO or national drinking water standards). Output: A comparison report or table – typically listing each parameter, the measured value, and whether it is within safe limits (often color-coded or flagged if exceeded).	For each sampling event, compare the lab results to established Maximum Contaminant Levels or guideline values. This is usually done by referencing a standards chart. Any exceedances are noted. No complex "analysis" beyond comparison is required, but it's a key monitoring outcome. Over time, track compliance status – e.g., persistent rising trends approaching a limit might trigger action. (Resources: WHO Drinking Water Quality Guidelines[28] and local regulatory standards documents provide the thresholds and recommended monitoring approaches.)

27 - https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/7a95729a-44e9-4996-b993-7a95a58fc75a/details

28 - https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/drinking-water-quality-guidelines

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
3) Water User Survey Analysis				
Community water use (demand) assessment	Information on how the community uses groundwater – for example, how much water is drawn per person per day, peak times of use, and total number of users. This insight quantifies demand on the groundwater source. It can highlight if usage is within the well's capacity or if demand spikes at certain times (e.g. dry season or morning hours). Essentially, it's understanding the human side of the water balance – "How is the water being used?"	Who: WASH project managers, humanitarian coordinators, water supply planners. Applications: Designing water supply systems (ensuring the well and pump can meet peak demand); water rationing or scheduling if needed (e.g. if a well can only support X liters/day sustainably); identifying needs for additional sources or storage when community grows; and providing context for abstraction data (high use might explain water level drawdown trends).	Data needed: Survey data from water users – could include household surveys on water collection (how many jerrycans per day, etc.), observations of pump usage frequency, and population figures. In some cases, flow meters on communal taps or pumps help quantify volumes used. Output: An estimate of per capita use (liters/person/day) and total daily abstraction by the community (which should align with the measured "daily abstraction volume" if available). Possibly charts of usage vs time of day or season.	**Water user surveys & monitoring** (e.g. **ANNEX A20**): Conduct surveys or interviews to understand water fetching habits (e.g. each household collects 4 jerrycans of 20L per day). Tally the number of households or users of the source. Use this to calculate total demand. Cross-check with any meter readings or bucket counts at the well. For accuracy, surveys might be done in both wet and dry seasons to capture seasonal demand changes. For qualitative responses, thematic analysis methods[29] can be used to tally common responses or findings in the data.
User perceptions & satisfaction (water user survey)	Qualitative and quantitative insight into how users perceive the groundwater supply's quality and reliability. This can include community opinions on whether the water is good (taste, appearance), if the supply is adequate, how often the well fails or runs dry, and their willingness to pay for improvements. Such surveys capture local knowledge and concerns that raw data might miss.	Who: Humanitarian project officers, water service providers, NGOs in WASH sector. Applications: Identifying issues needing attention (e.g. if many users fear the water is unsafe, one might test for contaminants; if reliability is an issue, maybe plan for backup sources or maintenance); measuring the success of a water project (community satisfaction); understanding socio-economic factors like ability to pay for water services.	Data needed: Interviews or questionnaires data – topics often include water quality perception, frequency of outages, queue times at the well, satisfaction levels, and any suggestions/ complaints. Also data on willingness-to-pay or community contributions, if relevant. Output: A summary report of survey findings, possibly with ratings (e.g. % of users who consider water quality "good" vs "poor") and direct quotes or comments. This insight is narrative but can be quantified through survey statistics.	Water user survey methods: Design a questionnaire or key informant interview to collect information on water user experience. Conduct the survey with a representative sample of the users. Analyse the responses by tallying common answers and noting key concerns. The data gleaned, e.g. perceived water quality, trust in the water provider, ability to pay, provides context to technical data. For qualitative (words, not numbers) responses, thematic analysis can extract important insights from the data. A study by Veness and Buytaert (2025)[30] used simple qualitative semi-structured interview and thematic analysis to analyse groundwater monitoring challenges in the Horn of Africa.

29 - https://us.sagepub.com/en-us/nam/the-coding-manual-for-qualitative-researchers/book273583
30 - https://www.sciencedirect.com/science/article/pii/S1462901125000309?via%3Dihub

DATA INSIGHT	EXPLANATION	USERS AND APPLICATIONS	OUTPUT FORMAT	ANALYSIS METHOD
Water security index (e.g. HWISE, WIA)	Tracking household or community-level water security through a standard index like the Household Water Insecurity Experiences Scale (HWISE).	Who: WASH program managers, researchers. Applications: Complementing technical data with social indicators; measuring impacts of interventions.	HWISE scorecards; trend reports.	Conduct household survey, score responses using HWISE method. The Household Water Security Experiences (HWISE) Scale survey user manual can be found here[31]. Water Insecurity Analysis (WIA[32]) is a sector-wide framework designed to inform evidence-based decision-making across the humanitarian–development continuum.

Table 10: Common data insights from groundwater monitoring data and the methods of analysis required to generate them.

6.4 COMMUNICATION OF DATA ANALYSIS

Producing good groundwater monitoring data and robust analysis is only part of the job. For monitoring systems to deliver value, the results must be communicated clearly, regularly, and in formats that match the needs and capacities of each user group. It is equally important that the results of the monitoring programme are communicated back to those responsible for collecting the data. Providing regular feedback helps maintain motivation and engagement by demonstrating how the information they collect is being used to support decision-making and groundwater management. It also reinforces the importance of accurate and consistent data collection, encourages a sense of ownership, and can improve the overall quality and sustainability of the monitoring programme.

Different stakeholders often have very different information needs and levels of technical knowledge. Some may want raw data files for further analysis, while others may only want a simple chart, dashboard, or a few key messages. **Table 11** summarises typical data format requirements for major stakeholder groups in an example data communication protocol (**ANNEX A19**). Although examples are given, remember that these requirements are specific to context and should be tailored to the project's scoping and user-design process.

BOX 29 - COMMON PITFALL
COMMUNICATION BREAKDOWN

A common pitfall is failing to maintain strong lines of communication. When data outputs are inconsistent, unclear, or too technical for some users, data goes unused and the expected value of the system will not be achieved. Keep communication simple, regular and tailored.

Whenever in doubt, test your outputs and get feedback from the actual users. A simple feedback session can reveal if they find the format clear, whether the frequency is right, and how they want to receive updates.

Figure 39: Systems that are managed from a distance are especially at risk of communication failures with the most important stakeholders – those using the monitored groundwater source. (ChatGPT+, 2025)

31 - https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2020/pdf-2020-9090-1-HWISE_User_Manual.pdf

32 - https://www.washcluster.net/WASH-insecurity-analysis#:~:text=The%20WASH%20Insecurity%20Analysis%20%28WIA%29%20is%20a%20sector-wide,to%20inform%20evidence-based%20decision-making%20across%20the%20humanitarian%E2%80%93development%20continuum.

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RECEIVING STAKEHOLDER GROUP	DATA FORMAT	FREQUENCY	HOW COMMUNICATED	RESPONSIBLE PARTY
National Water Authority	Raw monitoring data files (Excel/ Comma-Separated Values (CSV)); standardised data templates for national database upload; detailed monthly status reports; issue reports for urgent borehole problems; hydrographs and maps if needed	Monthly summary plus ad-hoc urgent alerts	Email, official letters, shared cloud folder, quarterly coordination meetings with Ministry focal points	Lead hydrogeologist and data manager; country programme manager for sign-off
Local Water Authority / District Office	Site-specific borehole status sheets; summary tables of key parameters (e.g. water levels, abstraction); simplified charts; verbal briefs for local decision-makers	Monthly, at start of month	Hard-copy printouts dropped at district office; local WhatsApp group for urgent issues; verbal updates at district WASH meetings	Local technician or district WASH coordinator
Humanitarian NGOs & UN Agencies	Short situation briefs; visual trend summaries (graphs, maps); recommendations for programming (e.g. risk of supply shortage); raw data if requested for donor reporting	Biweekly or monthly depending on field context	Email updates to WASH cluster mailing list; short slide deck for cluster coordination meetings; shared Google Drive folder for background data	NGO Monitoring & Evaluation officer with technical support from hydrogeologist; local or national WASH cluster
Local Water Utility (small towns)	Pump runtime logs; daily abstraction volumes; alert sheets for pump faults; flow meter records; simple "traffic light" chart showing well status	Weekly, on Monday morning	Printed pump station report; laminated charts on site; text or call to pump operator for immediate faults	Utility operations supervisor; field technician for site visits
Private Borehole Operators	Individual borehole performance sheets; manual water level checks summary; abstraction limits guidance; recommended maintenance actions	Monthly or as per local bylaws	Printed reports; SMS reminders for maintenance; 1:1 meetings with operator groups	Local borehole inspector or water officer
Community Water Committees	Simple posters showing borehole health; verbal updates; actions needed (e.g. reduce use in dry season); local language handouts explaining risks	Monthly at community meeting	Community meeting (facilitated by WASH officer); noticeboard posters at water point; door-to-door visits if needed	Community WASH facilitator; local trusted technician
Water Users / Households	Basic reassurance that supply is safe; clear guidance if there is a risk (e.g. contamination); visual reminders on good practice (e.g. queuing, payment); clear fee info if applicable	As needed; notice immediately for water quality issues	Verbal announcements; village meeting; simple posters in local language with icons	Local water committee leader; supported by WASH programme staff
Donors / Development Banks	High-level progress reports; results summaries; trend lines showing how monitoring improves sustainability; raw data files for independent verification; analysis of system's value-for-money	Quarterly or aligned with donor reporting cycle	Formal donor reports; slide decks for review meetings; shared cloud folder for raw data	Programme manager and finance officer; data manager for technical annexes
Research Institutions / Universities	Full raw datasets (CSV, Excel); metadata documentation; clear explanation of methods; any model files if developed; interpretation notes for context	Upon request or end of project phase	Shared drive with restricted access; formal data sharing agreement or MoU	Data manager with project PI; research partner focal point

Table 11: Example protocol for data communication (template available in **ANNEX A22**).
The table is filled with typical data communication requirements for major stakeholder groups.

KEY REMINDERS FOR EACH LINE:

- Match the level of detail and format to what the stakeholder can actually use.
- Keep frequency realistic. Too often is burdensome; too rare loses relevance.
- Always assign a clear internal responsible party to keep communication reliable.
- Continuous feedback and adaptive improvement of the design is always required.

ANNEX A19: DATA COMMUNICATION PROTOCOL EXAMPLE

Example protocol for data communication. The table is filled with typical data communication requirements for major stakeholder groups.

6.5 EVALUATION AND REPORTING

A pilot groundwater monitoring system should always be evaluated and adaptively improved until it is ready for expansion. Evaluation of a pilot is the same process as a full monitoring system: it requires a survey of the actors that are participating in monitoring activities, as well as all actors using the groundwater monitoring data.

6.5.1. EVALUATE THE SYSTEM'S OPERATIONS, DESIGN AND USE

Firstly, review how the **operational aspects** are performing:

- Are all monitoring tasks being completed as planned?
- Are manual measurements taken consistently and used for calibration?
- Are equipment failures managed well?
- Does data get cleaned, analysed and communicated on time?
- Are communication outputs shared in the right format for each user?
- Do expected stakeholders actually use the data? Is it understandable and trusted?
- Are the incentives for each implementing partner realistic and met?
- Are capacity building efforts working – is there enough capacity built in key roles for them to continue successfully without the additional external support that is typically on hand during setup?

These questions should be measured against the Key Performance Indicators (KPIs) agreed during the monitoring system's design stage. Underperforming indicators help identify what should be adapted before scaling up: e.g. more staff training, clearer roles, improved data management systems, or changes in communication formats.

6.5.2. EVALUATE THE SYSTEM'S COSTS AND VALUE

- **What did the pilot cost overall?**
  Record total costs for equipment, installation, staffing, training, local partner time, data management and communication.
- **What benefits have been delivered so far?**
  Gather clear examples: has the system provided early warnings, prevented well failures, improved abstraction efficiency, supported community trust, or helped secure new funding?
- **Link to real-world impacts.**
  Combine monitoring data with WASH and socio-economic indicators to show how monitoring supports improved services on the ground. As far as possible, try to compare system benefits with the costs to assess the **value proposition**.

6.5.3. CHECK READINESS TO EXPAND

Before committing to scale up, answer these key questions:

- **Are operational risks addressed?**
  Are known weaknesses being tackled, or at least understood, so they don't grow bigger at scale?
- **Is the system providing genuine value to intended users?**
  Does it meet the priority information needs that were identified at design stage?
- **Is the system running sustainably?**
  Are all key monitoring system deliverables, data collection, analysis and communication, being met consistently?
- **Are incentives and capacity needs satisfied?**
  Are all partners still motivated and capable to carry out their tasks long-term?

Templates for monitoring system evaluation are provided in **ANNEX A20**. A first template is provided for evaluating each individual monitoring activity, by surveying those involved in operating or using data from the activity.

A second template is provided for analysis of the monitoring system as a whole, once the survey of activities has been completed. The results of the second template can be used for reporting to those funding the system to summarise progress, value and ongoing risks in the monitoring operations.

ANNEX A20: MONITORING SYSTEM EVALUATION TEMPLATES

The first template is for evaluating each individual monitoring activity by surveying those involved. A second template is provided for analysis of the monitoring system as a whole once the survey of activities has been completed. The results of the second template can be used for reporting to those funding the system to summarise progress, value and ongoing risks in the monitoring operations.

6.6 ADAPTATION OF DESIGN

Once you have completed the periodic pilot evaluation, take time to review what worked well and what needs to improve. The goal of this step is to make practical adjustments so the system can operate better and deliver more value if you continue or expand it.

Good practice:

- Use the findings from your evaluation (underperforming KPIs) to identify exactly **which activities** need to change: for example, field monitoring routines, data cleaning, how results are shared, or how partner incentives are managed.
- Share this feedback directly with the person or team responsible for each activity. Discuss the results together to agree on **realistic action** points and **new KPIs**.
- **Keep it simple**: every action point should have a clear expected outcome. For example, "Reduce manual data entry errors by adding a double-check step" or "Improve data sharing with local authorities by switching from PDF reports to Excel files".
- If using **key performance indicators (KPIs)** for individual activities or responsibilities, use them to track whether changes are then working. This could be something like fewer missing data points, faster reporting, or more regular meetings with stakeholders.
- **Follow up regularly**. Short progress updates help everyone see what has improved and what still needs support.

Document your adaptation plan so that it is easy to review in the next evaluation, and so future teams can learn from the adjustments you made.

6.7 STAKEHOLDER MANAGEMENT AND CAPACITY BUILDING

Successful groundwater monitoring relies on good relationships, clear roles, and ongoing capacity strengthening. Each phase of the project should build towards a point where local partners and institutions can manage the system sustainably without external support.

6.7.1. KEEP TRACK OF KEY STAKEHOLDERS

It is common for a monitoring programme to rely on a small number of motivated individuals or local champions such as a trusted community volunteer, a district water officer, or a committed local technician. Losing track of these people during staff turnover or handover periods can jeopardise progress.

Good practice:

- Create and maintain a simple stakeholder database, noting each stakeholder's name, role, contact details, responsibilities, level of engagement, and if relevant, their ongoing performance in KPIs for which they are responsible.
- Log key communications with them (e.g., training provided, issues raised, agreements made).
- Review and update this database regularly.

A template for this Stakeholder Log is provided in **ANNEX A21**.

ANNEX A21: STAKEHOLDER COMMUNICATION EXAMPLE

Use this simple log to keep track of all stakeholders involved in the monitoring system. It helps maintain relationships, record key communications, and support smooth handover or continuity.

6.7.2. BUILD CAPACITY OF DATA USERS

Many partners need more than just raw data. They need the skills to understand, interpret, and act on it. The previous evaluation stages should identify which users may not have sufficient capacity to interpret or use the data, and can be targeted with capacity building trainings.

Practical ways to build data user capacity:

- Run short refresher sessions to help key stakeholders understand data outputs (e.g., what a falling water level trend means).
- Produce simple aids, tutorials or visual explanations that make sense for different literacy levels.
- Arrange practical field visits or community workshops so local target data users can see how the monitoring system works in practice.

6.7.3. BUILD CAPACITY OF THOSE OPERATING THE MONITORING SYSTEM

Technicians, volunteers, or local staff must have the technical skills and resources to do their tasks confidently and safely. This includes:

- Proper use of field equipment (e.g., sensors, dip meters, flow meters).
- Basic troubleshooting and calibration.
- Safe water quality sampling and data logging.
- Data cleaning, analysis, and secure storage.

Good practice:

- Conduct periodic refresher training (not just once).
- Use clear standard operating procedures (SOPs), based on best practices guidance (such as this document).
- Provide supportive supervision and regular feedback.

6.7.4. START TO BUILD THE CAPACITY OF THE INSTITUTION(S) THAT WILL EVENTUALLY OWN THE SYSTEM

In many contexts, a local or national water authority will eventually take on the monitoring system. For handover to work, the institution needs:

- Staff trained in both the technical and management aspects.
- Agreed roles, budget lines, and a clear reporting structure.
- IT systems and data storage that match national standards and are, ideally, inter-operable (data can be transferred) with other national environmental monitoring systems.

Start training and involving these institution(s) from the pilot onward, so they gain hands-on experience and a sense of ownership.

BOX 30 - COMMON PITFALL
POOR COMMITMENT TO CAPACITY BUILDING

A major pitfall is treating capacity building as a one-time training or an afterthought.

Without enough investment in skills and systems:

- Data users don't know how to interpret or act on the information.
- Operators struggle to keep the system working properly.
- The institution that should adopt the system later won't have the trained staff, digital infrastructure, or budget needed to run it independently.

Figure 40: Capacity-building requires genuine intent to ensure measurable learning outcomes, relevant to completing monitoring responsibilities, are reached. (ChatGPT+, 2025)

7. IMPROVEMENT, EXPANSION & HANDOVER

7.1 SCALLING-UP

A pilot groundwater monitoring system is just the starting point. Once you've learned what works, the next step is to expand, carefully, so that other areas and individuals can benefit too.

At this stage, the system should go beyond simply collecting data. It should reliably deliver trusted insights that help all stakeholders make better decisions, now and in the future. Recall **Figure 17** in **Section 4.3.2** – it should also maintain **incentives, capacity building commitments, feedback loops and communication of data outputs.**

1. **REPEAT THE PILOT IN PRIORITY AREAS**
   Use what you learned to roll out monitoring in areas (could be other sections of a displacement camp, different districts or catchments), based on agreed priorities (e.g. highest demand, biggest risks, or most vulnerable communities).

2. **ADAPT TO LOCAL NEEDS**
   Remember: each new area will have different users, risks and capacities. Take time to adapt the monitoring design, outputs and capacity building to fit local realities. Use the same local user design approach as the pilot to make sure stakeholders actually want and use the data.

3. **DECENTRALISE RESPONSIBILITIES STEP-BY-STEP**
   As the system grows, don't overload yourselves or the central institution managing the monitoring. Share responsibilities with local actors, like community volunteers, district water officers or local water committees, as early as possible and seek to systematically transfer responsibilities and know-how to them over time. For example:
   - Train local technicians to handle routine monitoring and sensor checks.
   - Let local teams manage basic data cleaning and reporting.
   - Build skills and confidence through capacity building so local authorities or committees can start to analyse simple trends and make decisions.

   This decentralisation reduces the burden on the institution that will eventually take over the monitoring system and makes local stakeholders feel true ownership.

4. KEEP EVALUATING AND IMPROVING

As you expand, continue regular evaluations and feedback sessions. These help you check that the monitoring system still delivers the right information, meets stakeholder expectations, and provides real value.

Use the same approach followed for the pilot, repeating evaluations and adaptations for each monitored area at an agreed interval (such as quarterly). Use the template in **ANNEX A20** as a guide for what to evaluate.

5. BUILD LONG-TERM CAPACITY FOR HANDOVER

Every round of expansion should strengthen the skills and systems needed for the monitoring network to be fully managed locally. Keep building up partners' capacity so that, when the time comes, the system can be handed over smoothly and continue running without external support. Use the **ANNEX A22** to monitor skills capacity.

BOX 31 - COMMON PITFALL

CHECKLIST: WHAT SHOULD A FULLY OPERATIONAL SYSTEM HAVE?

- **Full coverage:**
  - All agreed priority areas and boreholes are included in the monitoring network
  - All necessary equipment is installed, functional and maintained
- **Data management in place:**
  - All monitoring data (automated and manual) is digitised, stored securely, and regularly backed up
  - Data management systems are simple, clear and accessible to relevant institutions
  - Raw data is easy to export for use in national or regional water databases
- **Reliable data analysis and communication:**
  - Regular data cleaning and analysis processes are happening on schedule
  - Clear communication channels are active, so data insights reach all identified user groups in formats that match their information needs
  - Outputs are updated and adjusted based on stakeholder feedback
- **Operational sustainability (incentives and capacities maintained):**
  - Roles and responsibilities for all tasks, from daily measurements to dashboard updates, are clear and agreed
  - Local stakeholders are trained, confident and motivated to carry out their roles
  - Data users have sufficient capacities to access and use groundwater data
  - Any required incentives, funding or in-kind support are in place
- **Periodic feedback and improvement loop:**
  - There is a standing process for checking whether data is still useful and trusted
  - Stakeholder feedback is gathered at regular intervals and used to adapt the system
  - Practical KPIs and targets are tracked to maintain quality and trust
- **Institutional capacity being built for long-term ownership:**
  - The institution that will lead the system in the long term is approaching the stage where it has the people, systems and budget lines in place
  - Formal agreements or MoUs are already in place for data sharing and collaboration with partners

NEXT STEPS FOR INTEGRATION AND LONG-TERM OPERATION

Once the monitoring system is fully operational and has demonstrated its value, this is the right moment to take steps that will secure its sustainability and local ownership for the long term.

BOX 32 - COMMON PITFALL
LOSS OF INSTITUTIONAL MEMORY

A common pitfall is **failing to properly integrate the groundwater monitoring system into existing institutions.** Too often, good projects operate in isolation as stand-alone activities managed by a few committed individuals. When those key people leave or funding runs out, the project collapses because there is no wider institutional memory, no agreed budget line, and no embedded process to keep it going.

Figure 41: Capacity-building requires genuine intent to ensure measurable learning outcomes, relevant to completing monitoring responsibilities, are reached. (ChatGPT+, 2025)

At this stage, you should focus on **three key actions**:

- **Institutional Integration (Section 7.2)**
  Actively integrate the groundwater monitoring system into local or national water governance frameworks. This means formalising its place within government structures, ensuring it aligns with national data standards and reporting requirements, and embedding it in policies, plans, existing environmental or hydrological data platforms, and budget lines. This institutional integration, which is central for sustaining the system, should be considered from the beginning of the water monitoring program.

- **Securing Long-Term Financing (Section 7.3)**
  Use the evidence you have gathered: costs, clear benefits, and the system's value proposition, to develop a viable business case for its continued operation. This is essential to attract stable funding, whether through local government and partner budgets, utility revenue, community contributions, donor partnerships, or external finance mechanisms.

- **Handover Responsibilities (Section 7.4)**
  Formally transfer responsibilities from any temporary implementing partners such as international NGOs or intergovernmental organisations to local and national institutions. These stakeholders should now have the capacity, systems and incentives in place to manage the monitoring system effectively into the future.

7.2 INSTITUTIONAL INTEGRATION

To make it sustainable for the long term, a monitoring system must become a recognised part of how local or national institutions manage water. This might take the form at a local level of integration into a Water Basin Management Plan. At the national level, monitoring sites and data may be incorporated into a national groundwater or water resources monitoring network coordinated by the responsible government institution. Ideally, a lot of the groundwork will have already been done during the scoping and design phase.

CONTINUE FORMAL DISCUSSION ABOUT INTEGRATION

- As the monitoring programme is expanded and refined, continue to work with government counterparts to establish how it will be formally integrated into the responsible institution. Ideally, this institution should have been engaged from the design and pilot stages, allowing ownership, capacity and operational procedures to develop alongside the programme. Despite careful planning, new technical, institutional and financial challenges are likely to emerge as the programme evolves. Maintaining regular dialogue and adapting the monitoring system in response to these challenges will help ensure its long-term sustainability and successful institutionalisation.
- Clarify who will hold overall responsibility (who will own the system), who will maintain staff positions for key roles (e.g. data manager, field technicians), and how existing operational procedures will be preserved.

PLAN FOR DATA MANAGEMENT TOO

- If you have developed a digital platform, discuss how this can become, or be integrated with, the government or utility's *primary platform* for storing and managing groundwater data. This reduces duplication and ensures data stays available to the right people.

MAKE MONITORING A ROUTINE PART OF THE WATER SECTOR

- Institutionalisation often works best when it is supported by **clear legal or policy frameworks.**
- Work with decision-makers to encourage public legislation that makes groundwater monitoring mandatory for certain types of boreholes; for example, those with high discharge rates or significant public use. This helps ensure new and existing wells are properly tracked.

SUPPORT THE DRILLING, UTILITY AND PRIVATE SECTORS TO COMPLY

- Enforcing these rules can be challenging. Drilling contractors, supervisors, and private operators may worry about the extra costs and oversight.
- Take a constructive approach: work with them to build trust, share clear monitoring requirements, and help them see how contributing data can strengthen their reputation.
- For example, sharing high-quality drilling and groundwater data can become part of their *professional accreditation* with government regulators. In turn, this can help them win new business with investors or clients looking for reputable contractors.

WORK WITHIN STRATEGIC FRAMEWORKS

- Where possible, groundwater monitoring programmes should be developed within, or contribute to the creation of, strategic frameworks or roadmaps that provide a coordinated vision for the development, implementation and long-term management of water resources monitoring. These frameworks help communicate a shared strategy, align the activities of different organisations, and provide a common reference for all stakeholders involved in supporting water resources monitoring.
- A strategic framework should identify priority river basins or aquifers for monitoring, define the objectives of the monitoring programme and the intended use of the data, establish institutional roles and responsibilities identify capacity building and infrastructure requirements, and include a phased, costed implementation plan. By providing a clear strategic direction, such frameworks help coordinate investment, reduce duplication of effort, and support the long-term sustainability of monitoring programmes.

7.3 LONG-TERM FINANCING / ECONOMIC MODEL

No groundwater monitoring system is truly sustainable without a clear plan for how its **operating costs will be covered** once external project funding ends.

Initial funding commitments for a monitoring project, especially when led by international humanitarian organisations, are often made as short or medium-term commitments to setup the system to the operational phase, with a shared understanding that the long-term model of financing will eventually need to change.

This means moving beyond short-term grants to a long-term financial model that blends different funding sources and keeps the system running for years to come.

START WITH WHAT YOU ALREADY HAVE:

- Use the results of your cost-benefit evaluations to build a clear **business case** that shows how the system delivers value – for example, by reducing emergency response costs, improving water security, or supporting new investments.

ENGAGE PARTNERS EARLY:

- Keep in mind partners to which the system is delivering the greatest value, as well as the access to resources that each partner has. Note that institutional partners in humanitarian contexts may have limited capacity.
- Meet with partners, water users, and beneficiaries to explore their **willingness to contribute**, whether financially or in-kind (through actions, equipment and services). For example, local authorities may cover technician salaries or transport; universities might provide technical support; community committees might fund basic maintenance. Your records of cost-benefit through periodic evaluations will be helpful in communicating the respective value of groundwater monitoring in these conversations.
- Keep a clear record of these conversations and note potential contributions, so you can turn them into formal agreements or funding proposals.

BUILD CAPACITY FOR ONGOING RESOURCE MOBILISATION:

- External funding presents opportunities to upgrade, expand or maintain the system. This could include applying for new grants, climate or resilience funds, or even concessional loans if appropriate.
- Make it someone's clear responsibility within the institution managing the system to **prepare funding applications** as part of their paid time, not as an extra task. This helps ensure the system stays well maintained and has room to grow when new opportunities arise.
- Funding applications should be tailored to the specific interests of the funder. Evidence from evaluations of the system's value proposition and evidence of strong partnerships are critical to the strength of the application.

CONSIDER A BLENDED FINANCE APPROACH:

- There is rarely a single funding source that covers all costs long-term. Instead, aim to build a mix of public funding (e.g. local government & relevant ministry budgets), donor or development finance (e.g. climate resilience projects), and in-kind contributions.
- Think creatively about who benefits from the monitoring system and how they could fairly contribute to it.

Start building this financing plan while the system is still expanding, not afterwards. This helps keep momentum and shows funders that there is a clear path to sustainability. A strong business case, clear cost figures, and realistic funding commitments will make it much easier to secure the resources needed to keep the monitoring system running and growing over time.

7.4 HANDOVER RESPONSIBILITIES

A gradual, not rushed, handover is one of the most important final steps for ensuring that a groundwater monitoring system keeps working well after the initial project ends. But a successful handover only happens when the right capacity, trust and systems are in place. Handover should include, as well as technical capacities (operations, maintenance, data analysis and data sharing), the capacity to approach donors in order to secure the system in future.

Handing over is not about stepping back overnight. It is about a gradual, supported transition that sets up local institutions and staff to run, maintain and expand the system for years to come.

BUILD CONFIDENCE IN LOCAL CAPACITY FIRST

- Handover should only begin when you are confident that enough capacity has been built.
- The local monitoring staff and partner institutions must be able to manage their responsibilities **independently**, and ideally be capable of training others as new staff come on board.
- Think of this like an accreditation system: the goal is to move from basic understanding to *advanced understanding*, where people can **teach** the tasks to others.
- You can use a simple skills checklist or competency framework (see **ANNEX A22**) to help assess when teams are ready.

ANNEX A22: SKILLS CAPACITY CHECKLIST EXAMPLE

Use this checklist to assess local staff, technicians, and partner institution capacities to fulfil groundwater monitoring responsibilities. Mark the level of capacity demonstrated for each responsibility: Awareness (A), Experience (E), or Mentor-level (M) for ability to train others.

CLEARLY DOCUMENT ROLES AND RESPONSIBILITIES

- As you finalise handover, make sure there is no confusion about who does what, who reports to whom, and who pays for what.
- Update formal agreements, MoUs, or standard operating procedures as needed.

KEEP KEY TECHNICAL SUPPORT IN PLACE IF NEEDED

- Some external technical partners may still play a role. For example, the digital platform provider may continue to offer hosting and updates, or external data analysts might help with complex tasks until internal capacity grows.
- This is fine, as long as these partners are **properly resourced**, and their responsibilities are clear.
- Externalising some aspects of the monitoring programme may be a very useful way of ensuring long term operational success. Service contracts with private sector entities to support the operation and maintenance of monitoring systems has been proven to be one good way to ensure long term sustainability. Externalising digital management providers or data analysts might also help authorities with complex tasks until internal capacity grows.

8 DISCUSSION

This final section looks beyond the practical steps to consider some of the **wider lessons and strategic issues** that often shape the long-term success, or failure, of groundwater monitoring systems. These reflections draw together ideas and recommendations that can help both practitioners and decision-makers plan for the future.

The discussion is organised into **three short parts**:

- **The Challenge of Sustaining Monitoring Systems (Section 8.1)**

Why do so many groundwater monitoring systems fail to keep working over the long term? This section explores common pitfalls, the realities of operational costs, staff turnover, shifting priorities, and what this means for realistic planning.

- **Decentralisation as a Pathway to Sustainability (Section 8.2)**

This section highlights how decentralising responsibilities from national-level water authorities down to local technicians, community committees, or municipal utilities can help spread risks, build trust, and make monitoring systems more resilient over time.

- **Future Directions to Improve Feasibility (Section 8.3)**

Finally, this section looks ahead. What can implementers, governments, donors, and researchers do to make groundwater monitoring more feasible and practical in the places it is most needed? From technological innovations to better funding models, this part shares practical ideas for strengthening groundwater monitoring in the years ahead.

8.1 THE CHALLENGE OF SUSTAINING MONITORING SYSTEMS

Groundwater monitoring brings enormous potential benefits, but it is also technically and institutionally challenging. In many contexts, even well-designed monitoring programmes struggle to keep operating once the initial funding ends or key staff move on.

Recalling our interviews and lessons captured in **Figure 11** (**Box 5**), which show that many systems fail for reasons that repeat again and again: gaps in technical skills, loss of institutional memory, weak incentives for local partners, or poor communication of the data to decision-makers.

BE REALISTIC ABOUT FEASIBILITY

In some contexts, especially fragile, resource-constrained or remote settings, a full, high-tech monitoring system may simply not be feasible. It is far better to **under-promise and deliver** than to over-promise with complex plans that collapse after a few years.

DON'T UNDERESTIMATE TECHNICAL CHALLENGES

Maintaining continuous data collection is only half the job. The real value comes when the data is turned into genuinely useful insights, and shared in ways that local users understand and trust. This two-way process can be demanding: sensors need regular upkeep, communications must be reliable, and users need ongoing support to use the information well. Many of the **common pitfalls** discussed earlier, such as poor calibration or delayed outputs, show how easily systems break down when these tasks are neglected.

DESIGN WITHIN REAL LIMITS

This is why the **scope and structure** of any monitoring system must fit the local reality.

- In some places, a **simple manual system**, run by trained community volunteers or borehole operators, may be more reliable than an expensive network of automated sensors with telemetry that cannot be maintained.
- In others, a "**citizen science**" approach can keep communities engaged and build local ownership.
- Expensive, high-frequency monitoring is only worth the investment if the local institutions have the capacity and resources to keep it working.

Sustainable groundwater monitoring means balancing ambition with realism. Small, simple, reliable systems that genuinely serve local information needs are better than large, impressive systems that fail because they are impossible to maintain.

BOX 32: CASE STUDY
LESSONS FROM GROUNDWATER MONITORING IN NORTHEAST NIGERIA

Reflections from Action Against Hunger's Groundwater Surveillance Project (2020–2022)

The groundwater monitoring system developed by Action Against Hunger (AAH) in Borno and Yobe states, Nigeria, offers a candid illustration of both the promise and complexity of building groundwater infrastructure in fragile settings.

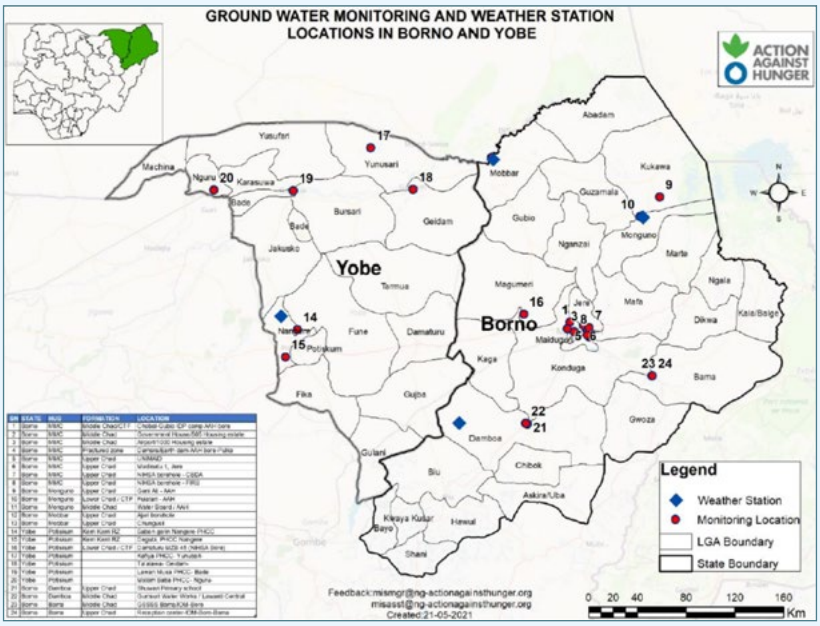

Figure 42: Groundwater and weather station monitoring sites in northeast Nigeria. (ACF)

Challenges Encountered:

- **Security Constraints:** Due to ongoing conflict, all automated monitoring infrastructure had to be located within six hubs in secure, key humanitarian intervention areas rather than more distributed sites.
- **Limited Institutional Capacity:** Despite being responsible for national monitoring, the Nigerian Hydrological Services Agency (NIHSA) had only one active monitoring point in the region at the time of project inception. Their small footprint in Borno meant they could not operate without external support.
- **Data Fragmentation and Poor Coordination:** Historical monitoring data was scattered across different agencies with varying formats and quality. AAH invested in compiling this information into a single GIS database of over 3,300 water points.
- **Infrastructure Compatibility:** Many existing water points lacked dipper pipes, making retrofitting with loggers complex and costly. In some cases, concrete platforms had to be removed and rebuilt just to allow sensor installation.
- **Laboratory Limitations:** Local labs were poorly equipped and often produced unreliable water quality results, prompting a shift toward field-based testing.

Practical Solutions and Innovations:

- **Digital Platform (mWater):** The team adopted the mWater mobile app for tracking functionality, groundwater levels, and water quality, ensuring real-time data flow and unique water point identifiers across the network.
- **Manual Monitoring Culture:** Recognising technical and logistical constraints, AAH placed strong emphasis on building local manual monitoring routines to complement automation, viewing them as essential for long-term capacity and data trustworthiness.
- **Stakeholder Engagement:** A WASH Cluster Technical Working Group (TWG) was created, fostering collaboration between INGOs, NIHSA, UNIMAID, and others. This enabled more standardised data collection and opened pathways for gradual handover to national institutions.
- **Realism About Limitations:** AAH acknowledged that building a fully decentralised, sustainable monitoring system will take years of capacity building, training, and gradual integration into government processes and adapted their strategy accordingly.

This case exemplifies that success in groundwater monitoring is less about installing equipment, and more about the patient, persistent work of building trust, systems, and technical capacity over time.

8.2 DECENTRALISATION AS A PATHWAY TO SUSTAINABILITY

Decentralising groundwater monitoring, through working through a basin management or aquifer management plan may enable responsibilities to be shared with local actors like district water officers, community technicians, or local water committees, instead of keeping everything under one central authority. This approach strengthens local ownership, builds technical capacity closer to the resource, and enables monitoring to become part of routine water resources management. In post-crisis settings, where national institutions may have limited capacity, decentralised monitoring can play a particularly important role in supporting recovery, improving resilience and establishing monitoring systems that remain operational as humanitarian programmes transition to long-term development.

WHEN RESPONSIBILITIES ARE DECENTRALISED:

- The workload does not overstretch central technical staff.
- Local teams stay close to the people managing water every day.
- Data collection, analysis and communication stay relevant to real local needs.

Regular evaluations of capacity, for example, during annual reviews using the skills capacity checklist example provided in **ANNEX A22**, should check whether there are parts of the monitoring system that could now be decentralised. For instance:

- Could local technicians handle more sensor installations?
- Are community monitors ready to do basic real-time checks and share data?
- Do local staff have the skills and motivation, or do they need more training or incentives?

Over time, the best monitoring infrastructures evolve from just providing data themselves to supporting others to collect, share and use groundwater data too. This means they start to act more

like an enabler than a *provider*. They can attract support and new data by:

- Offering training, equipment and access to monitoring sites.
- Helping with community permissions and technical advice.
- Providing secure data storage, easy-to-use dashboards, and fair data-sharing agreements.

Figure 43 shows how this works in practice. On the left is a more traditional, centralised water resources management system. Data is scarce, communication is slow, and decisions are mostly reactive. On the right is a decentralised, data-enabled system. Here, local communities, authorities and private suppliers all help monitor and share groundwater data. This creates a feedback loop where better evidence leads to better decisions, fairer financing, and stronger cooperation. The whole system becomes more resilient and responsive to change.

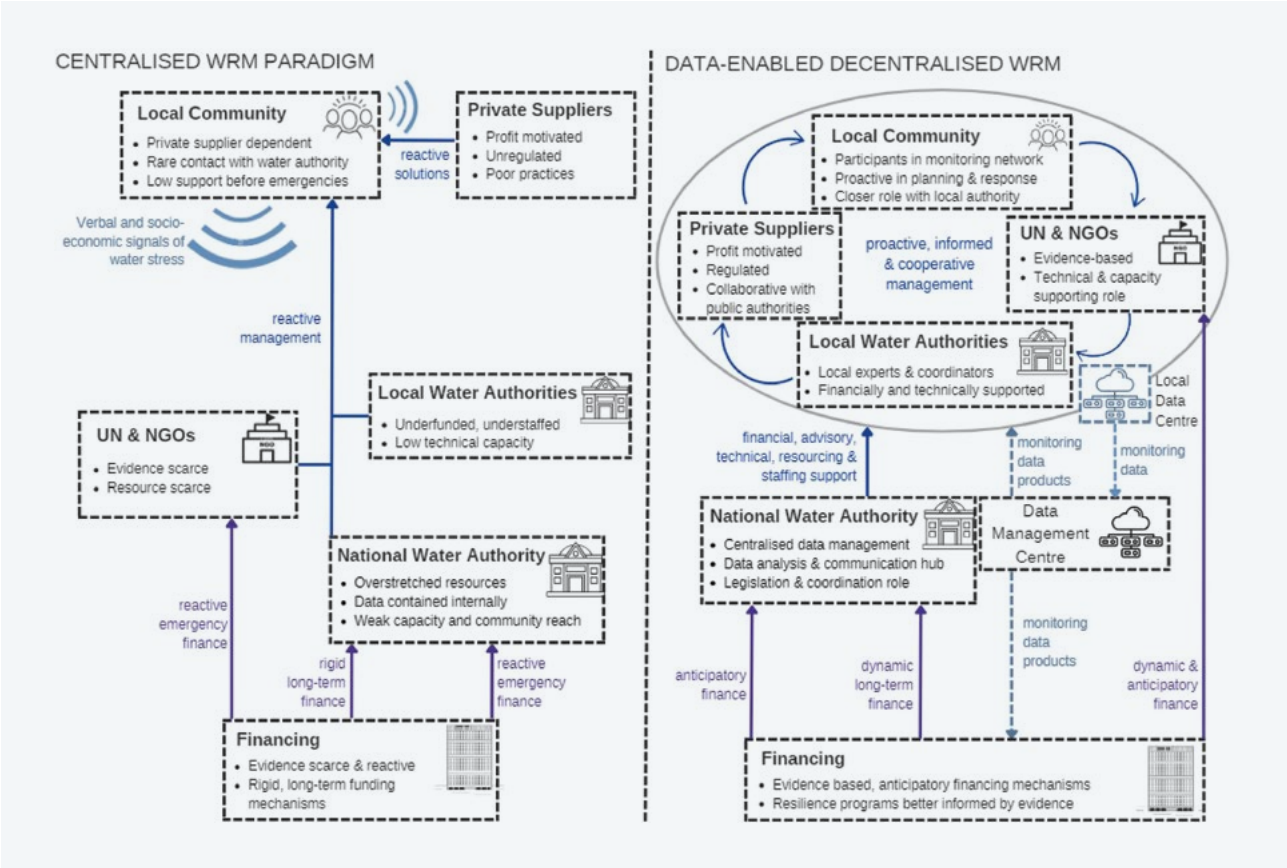

Figure 43: How local use and management of groundwater data can foster decentralisation and improve long-term water resources management. (Veness & Buytaert, 2025)

In summary, when local partners are trusted, trained and supported to play an active role, groundwater monitoring becomes not just a technical task, but a shared responsibility, and a shared opportunity to keep water supplies secure for the future.

8.3 FUTURE DIRECTIONS TO IMPROVE FEASIBILITY

To overcome some ongoing challenges with groundwater monitoring, there are practical ways forward that can make these systems more feasible, affordable and effective in the future.

INVEST IN APPROPRIATE TECHNOLOGIES

New tools like the Internet of Things (IoT), low-cost digital sensors and simple data-sharing platforms are becoming more accessible. But they must be fit for purpose. This means developing "appropriate technologies" – tools that are not only affordable but also easy to use and maintain locally. For example, low-cost ultrasound water level sensors that do not touch the water are becoming more common and affordable, reducing wear and tear. The global community should seek to fund, develop and support experimental implementations of more innovative monitoring approaches in the field to accelerate their development.

STRENGTHEN INSTITUTIONAL CAPACITY

Technology alone is not enough. Local and national water institutions need people with the skills, training and time to keep monitoring systems going. This means regular training, clear responsibilities and enough resources to support staff and community monitors.

BOX 33: CASE STUDY

STRENGTHENING INSTITUTIONAL CAPACITY IN THE HORN OF AFRICA

The *Groundwater for Resilience project*, supported by the World Bank with over $300 million in funding, is working across the Horn of Africa to strengthen how governments manage and protect groundwater. A big part of the project focuses on **building the capacity of national and local institutions**; for example, by:

- Training local water staff and technicians to collect, manage and analyse groundwater data.
- Providing digital tools and equipment to modernise monitoring systems.
- Supporting better coordination between countries that share groundwater resources.

BUILD DEDICATED DIGITAL AND OPERATIONAL INFRASTRUCTURE

Local and national institutions should have clear systems in place to collect, store and share groundwater data. Dedicated data hubs and clear data management procedures make it easier to keep data safe, up-to-date and accessible when needed.

ENSURE GOOD GOVERNANCE AND LONG-TERM COMMITMENT

Governance with clear rules, partnerships and honest communication keeps monitoring on track. Long-term political and financial commitment is needed so that monitoring is not just a short project, but that it becomes a regular part of managing water resources nationally.

SHARE SUCCESSES AND FAILURES

Finally, the global community must get better at learning from each other. Too often, groundwater monitoring projects that struggle or fail are not written about. This means the same mistakes get repeated again and again. Sharing honest lessons about what worked, what didn't, and why, including practical solutions, helps everyone do better.

By investing in technology that fits local needs, building strong institutions and infrastructure, and being honest about what works and what doesn't, the feasibility of long-term groundwater monitoring can keep improving, supporting safer, more reliable water supplies for the communities who need them most.

9 CONCLUSION

Groundwater monitoring is a powerful tool for ensuring water security in the long-term, especially in humanitarian and low-resource contexts where water systems can be especially vulnerable. Throughout this guide, examples have illustrated how monitoring helps communities, local authorities, and national agencies understand how much groundwater they have, how it changes over time, and how they can respond to droughts, floods, and everyday demands in a more proactive way.

This guide illustrates how groundwater monitoring goes far beyond being a technical task or box-ticking exercise. It is itself a significant project (with eventual integration) that requires careful **planning, clearly defined responsibilities, and a tailoring of systems to local problems.** Done well, it helps local authorities and communities take better care of vital groundwater resources, plan for the future, and secure a more sustainable financing for groundwater projects designed on good evidence.

IN THIS GUIDE, YOU HAVE LEARNT:

- **Why groundwater monitoring matters**, including real examples and common pitfalls to avoid.
- **Practical steps to design**, set up and sustain a basic monitoring system.
- **Important considerations for handing over systems** that can keep running long after the initial set-up.
- **How partnerships can work together**, sharing responsibilities and using data to make better decisions.

WHAT NEXT?

The benefits of groundwater monitoring multiply when more people get involved. Here are some ways you can take this forward:

- If you work for an **NGO, humanitarian organisation or government agency** – think about how you can adopt monitoring in your water projects, or support local communities to do it themselves.
- If you are in local government, or a **community leader** – see if there are opportunities to involve volunteers in citizen science monitoring.
- If you are a **technical specialist** – share your lessons learned, both successes and challenges, so the global community can keep improving.
- If you are a **donor or funder** – consider offering long-term investment in monitoring and the capacity building of institutions responsible for running it.

A wider understanding and common adoption of groundwater monitoring will go a long way to protect safe water access, for both emergency situations today, and for the generations to come who need us to manage finite groundwater resources more sustainably.

10 CASE STUDIES

This chapter presents full case studies illustrating how the groundwater monitoring roadmap set out in **Chapters 2–8** has been applied in complex humanitarian contexts.

10.1 **BANGLADESH:** GROUNDWATER MONITORING IN COX'S BAZAR

10.1.1 INTRODUCTION AND PURPOSE OF THE CASE STUDY

Since August 2017, large numbers of Rohingya refugees from Rakhine State, Myanmar, arrived into Cox's Bazar District, Bangladesh. By 2018–2019, most were concentrated within the Kutupalong-Balukhali "Mega Camp", which accounted for over 80% of the refugee population in Cox's Bazar. Water supply for both refugee and host communities relied almost entirely on groundwater, leading to a rapid increase in abstraction from aquifer systems that were poorly characterised and previously lightly exploited.

The humanitarian WASH response involved multiple national and international actors. **Médecins Sans Frontières – Operational Centre Amsterdam (MSF-OCA)** developed and operated groundwater-based water supply systems, including high-yield production boreholes. In December 2017, MSF-OCA requested hydrogeological support from **Groundwater Relief (GWR)**, including support to establish a groundwater monitoring programme. At a wider scale, coordination, planning and longer-term water resource management were led by agencies such as the **International Organization for Migration (IOM)** and the Government of Bangladesh through the **Department of Public Health Engineering (DPHE)**.

Groundwater level, water quality and additional hydrological and survey data were required to support day-to-day borehole operation, identify emerging risks early, and provide evidence to guide water supply planning as the response transitioned from emergency to more sustained operations.

This case study documents the development of groundwater monitoring in Cox's Bazar from scoping (**Chapter 3**) through design (**Chapter 4**), preparation and procurement (**Chapter 5**), pilote phase (**Chapter 6**), improvement, expansion and handover (**Chapter 7**), following the monitoring roadmap set out in **Chapter 2** of this document.

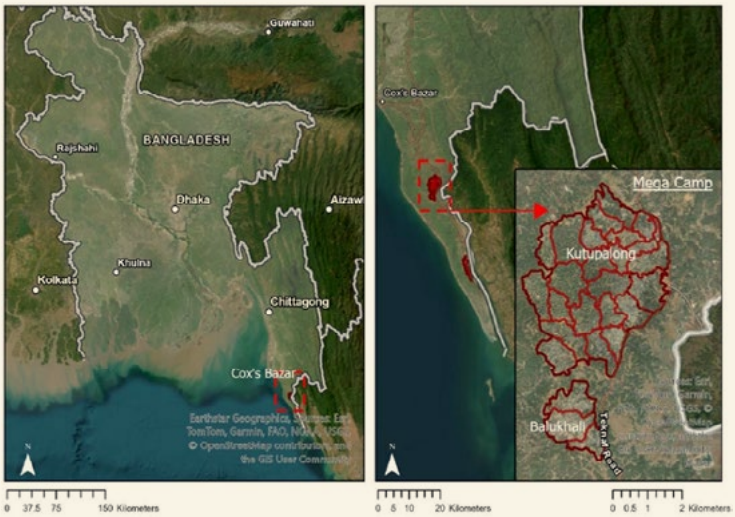

Figure 44: Location of the Kutupalong-Balukhali Rohingya refugee camps in Cox's Bazar District, southeastern Bangladesh. (GWR)

10.1.2 SCOPING AND DESIGN EVIDENCE

Scoping in Cox's Bazar followed the five core areas set out **in Chapter 3** of this document.

(I) KEY STAKEHOLDERS AND THEIR INFORMATION NEEDS

Scoping confirmed that groundwater monitoring was required primarily to support operational decision-making for MSF-OCA's water supply systems in Camp-01, where 14 production boreholes across 10 networks were supplying over 80,000 people. Key decisions related to pumping water levels, abstraction volumes, and long-term planning with early concerns already emerging around borehole interference and reports of shallow tubewells running dry. Beyond MSF-OCA operations, monitoring data were also expected to support coordination discussions involving other WASH actors, IOM and Bangladeshi authorities.

(II) UNDERSTANDING OF THE HYDROLOGY & ASSOCIATED RISK

This understanding was built through desk study, Geographic Information System (GIS) analysis, field surveys, interviews with MSF-OCA staff and drilling contractors, review of borehole construction records, geological mapping, and interpretation of available geophysical survey data.

The Mega Camp was underlain predominantly by the **Dupi Tila Formation**, comprising heterogeneous interbedded sands, silts and clays. This heterogeneity was reflected in variable borehole yields and groundwater level responses across short distances. Underlying the Dupi Tila Formation was a secondary aquifer called the Tipam Sandstone aquifer that was separated from the Dupi Tila by a clay formation known as the Girujan Clay. Original geology maps for the area were later proven to be inaccurate and the geology of the region was remapped by Groundwater Relief and Dhaka Univeristy.

Production boreholes were mostly drilled to depths of up to approximately **250 m**, with a few drilled deeper and penetrating beneath the Girujan Clay into the **Tipam Sandstone**.

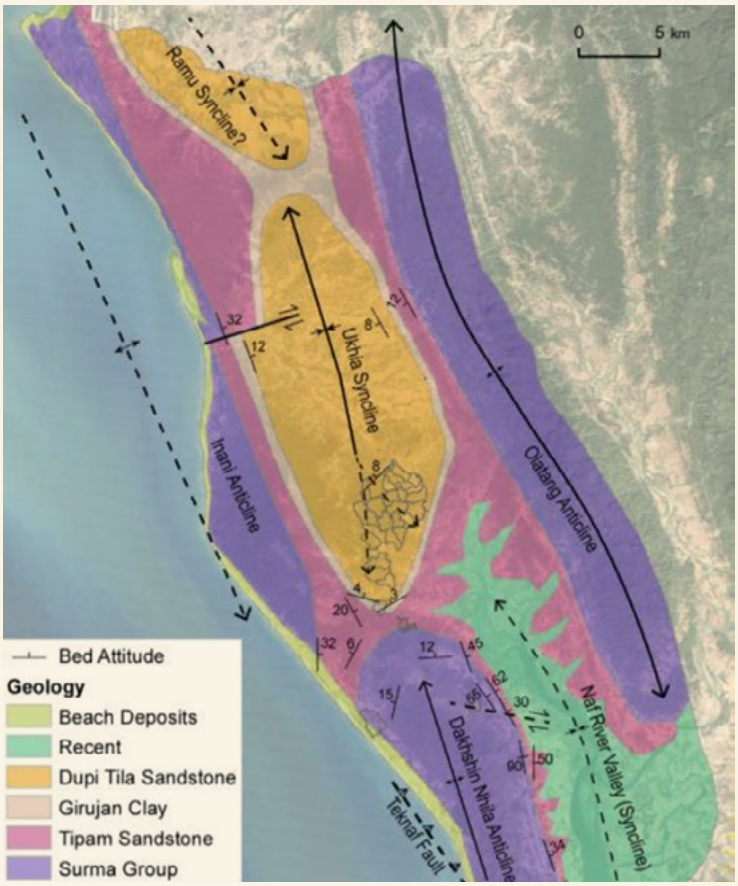

Figure 45: Simplified geological and structural map of the Cox's Bazar area, showing the distribution of the Dupi Tila Sandstone and adjacent formations, major folds (anticlines and synclines), and fault structures. (GWR)

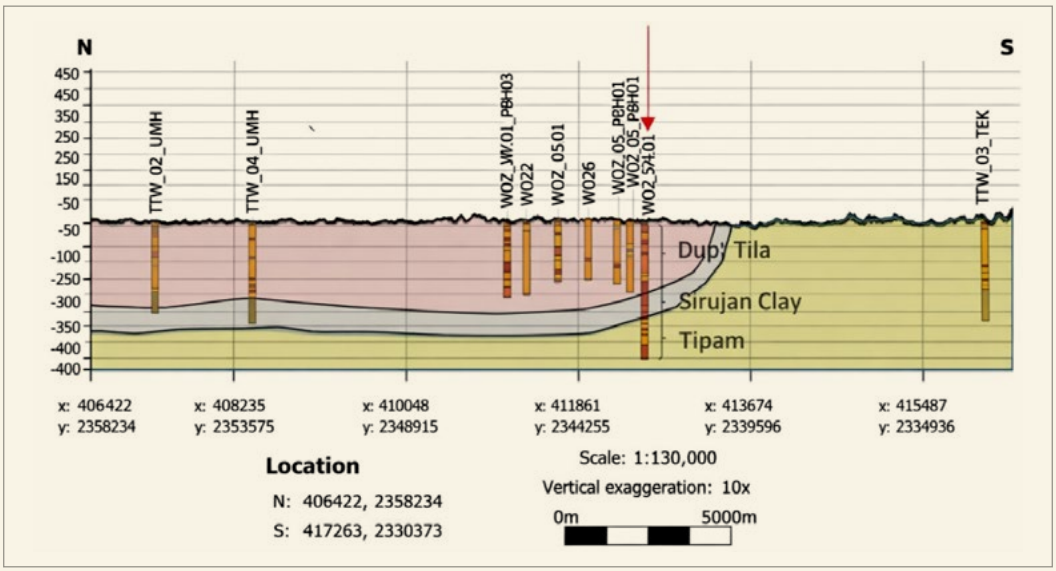

Figure 46: Conceptual aquifer geology and borehole penetration, interpreted from drilling logs and geophysical survey data. (GWR)

(III) OPTIONS FOR LONG –TERM OPERATION OF THE SYSTEM

The monitoring programme was not originally designed for handover to the local or national authorities. It was a programme designed to support MSF-OCA operational requirements and to provide data for the overall humanitarian response in Cox Bazar.

(IV) OPERATIONAL CONSTRAINTS

Boreholes had been drilled rapidly under emergency conditions, often with incomplete construction records, and were operated using solar-powered pumps that generated strong daily drawdown-recovery cycles. Routine monitoring would need to rely on non-specialist staff, including pump house guards, rather than dedicated hydrogeologists. Scoping also identified a politically sensitive operating environment, characterised by strong government oversight of refugee infrastructure, uncertainty around the long-term status of the camps, and a need for transparency and coordination in groundwater monitoring activities.

(V) EXISTING RESOURCES

Baseline groundwater data were extremely limited. However, production boreholes already offered immediate monitoring opportunities through manual groundwater level measurements, some automated logging, abstraction data from flow meters, and routine MSF water quality testing. These existing systems were therefore identified as a foundation for early monitoring.

10.1.3 HYDROGEOLOGICAL UNDERSTANDING AND ASSOCIATED RISKS

KEY GROUNDWATER RISKS IDENTIFIED.

- **Excessive drawdown**
  There was significant uncertainty around the storage and recharge of the aquifer systems being exploited. As water supply systems were commissioned, combined abstraction increased progressively to approximately **850–950 m^3/day**. There was a clear need to start to understand the long-term impacts of this new abstraction on regional water levels.

- **Borehole interference and localised impacts**
  Groundwater level data from production boreholes showed strong daily drawdown and recovery cycles driven by solar-powered pumping. As a result of dynamic drawdown, well interference and localised groundwater suppression caused by the increased pumping, several boreholes started operating close to pump intake depth as water levels declined.

  Many local host community water supplies relied on the shallow groundwater system and were often fitted with suction pumps that were vulnerable to even small changes in water level. There were significant concerns that the new water supplies installed to support the refugees would have significant impact on local water supply as a result of suction pumps no longer being able to operate.

- **Water quality risks under sustained abstraction**
  Routine water quality monitoring indicated that deep production boreholes generally produced water of acceptable chemical quality. Iron concentrations were commonly elevated and required ongoing attention, while arsenic and manganese were below detection limits in sampled locations. There were concerns that the shallow groundwater system could become contaminated from the large number of pit latrines installed to support the refugee populations that could lead to disease outbreak.

IMPLICATIONS FOR GROUNDWATER MONITORING

With limited information about the multilayered aquifer system underlying the camp, a large increase in groundwater use as a result of the refugee influx and with significant risks of new abstractions impacting on local water supply systems, it was imperative to start collecting information on groundwater levels within the aquifer system at different depths and at different locations around the camp. With limited resources to put into monitoring, but with significant operational activities being undertaken, monitoring was initially focussed on operational production boreholes, using pump operators to support the monitoring programme.

This is a short summary of an extensive, multi-year hydrogeological assessment and support programme by Groundwater Relief. For more details, read more[33].

10.1.4 MONITORING SYSTEM DESIGN, RESOURCING AND FINANCING (MONITORING PACKAGES)

By 2019, groundwater monitoring implemented by MSF-OCA in Cox's Bazar can be described as a set of complementary monitoring packages, each designed to address specific operational and risk-management needs. Together, these packages formed an integrated monitoring system that could be delivered within funding, staffing and governance constraints.

MONITORING PACKAGE	EVIDENCE BASIS	EXPECTED BENEFITS	SETUP COSTS*	ADDITIONAL RESOURCES REQUIRED	KEY RISKS & MITIGATION
1. Automatic groundwater level monitoring in high-demand production boreholes (Camp-01)	Hydrogeologist assessment; high abstraction rates; observed drawdown and interference.	Detailed information including the tracking of daily pumping impacts on drawdown and recovery; supports pump scheduling; identifies boreholes at risk of failure; enables interpretation of abstraction impacts.	Initial costs to invest in the installation of dip tubes, well head modifications and procurement of automated data loggers with associated training support from GWR.	Periodic secondments of hydrogeologist experts into MSF team to support: technical oversight; periodic site visits;periodic training updates, data management capacity.	Failure of equipment, mitigated by parallel manual checks.
2. Manual groundwater level monitoring in production boreholes (Camp-01)	Operational need; staff availability; redundancy requirement.	Low-cost verification of automated data; resilience against sensor failure; supports handover.	Initial costs to invest in the installation of dip tubes, well head modifications and procurement of a dip meter. Training of pump house guards; simple SOPs.	Manual transfer of date from paper forms to excel and server.	Inconsistent readings; mitigated by hourly schedule and spot checks.
3. Observation borehole monitoring (Mega Camp baseline network)	Need for baseline trends; lack of national monitoring nearby.	Distinguishes seasonal variability from abstraction effects; provides longest continuous dataset in the response.	Borehole construction costs (unless non operational boreholes could be utilised) Procurement of automated loggers and support equipment, training .	Hydrogeological input; secure access.	Loss or damage of boreholes; mitigated by distributing sites.

33 - https://drive.google.com/file/d/1ufhAzcrk8EyrrCb-ZjFWqRdm1D5rFm5o/view

4. Abstraction monitoring at all production boreholes	Need to link pumping to groundwater response.	Quantifies cumulative abstraction; enables interpretation of drawdown and interference.	Purchase of flow meters, Integrated into pumping system.	Data collation and review.	Coarse resolution (m^3 increments); mitigated by trend analysis.
5. Rainfall monitoring at water networks	Need to interpret groundwater recharge; loss of earlier gauges.	Supports seasonal interpretation; compensates for unreliable external rainfall data.	Procurement of low cost manual gauges installed at MSF compounds.	Routine maintenance.	Gauge damage; mitigated by multiple sites.
6. Routine water quality monitoring at production boreholes (monthly)	Known regional risks; drinking water safety requirements.	Detects trends in EC, iron, pathogens, supports public health assurance and trust.	Cost of procurement of water quality monitoring equipment that can be used for spot sampling in the field. Cost of setting up a field-based laboratory operated by MSF team.	Consumables, technician to take samples and carry out analysis.	Limitations of the field equipment.
7. Daily free residual chlorine (FRC) monitoring	Operational water safety requirement.	Ensures safe disinfection; supports confidence in supply.	Low.	WASH staff time.	Operational lapses; mitigated by daily checks.
8. Periodic laboratory testing of water	Known regional risks; drinking water safety requirements.	Detects trends in metals, arsenic, ionic balance changes.	Cost of sample collection, sample delivery and sample analysis.	Time commitment required by staff to take the samples. Support from hydrogeologist to analyse results.	Laboratory accuracy mitigated by duplicate samples.
9. Tank level and usage monitoring (periodic)	Need to understand demand patterns.	Supports interpretation of abstraction data; informs network optimisation.	Low.	Staff time.	Data gaps; mitigated by periodic rather than continuous use.

Table 12: Summary of monitoring packages in groundwater monitoring design.

**Exact financial costs were not ring-fenced for groundwater monitoring; these packages were delivered largely through integration with existing MSF-OCA WASH budgets and infrastructure.*

HOW THE PACKAGES WORKED TOGETHER

- Production borehole monitoring (Packages 1, 2, 5, 6, 7,8) formed the core operational monitoring system, directly supporting day-to-day water supply management and water availability and quality assurance.
- Observation boreholes and rainfall monitoring (Packages 3 and 5) provided context, allowing groundwater responses to be interpreted beyond individual boreholes.
- Usage monitoring (Package 9) helped triangulate supply, demand and groundwater response.

RESOURCING, FINANCING AND SUSTAINABILITY CONSIDERATIONS

- Monitoring packages were **not funded as a standalone project.**
- Costs were absorbed within:
  - MSF-OCA WASH operational budgets
  - Existing pumping and treatment infrastructure
  - Routine staff roles
  - Part of activities engaged on by GWR hydrogeologists seconded into MSF team
- This approach:
  - Reduced financial barriers to implementation
  - Allowed incremental scaling as networks expanded
  - Supported continuity during the **planned handover to BRAC**

KEY DESIGN LESSONS

- **Package-based monitoring** allows systems to scale pragmatically.
- Embedding monitoring into **core operations** is more sustainable than creating parallel systems.
- Required **secondments of groundwater professionals into MSF WASH team** to support implementation (in total GWR provided MSF with 7 hydrogeologist secondments, each of 3-month duration.
- International companies and proprietary systems can add value but must be complemented by **independent**, **low-tech methods.**

10.1.5 PREPARATION AND PROCUREMENT

Stand-alone groundwater level loggers were procured in limited numbers for selected observation boreholes, while manual dip meters were used to provide low-cost redundancy.

Rainfall and water quality monitoring equipment was procured initially through Groundwater Relief using international markets and later through existing MSF-OCA WASH supply chains. Early reliance on a small number of rain gauges proved vulnerable to damage, leading to a shift towards multiple simpler gauges distributed across water networks. Water quality monitoring used routine sampling and laboratory arrangements already in place for drinking water safety.

10.1.6 PILOT MONITORING AND INITIAL ASSESSMENT

The pilot phase tested whether the monitoring system could reliably support operational decision-making and identified gaps or challenges requiring refinement.

Groundwater level monitoring using manual dip measurements and automated loggers proved suitable for operational use. However, over time the loggers were vulnerable to becoming damaged and in hindsight it might have been better to have installed loggers with direct read cables to avoid needing to remove them from the boreholes when collecting the data. Hourly monitoring was essential to capture strong daily drawdown and recovery cycles driven by solar-powered pumping.

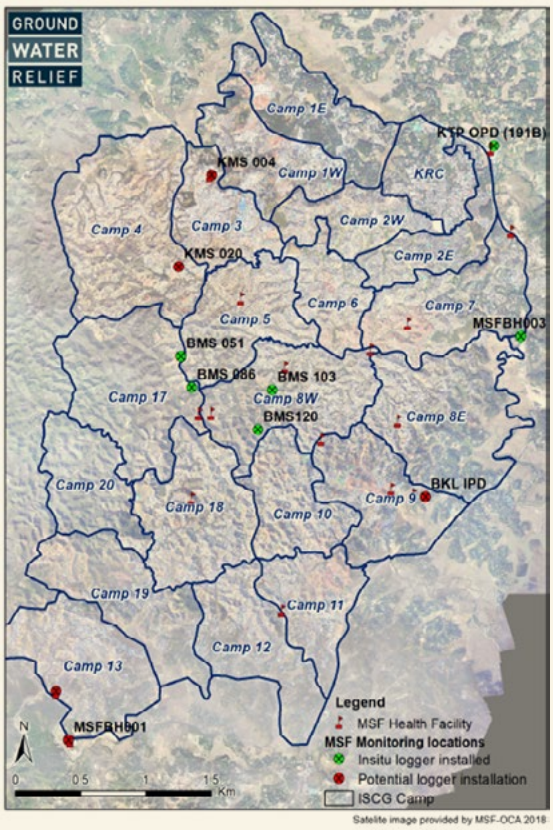

Figure 47: Additional MSF-OCA groundwater level monitoring locations across the Kutupalong–Balukhali Mega Camp during the pilot. (GWR)

Pilot water quality monitoring began in early 2018 using a dedicated sampling team. **Eighty water points** were sampled between January and March 2018. Results showed **low electrical conductivity (EC) and chloride. Iron concentrations were elevated** in most samples, while **arsenic and manganese were below detection limits**. Sampling protocols were refined after identifying bacterial contamination from hand-pump faucets, leading to standardised disinfection procedures and improved data quality.

Figure 48: : Installation and operation of in situ groundwater level loggers at an MSF-OCA monitoring borehole, including staff training, secure housing of monitoring equipment, and routine data download procedures. (GWR)

Data management during the pilot relied on manual recording and periodic downloads, with analysis undertaken by Groundwater Relief. The process was supported by the secondment of hydrogeologists into the MSF WASH team.

Overall, the pilot demonstrated that the monitoring system was **fit for purpose**, validated the need for high-frequency groundwater level data, and confirmed water quality risks were manageable but required continued trend monitoring.

10.1.7 IMPROVEMENT, EXPANSION & OPERATION

Following the Camp-01 pilot, groundwater monitoring was progressively expanded and formalised across the camp during 2019.

Data collection responsibilities were split between two existing MSF-OCA WASH functions. A **Field Support and Monitoring (FSM)** team undertook **monthly monitoring rounds**, including downloading groundwater level loggers, digitising manual measurements, and compiling datasets. In parallel, the **maintenance team** coordinated **continuous manual groundwater level monitoring** at production boreholes, with hourly measurements recorded by pump house guards. This division allowed monitoring to scale without creating new specialist roles.

Data handling procedures were streamlined as the system expanded. Compiled groundwater level datasets **(Figure 49)** were reviewed and analysed by Groundwater Relief and reported through regular technical updates. During 2019, MSF-OCA began transitioning from ad hoc email-based data transfer to a shared online system to improve consistency and quality control.

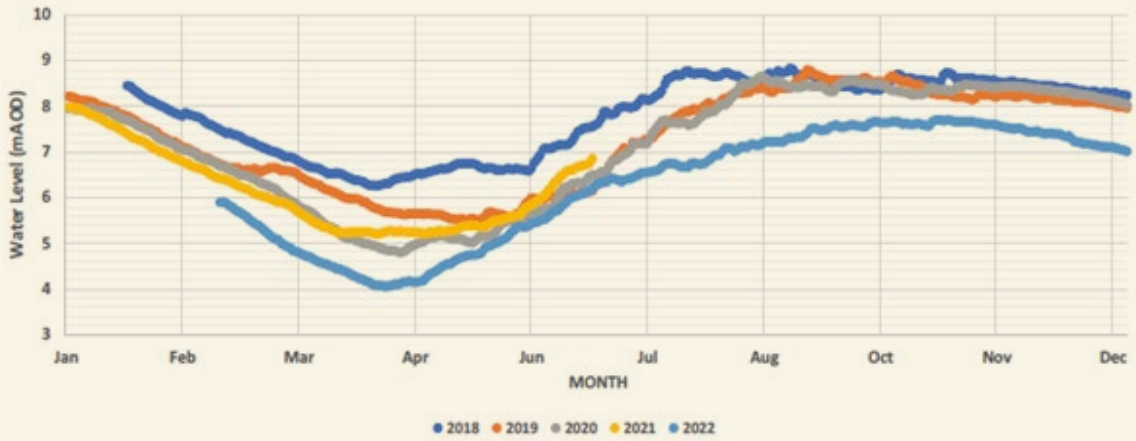

Figure 49: : Quality-controlled and verified groundwater level time series for observation borehole BMS086 (2018–2022), showing consistent year-on-year seasonal variation and overall stable groundwater levels remaining within operationally safe limits. (GWR & MSF-OCA)

The monitoring plan was updated mid-2019 to reflect the full commissioning of **fourteen production boreholes in Camp-01**. Monitoring was extended to all operational boreholes in Camp-01 and in other camp areas using a combination of manual measurements and automated loggers, with parallel measurements at selected sites to support quality assurance.

Expansion of the monitoring system confirmed remaining evidence gaps, particularly for **shallow groundwater within Camp-01**, and informed recommendations for additional observation points, improved coordination, and preparation for longer-term operation and handover.

Groundwater Relief also used the monitoring data to develop a groundwater flow model for the aquifer systems underlying the mega camp. The model, commissioned by The International Organisation for Migration with funding from the Government of Japan, simulated the long-term impact of abstractions on the underlying aquifer systems. The model was calibrated using groundwater level data provided by the MSF-OCA monitoring network.

The model was able to provide decision makers confidence in the plans for the development of a Water Supply Master Plan for the refugee population, as well as provide information on potential impacts associated with drawdown on local community suction pumps.

10.1.8 INTEGRATION, HANDOVER AND KEY LESSONS

The monitoring design considered the capacity and priorities of MSF. Monitoring procedures prioritised simplicity, standard equipment and clear documentation to support continuity of the network despite the rapid turnover of staff.

Data were primarily used to support internal operational decisions but also provided a credible evidence base for engagement with coordination mechanisms and government counterparts, helping to manage risks without overstepping institutional mandates in a politically sensitive setting.

Key lessons for groundwater monitoring in humanitarian settings

- Embed monitoring in operations. Systems endure when they directly support water supply reliability and decision-making, and when financed as a core infrastructure.
- Secondment of groundwater experts into the MSF team to support groundwater activities and the set up and management of the monitoring network.
- Regular repeat training to take account of the turnover of staff within the MSF WASH team.
- Build redundancy. Combining manual and automated methods improves resilience and confidence in the data.

This case study demonstrates how groundwater monitoring can be progressively developed, expanded and integrated within a complex humanitarian response, following the staged monitoring roadmap presented in this document.

10.2 **NORTHEAST SYRIA:** GROUNDWATER MONITORING IN PRACTICE

10.2.1 INTRODUCTION AND PURPOSE OF THE CASE STUDY

Water supply and the sustainability of groundwater resources are pressing concerns in Northeast Syria. Public water services in the region rely heavily on groundwater, yet water availability is strongly influenced by inflows from elevated areas to the north, including transboundary aquifers extending into Turkey. Climate change, heavy abstraction upstream, and the impacts of prolonged conflict on water regulation and infrastructure have increased the region's vulnerability to water shortages and reduced the capacity of local institutions to manage water resources effectively.

Against this backdrop, **ACTED**, with technical support from **Groundwater Relief**, initiated groundwater monitoring activities to improve understanding of groundwater availability, support more informed decision making on investments in water supply infrastructure.

This case study documents how a groundwater monitoring programme was scoped, designed, piloted and expanded in Northeast Syria.

Figure 50: Location of Al-Hasakah Governorate in northeast Syria (left) and key cities, districts and sub-districts within the Governorate (right). Maps compiled from published sources and operational GIS datasets. (GWR & ACTED)

10.2.2 SCOPING / DESIGN EVIDENCE

Early scoping and monitoring design were informed by a regional groundwater resource desk study that incorporated satellite data analysis, and data provided through interviews with key informants arranged by ACTED. This consolidated fragmented pre- and post-conflict groundwater information and provided a starting evidence base for defining monitoring priorities in a data-scarce environment.

At a regional scale, the desk study confirmed that Al-Hasakah Governorate lies within the Khabour River Basin, historically supported by discharge from the Ras al-Ain springs fed by the transboundary Jezira Limestone aquifer. Long-term decline in spring discharge and loss of perennial flow in the Khabour River were linked to sustained upstream abstraction and regional groundwater pressure.

Remote sensing analyses using GRACE and SWAcMOD indicated a net decline in groundwater storage between 2002 and 2021, with recharge concentrated in northern outcrop areas and along wadi systems. Geological evidence also indicated a risk of increasing groundwater salinity, particularly where deeper or evaporite-rich formations are exploited under declining water levels.

These findings highlighted groundwater depletion, spatial variability in recharge, and transboundary pressures, and water quality (salinity) as key risks, reinforcing the need for groundwater monitoring to reduce uncertainty and support evidence-based management.

KEY STAKEHOLDERS AND INFORMATION NEEDS

The desk study and key stakeholder interviews identified the Qamishli Water Department and Hasakah Water Department, **operating under the Self Administration for North and East Syria**, as critical stakeholders responsible for groundwater-dependent public water supply. Critical information required by these Water Departments related to day-to-day operation and maintenance of existing water supplies and information that would support long-term planning of water provision.

ACTED required groundwater information to guide decisions on where monitoring should be re-established and where to prioritise future water supply and WASH interventions under constrained resources.

OPERATIONAL AND INSTITUTIONAL CONSTRAINTS

Much historical groundwater information had been lost, was inaccessible, or existed only in non-standard formats following years of conflict. Access to potentially valuable petroleum borehole data for structural interpretation was not possible due to institutional and political restrictions. These constraints reinforced the need for a monitoring system that could function independently, with limited baseline data, and be developed incrementally.

Security considerations also needed to be considered when determining monitoring locations and equipment use.

EXISTING DATA AND INFRASTRUCTURE

Available groundwater data were fragmented and uneven in quality. Existing information included borehole inventories, limited construction records, regional geological maps, and isolated groundwater assessments from previous humanitarian interventions. Existing abstraction points and historic groundwater monitoring points represented the primary opportunity for re-establishing a groundwater monitoring network.

LONG-TERM OPERATION AND SUSTAINABILITY CONSIDERATIONS

Increasing engagement with the Al Hasakah local Water Departments were identified as important for sustaining monitoring activities beyond initial project phases. Partnerships and institutional capacities in the authorities would need to be developed with time for eventual handover of the monitoring network. At the same time, borehole operator-level capacities to operate and interpret monitoring information were highlighted as important for monitoring to continue in the event of conflict, changing politics or personnel.

10.2.3 HYDROGEOLOGICAL UNDERSTANDING AND ASSOCIATED RISKS

CONCEPTUAL UNDERSTANDING OF THE AQUIFER SYSTEM

This regional context was established by Groundwater Relief as contracted hydrogeologists through: review of existing **hydrogeological literature; the collection of field data; remote sensing analysis including utilisation of GRACE; the development of a surface water accounting model (SwaCMod) and the construction of a 3D geological model using Leapfrog Works.**

The Al Hasakah Governorate sits within the Khabour River Basin, part of the wider Euphrates system. Historical records and published hydrological studies show that the Khabour River was sustained year-round by **large limestone-sourced springs at Ras al-Ain**, located near the Syrian–Turkish border. These springs were fed by the Jezira Limestone aquifer, a transboundary groundwater system extending across Syria and Turkey. Since the late 20th century, discharge from these springs has declined (from around **40 m^3/s** in the mid-1900s to approximately **3 m^3/s** by 2009) and the Khabour River has become seasonal, **running dry in recent years.**

Climate strongly limits groundwater recharge. Analysis of satellite-derived rainfall datasets (2002–2021) and published climate assessments shows that the Governorate experiences high evapotranspiration (~2800 mm/year) and rainfall that is both highly seasonal and unevenly distributed. Most precipitation falls between October and May, with higher totals in the northern uplands near the Turkish border (up to ~900 mm/year) and much lower rainfall in the southern and southeastern lowlands (as little as ~35–360 mm/year). As a result, **meaningful groundwater recharge occurs mainly during occasional high-rainfall events**, and primarily in uplands outside the main abstraction zones.

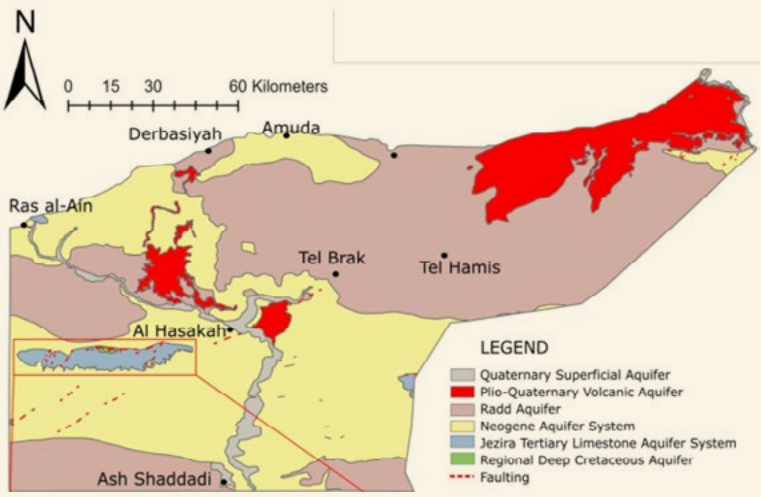

Figure 51: Regional surface hydrogeology of Al-Hasakah Governorate, showing major geological units and structural features relevant to groundwater occurrence and flow. (GWR & ACTED)

Geological and structural understanding was developed through review of regional geological maps, cross-sections, and previous deep well records. Al-Hasakah Governorate lies within the Jezira Basin, where sedimentary and volcanic rocks are folded and faulted around prominent structural features such as the Jebel Abdel Aziz and Sinjar uplifts. These structures mean groundwater behaviour can change significantly over short distances.

Based on this geological framework, five main aquifer systems were identified, ranging from shallow, locally productive units (such as the Radd Aquifer) to deeper, regionally important systems (notably the Jezira Tertiary Limestone Aquifer). Published hydrogeological studies indicate that **some aquifers contain good-quality groundwater at shallow depths but become increasingly saline with depth**, while deeper Cretaceous formations are generally saline and unsuitable for water supply.

AQUIFER SYSTEM	DOMINANT GEOLOGY	TYPICAL PROPERTIES	IMPORTANCE FOR WATER SUPPLY	KEY RISKS AND UNCERTAINTIES
Quaternary / Recent superficial deposits (Typical depth: 0-30 m below ground level*)	Alluvial sands, gravels and silts along rivers and wadis.	Limited data; shallow, locally productive where hydraulically connected to surface water.	Important for small-scale and local supply near rivers and wadis.	Vulnerable to seasonal drying, pollution and over-abstraction; limited storage.
Plio-Quaternary Volcanic Aquifer 50-100 m)	Fractured and weathered basalts of the Euphrates Volcanic Field.	No robust regional aquifer property data; groundwater stored in fractures and cooling margins.	Locally important source of fresh groundwater, particularly in northern areas.	Highly heterogeneous; productivity and extent poorly constrained; limited understanding of sustainable yields.
Radd Aquifer (Bakhtiari Formation; 30 - 150 m)	Sandstones, conglomerates and clays, locally overlain by volcanic units.	Moderate permeability; specific yield ~0.1–0.3 (literature estimates).	One of the most widely used shallow aquifers; often provides relatively fresh water.	Water quality may deteriorate southwards where gypsum-rich layers are present and recharge is less.
Neogene Aquifer System (Upper & Lower Fars; 200-570 m)	Sandstones, marls, clays with widespread gypsum, anhydrite and halite (especially Lower Fars).	Highly variable transmissivity (2–1300 m^2/day); productivity often lower than literature values suggest.	Important regional aquifer, widely tapped where shallower aquifers are insufficient.	High salinity and sulphate concentrations common; water quality often worsens with depth; strong heterogeneity.
Jezira Tertiary Limestone Aquifer System (400 - 1000 m)	Karstic limestones and dolomites. (Jeribe, Dibbane, Chilou, Jaddala formations)	High transmissivity in places (up to ~3,450 m^2/day); karstic behaviour; confined/unconfined conditions.	Historically critical, feeding Ras al-Ain springs and the Khabour River; still important near recharge zones.	Declining spring discharge due to over-abstraction; variable salinity with depth; complex flow paths.
Regional Deep Cretaceous Aquifer System (> 500 m)	Thick Upper Mesozoic sedimentary sequence.	Generally low productivity for water supply; limited recharge.	Limited practical importance for drinking water.	Groundwater typically saline; largely non-renewable; unsuitable for humanitarian water supply.

Table 13: Major geological units, their properties and associated risks. (GWR)

**Depths are indicative and vary significantly due to structural complexity such as folding and faulting, with generally deeper units recharging at the surface at uplifted sites.*

A baseline survey of groundwater levels was also developed by compiling available historical records and supplementing these with field measurements. This confirmed basin groundwater flow patterns generally from uplands to the lower riverine areas towards the South.

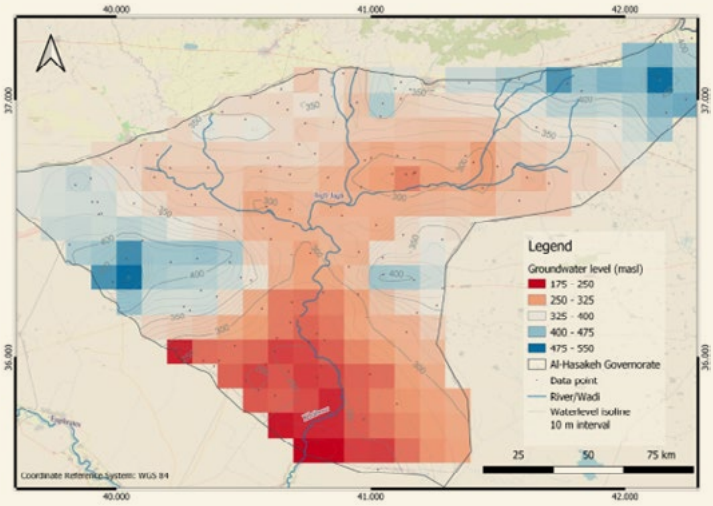

Figure 52: Interpolated groundwater levels (metres above sea level, masl) across Al-Hasakah. (GWR & ACTED)

KEY GROUNDWATER RISKS IDENTIFIED

Declining groundwater levels
Available evidence indicated that groundwater levels across northeast Syria have been falling for several decades. Reported declines of over 20 metres in parts of the wider region, together with the drying of the Ras al-Ain springs that once fed the Khabour River year-round, point to significant long-term depletion. Satellite-based analyses (GRACE and SWAcMOD) further indicated an overall loss of groundwater storage between 2002 and 2021. However, because systematic groundwater monitoring has been largely absent, the scale and location of ongoing declines remains poorly constrained.

Uncertain aquifer properties
There was very limited site-specific information on how much water different aquifers can reliably store and supply. Available estimates of aquifer properties are mostly drawn from literature or neighbouring countries and show large variability, even within the same geological units.

Salinity as a major water quality risk
Salinity is the most widespread and limiting groundwater quality issue in northeast Syria. Many aquifers contain gypsum-, anhydrite- or salt-rich layers that can release dissolved salts into groundwater, particularly at depth or where water moves slowly. Data from 128 sampled water points show that brackish to saline groundwater is common, with concentrations frequently exceeding Syrian and WHO drinking water limits, especially within the Neogene Aquifer System.

Risks from deep and mixed well construction
Many boreholes are screened across multiple aquifer layers, sometimes combining shallow fresher water with deeper, more saline groundwater. In heavily abstracted areas, such as the Al Himme wellfield, evidence suggests that intensive pumping may have caused poorer-quality water to migrate upward into wells, rapidly degrading water quality and forcing abstraction to cease. Without monitoring, these changes may only be detected after supplies are already compromised.

Implications for groundwater monitoring
Monitoring was needed operationally to track groundwater levels, abstraction volumes and salinity, with enough spatial coverage to capture differences between aquifers, depths and recharge zones. Regular groundwater level measurements, routine salinity indicators (such as EC or TDS), and basic pump testing were essential to identify emerging risks early and improve understanding of hydrogeological risks to support safer water management.

10.2.4 MONITORING SYSTEM DESIGN (MONITORING PACKAGES)

Groundwater monitoring was implemented as a phased, component-based system designed to rebuild baseline information and support operational management of priority risks. Monitoring focused primarily on groundwater levels and salinity, supported by targeted abstraction information and a strong emphasis on training, quality control and data handling.

MONITORING PACKAGE	EVIDENCE BASIS	WHAT WAS IMPLEMENTED	EXPECTED BENEFITS	RESOURCING & FINANCING	KEY RISKS & MITIGATION
1. Automated groundwater level monitoring (observation boreholes)	Reported long-term groundwater decline; lack of baseline data; satellite-based groundwater storage decline signals.	Pressure transducer data loggers installed in eight observation boreholes across key aquifer systems (Radd, Neogene and Jezira Limestone) during 2023.	Establishes baseline trends; captures seasonal variability; supports regional-scale water resource assessment and calibration of a future groundwater model.	Initial investment in borehole camera surveys to identify suitable boreholes for monitoring. Installation of dip tubes and well head modifications. Procurement and installation of data loggers with associated training on their use.	Logger loss or malfunction; mitigated through staged rollout, spare equipment and parallel manual checks.
2. Manual groundwater level monitoring (calibration and redundancy)	Need to calibrate automated data and ensure accuracy.	Monthly manual water level measurements at all monitoring sites by Water Department staff.	Provides absolute reference levels; validates automated data; builds local monitoring capacity.	Procurement of dip meters, initial training travel costs integrated into routine duties.	Transcription errors; mitigated through standard operating procedures, training and cross-checking.
3. Routine groundwater salinity monitoring (electrical conductivity / total dissolved solids (TDS))	Salinity identified as the dominant groundwater quality risk; evaporite-rich formations.	Groundwater quality data compiled from 128 water points, with ongoing salinity monitoring at selected sites through the procurement of data loggers with electrical conductivity sensors.	Early warning of salinisation; protects drinking water supplies.	Procurement of data loggers with electrical conductivity sensors Procurement of handheld electrical conductivity probes.	Logger loss or malfunction, calibration of equipment, mitigated in part through manual checks using handheld conductivity probe.
4. Barometric correction and data calibration	Atmospheric variations in pressure needed to also be measured in order to compensate for impacts on groundwater levels.	Two dedicated atmospheric pressure loggers installed at Water Department offices.	Barometric pressure data collection to mitigate impacts of atmospheric pressure on water level pressure transducers.	Purchase of barometric data loggers and training on how to use them.	Data handling complexity; mitigated through standardised processing.
5. Rainfall monitoring at water networks	Need to interpret groundwater recharge; loss of earlier gauges.	Supports seasonal interpretation; compensates for unreliable external rainfall data.	Procurement of low cost manual gauges installed at MSF compounds.	Routine maintenance.	Gauge damage; mitigated by multiple sites.

Table 14: Groundwater monitoring packages implemented in northeast Syria. (GWR)

Resourcing, financing and sustainability considerations

Design choices prioritised use of existing boreholes, limited equipment and strong involvement of local Water Departments, allowing the monitoring network to be established despite security, access and governance constraints. Long-term sustainability was explicitly recognised as dependent on transitioning data management and analytical capacity to these local institutions while maintaining funding. Procurement was supported by ACTED and equipment was purchased through local supply chains where possible.

Figure 53: Example of an observation borehole with no pumping equipment. (GWR)

10.2.5 PILOT MONITORING AND INITIAL ASSESSMENT

Pilot groundwater monitoring began in January 2023, with 8 monitoring sites installed progressively across Al-Hasakah Governorate by Groundwater Relief, Acted and the Qamishli and Al-Hasakah Water Departments. The first year of groundwater monitoring produced an initial baseline for groundwater level trends and salinity risk across Al-Hasakah Governorate.

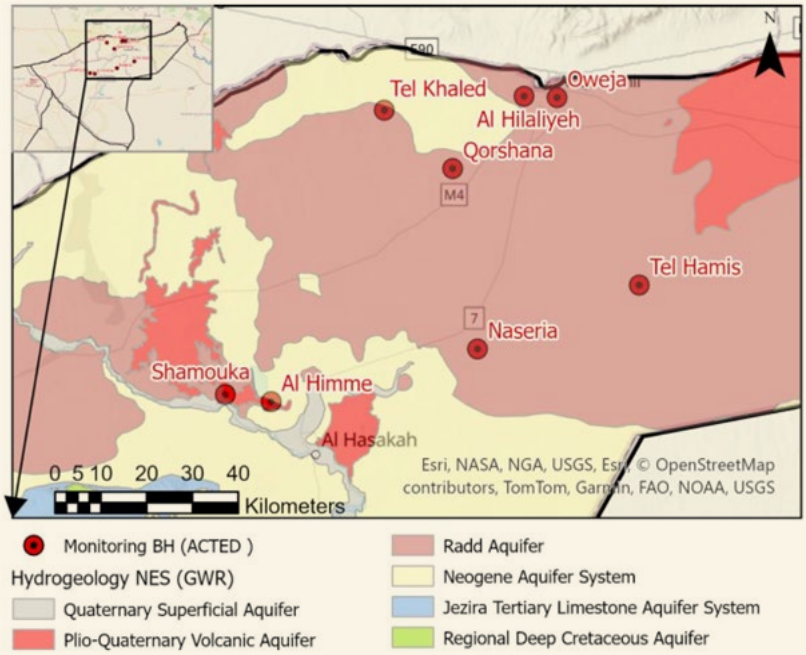

Figure 54: Location of the initial groundwater monitoring network established in 2023, showing eight boreholes distributed across key aquifer systems. (GWR & ACTED)

Over the monitoring year, groundwater levels fell at all sites with the largest declines were in the north. Seasonal patterns broadly followed expectations (rises in the wetter months; declines in the dry season), but at certain locations, groundwater continued falling into months when recharge would normally be expected, which is an early warning that needs longer records to confirm as a long-term trend.

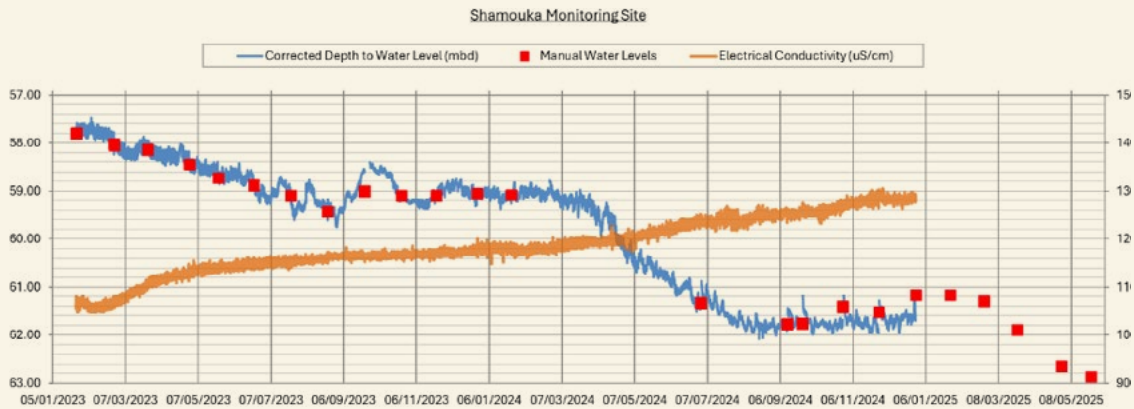

Figure 55: Groundwater level and electrical conductivity time series at Shamouka, showing continued groundwater decline, limited winter recharge and a gradual increase in salinity. (GWR & ACTED)

10.2.6 IMPROVEMENT AND EXPANSION

The preliminary hydrogeological assessment was undertaken in 2022. An initial monitoring network was then established in January 2023. Following a year of data collection a review of the monitoring network was undertaken in March 2024. Recommendations included: keeping the pilot network operational; undertaking a regional scale hydrochemistry study; extending coverage **with a prioritisation on manual monitoring** and installation of additional data loggers when budget allowed; and focusing investment into a monitoring unit within the Water Department and embedding routine operation in local institutions.

MAINTAIN AND STRENGTHEN THE EXISTING NETWORK

Longer time series are needed to improve understanding about aquifer trends. In practical terms, this means building on field data collection and data analysis protocols and procedures and supporting operation and maintenance costs of the monitoring network including the replacement of some loggers that were no longer operating. Improving the reliability of manual water level measurements through refresher training for field staff was also prioritised, since manual readings remain critical for calibration and quality control.

STRENGTHEN WATER QUALITY MONITORING BEYOND SALINITY SCREENING

While electrical conductivity monitoring provides valuable early warning, a larger-scale hydrochemistry study was also considered for future proposal development, to properly understand groundwater origins, recharge and mixing, and to identify priority contaminants. As a minimum, this would involve sampling across aquifers and seasons, including surface water where relevant, and analysing major ions, trace elements and selected isotopes. Longer-term, stronger laboratory capacity in northeast Syria was identified as a key enabling factor for making this feasible.

EMBED OPERATION WITHIN WATER DEPARTMENTS

A core sustainability recommendation was to invest in training Water Department staff on groundwater monitoring who would take responsibility for routine monitoring, maintenance, and basic data handling, reducing dependence on external actors and enabling long-term continuation. A sharepoint database was established in 2025 in order to support the Water Departments with the management of the monitoring data.

EXPANSION OF THE MONITORING NETWORK

In 2025 the monitoring network was expanded with another 10 monitoring points established covering identified gaps in coverage.

GROUNDWATER MODEL DEVELOPMENT

Over the course of 2026 a groundwater model is being developed by ACTED and Groundwater Relief, which will be calibrated using the groundwater monitoring data collected since January 2023. This groundwater model will support understanding about the regional water resources of the Al Hasakah Governorate.

10.2.7 INTEGRATION, HANDOVER AND KEY LESSONS

INTEGRATION WITH PROGRAMMES AND INSTITUTIONS

Groundwater monitoring in northeast Syria was embedded within **ACTED's wider water supply programming**, ensuring that data collection supported operational decisions and risk identification. Monitoring activities were implemented jointly with the **Qamishli and Al-Hasakah Water Departments**, who were involved in site selection, routine measurements and basic system management. This helped anchor monitoring within existing institutional roles.

HANDOVER AND SUSTAINABILITY

Routine data collection was transferred early to Water Department staff, supported by training and standard operating procedures. However, **data compilation, quality control and interpretation remained externally supported** during the pilot phase. This arrangement ensured technical reliability but also reflects a deliberate interim model. Long-term sustainability will depend on progressive localisation of data management, dedicated staff time and continued resourcing, which remain challenging in a conflict-affected context.

EXPLICIT LIMITS OF THE CURRENT SYSTEM

The monitoring network was initially designed as a **first step rather than a complete system.** Key limitations include the small number of sites, short monitoring records, limited abstraction data and security constraints. Over time the monitoring programme was built on and invested in.

KEY LESSONS FOR OTHER CONTEXTS

1. **Embed monitoring within delivery programmes.** Monitoring is more likely to persist when it directly informs operational decisions.
2. **Prioritise continuity over complexity.** Simple, repeatable measurements are more valuable than large or technically ambitious systems that cannot be maintained.
3. **Manual measurements are essential.** They provide robustness, calibration and resilience where automation fails.
4. **Plan for uncertainty and transition.** Early systems can still be installed and led by humanitarian organisations in uncertain settings whilst longer-term capacity and partnerships are developed with local institutions.

This case study shows how groundwater monitoring can generate useful insights even in highly constrained, conflict-affected settings. The monitoring system provided early warning of groundwater decline and salinity risks, supported the development of relationships with the authorities and began to address critical knowledge gaps, all while remaining operationally sustainable and built to scale in the future. The data collected is now being utilised to develop a groundwater model for the region.

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ANNEX

GROUNDWATER MONITORING IN HUMANITARIAN CONTEXTS

Terms of Reference, Procedures, Templates, Checklists, Forms and Examples

ANNEX A1

GROUNDWATER MONITORING DESIGN SCOPING CHECKLIST

This checklist supports the scoping phase described in **Chapter 3**. It helps implementers document responses to key questions across five key areas. Example answers are included for reference but should be adapted to the local context and completed in more detail.

SCOPING QUESTION	EXAMPLE ANSWER
1. KEY STAKEHOLDERS AND THEIR INFORMATION NEEDS	
Why is groundwater information needed in this context?	To track borehole sustainability in a high-use displacement camp. Early warning for salinity issues. Prevention of poor water quality.
Who will use the data? What decisions will it support?	WASH cluster agencies and borehole operators to plan pump scheduling and upgrades.
Could interventions affect the groundwater (e.g. drilling too many boreholes)?	Yes, risk of over-abstraction from the shallow aquifer.
Are there risks to existing users or the environment?	Yes, host communities may experience reduced access.
What benefits could monitoring bring to different user groups?	Improved reliability, reduced maintenance costs. Health benefits by reducing water quality (especially arsenic) threats.
Are there other potential users who could benefit from the data?	Yes, donors, national water regulators, and researchers.
Are there possible co-benefits from monitoring, such as local employment or technician roles?	Yes, local women trained as monitoring technicians and analysts.
How can we ensure that monitoring data will be trusted, used, and shared?	Stakeholder workshops and regular info briefs.
2. UNDERSTANDING OF THE HYDROGEOLOGY & ASSOCIATED RISKS	
What groundwater risks are already known in the area?	Seasonal drying of shallow wells; possible salinity issues.
Will increased abstraction put extra pressure on the aquifer?	Yes, modelling suggests declining levels during dry season.
How well understood is the local hydrogeology?	Moderately understood; few borehole logs available.
Would a basic hydrogeological study help clarify risks?	Yes, especially to map flow direction and recharge zones.
Is additional monitoring (e.g. geophysical survey or water level monitoring) needed?	Yes, water levels at 5 key boreholes need monitoring to understand hydrogeology properly.

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3. OPERATIONAL CONSTRAINTS	
Has groundwater monitoring been tried in this area before?	Yes, but was discontinued due to funding cuts.
Are there access constraints (e.g. roads, insecurity, remoteness)?	Yes, one area only accessible during dry season.
Are there national or local laws, ethical approvals, or planning permissions needed?	Yes, must submit to District Water Office.
Will local authorities or communities support or resist groundwater monitoring?	Supportive, especially with community technician roles.
Is there enough capacity to manage the system in the long term?	Partial; need training and mentoring of district staff. National authority has a digital system ready to integrate with.
Can the required equipment and materials be purchased locally or imported?	Some (e.g. dip meters) available locally.
Will the costs (setup and ongoing) be manageable within the available budget?	Yes, if phased and kept basic.
Is the expected value of the monitoring high enough to justify the costs?	Yes, supports high-priority emergency water supply.
Are there any data security or privacy concerns?	Some, especially if health-related water data is shared.
4. AVAILABLE RESOURCES AND OPPORTUNITIES	
Is funding available for setup and ongoing operation? For how long?	Setup covered, 18 months of operational budget secured.
Are there opportunities to share costs or partner with other organisations?	Yes, UNICEF and NGO X interested.
Is there existing infrastructure (e.g. boreholes, piezometers, labs) that can be used?	Yes, 10 boreholes have flow meters.
What technical expertise exists in-country?	National hydrogeologist network and local university department.
Can you find equipment and laboratory support locally?	Basic test kits available; central lab in capital for advanced tests.
What digital systems or data platforms already exist?	Simple Excel-based database at district level.
Are there organisations or experts who may want to support or co-deliver the monitoring?	Yes, WaterAid local office and UNICEF.
5. OPTIONS FOR LONG-TERM OPERATION	
Who is the most appropriate authority to manage it long-term?	District Water Office with national support.
What are their goals and responsibilities related to groundwater?	Monitoring and protection of rural water sources.
Do they currently need the kind of data your system would produce?	Yes, for annual planning and drought preparedness.
Are they interested in partnering on this project?	Yes, strong interest already shown.
Will they have the budget, staff, and mandate to continue the work?	Not currently, but could with co-funding.
Could capacity be realistically built during the project?	Yes, through phased handover and mentoring.
Do national policies or water laws support long-term monitoring?	Yes, groundwater monitoring included in 5-year WASH strategy.
What funding options exist for ongoing monitoring after handover?	Government budget line + donor extension proposal.
What results would the system need to show to secure future support or funding?	Evidence of early warning function and reliability.
Are these outcomes realistically achievable in this context?	Yes, with proper rollout and early engagement.

ANNEX A2

USER OBJECTIVES, INFORMATION NEEDS & BENEFITS OF GROUNDWATER DATA

Table A2 is referenced in **Section 4.1.1** and focuses on understanding user needs and the benefits they expect from groundwater data. The examples provided are illustrative and will be different according to local context and stakeholder landscape.

STAKEHOLDER	OBJECTIVES & ACTIVITIES RELEVANT TO GROUNDWATER	LOCAL GROUNDWATER CONCERNS	GROUNDWATER INFORMATION NEEDS	EXPECTED USES OF GW DATA	EXPECTED BENEFITS OF DATA USE	DATA FORMAT REQUIREMENTS	ADDITIONAL SUPPORT NEEDS
LOCAL WATER AUTHORITY	Manage and regulate groundwater use; allocate resources	Falling water tables in dry season	Weekly water level trends; borehole abstraction rates	Plan dry season pumping schedules; site new boreholes	Avoid supply interruptions; improve planning	Email summary, GIS maps	Basic data analysis training
NATIONAL WATER AUTHORITY	Oversee national groundwater policy and integration	Inconsistent local data collection; underreporting	Standardised datasets across regions; annual groundwater trends	National planning and regulatory oversight	Improved national reporting and resource planning	Spreadsheets; official reports	Interoperability with national databases
NGO WASH TECHNICIAN	Supervise borehole operation and maintenance	Frequent pump breakdowns and unclear yields	Real-time alerts for abnormal drops; abstraction data	Schedule preventive maintenance; monitor usage	Reduced downtime; better service reliability	Mobile dashboard or SMS alerts	Visual tools and threshold alerts
COMMUNITY WATER COMMITTEE	Oversee local borehole usage and water allocation	Unequal access; confusion during shortages	Simple summaries of usage and water availability	Support equitable scheduling; inform community	Fairer access; reduced conflict	Printed posters; community meetings	Facilitated workshops on interpreting charts
AGRICULTURAL COOPERATIVE	Coordinate irrigation schedules among farmers	Over-extraction leading to declining water tables	Seasonal water availability forecasts	Optimize irrigation timing; plan crop cycles	Sustained agricultural productivity	Weekly bulletins; mobile app	Training on data interpretation

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STAKEHOLDER	OBJECTIVES & ACTIVITIES RELEVANT TO GROUNDWATER	LOCAL GROUNDWATER CONCERNS	GROUNDWATER INFORMATION NEEDS	EXPECTED USES OF GW DATA	EXPECTED BENEFITS OF DATA USE	DATA FORMAT REQUIREMENTS	ADDITIONAL SUPPORT NEEDS
PRIVATE WATER SUPPLIER	Provide water to urban and peri-urban areas	Contamination risks; supply reliability	Water quality indicators; supply-demand analytics	Ensure compliance; plan infrastructure investments	Enhanced service delivery; regulatory compliance	Interactive dashboards	Technical assistance on data integration
ENVIRONMENTAL NGO	Monitor ecosystem health and advocate for sustainable practices	Habitat degradation due to groundwater depletion	Groundwater levels in sensitive ecosystems	Inform conservation strategies; policy advocacy	Protection of biodiversity; informed policymaking	GIS layers; periodic reports	Collaboration on data collection methods
ACADEMIC INSTITUTION	Conduct research on hydrogeology and water management	Data scarcity; lack of long-term monitoring	Historical and real-time groundwater data	Support research projects; publish findings	Contribution to scientific knowledge; policy input	Access to raw datasets	Partnerships for field studies
HEALTH DEPARTMENT	Monitor public health related to water quality	Waterborne diseases linked to contaminated sources	Water quality parameters; contamination alerts	Public health advisories; intervention planning	Reduced incidence of waterborne diseases	Alerts; health bulletins	Integration with health monitoring systems
BOREHOLE OPERATOR	Operate and maintain pumping infrastructure	Unpredictable well performance; rising costs	Pump runtimes, abstraction volume, static water level	Adjust maintenance schedules; report issues	Efficient operations; fewer breakdowns	Printed logs or SMS summaries	Training on meter reading and reporting
REGULATOR	Ensure legal compliance, reporting, and water use controls	Unreported abstraction; scattered data	Metered abstraction, verified quality data	Compliance audits; enforcement decisions	Fair regulation; transparency	Spreadsheet format; monthly reports	Training on use of data for inspection targeting

ANNEX A3

OPERATIONAL CONSTRAINTS, RESOURCES & PARTNERSHIP OPPORTUNITIES

Table A3 is referenced in **Section 4.1.1** and can be used to evidence practical considerations, such as implementation constraints, available resources, and partnership opportunities for long-term operation, financing and use of the monitoring system. The examples provided are illustrative and should be adapted to the local context and stakeholder landscape.

STAKEHOLDER	EXPECTED CHALLENGES / CONSTRAINTS	SOLUTIONS TO CHALLENGES	INTEREST IN SUPPORTING MONITORING	RESOURCES THEY COULD PROVIDE	EXISTING INCENTIVES	ADDITIONAL INCENTIVES NEEDED	CAPACITY BUILDING NEEDS
LOCAL WATER AUTHORITY	Limited technical staff; unclear budget lines	Assign dedicated focal point; external support for setup	High	Office space, staff time, existing borehole records	Improved data for planning and regulation	Training, modest funding for operational costs	Training in sensor use and data interpretation
NATIONAL WATER AUTHORITY	Fragmented monitoring responsibilities; lack of standardisation	Develop national protocols and integration tools	High	National coordination platforms, reporting staff	Improved decision-making, international reporting compliance	Ongoing financing and political buy-in	Capacity development for standardised methods
NGO WASH TECHNICIAN	No prior experience with monitoring tools	Simple protocols; on-the-job training	High	Time for site visits; existing logistics network	Better borehole performance	Recognition, training certificate	Hands-on setup and use of sensors
COMMUNITY WATER COMMITTEE	Low awareness; concerns about equipment theft	Engagement workshops; community technician role	Moderate	Local security, volunteer time	Trust in system; water equity	Public recognition, local data access	Orientation session; ongoing mentoring
AGRICULTURAL COOPERATIVE	Resistance to change; lack of data literacy	Demonstrate benefits; provide user-friendly tools	High	Access to farmer networks; meeting spaces	Improved crop yields; efficient water use	Subsidies for water-saving technologies	Training on data interpretation and application

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STAKEHOLDER	EXPECTED CHALLENGES / CONSTRAINTS	SOLUTIONS TO CHALLENGES	INTEREST IN SUPPORTING MONITORING	RESOURCES THEY COULD PROVIDE	EXISTING INCENTIVES	ADDITIONAL INCENTIVES NEEDED	CAPACITY BUILDING NEEDS
PRIVATE WATER SUPPLIER	Data privacy concerns; competitive market	Data-sharing agreements; anonymized data	Conditional	Technical infrastructure; customer base	Regulatory compliance; service improvement	Assurance of data confidentiality	Legal guidance on data sharing
ENVIRONMENTAL NGO	Limited funding; need for scientific rigour	Partnerships with academic institutions; grant applications	High	Expertise in ecological monitoring	Conservation goals; policy influence	Access to long-term data sets	Training in data collection methodologies
ACADEMIC INSTITUTION	Funding constraints; need for field data	Collaborative research projects; student involvement	Low	Research personnel; analytical tools	Publication opportunities; academic advancement	Access to diverse data sources	Field training programs for students
HEALTH DEPARTMENT	Integration with existing health data systems	Develop interoperable platforms; cross-sector collaboration	Low	Health data; outreach programs	Improved public health outcomes	Funding for integrated monitoring systems	Training on environmental health indicators
BOREHOLE OPERATOR	No structured reporting; poor records	Simple logbooks; SMS reporting templates	High	Pump access and field observations	Improved system performance; fewer breakdowns	Modest incentives; role formalisation	Introductory training on monitoring routines
REGULATOR	Irregular reporting; lack of enforcement linkage	Digital submissions and audit triggers	High	Regulatory mandate; inspection teams	Stronger enforcement capacity	Technical support and digital tools	Use of monitoring data in audit systems

ANNEX A4

HUMANITARIAN HYDROGEOLOGICAL CONCEPTUAL MODEL & RISK ASSESSMENT TERMS OF REFERENCE

ANNEX A4 links to **Section 4.1.2c** on creating a hydrogeological conceptual model and **Section 4.1.2d** on developing a risk assessment.

PURPOSE

To produce a fit-for-purpose conceptual understanding of the groundwater system and identify groundwater-related risks to inform the design and operation of a groundwater monitoring system in a humanitarian or development context.

COMMISSIONING ORGANISATION

[Insert name of implementing organisation]

LOCATION

[Insert project location]

DURATION

[Insert estimated duration, e.g., 15–25 working days over 4 weeks]

BACKGROUND

Groundwater is the primary water source in many humanitarian and development contexts. However, it is often poorly understood due to limited monitoring or hydrogeological assessment. This ToR supports the commissioning of a simplified conceptual model of the aquifer system, supported by a risk assessment, to guide the setup of a targeted groundwater monitoring network.

This model is intended to be functional, graphic, and suited to local operational realities - not overly technical. It will help identify key uncertainties, risks, and monitoring priorities and serve as a communication tool for stakeholders and donors.

SCOPE OF WORK

The hydrogeologist will be responsible for:

1. DESK-BASED DATA REVIEW

- **Review all existing data shared by the implementing organisation, including:**
  - Borehole logs and pumping test results
  - Geological and hydrogeological maps
  - Water level and water quality data
  - Meteorological and surface water data
  - Previous hydrological or WASH assessments

2. CROSS-SECTIONAL SURVEY DESIGN SUPPORT (OPTIONAL)

- **Advise or assist in the design of a field-based survey of selected boreholes or wells.**
- **Review survey results, including static/dynamic water levels, borehole construction details, and basic water quality.**

3. CONCEPTUAL MODEL DEVELOPMENT

- **Produce at least one graphic illustration of the groundwater system, including:**
  - Aquifer units and structure
  - Recharge pathways and discharge zones
  - Groundwater flow directions and potential interactions
  - Locations of key infrastructure (e.g. boreholes, wadi systems, camps)
- **Use visual aids suitable for technical and non-technical audiences.**

4. GROUNDWATER RISK ASSESSMENT

- **Identify and prioritise risks to groundwater quantity and quality, such as:**
  - Over-abstraction
  - Seasonal drying
  - Salinity, arsenic or nitrate contamination
  - Reduced recharge or climate vulnerability
  - Institutional or data-use risks
- **Recommend practical monitoring actions in response to each risk.**

5. RECOMMENDATIONS FOR MONITORING DESIGN

- **Suggest:**
  - Priority locations for monitoring points
  - Parameters to be measured
  - Frequency and methods of monitoring
  - Areas where additional investigation may be needed

6. DELIVERABLES

- **Short report (maximum 15 pages) including:**
  - Narrative summary of hydrogeological setting
  - Annotated conceptual model diagrams
  - Risk matrix with recommended monitoring responses
  - Suggested monitoring framework and data needs
- **PowerPoint slide version of the conceptual model for stakeholder use.**
- **Optional: A one-page "visual summary" for community or stakeholder engagement.**

QUALIFICATIONS

- Advanced degree in hydrogeology, water resources, or related field.
- Minimum 5 years of experience conducting groundwater assessments.
- Familiarity with low-resource or humanitarian contexts.
- Ability to translate technical concepts into practical recommendations and accessible visuals.
- Experience with GIS, groundwater modelling, or aquifer conceptualisation is a plus.

TIMELINE AND REPORTING

- Start date: [Insert date]
- End date: [Insert date]
- The consultant will report to: [Insert name and title of project lead or technical advisor]

ANNEX A5

MONITORING COMPONENT DESIGN CHECKLIST

This checklist supports the design of monitoring system components as described in **Section 4.3.1**. It can be used during planning meetings, partner workshops, or budget planning sessions to ensure the system is well-targeted, feasible, and meets local information needs.

1. LOCATIONS

- Have monitoring points been placed near each key groundwater risk (e.g. over-abstraction, pollution, salinity)?
- Are there enough monitoring points to show trends across the area, not just at problem sites?
- Are some sites included where no known risks exist (baseline/control points)?
- Are site locations accessible and secure enough for regular monitoring?
- Have communities, authorities, and landowners agreed to hosting the monitoring point?

2. EQUIPMENT

- Is the selected equipment appropriate for the parameter and frequency of monitoring?
- Have simpler or lower-cost tools been considered where appropriate (e.g. manual vs. automatic)?
- Are replacement parts and consumables available locally or regionally?
- Does the team have the skills to install and use the equipment, or is training needed?
- Has the total equipment cost been confirmed within the available budget?

3. ADDITIONAL INFRASTRUCTURE

- Will new piezometers, dedicated dip tubes or wellhead modifications provide secure housing and safe access for groundwater monitoring equipment?
- Are suitable facilities and procedures in place for the secure storage, maintenance and calibration of monitoring equipment?
- Is a laptop, tablet, database, data visualization platform, or data management tool included for data upload, analysis and communication?
- Are appropriate hardware and data management systems available to support data upload, storage, analysis, visualisation and communication?
- Is solar or battery power available for automatic sensors if mains power is not?
- Have data download and transmission needs (e.g. mobile signal, USB access) been considered?

4. GENERAL DESIGN CONSIDERATIONS

- Does this design reflect the highest-priority recommendations from Step 2?
- Is the system affordable to install and maintain with expected resources?
- Are implementation partners involved in choosing where and how monitoring will happen? Is there a plan for local engagement?
- What reporting systems are in place to hold accountable those who are collecting the data (e.g. monthly reporting to head office)?
- What process is in place for data cleaning, analysis and monitoring network review (e.g. commissioning an annual monitoring report) and how will this be fed back to the data collectors?

ANNEX A6

OPERATIONAL RESPONSIBILITIES AND ASSIGNMENTS

This annex links to **Section 4.3.2**; it provides a template and some examples of individual operational activities within the groundwater monitoring system. Each row corresponds to a specific task or function that must be assigned, with clarity on who is responsible, how often it must be done, who they report to, what support may be needed for them to carry it out, and the reportable key performance indicator (KPI).

OPERATIONAL RESPONSIBILITY	ASSIGNED ACTOR / ORGANISATION	REPORTING FREQUENCY OR DEADLINE	REPORTS TO	CAPACITY BUILDING REQUIRED	INCENTIVE, FINANCING OR IN-KIND SUPPORT NEEDED	KEY PERFORMANCE INDICATOR (KPI) AND [TARGET]
Daily manual water level measurement in shallow wells	Water committee or hosting community volunteer	Daily (recorded in logbook or phone application)	Monitoring Technician	Initial training on measurement technique and form use	Logbooks, dip meter, mobile phone/tablet airtime, small payment for meeting KPIs	% of planned daily measurements completed on time [≥ 95% per month]
Monthly sensor check and battery status confirmation	Monitoring Technician	Monthly	Institution Managing the Network	Refresher on troubleshooting and calibration	Transport allowance, spare batteries	% of monthly checks completed and logged [100% each month]
Monthly download of groundwater level logger data	Monitoring Technician	Monthly (by 5th of each month)	Institution Managing the Network	Training in logger software and data transfer	Laptop, USB cable, software licence if needed	% of loggers downloaded as scheduled [≥ 95%]
Water quality sampling at priority boreholes	Local Water Authority and Monitoring Technician	Quarterly (once every 3 months)	Institution Managing the Network + WASH partners	SOPs and safe sampling protocols	Test kits or lab access, sampling bottles, transport allowance	% of priority boreholes sampled and results recorded [≥ 90% per month]
Review and upload of monitoring data to dashboard	Data manager at institution managing the network	Monthly (by 10th of each month)	National coordination platform or donor	Orientation on dashboard platform and formatting	IT setup, internet connection, time allocation	% of data sets uploaded correctly and on time [100% monthly]
Provide feedback summary to community water committees	Monitoring Technician or Local Authority field staff	Six monthly	Community leadership	Support with summary visualisations and explanations	Travel time, expenses and printed summary materials	% of committees receiving feedback each quarter [≥ 90% of target communities]
Routine maintenance and cleaning of monitoring equipment	Monitoring Technician	Every 3 months or after major storm event	Institution Managing the Network	Equipment care protocols	Cleaning tools, field gloves, spare parts	% of equipment maintained per schedule [100%]

ANNEX A7

PARTNERSHIP CONTRACT TEMPLATE

Example partnership contract linked to **Section 5.1** for a groundwater monitoring project. This template is intended as a starting point for development, rather than a legally-robust solution. Any legal contract should be developed with lawyers and aim to comply with the laws and regulations of the country hosting the groundwater monitoring project.

This Agreement is made on date: _____, by and between:

[Partner A Name], a ***[type of organisation]*** with offices at ***[address]***, hereinafter referred to as "Partner A," and

[Partner B Name], a ***[type of organisation]*** with offices at ***[address]***, hereinafter referred to as "Partner B."

Together referred to as "the Parties."

1. PURPOSE

The purpose of this Agreement is to define binding roles, responsibilities, financial and in-kind contributions, and operational protocols for the joint implementation of a groundwater monitoring system in ***[project location]***.

2. SPECIFIC ROLES AND RESPONSIBILITIES

2.1 Partner A shall:

- Procure and deliver (one-time setup):
  - 3 groundwater loggers
  - 6 manual dip meters
  - 1 automatic weather station
  - Water quality starter kits for 12 locations
- Lead installation of all sensors with joint field teams (setup).
- Set up and maintain a cloud dashboard for data sharing (setup and ongoing).
- Provide part-time hydrogeological support (3 days/month for 12 months, renewable annually).
- Train technicians and community monitors in data collection and recording protocols (setup and periodic refreshers).
- Cover cost of initial workshops, training materials, and software tools (setup).

2.2 Partner B shall:

- Provide secure access and permission for all identified monitoring locations (setup).
- Assign two full-time field technicians (ongoing, indefinite):
  - Monthly logger downloads
  - Weekly manual dip checks and water quality tests
- Provide storage for all field equipment and backup sensors (ongoing).
- Supply transport for monthly field visits (with fuel and driver) (ongoing).
- Host a data management station with desk space, power, and internet (ongoing).
- Cover stipends, uniforms, and phone credit for technicians (USD 300/month each) (ongoing).
- Host quarterly data review and community feedback meetings (ongoing).

3. FINANCIAL CONTRIBUTIONS

The Parties agree to the following cost-sharing arrangement:

ITEM	PARTNER A CONTRIBUTION (USD)	PARTNER B CONTRIBUTION (USD)	FREQUENCY
SETUP EQUIPMENT	20,000	0	One-time setup
TECHNICIAN SUPPORT	2,000	7,200	Annual (ongoing)
DATA PLATFORM AND ANALYSIS TOOLS	3,000	500	One-time setup + annual maintenance
HYDROGEOLOGIST SUPPORT	4,500	0	Annual (renewable)
LOCAL TRANSPORT AND LOGISTICS	0	2,000	Annual (ongoing)
COMMUNICATION AND COMMUNITY ENGAGEMENT	1,500	1,200	Annual (ongoing)
TOTAL	31,000	10,900	Mixed

4. DATA MANAGEMENT

- All groundwater data collected will be co-owned.
- Partner A shall manage the database and dashboard interface.
- Both partners may access data and request analysis.
- Any third-party sharing shall require mutual written consent.

5. TERM AND TERMINATION

- This Agreement shall remain in effect for five (5) years from the signing date.
- Either Party may terminate the Agreement with 60 days' notice in writing.
- On termination, each Party shall share relevant documentation and lessons learned.

6. DISPUTE RESOLUTION

Disputes arising under this Agreement shall be settled through negotiation. If unresolved, they shall be referred to arbitration in ***[jurisdiction]***.

7. GOVERNING LAW

This Agreement shall be governed by and construed in accordance with the laws of ***[country or jurisdiction]***.

8. SIGNATURES

Signed on behalf of Partner A:
[Name, Title]
Date: _____

Signed on behalf of Partner B:
[Name, Title]
Date: _____

EXAMPLE ANNEXES:

ANNEX A: Monitoring Site Locations & GPS Coordinates
ANNEX B: Data Sharing Policy & Visualisation Plan
ANNEX C: Training and Capacity Building Schedule

ANNEX A8

DATA SHARING AGREEMENT TEMPLATE

Example data sharing agreement for a groundwater monitoring project **(Section 5.1)**. This template is intended as a starting point for development, rather than a legally-robust solution. Any legal contract should be developed with lawyers and aim to comply with the laws and regulations of the country hosting the groundwater monitoring project.

This Agreement is entered into on date: _____, by and between:

[Partner A Name], a ***[type of organisation]*** with offices at ***[address]***, and

[Partner B Name], a ***[type of organisation]*** with offices at ***[address]***,

Together referred to as "the Parties."

1. PURPOSE

This Data Sharing Agreement sets out the terms and conditions under which groundwater monitoring data will be shared, accessed, used, and managed between the Parties. The aim is to support transparency, coordination, and evidence-based water management in ***[project location]***.

2. SCOPE OF SHARED DATA

The data covered under this Agreement includes:

- Groundwater level measurements (manual and automated).
- Groundwater quality measurements (chemical, microbiological, salinity).
- Borehole information (location, construction, usage).
- Meteorological data (where collected in conjunction with groundwater data).
- Any hydrogeological interpretations and conceptual models developed from the data.

3. DATA OWNERSHIP

- The Parties acknowledge joint ownership of all data collected through the joint monitoring activities unless otherwise agreed in writing.
- If data is collected on infrastructure not owned by either Party, written consent must be obtained from the infrastructure owner before sharing externally.

4. ACCESS AND USE

- Both Parties will have full access to all raw and processed data for internal use.
- The data may be used for planning, research, reporting, and operational decision-making.
- Publication of data, interpretations, or analyses must include appropriate credit to both Parties.
- Third-party access (e.g. donors, researchers, government institutions) must be approved in writing by both Parties, unless anonymised and used solely for public good.

5. CONFIDENTIALITY AND SENSITIVITY

- Data relating to privately or community-owned water points will be treated with care.
- Any data considered sensitive (e.g. locations of vulnerable water sources, infrastructure owned by private or community actors) must not be published or disclosed without specific consent.
- All Parties agree to respect national regulations on data protection and privacy.

6. DATA MANAGEMENT AND SECURITY

- Partner A will host the primary data platform, ensuring appropriate backup and security protocols.
- Partner B will support with local collection, digitisation, and transmission of data.
- Access controls and user permissions will be defined and documented in ANNEX A.

7. DISPUTE RESOLUTION

Any disputes arising from this Agreement will be resolved first through negotiation between the Parties. If no resolution is reached, the matter may be referred to mediation or arbitration in [jurisdiction].

8. TERM AND TERMINATION

- This Agreement will remain in force for a period of five (5) years from the date of signing.
- Either Party may terminate the Agreement with 60 days' written notice.
- Upon termination, both Parties will retain access to data collected during the term of the Agreement.

9. AMENDMENTS

This Agreement may only be amended by mutual written consent of the Parties.

8. SIGNATURES

Signed on behalf of Partner A:
[Name, Title]
Date: _____

Signed on behalf of Partner B:
[Name, Title]
Date: _____

EXAMPLE ANNEXES:
ANNEX A: User Permissions and Data Platform Access List
ANNEX B: Sensitive Sites and Disclosure Conditions
ANNEX C: Glossary of Data Types and Formats

ANNEX A9

MANUAL WATER LEVEL MONITORING STANDARD OPERATING PRODEDURE (SOP)

This annex extends the explanation of manual water level monitoring from **Section 6.2.1A.**

INTRODUCTION

The following procedure is for collection of manual water levels at monitoring wells.

Equipment required includes the following:

- Dip meter (50 - 100m) + extra batteries.
- Android cell phone (minimum version 10.0) + charging cord.

Manual water level measurements are taken in the field using a water level dip meter, which consists of a sensor probe attached to a measuring tape on a cable reel.

Dip meters operate through electrical current passing between two wires that run down the measuring tape. A connection is established between the two wires when the sensor probe contacts water and sets off a buzzer in the cable reel.

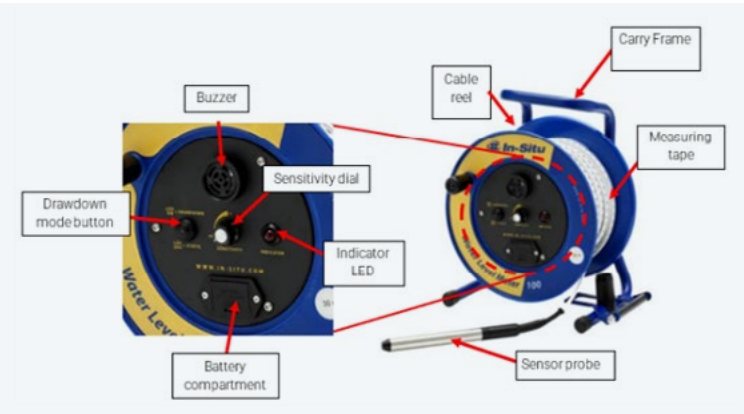

Figure A1: Example of a water level dip meter. (In-Situ)
(Water Monitoring Equipment, Water Quality Testing, & More | In-Situ)

DIP METER HANDLING

The dip meter is a delicate piece of equipment, and must be handled with care to avoid damaging the wiring inside the tape. Take care not to drop the unit, and avoid twisting, bending or tangling cables when reeling the cable back in. Over time, the batteries inside the unit will need replacement.

METHOD

1. Before measurement, test the dip meter to make sure batteries are working and buzzer sounds when coming into contact with water.

   Make sure to charge your cell phone.

   Dip meter measurements are taken from a consistent single **datum point** at the top of the well, located inside the well access port. The datum point should be clearly marked on the well and recorded on the field form. For instance, the point may be identified by a **white spray paint marked**

with an arrow denoting the location you should read the tape from. Open the well access port using the well keys provided and identify this point prior to taking the measurement. It is important that all readings are taken from a consistent location.

Figure A2: Examples of datum point. (GWR)

2. To take a water level measurement, lower the dip meter probe **into the dip tubing** (not the open well) until the buzzer is sounded.

   The sound should appear sharp and clear. If it sounds 'fuzzy' or intermittent, then it is likely that the probe is detecting water on the side of the dip tubing and not the true water level.

   When the buzzer sounds, check several times the exact depth against your datum point at the top of the well. The dip meter should be carefully raised and lowered by small increments to confirm the exact depth of the water level.

3. Follow the format below for reading the dip meter tape, recording three decimal places:

Figure A3: How to read a deep meter. (GWR)

On the figure above:
- The first number is the largest number on the tape and it is the unit meter (1-50 or 1-100).
- The second and third number, after the period, are the tenths and hundredths values (00-99).
- The fourth value is the thousandth value (0-9).

In this example, if the tape crosses the datum point at the location marked by the red line above on the **right**, then the reading of the depth to water from the datum point is **2 meters and 2.3 centimeters.** Altogether in meters, this is **2.023 meters.**

4. For each water level measurement, the field form and cell phone application is both used. The field form is completed before entering data on the phone.

5. On the field form, first record the following well details:
   - Borehole name
   - Borehole location
   - GPS coordinates
   - Elevation (meters above sea level)
   - The location of the datum point
   - Borehole (if open) or casing depth (meters below datum)
   - Pump intake depth (if applicable) (meters below datum)

   Then for each measurement, record the following:
   - **Date**
   - **Time**
   - **Depth to water** (from datum point)
   - **Comments or observations** for each measurement taken (e.g., if there is a pump, record if it is operating or not at the time of the measurement and how long the pump has been on or off for)

   For wells with operational pumps, it is best if the manual water level measurements are taken **BEFORE** turning the pump on for the day, while also recording how many hours the pump has been off overnight. If this is not possible, the measurement should be taken **JUST BEFORE** turning the pump off for the day, while also recording how many hours/since what time the pump has been on during the day.

6. After completing the field form, upload the water level measurements using the Kobo tool and cell phone through the KoboCollect application as follows.

   Select **'Start new form' > 'Well Monitoring Form'** and follow the prompts on the form.

   Input the following details into the form:
   - Name of data collector (your name)
   - Name of the well (label on well)
   - Select date
   - Select time
   - To enter longitude and latitude, select **'Next'** on both pages to be directed to **'Location (auto)'** and select **'Get point'** and the application will automatically determine the GPS coordinates.
   - Groundwater level (meters below datum)
   - Is the well pumping?
   - If yes, what time was the pump turned on?
   - Any notes you recorded under comments/observations

   If there is no information to input, input a dash (—) or period (.) and move to the next page. You will do this for:
   - Electrical conductivity
   - Total dissolved solids
   - pH

   When you have finished with the form, select **'Finalize'**.

   When you have an internet connection, navigate from the home page of the KoboCollect application to **'Ready to send'**.

   Select the boxes to the right of the monitoring forms you wish to send/upload, and then select **'Send Selected'** at the bottom of the page.

7. Finally, ensure the well access port is locked after you have finished taking the measurement and carefully store the dip meter for next use.

For any questions, please contact help@groundwater-relief.org

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ANNEX A10

MANUAL WATER LEVEL MONITORING FORM

AGENCY			
NAME OF DATA COLLECTOR			
DATE / TIME			
BOREHOLE NAME			
BOREHOLE LOCATION			
GPS COORDINATES			
ELEVATION (METERS ABOVE SEA LEVEL)			
LOCATION OF DATUM POINT			
BOREHOLE/ SCREEN DEPTH (METERS BELOW DATUM)			
PUMP DEPTH (IF APPLICABLE) (METERS BELOW DATUM)			
DATE	**TIME**	**DEPTH TO WATER LEVEL (METERS BELOW DATUM)**	**COMMENTS/OBSERVATIONS**

ANNEX A11

AUTOMATIC WATER LEVEL MONITORING STANDARD OPERATING PROCEDURE (SOP)

This annex extends the explanation of automatic water level monitoring from **Section 6.2.1B**.

EQUIPMENT CHECKLIST

Used for automatic monitoring sites:

- ☐ **Dip meter** – to take manual water level readings (must be long enough for the borehole depth).
- ☐ **Data logger** – for each borehole you want to monitor.
- ☐ **Barologger** – to record air pressure (if the data loggers are not specially 'vented'); ideally one per area or every 30 km.
- ☐ **Datum marker** – a fixed reference point for all water level readings .
- ☐ **Smartphone or camera** – to record installation.
- ☐ **Water Level Data Collection Form** – for field notes and manual readings .
- ☐ **Spare batteries** – especially for dip meters and field equipment.
- ☐ **Strong Kevlar cord or logger-specific suspension cable** – for fixing and hanging the sensor so it can be pulled up and later retrieved from the well.
- ☐ **Dip tube** – plastic tube installed inside the borehole (minimum 32 mm wide) to hold the logger safely.

If downloading data manually:

- ☐ **A logger reader** or connection cable (brand-specific).
- ☐ **A laptop or smartphone with the correct software.**

If using telemetry (remote data transfer):

- ☐ **Telemetry unit** (must be compatible with the logger).
- ☐ **Long-life battery or solar panel** for telemetry.
- ☐ **SIM card** (or satellite link, depending on system).
- ☐ **App or software** to receive and check the data remotely.

A. PRE-INSTALLATION PREPARATIONS

Before installing automatic water level loggers or barologgers, carry out a short but careful site assessment. This ensures the equipment will work as intended and avoids problems later on.

1. SELECT AND PREPARE THE BAROLOGGER LOCATION

Barologgers (used to correct for changes in air pressure if the logger is not specially 'vented') should be placed in a suitable location, ideally:

- **In a secure place** that is protected from theft, tampering, or major temperature changes (e.g. inside a health centre, school, or partner office, but not in an air-conditioned room).
- Hanging **freely in the air**, not submerged in water. A barologger can be placed inside a borehole as long as it stays completely dry.

If an automatic weather station is installed nearby, its barometer pressure readings can be used instead of installing a dedicated barologger. If the data loggers are vented, which removes the effect of atmospheric pressure using a small air tube up to the surface, then this step is not required. Note: vented data loggers are less commonly used as they are more expensive, more technical to install, and can introduce error if the air tube becomes blocked.

2. CHECK AND RECORD MONITORING BOREHOLE DETAILS

For each borehole or well that will host a logger:

☐ Confirm access is allowed and safe.

☐ Define and **clearly mark a fixed datum point** at the top of the well .

☐ Take **photos** of the borehole, showing the site and the datum.

☐ Measure the **internal diameter** of the borehole (minimum 32 mm).

☐ Measure the **total depth** of the borehole,using a plumb line.

☐ Record any information about borehole construction:

- o Pump type and depth (if installed)
- o Screen depth and length
- o Geological materials (if known)

☐ Record the **GPS coordinates and elevation** of the borehole.

☐ Measure the **datum height** above ground level (e.g. 0.5 m above ground).

☐ Measure the **depth to the top of the pump** from the datum (if known).

3. PREPARE FOR INSTALLATION

Check if there is a **fixed anchor** point (like a hook or eyelet) to secure the logger at the wellhead. If none exists, install one:

- Drill an eyelet into the wellhead cover.
- Use a locking nut or strong glue to secure it.
- Make sure it is durable and protected from tampering.

B. LOGGER PROGRAMMING AND INSTALLATION

Once the site has been prepared, the next step is to correctly program and install both the data logger and (if applicable) its telemetry unit.

BEFORE INSTALLATION:

- **Decide the depth at which the logger should be installed.**
  It must always stay submerged, even in the dry season, but should not be too close to the pump. As a rule of thumb, install it **at least 1 metre above the pump, and below the expected minimum water level.** Note: it is common to underestimate how low water levels could reach during dry seasons or periods of high abstraction.
- **Synchronise the logger and barologger to local time.**
  This is essential for aligning and correcting the data later. Be careful when doing this, many errors in data interpretation come from incorrect time settings.
- **Set the logging interval.**
  In most cases, logging once every hour is sufficient. However, if users want detailed information on aquifer properties, accurate records of pump runtimes, or estimations of water abstraction volumes, 5 or 15-minute intervals will capture this information better (at the expense of battery life). Choose a logging schedule that measures at consistent times (e.g. on the hour) for easier comparison and processing.
- **Install the barologger.**
  As explained in Section (a), this should be placed in a **safe, well-ventilated location above water level** (such as at ground level).
- **If using telemetry:**
  Set up the telemetry equipment according to the manufacturer's instructions. Make sure the SIM card is inserted, battery is charged, and mobile signal is strong enough for the logger to send data.

Figure A4: Technician setting up an In-Situ datalogger in Cox's Bazar, Bangladesh. (GWR)
(Water Monitoring Equipment, Water Quality Testing, & More | In-Situ[39])

39 - https://in-situ.com/

DURING INSTALLATION:

- **Measure and cut the Kevlar cord or cable** to the correct length, based on the intended logger depth. Leave an extra **1 m of length** to allow for secure tying.
- **Attach the logger securely** to the cord using a bowline knot (which doesn't slip) or connect it to a dedicated cable if supplied.
- **Lower the logger gently** into the borehole through the dip tube until it reaches the planned depth. Time this to happen shortly before the logger is scheduled to begin recording.
- **Secure the suspension cord or cable** at the wellhead using a cap, eyelet, or protective casing. Keep the setup as **discreet and tamper-proof as possible**, especially in areas with public access.
- **Record key installation information** on the Data Logger Installation Form (**see ANNEX A12**). This includes:
  - Final installed depth (measured from the datum)
  - Logger serial number
  - Date and time of installation
  - Name of the technician
  - Any special installation notes

ANNEX A12: DATA LOGGER INSTALLATION FORM

This form should be completed during the installation of each groundwater level data logger to ensure accurate and traceable setup.

Figure A5: Groundwater level sensors, such as Solinst Levelogger[40] piezometers, typically have a computer software and adapter that can be used to setup the sensors. Some of these software also provide data analysis support. (Solinst) (Solinst Groundwater Monitoring Instruments[41])

40 - https://www.solinst.com/instruments/dataloggers-and-telemetry-systems/3001-levelogger/
41 - https://www.solinst.com/en-gb/

C. CALIBRATION AND MANUAL WATER LEVEL CHECKS

Installing an automatic logger alone is **not enough** to get usable groundwater level data. These sensors don't measure water level directly - they measure **pressure**.

That pressure comes from both:

- The weight of the water above the sensor (which we want), and
- The surrounding **air pressure** (which must be removed).

To convert the pressure reading into a correct water level depth, we must:

1. **Correct** for changes in air pressure using a **barologger** (unless the logger is 'vented', then this has been done already).
2. **Calibrate** the pressure data using at least one known manual **depth-to-water** measurement taken with a dip meter.

Without this correction and calibration, the data won't reflect true groundwater levels.

WHEN TO TAKE MANUAL CALIBRATION MEASUREMENTS

Use a dip meter to record the actual water level in the well at these key times:

- **Right after installing** the logger.
- **Before removing** the logger to download or reprogram it.
- **After reinstalling** the logger.
- **Any time** the logger is moved or disturbed (e.g. during pump servicing).
- **Every 3-4 months minimum** even if the logger has not been moved.

These manual readings must be taken at the **same moment** the logger is set to record. For example, if the logger records at 08:00, take your dip reading exactly at 08:00.

WHAT TO RECORD

Each time you take a manual measurement, record:

- The **depth to water** (from the borehole's datum point).
- The **exact time and date.**
- The **pump status**:
  - Is the pump ON or OFF?
  - If ON, how long has it been running?
  - If OFF, how long since it stopped?

This helps identify whether the logger is recording static (resting) or dynamic (pumped) water levels.

FORMS TO USE

To keep everything well-documented and easy to interpret later:

- Use the **Manual Water Level Monitoring Form** (**ANNEX A10**) for regular manual dip readings throughout the monitoring period.
- Use the **Data Logger Download Form** (**ANNEX A13**) when installing, removing, or reprogramming a logger.

ANNEX A10: MANUAL WATER LEVEL MONITORING FORM

Use this form to record regular manual water level readings using a dip meter during the monitoring period.

ANNEX A13: FIELD FORM

Use this form whenever a data logger is removed, downloaded, or reinstalled to maintain a record of calibration and data collection.

D. LOGGER RETRIEVAL AND DATA DOWNLOAD

If your monitoring setup uses **non-telemetered data loggers**, you'll need to retrieve each device manually to download its stored data. This process should be done carefully to avoid equipment damage or data loss.

1. TAKE A MANUAL WATER LEVEL READING

- Use a dip meter to record the **exact water** level at the **same time** the logger is programmed to take a reading.
- Log this manual measurement along with:
  - **Date and time**
  - **Pump status** (Is the pump on or off? If on, how long has it been running? If off, how long since it stopped?)
- This measurement will be used to **calibrate** the logger data and ensure accuracy.

2. REMOVE THE LOGGER CAREFULLY

- Slowly and steadily **pull the logger up** using its cord or cable.
- Take care not to let the logger:
  - Snag against pump parts or rising main
  - Hit the side walls of the borehole
- Avoid yanking the logger - this can damage the sensor or the borehole structure.

3. DOWNLOAD THE DATA

- Connect the logger to a **laptop**, **tablet**, or **smartphone** using the manufacturer's recommended method:
  - USB cable
  - Bluetooth adapter
  - Interface docking station
- Open the **software or mobile** app provided by the logger manufacturer and follow the instructions to:
  - **Download and save the data**
  - View or export the file in a usable format (e.g. .csv, .txt)

4. SAVE AND BACK UP THE DATA

- Store the downloaded file in a **clearly labelled digital folder**, linked to the correct borehole and date.
- Enter relevant details in the **Data Logger Download** Form (**ANNEX A13**), including the date of removal, logger ID, and any observations.
- **Back up the data** in at least one other location (e.g. USB stick, shared server, cloud storage) to avoid data loss.

E. LOGGER DATA HANDLING

Follow these simple steps to keep your logger data safe and usable:

1. CHECK THE DOWNLOAD

- After downloading, **open the file** immediately to make sure:
  - The export was successful
  - The file isn't corrupted
  - The data covers the full-time period you expect

2. STORE THE FILE SAFELY

- Save the file to your project's **designated "raw data" folder** (e.g. ...\Groundwater Monitoring\Raw Logger Data\).
- Make sure it's stored somewhere secure and backed up, **never just on a single personal device.**

3. USE A CLEAR AND CONSISTENT FILE NAME

- Rename the file using a simple format that makes it easy to identify later.
- Use the **ISO 8601 date format (YYYY-MM-DD)** to keep files sorted and readable.
- Avoid special characters or spaces in file names.

Example: GWR_BH3_2025-05-01_to_2025-05-03.csv

This naming convention tells you the organisation, borehole, and date range without opening the file.

F. BAROMETRIC COMPENSATION

To isolate just the water level, you must **remove the influence of air pressure**. This step is called **barometric compensation**, and it's essential for accurate groundwater level monitoring.

1. USE A BAROLOGGER OR AUTOMATIC WEATHER STATION (IF AVAILABLE)

- A **barologger** measures air pressure near your monitoring site.
- Use software provided by your logger manufacturer to subtract barometric pressure from your water logger data.
- Make sure:
  - The **barologger is close enough** (within 30 km and 300 m elevation)
  - Its **clock is synchronised** with your logger
  - Units are aligned (e.g. mBar, °C)

2. NO BAROLOGGER? USE BACKUP ATMOSPHERIC DATA

If you don't have a barologger:

- You can download **historical air pressure data** from a nearby weather station. A common source is: World Weather Online[42]

This method is **less accurate** and should only be used as a **last resort**, as weather station pressure may differ from your site (especially with elevation differences or fast-moving weather systems).

3. MATCH LOGGER AND BAROLOGGER TIMESTAMPS

- Check that both devices:
  - Were recording at the same intervals (e.g. every hour)
  - Used the same **time zone**
  - Have **aligned clocks** (if not, apply a time correction)

Some software tools will automatically handle barometric compensation if both datasets are imported together. Always check the final output with a manual inspection to ensure it looks reasonable.

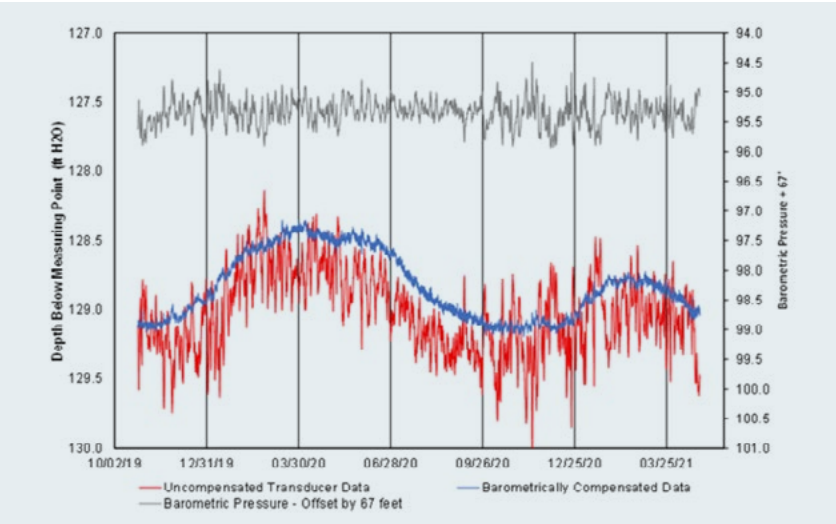

Figure A6: This example from the Washington State Department of Ecology[43] shows the benefits of barometric compensation for data accuracy. (Washington State Department of Ecology)

42 - https://www.worldweatheronline.com
43 - https://apps.ecology.wa.gov/publications/parts/1711005part1.pdf

G. LOGGER DATA CLEANING

Once data has been downloaded, it's important to clean it before any interpretation or sharing. Raw logger data often contains small errors, gaps, or unexpected values caused by things like power interruptions, logger movement, or environmental factors. If not checked and cleaned, these issues can lead to poor decisions later.

The following checks should be done on each logger file:

- **Time consistency:** Are time intervals correct? Are there gaps or duplicates?
- **Sudden jumps in water level:** Could these be caused by pump activity, logger movement, or data errors?
- **Obvious errors:** Such as negative values or unrealistic depths.
- **Barometric compensation**: If not done automatically by the software, use data from the barologger to correct the pressure values into actual water levels.
- **Calibration match:** Compare logged water levels to **manual readings** taken at the same time: adjust as needed.

USE FIELD METADATA TO HELP CLEANING

Make sure you have:

- **Logger depth** from installation notes.
- **Borehole construction** details.
- Any changes made during the monitoring period (e.g. logger re-installed or repositioned).
- Records of pump status (on/off) for flagged anomalies.
- Notes from field staff about anything unusual.

These details provide context and help you **interpret outliers** rather than deleting valuable data.

Where possible, data cleaning should be done by a **trained groundwater specialist**, or someone with experience in logger data and local site conditions. Sometimes what looks like an error is actually a real, important event (e.g. a drawdown due to over-abstraction).

WORK FROM A COPY, NOT THE ORIGINAL

- Always **save a copy** of the original raw logger file in a separate "Processed Data" folder.
- Never edit the original raw file - keep it unchanged for traceability.

REMOVE OR CORRECT KNOWN ERRORS

You may need to delete or adjust certain values. Common reasons include:

- The logger was **briefly removed from the borehole**.
- The sensor was **blocked or fouled**.
- The logger **shifted depth** after pump maintenance or a cord issue.

If you make any changes:

- **Document them clearly** in a cleaning log (such as an additional Excel sheet describing what was changed and why).
- Keep the cleaned file **separate** from the raw and validated datasets.

Where possible, use simple colour codes or comments in Excel or your chosen software to flag and track edits.

USGS guidance[44] provides additional detailed instructions on automatic water level monitoring, barometric compensation and data cleaning.

44 - https://pubs.usgs.gov/tm/1a1/pdf/GWPD16.pdf

ANNEX A12

DATA LOGGER INSTALLATION FORM

This form, linked to **ANNEX A10**, should be completed during the installation of each groundwater level data logger to ensure accurate and traceable setup.

FIELD	ENTRY/DESCRIPTION
Well_identification	
Location description/address	
Owner	
Contact number	
Coordinates (decimal degrees, 6 decimal points)	
Total Depth (m)	
Screen depths (mbd)	
Pump depth (mbd)	
Date constructed	
Logger Serial number	
Logger Brand and Model	
Date requiring next service/calibration	
Logger programmed interval (e.g. 60 minutes or 1 hour)	
Telemetry Device Serial Number (if applicable)	
SIM Card Number (if applicable)	
Mobile Network and Signal Strength (if applicable)	
Logger depth (mbd)	
Datum height (negative value if below ground level)	
Datum description	
Additional Notes	
Photo	

Activity/download history

DATE	TIME	ACTIVITY/ DOWNLOAD	STAFF
2021-09-16	13:00	Logger installation	X
9/20/2021	09:26	Download	X
9/27/2021	15:20	Download	Y
09/30/2021	12:21	Download	Y
23/01/2023	13:00	Download	Y

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ANNEX A13

FIELD FORM

The Field Form is printed prior to field visit, one per well per field visit OR can be made into a table to have one form at each well location.

GENERAL DETAILS

Date: _____ (Day/Month/Year)

Time of arrival on site: _____

Well number: _____

Data collector name: _____

Weather conditions: _____

PUMP DETAILS

Is there a pump? **Yes/No** *(circle one)*

Is the pump on or off? **On/Off** *(circle one)*

How long has the pump been on for or off for? _____ Hours/Minutes (circle one)

MANUAL WATER LEVEL MEASUREMENT

Time of measurement: _____

Depth to water level from datum: _____ meters

WATER QUALITY MEASUREMENT

Time of measurement: _____

Temperature: _____ °C

Electrical conductivity (EC): _____ µS/cm or mS/cm (circle one)

Total dissolved solids (TDS): _____ ppm

pH: _____

Observations (e.g. color, odor etc.)

_____

_____

_____

_____

DATA LOGGER

Time data logger was removed: _____

Serial number: _____

Log stopped? **Yes/No** *(circle one)*

Log downloaded? **Yes/No** *(circle one)*

Data cleared? **Yes/No** *(circle one)*

Battery remaining: _____

Memory available: _____

Time set/synced? **Yes/No** *(circle one)*
Location added, if not already? **Yes/No/Already added** *(circle one)*
Data logger calibrated? **Yes/No** *(circle one)* **(not applicable to barometric logger)**
Calibration value: _____ mbar

New log name: _____
Location selected: _____
Parameters and units:
- Pressure (mbar) ☐
- Temperature (°C) ☐
- Level (m) ☐

Level mode: Depth ☐
Specific gravity: Fresh water ☐
Logging method: Linear ☐
Logging frequency: Hourly ☐

Scheduled start: Time: _____ (soonest ON the hour, e.g., 8:00, 9:00, etc.)
Date: _____ (Day/Month/Year)

Manual stop ☐
DO NOT PRESS START ☐
Disconnect ☐

Well and equipment condition notes:

_____
_____
_____
_____

ANNEX A14

PUMP OPERATOR ABSTRACTION LOG TEMPLATE

This sheet, linked to **Section 6.2.2** describing abstraction monitoring, is to be completed daily by the pump operator or site technician to record groundwater abstraction from a borehole or well. The information helps monitor usage, plan supply, and ensure safe, sustainable management of groundwater resources.

DATE	TIME	FLOW METER READING (m^3)	FLOW RATE (m^3/d)	GROUNDWATER LEVEL (mbd)	NOTES

- An inline flow meter should be fitted on all abstraction boreholes to monitor daily flow rates.
- Borehole guard/operator should be trained on measuring abstraction rates.
- A field template should be used to record time and flow meter reading at the start of the day, prior to pumping and again at the end of the day, when the pump is off (similarly to water level measurements).
- Daily abstraction rate should be calculated in the excel spreadsheet by: Flow meter reading at end of day- flow meter reading at start of day = Volume abstracted per day.

Figure A7: Example of inline flow meter. (Unknown)

ANNEX A15

MANUAL WATER QUALITY MONITORING STANDARD OPERATING PROCEDURE (SOP)

This annex extends the explanation of water quality monitoring from Section **6.2.3**.

EQUIPMENT NEEDED FOR BASIC PARAMETER MONITORING

- Calibrated handheld probe (refer to the manufacturer's instructions for calibration procedures).
- Calibration solutions for each parameter.
- Spare batteries for the probe.
- Peristaltic Pump or Bailer, if collecting a sample from a monitoring well not equipped with a pump.
- Clean plastic jug or bucket for water sampling.
- Smartphone or camera (to document readings or site conditions).
- Data collection form (**see ANNEX A13**).
- If sending water samples to a lab:
  - Clean sample containers
  - Cooler box with ice packs or refrigeration
  - Labels and field documentation
  - Confirm procedures with the laboratory in advance

ANNEX A16: MANUAL WATER QUALITY MONITORING FORM
Use this form to record regular manual water quality readings.

TRIP PLANNING

Trip planning should include:

a. Preparation of the itinerary, route planning and logistical requirements.

b. Preparation of a Health, Safety and Security Plan.

c. Designation of a team leader and briefing of all team members.

d. Retrieval and review of:
   - historical monitoring data to understand expected groundwater quality; and
   - borehole construction records to determine appropriate purging and sampling requirements.

e. Collection, inspection and calibration of all sampling equipment, field-testing instruments and reagents.

f. Preparation of pumps, hoses, generators and other equipment required for sampling.

g. Liaison with the analytical laboratory to confirm sample bottles, preservatives, filtration requirements, labels, cool boxes and sample holding times.

h. Preparation of a Quality Assurance and Quality Control (QA/QC) plan.

SITE VISIT

The site visit should include:

a. Verification that the site can be accessed safely.

b. Recording site conditions and any changes since previous visits.

c. Validation of the monitoring location using a smartphone or GPS, including coordinates, date and time.

d. Inspection of the borehole or well condition.

e. Measurement of groundwater level prior to sampling.

f. Where appropriate, discussions with well owners or users regarding abstraction patterns, maintenance or any changes since the previous visit.

WELL PURGING AND SAMPLING

Sampling procedures should be appropriate for the type of groundwater source.

a. **Drilled wells with an operational pump**
Where a sample is collected during normal pumping operations, additional purging is generally not required.

b. **Drilled wells without an operational pump**
Where equipment is available, low-flow sampling is the preferred method, allowing groundwater to be collected directly from the screened interval with minimal disturbance to the aquifer. Where low-flow sampling is not feasible, the well should be purged using a suitable pump or bailer until approximately three casing volumes have been removed, or until field parameters have stabilised, before the sample is collected.

c. **Large-diameter dug wells**
Obtaining a representative groundwater sample from a dug well is inherently difficult because of mixing within the well. Where possible, samples should be collected from the installed pump during the middle of its normal operating cycle. Grab samples collected directly from the well should be avoided.

HOW TO TAKE READINGS – FIELD MEASUREMENTS

Measurement of electrical conductivity (EC), temperature, pH and, where appropriate, total dissolved solids (TDS), dissolved oxygen (DO) and oxidation-reduction potential (ORP) can be carried out at the field site using a calibrated multiparameter probe.

Measurements should ideally be taken from a gently flowing discharge and monitored until values stabilise before they are recorded and the groundwater sample collected.

As well as the probe measurement the sampler should also record observations of water colour, odour, turbidity and the presence of any exsolving gases.

Figure A8: Using two handheld water quality probes to take manual measurements in Cox's Bazar, Bangladesh. (GWR)

SAMPLE COLLECTION FOR LABORATORY ANALYSIS

a. Samples should be collected in clean laboratory-supplied containers containing preservatives where required. Bottles should be labelled in accordance with the laboratory's requirements and sampling information recorded in the field data collection system.

b. Sample bottles should be filled according to the laboratory's instructions. Bottles containing preservatives should not be overfilled to avoid dilution of the preservative.

c. Where specified by the laboratory, samples should be filtered immediately after collection using an appropriate disposable filter assembly.

d. Samples should be stored in cool boxes with ice packs immediately after collection and transported to the laboratory within the required holding times, preferably within 24 hours.

QUALITY ASSURANCE AND CHAIN OF CUSTODY:

a. Both the sampling organisation and the analytical laboratory should operate under documented Quality Assurance (QA) procedures.

b. Analytical laboratories should be accredited in accordance with recognised national or international standards wherever possible.

c. A documented Chain of Custody procedure should accompany all samples from preparation of sampling containers through field collection, transport, laboratory receipt and reporting of analytical results.

d. Quality control samples should be collected in accordance with the QA/QC plan and should include, as a minimum, field duplicate samples and laboratory-supplied trip blanks. Additional quality control samples, such as equipment blanks or field blanks, should be collected where required by the analytical programme.

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ANNEX A16

MANUAL WATER QUALITY MONITORING FORM

Use this form, linked to **ANNEX A14**, to record regular manual water quality readings.

GENERAL INFORMATION	
DATE:	
TIME:	
NAME OF SAMPLER:	
BOREHOLE ID:	
GPS COORDINATES:	
MONITORING EQUIPMENT SERIAL NUMBER	
ON-SITE MEASUREMENTS	
Groundwater Level	
Temperature (°C)	
Conductivity (µS/cm)	
pH	
ON-SITE VISUAL	
Colour	
Silt/sand	
Odour	
Sheen/oil	

SAMPLES COLLECTED

Sample ID	Analysis requested	Notes

ANNEX A17
WATER USER SURVEY TEMPLATES

This annex provides templates for water user surveys described in **Section 6.2.5**.

1. HOUSEHOLD WATER USE SURVEY	
Survey Question	**Response**
How many buckets of water do you collect each week?	
What is the size of the bucket used (in litres, if known)?	
Estimate the proportion of water used for each activity: - Cooking - Drinking - Washing and hygiene - Laundry - Irrigating gardens - Livestock	
Has your use changed in the last 6 months? If yes, why?	

See Household Water Security Experiences (HWISE) Scale survey user manual[45].

2. BOREHOLE OPERATOR / COMMITTEE SURVEY	
Survey Question	**Response**
Approximately how many users rely on this borehole?	
Breakdown of users: - Households - Livestock owners - Small-scale farmers/gardeners - Institutions	
What is the estimated total daily or weekly usage (in buckets or cubic metres)?	
Estimate percentage of water used for: - Domestic - Livestock - Irrigation - Institutional use	
Are there any issues with access, maintenance, or supply?	
Who decides how the borehole is managed and maintained?	

45 - https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2020/pdf-2020-9090-1-HWISE_User_Manual.pdf

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3. QUALITATIVE FEEDBACK	
Survey Question	**Response**
Do you face any problems with your water access?	
What do you think causes these problems?	
What would be your suggested solutions?	

4. WATER PRICE MONITORING	
Survey Question	**Response**
What is the price per jerrycan or bucket at formal sale points?	
What is the price at informal sale points or water trucks?	
Are prices stable or do they change seasonally?	
Who sets the price (committee, private supplier, etc.)?	

ANNEX A18

QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) CHECKLIST

A checklist of important QA/QC checks, typical issues identified and recommended actions linking to **Section 6.2.8**. This can be setup in a spreadsheet alongside a log of changes made and why.

QA/QC CHECK	WHAT TO CHECK	TYPICAL ISSUES IDENTIFIED	RECOMMENDED ACTION
Range checks	Values are physically realistic (e.g. groundwater level, abstraction, EC)	Impossible values (e.g. negative EC, negative abstraction, groundwater level above ground surface)	Flag values; investigate source; correct or exclude if confirmed erroneous
Unit checks	Units are consistent and correctly recorded (e.g. m vs cm, µS/cm vs mS/cm)	Scaling errors, unit conversion mistakes	Correct units; document assumptions
Reference datum checks	Groundwater levels use a consistent reference point (e.g. casing top, ground level)	Apparent step changes caused by datum change	Correct data to a common reference; document changes
Step-change checks	Sudden jumps or drops between consecutive measurements	Sensor movement, damaged sensor, reference point change, transcription error	Flag data; check field notes and installation; apply correction if justified
Missing data checks	Gaps in time series where data should exist	Power loss, telemetry failure, missed manual measurements	Record gaps; do not interpolate unless justified and documented
Duplicate data checks	Repeated timestamps or identical values	Upload errors, logging faults	Remove duplicates after confirming correct value
Manual–sensor cross-checks (where sensors are used)	Manual groundwater level vs sensor reading at same site and time	Sensor drift, sensor movement, installation issues	Trust manual measurement; correct sensor data; assess need for calibration or replacement
Repeated correction patterns	Similar offset between manual and sensor readings over time	Systematic sensor bias or drift	Apply documented correction factor or replace sensor
Sensor diagnostics	Battery level, signal strength, data transmission success	Imminent sensor failure, partial data loss	Schedule maintenance or replacement before data quality degrades
Spatial consistency checks	Comparison with nearby boreholes or wells	Isolated outliers not seen elsewhere	Flag for review; retain unless error is confirmed
Contextual consistency checks	Agreement with related data (e.g. rainfall, abstraction, pumping schedules)	Implausible trends or timing	Flag for review; investigate before analysis

ANNEX A19

DATA COMMUNICATION PROTOCOL EXAMPLE

Example protocol for data communication linked to **Section 6.4**. The table is filled with typical data communication requirements for major stakeholder groups.

STAKEHOLDER GROUP	DATA FORMAT	FREQUENCY	HOW COMMUNICATED	RESPONSIBLE PARTY
National Water Authority	Raw monitoring data files (Excel/CSV); standardised data templates for national database upload; detailed monthly status reports; issue reports for urgent borehole problems; hydrographs and maps if needed	Monthly summary plus ad-hoc urgent alerts	Email, official letters, shared cloud folder, quarterly coordination meetings with Ministry focal points	Lead hydrogeologist and data manager; country programme manager for sign-off
Local Water Authority / District Office	Site-specific borehole status sheets; summary tables of key parameters (e.g. water levels, abstraction); simplified charts; verbal briefs for local decision-makers	Monthly, at start of month	Hard-copy printouts dropped at district office; local WhatsApp group for urgent issues; verbal updates at district WASH meetings	Local technician or district WASH coordinator
Humanitarian NGOs & UN Agencies	Short situation briefs; visual trend summaries (graphs, maps); recommendations for programming (e.g. risk of supply shortage); raw data if requested for donor reporting	Biweekly or monthly depending on field context	Email updates to WASH cluster mailing list; short slide deck for cluster coordination meetings; shared Google Drive folder for background data	NGO Monitoring & Evaluation officer with technical support from hydrogeologist
Local Water Utility (small towns)	Pump runtime logs; daily abstraction volumes; alert sheets for pump faults; flow meter records; simple "traffic light" chart showing well status	Weekly, on Monday morning	Printed pump station report; laminated charts on site; text or call to pump operator for immediate faults	Utility operations supervisor; field technician for site visits
Private Borehole Operators	Individual borehole performance sheets; manual water level checks summary; abstraction limits guidance; recommended maintenance actions	Monthly or as per local bylaws	Printed reports; SMS reminders for maintenance; 1:1 meetings with operator groups	Local borehole inspector or water officer
Community Water Committees	Simple posters showing borehole health; verbal updates; actions needed (e.g. reduce use in dry season); local language handouts explaining risks	Monthly at community meeting	Community meeting (facilitated by WASH officer); noticeboard posters at water point; door-to-door visits if needed	Community WASH facilitator; local trusted technician
Etc.				

ANNEX A20

MONITORING SYSTEM EVALUATION TEMPLATES

Background to these templates is described in **Section 6.5**. The first template is for evaluating each individual monitoring activity by surveying those involved. A second template is provided for analysis of the monitoring system as a whole once the survey of activities has been completed. The results of the second template can be used for reporting to those funding the system to summarise progress, value and ongoing risks in the monitoring operations.

ACTIVITY EVALUATION

Activity Under Evaluation: e.g. automatic water level monitoring of 6 main boreholes	**Summary / Notes:** e.g. water level monitoring led by technician, reporting to national water authority responsible for data analysis, communication and capacity building of technician
Monitoring tasks completed consistently?	Notes:
Manual checks done regularly?	Notes:
Equipment maintenance & uptime?	Notes:
Data cleaning & analysis completed on time?	Notes:
Data communication delivered as planned?	Notes:
Data used and trusted by stakeholders?	Notes:
Incentives for implementing partners met?	Notes:
Capacity building activities (if any) effective?	Notes:
Performance against agreed Key Performance Indicator (KPI)	Target: Current Performance:

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SYSTEM EVALUATION

Evaluation Aspect	Summary / Notes
Total Costs and Funding Sources	E.g. total equipment, staff time, partner contributions, operating costs
Delivered Benefits	E.g. early warnings, improved well performance, WASH impacts, user trust, new partnerships
Overall Operational Performance	
Monitoring tasks completed consistently?	Notes:
Manual calibration checks done regularly?	Notes:
Equipment maintenance & uptime?	Notes:
Data cleaning & analysis completed on time?	Notes:
Data communication delivered as planned?	Notes:
Data used and trusted by stakeholders?	Notes:
Incentives for implementing partners met?	Notes:
Capacity building activities effective?	Notes:
General performance against agreed Key Performance Indicators (KPI)	Notes:
Readiness for Expansion (if in pilot or expansion phase)	
Known operational risks addressed or understood (Yes/No)	Evidence:
Genuine value delivered to key data users (Yes/No)	Evidence:
System running sustainably (Yes/No)	Evidence:
Stakeholder incentives & capacity needs satisfied (Yes/No)	Evidence:
Additional improvements needed before scale-up?	Evidence:
Recommendations and Next Steps	
Is the system ready be expanded, adapted, or handed over?	Notes:
Recommended priority improvements	Notes:
Proposed funding sources or partners for next stages	Notes:

ANNEX A21

STAKEHOLDER COMMUNICATIONS EXAMPLE

Use this simple example, linked to **Section 6.7**, to keep track of all stakeholders involved in the monitoring system. It helps maintain relationships, record key communications, and support smooth handover or continuity.

DATE	STAKEHOLDER NAME	ROLE / ORGANISATION	CONTACT DETAILS	KEY RESPONSIBILITIES	COMMUNICATION / MEETING NOTES	FOLLOW-UP ACTIONS
01/02/2025	Jane Ali	District Water Officer	jane.ali@email.org / +xxx	Oversees local borehole monitoring	Agreed on monthly data uploads	Send summary report by end of month
02/02/2025	John Doe	Community Water Committee Chair	john.doe@email.com / +xxx	Leads manual well monitoring in village	Training on new logbook completed. Introduced us to new borehole operator Jack Doe and agreed to train Jack on monitoring	Check-in next quarter for refresher needs

ANNEX A22

SKILLS CAPACITY CHECKLIST EXAMPLE

Use this checklist example, linked to **Section 8.2**, to assess local staff, technicians, and partner institution capacities to fulfil groundwater monitoring responsibilities. Mark the level of capacity demonstrated for each responsibility: **Awareness (A), Experience (E), or Mentor-level (M) for ability to train others**. The responsibilities listed are given as examples and should be modified according to the individual responsibilities required to operate your groundwater monitoring system.

RESPONSIBILITY AREA	SKILL LEVEL TARGET FOR HANDOVER STAGE	CAPACITY PRESENT (A / E / M)
Daily manual water level measurement	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Automated logger programming, calibration and retrieval	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Data cleaning and validation	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Basic data analysis and interpretation	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Data storage and secure backup	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Data communication to stakeholders	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Community engagement and awareness	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Routine sensor maintenance and troubleshooting	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Management of digital platform	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Oversight of staff performance	Mentor (Able to teach others)	☐ A ☐ E ☐ M
Updating SOPs and training materials	Mentor (Able to teach others)	☐ A ☐ E ☐ M

Use this table for periodic reviews. Each core responsibility should reach at least 'Mentor' level for long-term sustainability at the stage of handover.

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NOTES

GROUNDWATER MONITORING IN HUMANITARIAN CONTEXTS

A Guide for Practitioners and Decision Makers

In a time of overlapping challenges: climate disruption, prolonged conflict, and rapid urban growth, groundwater is often the primary safety net for reliable and safe water supply. Yet in many of the world's most vulnerable regions, monitoring of the resource to support evidence-based, sustainable management remains scarce.

Groundwater Monitoring in Humanitarian Contexts offers a practical response. Bringing together field experience and global good practice, this guide provides clear and adaptable advice for designing and maintaining groundwater monitoring systems in demanding settings. It covers the full monitoring process from initial scoping and design through to full operation and handover, and it includes guidance tailored for both short term emergency work and long term resilience building.

Developed through collaboration between humanitarian organisations and researchers, this resource is intended for programme leads, engineers national counterparts, and all those working to protect groundwater for communities under stress. It draws lessons from complex water environments across the globe, including drylands in East Africa, conflict-affected areas in Yemen and West Africa, and international displacement camps in Asia.

Whether you are planning a new monitoring system, working with an existing one, or seeking to learn more in a supporting capacity, this guide supports you with structured recommendations and honest reflections. It aims not just to promote and improve groundwater monitoring practices, but to also start a more open ongoing conversation about the challenges of groundwater monitoring and how better practices can be continually developed to overcome these.

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Related Publication

Readers may also wish to consult the related academic study which informed this study:
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