Towards Effective Groundwater Development

A Roadmap for Scaling Up Sustainable Groundwater Supply in Rwanda

Prepared for UNICEF, in cooperation with the Rwanda Water Resources Board

15 August 2023

This document was produced for review by the UNICEF and the Rwanda Water Resources Board. It was prepared by Hydro Nova and We Consult as an in-kind contribution to the UNICEF project 'Groundwater Mapping in the Eastern Province and Amayaga Region of the Southern Province of Rwanda'.

Contact:
Casey Walther, Head of Groundwater Development (casey@hydronova.tech)
Ron Sloots, Technical Lead (ron@we-consult.info)

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Prepared by:
Hydro Nova
Casey Walther
Kenneth Hardcastle

We Consult
Ron Sloots
Zebulon Spruijt

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1. Introduction

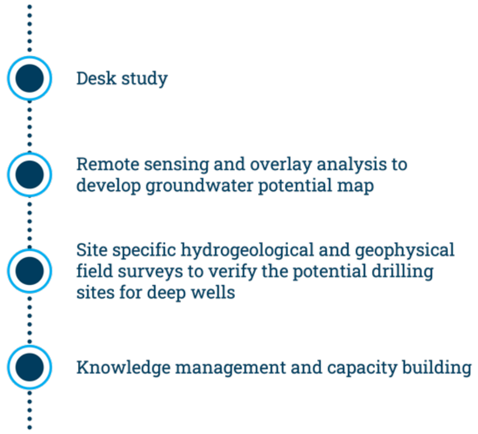
Background

With the southeastern region of Rwanda facing persistent drought and water, the Rwanda government has sought to expand water supplies with groundwater to make it easier for people to get clean water. But many boreholes have failed or producing too little water, and planners haven't had enough good information about how locate and design successful wells. From May 2022 to July 2023, the Rwanda Water Resources Board, with support by UNICEF, commissioned a consultant team comprised of Hydro Nova and WE Consult to map the groundwater in eight districts in the Eastern Province and Amayaga Region and find out more about how and where to set up new water supplies in the region.

The assignment used satellite technology to scan the earth and simulate fractured bedrock geology, developing a regional suitability map of groundwater development. A total of 72 potential sites were identified that could be developed into an additional water supply that could potentially serve over 200,000 people. In addition, the project identified 126 discrete areas across the region where government and water providers could focus their investment on building new water supply infrastructure. The groundwater potential maps, intelligence and procedures for sustainable groundwater development helps to set the stage for improved water access in Rwanda by providing an actionable step-by-step roadmap for expanding the country's groundwater supply. The project outputs and tools are showcased in the Annex 1.

The scope of services for the project were adapted to a limited time and budget, allowing for a limited amount of field investigation and borehole siting works to be undertaken, and allowed for the core methodology for planning groundwater development to be demonstrated (Figure 1).

Figure 1. Project scope of work



If the project's specific outputs are carried forward and implemented, they will be extremely valuable. Groundwater potential maps and identified target areas are critical starting points for Rwanda water planners in determining where new water supplies can be developed. The drilling sites proposed provide ready-to-build locations for new boreholes and water supply systems. The geophysical survey data and other field analysis provide valuable information about the drilling conditions in those specific areas.

However, even with compelling maps and new data, future water supply boreholes may be ineffective or constructed too far away from where consumers require water. Boreholes must be improved in order to optimize water supply volumes and produce water over time. They must be placed in better locations, close to both a favorable groundwater potential and a target community that will use the water. The project's experience has also highlighted the Rwanda water sector's lack of a comprehensive approach to planning new groundwater development projects in order to achieve better, more sustainable, and more reliable results.

Therefore, this roadmap has been prepared to provide a framework for planning groundwater development in Rwanda and to describe the steps that the water sector can take to achieve better results when installing a new borehole for water supply.

Objective

The Roadmap's goal is to describe the most efficient and effective groundwater development approach and methodology in Rwanda. The current project serves as the foundation for the approach, but it also reveals areas where the project approach and methodology can be improved. The improved approach and methodology are described further below. Furthermore, the Roadmap will recommend the activities that will be required in the future to create an enabling environment for improved groundwater development.

Document Structure

The roadmap document includes six parts:

- Chapter 2 summarizes the current groundwater development activities and institutional set up in Rwanda. The description is followed by a recommended optimal approach.
- Chapter 3 provides information on the recommended approach for groundwater development in Rwanda – the 'Roadmap'.
- Chapter 4 describes the groundwater potential map as a tool for exploration and planning.
- Chapter 5 – 7 lay out the optimum approach recommended for three different types of groundwater development projects in Rwanda. The recommended approach is slightly different for boreholes with hand pumps, boreholes installed with solar-powered pumps and production wells. In these chapters, we describe how the groundwater potential map can be used and what activities are required in each phase of the groundwater development process, from planning to actual drilling, as well as the approximate costs involved in developing groundwater.
- Chapter 8 lists our recommendations to Government of Rwanda and UNICEF for follow up to the current project and as a way forward for groundwater development in Rwanda.

2. Groundwater Sector in Rwanda

Introduction

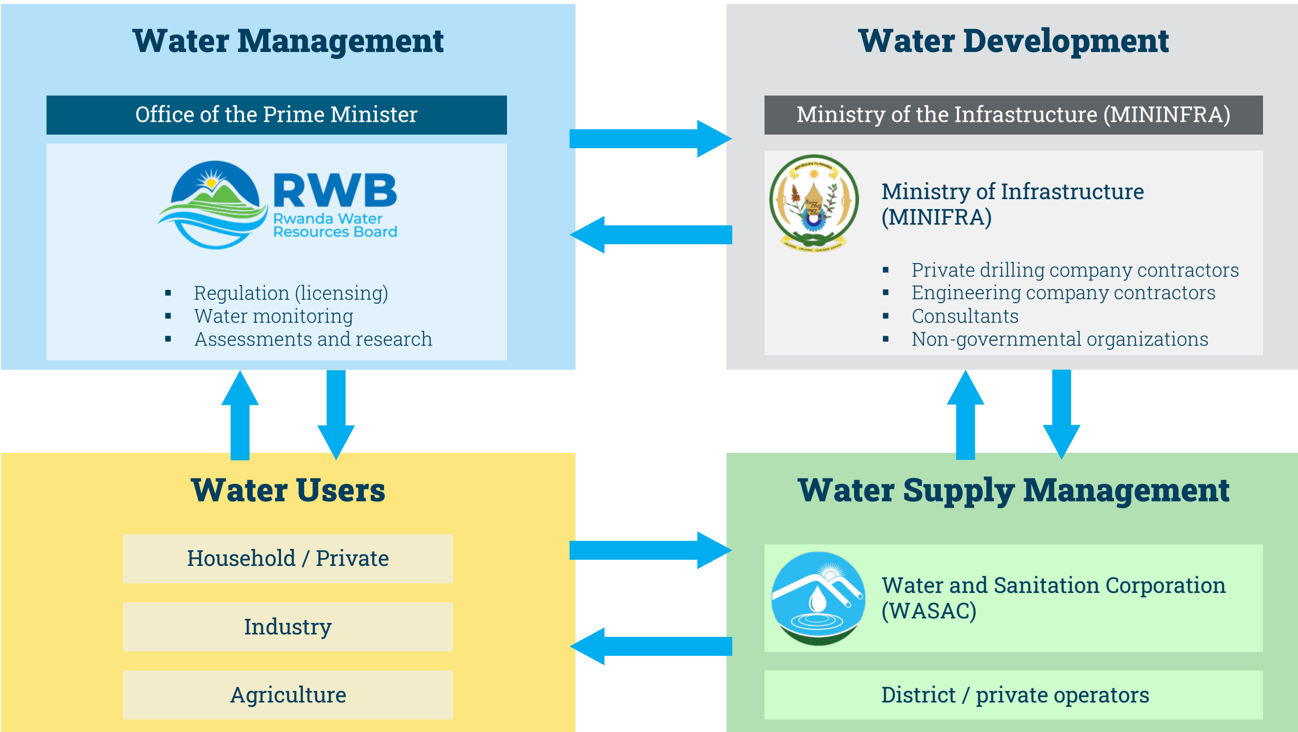
Rwanda has an abundance of surface water resources in the form of lakes and rivers. As a result, groundwater has never received much attention. The majority of the population is supplied with water by piped systems fed by rivers, lakes, and springs. Because of the rising demand for household and agricultural use, groundwater development in Rwanda has become a key focus of the Rwandan government in recent years. Groundwater use accounts for around 19% of Rwanda's water resources, with households, agriculture, and water utilities accounting for approximately 45, 22, and 19%, respectively.

The Rwanda Groundwater Sector

Various stakeholders are involved in the undertaking of planning groundwater development and implementing groundwater-based water supply systems in Rwanda (Figure 2). The Rwanda Water Resources Board (RWB) is the primary regulating authority. Private drilling companies and NGOs undertake the physical drilling of boreholes. The siting of new borehole systems is typically performed by consultants such as hydrogeologists, geologists and other specialists who are either engaged directly by the contractor, the end user, or the Ministry of Infrastructure (MININFRA).

Private drilling companies must obtain a license issued by RWB to drill a specific borehole. However, private drilling companies are not obliged to operate in Rwanda under an operating license, unlike in other countries in the region. Government also has not set up a proper system to record the drilling activities. Some stakeholders record information when drilling, but data collection forms/records do not cover the relevant data to be collected. Drilling contractors and NGOs are not obliged to submit borehole completion reports to the RWB. There is no comprehensive national borehole database or national borehole numbering system. For this reason, performing the work of siting of new boreholes cannot take advantage of data pertaining to other existing boreholes in the area, a critical source of information that guides effective planning of new borehole supply systems. Several attempts have been made to compile borehole data and improve collection of borehole data, though no standardized database and collection system has been implemented or enforced at the national level.

Figure 2. Rwanda water sector setup



Current Practices in Groundwater Development

Groundwater development in Rwanda is mainly focused on satisfying the demand in the rural areas. NGOs and rural water supply projects supported by organizations such as JICA, ChinaAid have implemented drilling programmes for rural water supplies (handpump boreholes and small piped systems). WASAC has initiated some large scale water supply projects comprising shallow large diameter wells along the banks of the large rivers that form well fields suppling part of Kigali.

There are no clear specifications in place that stipulate the activities required for hydrogeological surveys for groundwater development projects. The boreholes for the rural water supply projects have been drilled without a survey or based on simple surveys (VES only). The success rates of these drilling programmes are rather low.

The specifications for the drilling and test pumping are also not standardized. The lack of some of them may lead to non-sustainable water supplies. If a borehole is test pumped for 1 hour only one will not know the effect of pumping after three hours. In some cases, these boreholes were installed based on the 1-hour test but appeared to be without water after 2 hours.

The funding of the projects never took into account the need for a professional approach during development and afterwards. There are also no laws in place that stipulate the required activities and use of standards.

Groundwater management

Groundwater can only be well managed if the overall hydrogeology of an area is well understood. To get this understanding geological maps and borehole data (well logs, water level data, aquifer characteristics, groundwater quality data) are required. This data has to be collected by consultants and contractors working in the country for NGOs, private clients and the government and then submitted to the RWB who is the authority for groundwater management in Rwanda.

Currently, these practices are not being applied, nor is there a good format for the data collection. Legally speaking, the contractors and the consultants are supposed to submit the information to RWB, but compliance is not regular.

The GoR recently has constructed some groundwater level monitoring wells and installed data loggers to collect groundwater levels The groundwater levels are useful but could be even more useful if the hydrogeological environments of the areas were better known. Monitoring well locations should be chosen based on hydrogeological grounds and drilled in locations where they serve the purpose of the monitoring.

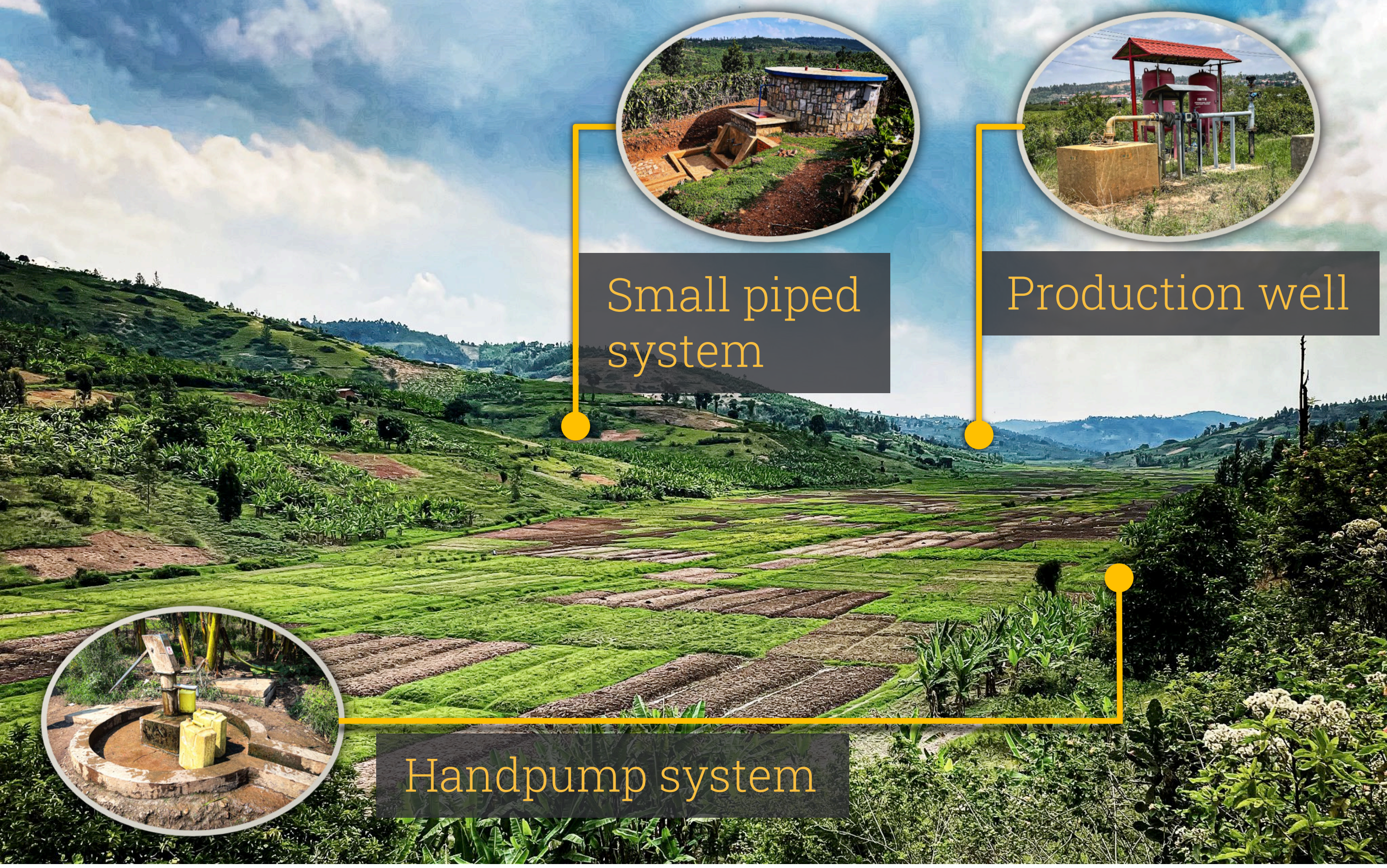
The groundwater users (factories, individuals with boreholes equipped with submersible pumps) are not recording and submitting water levels and volumes abstracted. This information could be analyzed and used to gain more knowledge about aquifers.

Groundwater becomes more and more important in Groundwater management will have to be taken to a next level in Rwanda in terms of regulation and enforcement, groundwater monitoring and information management.

UNICEF-supported project approach

As the southeastern regions of Rwanda saw greater water insecurity, the demand for groundwater-based water supply solutions has risen, necessitating improved capacities in exploring for and developing groundwater more effectively. In this context, UNICEF launched a project in 2022 to support the RWB to study groundwater potential and develop exploration tools and methods useful for stakeholders to plan successful groundwater-based water supply systems, with a view to ultimately increasing resilience and access to freshwater in that part of the country. The authors of this Roadmap were engaged by UNICEF in 2022-2023 to conduct the services of the project, which included the study and mapping of regional groundwater potential, identifying targeted areas where conditions for new borehole systems could be planned, and siting potential locations where new boreholes could be installed. The details of the project as well as the follow up options and recommendations for this project are given in Annex 1.

The UNICEF-supported project is a good first step in professionalizing the groundwater sector in Rwanda. It also became clear that the sector needs a guiding document for more sustainable groundwater development in Rwanda. The next Chapter will suggest the various steps that are recommended for



3. Roadmap for Sustainable Groundwater Development in Rwanda

Groundwater development projects

There are three type of water supply systems that each require a slightly different approach to ensure sustainable groundwater development. The systems have different characteristics in terms of amounts of water produced, borehole designs, and survey to be carried out to find the best locations for these boreholes as well as the requirements to operate the boreholes and to monitor their impact on the water resources (Table 1).

Table 1. Types of groundwater-based water supply systems and their characteristics

	Type A	**Type B**	**Type C**
Type	**Handpump Supply System**	**Medium-sized Water Supply System**	**Large Supply System**
Example image			
Characteristics	Shallow-drilled, low-production water supply boreholes with manual pump that is operated intermittently over a 10-hour period each day. Boreholes can usually be located close to Village Preferred Sites (VPS) due to low yield requirements.	Boreholes with small-capacity electrical submersible pumps and powered by solar panels, sometimes connected to electricity grid or by a diesel generator. Solar power only operates for 8 daylight hours. Boreholes usually in located in valleys in close vicinity to the demand (served) area. System typically includes a raise tank reservoir for storage.	The production well with high capacity large submersible pump. Large systems can include a single well, or a multiple well field. Boreholes require the highest yield possible, and therefore drilled in areas with high potential, sometimes kilometers away from demand (service) area.
Required production per borehole (per day)	500 liters per hour x 10 hours = 5,000 liters per day	Between 2,000 and 5,000 liters per hours for 8 hours = up to 40,000 liters per day	Between 5,000 and 25,000 liters per hours, or 100 to 500,000 liters per day
Surveys required	Relatively simple geophysical survey required. Details depend on known hydrogeological conditions. In some areas, siting these systems with the use of VES alone is sufficient to get the required yield. However, in areas with many dry boreholes, investigations need to be adapted. Surveys can be done by junior hydrogeologists.	Surveys should be more detailed with at least 1D resistivity profiling using anomalies for drill sites.	Detailed and extensive surveys required in areas with high groundwater potential are required. ERT and 1D surveys preferably under the guidance of a hydrogeologist with 10 years' experience or more. Parallel profiles required to confirm orientations of lineaments. More measurements lead to a better hydrogeological understanding of an area.
No. of people served	200-300	400-1,000	1,000 - >10,000

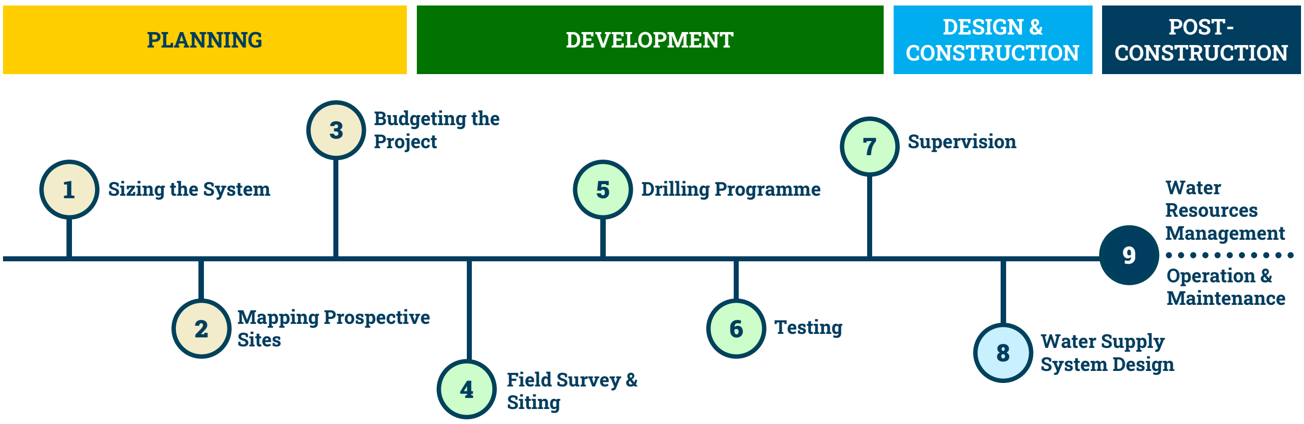
Planning Sustainable Groundwater-based Supply Systems

This roadmap document gives a background on how the groundwater development activities should be integrated in a water supply project. The approach for sustainable groundwater development comprises the following activities:

- Selecting the type and size of a groundwater supply system
- Determining the optimal exploration areas for the system, in relation to the best groundwater potential and the intended service area (demand);
- Budgeting for the full system;
- Planning field surveying and siting works;
- Planning the suitable drilling, testing and supervision programme;
- Designing a suitable delivery and storage system; and
- Putting in place a water supply operator and a framework that ensures the availability of funds for the management of the water resources.

The flow chart in Figure 3 shows the different steps and phases of the groundwater development process. Each step is discussed below and what follows is a demonstration of these steps for the three types of groundwater supply systems.

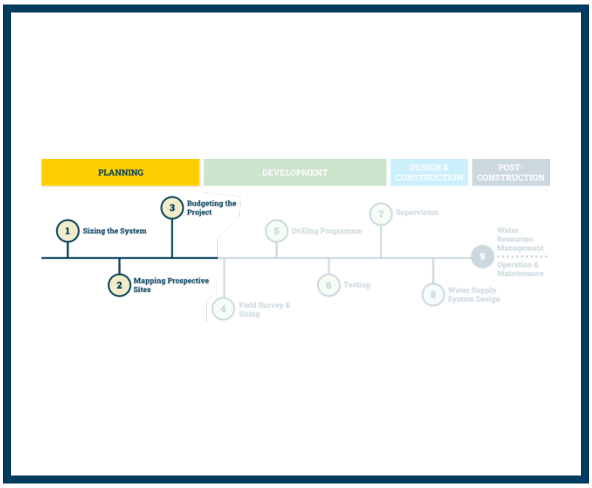
Figure 3. Recommended process for scaling up sustainable groundwater supply in Rwanda



Steps to Follow

PLANNING PHASE

Three important steps in the typical groundwater planning process include: (1) sizing the system, (2) mapping the prospective sites, and (3) budgeting the project. As part of the planning process, **sizing the system** to the target location and demand area, **mapping the prospective sites** with the aid of the GWP map, and **costing out the project** components should be conducted to understand the scope and feasibility of the new water supply project. If the borehole has been drilled the water also needs to be transported to the demand area and a budget should be prepared for that. These steps precede any field or drilling work and are critical to effective development planning.



1. Sizing the System

For practical reasons, it is useful at the start of the planning process for planners of new groundwater supply systems to consider the type and size system that would be most suitable for their project. In this step, the planner selects of demand areas—areas where the new water system will serve a population. The main concerns are: (1) where is the water needed, and (2) how much water? Planners should consult any existing water master plans, emergency demand assessments, or official information on any water shortages in an area. Also, consider the location of any existing infrastructure in relation to the demand area. Maybe, the existing infrastructure can be used to satisfy the demand in the demand area. More solutions may be possible and the best solution is formed by the most cost effective solution.

Where are the exact locations of existing water reservoirs or tanks in the demand area. Determine if the existing reservoir can handle additional water, or if new reservoirs should be planned. For new systems, consider where the reservoir will be built and make that the exact demand area. Is that land available and at what cost? Based on the local demand, the appropriate size and type of borehole system can be selected (Table 2).

Table 2. Estimated water supply volumes by water supply system type

	Type A	**Type B**	**Type C**
	Handpump supply system	**Small-medium sized piped water supply system**	**Large production well piped system**
Rate of vol. delivered (m^3/hr)	0.5	2-10	10-50
Rate vol. delivered (m^3/day)	5	15-80	200-1,000

2. Mapping Prospective Sites

Once the decision has been made on the type and size of the new groundwater supply system, the next step in the planning process is to pinpoint an optimal location for the new system in relation to local groundwater potential and the demand area (area to be served). The selection of the areas depends on the type of water supply that is targeted. The target areas are selected with the aid of the groundwater potential map (GWP map).

The map will be used to determine the groundwater potential in the demand area. The main considerations of using the GWP map for local prospecting include:

- Are there any high potential areas nearby the demand area?
- Where can the best test holes be drilled?
- What are the expected success rates for boreholes with specific required yields?

These numbers are required to calculate approximate costs of the groundwater development programme. The final costs are a combination of distance and expected success rates for a particular yield. The GWP map can be used to come up with expected success rates in various groundwater potential zones. This is explained in Chapter 4.

3. Budgeting the Project

The third planning step is to determine the approximate investment needed to cover the cost of developing and constructing a new groundwater-based supply system or an extension. The main considerations in budgeting are:

- Is the budget for the whole system available or only for part of the system?
- What is possible within the budget or what (additional) budget needs to be requested?
- Consider costs for all activities including groundwater development, water engineering (pumps, transmission mains, electricity, storage, maybe even distribution, design, tender documents for construction, supervision of construction) and water resources management / water supply system management.
- The indicative costs for groundwater development components (preparation of a national groundwater potential map, hydrogeological surveys, drilling and test pumping, supervision and contract management of the drilling programme, groundwater management).
- While making the planning and scenario evaluations keep in mind that the overall cost for the bigger systems is higher but the unit rates (per capita costs and USD per m^3 cost) are often orders of magnitude smaller.

Some indicative cost indications are provided in Table 3 below. It should be noted that the costs of the systems depend on the size of the systems.

Table 3. Guidelines for budgeting groundwater supply systems, by type (development and transmission components only)

System type	Budgeting guidelines	Unit cost ($/m³/day)
Handpump supply system (Type A)	USD $7,000 – 10,000 / borehole	USD $2,000
Medium sized piped water supply system (Type B)	USD $25,000 – 50,000 / system (Q = 2.5 m³/hr, or 20 m³/day)	USD $1,250
Large production well piped system (Type C)	USD $250,000 – US$ 1,000,000 / system (variable) (Q = 40 m³/hr, or 800 m³/day)	USD $650

A Form for calculating budget for projects is provided in Box 1. The costs also depend on the attained success rates as well as indicative development costs, production capacity and consumer requirements.

For handpump boreholes it is clear how many boreholes we need to cost for siting and drilling but for the piped system boreholes all depends on the success rates for particular borehole capacities. The information in Box 2 shows how we can come up with a number of boreholes to be sited and to be drilled.

Different success rates and average yields are found in other towns as a result of differences in the hydrogeological environments surrounding the towns.

Box 3 gives an example of the parameters that determine the cost of a case study involving four groundwater development projects in Uganda.

It is important to understand that boreholes can be dry and yield results in less than expected. A cost analysis based on success rates and average yields must be performed. Similar cost estimates can be made using the spreadsheet for handpump boreholes (eg. use 'X' percent success rate to get 500 l/hr) and solar pump boreholes (use 50% success rate to get 2,500 l/hr). The capacity of boreholes drilled for town water supply drilling programs is shown in the lower part of the box. It demonstrates, for example, that there is a 30% chance of discovering a 19.2 m^3/hr borehole in Mubende. A borehole drilled as part of the test drilling in Mubende has an average yield of 5.8 m^3/hr.

Box 1. Form for estimating unit costs for new water supply systems

Despite the fact that large systems (Type C) have a significantly higher investment cost than small systems (Type A), the unit costs for the larger systems are frequently lower. The various cost components can be entered in the yellow cells of the Form below to calculate the overall unit cost of the proposed system. Numbers in red represent successful borehole unit costs, assuming m3/hr, m3/day, and per capita costs. The latter is based on the daily consumption assumption, which is given in liters per person per day (l/p/day).

Groundwater development only

System	Consultancy: Siting	Consultancy: Drilling supervision	Construction: Drill	Construction: Testpump	Total per BH	successrate	Cost successful BH	production m3/hr	Cost per m3/hr
Handpump	$ 500	$ 500	$ 7,500	$ 500	$ 9,000	85%	$ 10,588	0.5	$ 21,176
Solar	$ 1,000	$ 750	$ 8,000	$ 1,000	$ 10,750	60%	$ 17,917	3	$ 5,972
Production	$ 3,000	$ 2,000	$ 15,000	$ 3,000	$ 23,000	33%	$ 69,697	25	$ 2,788

plus transmission and distribution

water use per person in liters per day 20 *lpppd*

System	Costs delivery system	Total costs	production m3/hr	Cost per m3/hr	production m3/day	USD per m3/d	people served	USD per person served
Handpump	$ -	$ 10,588	0.5	$ 21,176	5	$ 2,118	250	$ 42
Solar	$ 25,000	$ 42,917	3	$ 14,306	24	$ 1,788	1,200	$ 36
Production	$ 250,000	$ 319,697	25	$ 12,788	500	$ 639	25,000	$ 13

Box 2: Designing and budgeting groundwater supply systems

It is a common misconception that if new systems are planned professionally, each borehole drilled will be suitable for inclusion in a new borehole-based water supply system. In fact, only about 30-50 per cent of boreholes drilled as part of a drilling program for a town water supply are ultimately used as production boreholes. This rate of drilling means that great care should be taken when planning and budgeting a groundwater development program for a municipal water supply system. Assumptions must be made about the average yield of a sited production well and the success rate for a production well when the average yield of a production well is considered. Assumptions are more reliable if data from existing boreholes is made available. The Form below illustrates an example of the design and budgeting of the siting and drilling component of a well field development program. By changing the values in the yellow cells, a simple spreadsheet can be used for different scenarios to calculate the number of days for surveying and the number of boreholes to be drilled. Box 6 demonstrates a case study of calculating budgets for a drilling program examples from Uganda.

Form 2: Calculating the number of boreholes to be drilled and sited

1	Assumptions	Parameter	Unit	Assumption
	A	Amount of water needed	m^3/day	1000
		hours of pumping per day	hours	20
	B	*per hour based on 20 hrs pumping*	m^3/hr	50
	C	Average yield production hole	m^3/day	10
	D	Succes rate for production borehole	m^3/day	50%
	E=B/(C*D)	number of boreholes to be drilled	m^3/day	10.0
	F	number of siting days per borehole site	days	1
	G=E*F	number of days of geophysical survey	no.	10.0

2	Assumptions	Parameter	Unit	Assumption
	A	Amount of water needed	m^3/day	400
		hours of pumping per day	hours	20
	B	*per hour based on 20 hrs pumping*	m^3/hr	20
	C	Average yield production hole	m^3/day	10
	D	Succes rate for production borehole	m^3/day	33%
	E=B/(C*D)	number of boreholes to be drilled	m^3/day	6.1
	F	number of siting days per borehole site	days	1
	G=E*F	number of days of geophysical survey	no.	6.1

Box 3: Case Study: Designing and budgeting groundwater supply systems in Uganda

Four examples of calculating number of boreholes and sites in Uganda are given here. Production well success rates are generally around 30%, but in some areas, higher success rates can be expected. The success rates are also affected by the yield threshold/cut for boreholes to be considered as production boreholes. The graphs depict the yields of the boreholes drilled in the particular projects. It is interesting to note that not always the highest ranked location (drilled first) gives the highest yielding borehole.

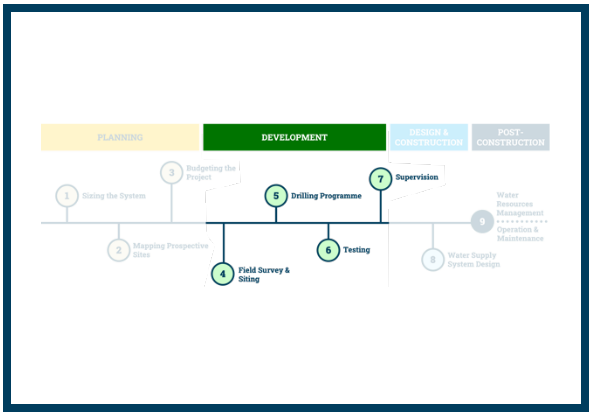
Form 2 example: Calculating the number of boreholes to be drilled and sited for four locations in Uganda

			Mubende	Hoima	Bombo	Yumbe	Average
A	BHs drilled	No.	20	16	12	7	13.8
B	Cut off yield	m^3/hr	10	20	5	15	12.5
C	No of production BH	No.	6	10	4	2	5.5
D=C/A	Production BH success rate	%	30%	63%	33%	29%	39%
E=Sum Yield of C	Total yield production BHs	m^3/hr	115	342	67	42	
F=E/C	Average yield production BH	m^3/hr	19.2	34.2	16.8	21	25.7
G=E/A	Average yield per production BH / no. BH drilled	m^3/hr	5.8	21.4	5.6	6	13.9

Drilling success rate charts for four locations, Uganda

DEVELOPMENT PHASE

Four important steps in the typical groundwater development process include: (1) Hydrogeological survey, (2) drilling programme, (3) test pumping, and (4) supervision of the drilling and test pumping. As part of the development process, **a hydrogeological survey** is needed to identify the drilling site. A **drilling programme** will be executed, combined with a **test pumping**, an important task needed to determine the sustainable yield of the borehole. **Supervision** of the drilling and pump testing is emphasized to ensure proper procedures. These steps precede the phase of designing the delivery system.



4. Field Surveying and Siting

The implementing agency / donor should start this phase by preparing a tender procedure for the selection of qualified consultant for the hydrogeological study and the design and management (supervision) of the drilling programme. The required qualifications of the consultant and the details of the activities depend on the type of water supply (for details see subsequent chapters) that is considered in the project.

The specifications for the consultant should also give the requirement to only use the resistivity method (1D profiling, ERT and VES using an ABEM terameter or equivalent). Recently cheaper equipment using other methods came on the market, but the effectiveness of the method and equipment has not been proven yet

The selected consultant should carry out site-specific hydrogeological study (desk studies, reconnaissance surveys, geophysical fieldwork, analysis, and reporting) in target areas as identified during step 2 of the planning phase and / or other areas that may show up during the desk study for the identification of the drill sites.

The desk study should be as detailed as needed for the purpose of the borehole. The details are given in the specific water supply type chapters.

The type and size of the surveys to be carried out depend on the type of water supply. Table 4 gives an idea on the volume of work to be executed during the geophysical fieldwork in order to be able to come up with enough drill sites. The numbers are indicative and depend greatly on the knowledge of an area and the groundwater potential of an area. In areas with lower potential more measurements may be needed to get sufficient drill sites.

Table 4. Guidelines for planning geophysical surveys for 3 types of water supply systems

System type	Guideline for geophysical surveys
Handpump supply system (Type A)	1 day per borehole, profile lengths of 500 – 1,000 m, plus 2 VES surveys
Small - medium sized water supply system (Type B)	2 days per borehole, profile lengths of 1,000 – 1,500 m, plus 3-5 VES surveys
Large production well system (Type C)	2-4 days per test borehole, minimum of 5 test boreholes, 10-20 days of surveying, profile lengths of 1,000 – 1,500 m

The output of this activity is a hydrogeological report that should contain a list of possible drill sites (recommended sites plus alternative sites in case the recommended sites do not have enough water). It is also recommended to formulate a "Decision Tree" for the drilling of the boreholes (example in Figure 4). Boreholes will be drilled in the order determined by the success of the earlier drilled boreholes. Locations with similar hydrogeological characteristics and/or geophysical responses as locations where a higher ranked borehole gave disappointing results, should not be drilled.

5. Drilling Programme

A drilling program will be carried out. The drilling program's design is determined by the type of water supply required. Production well-based systems require a test drilling and/or production well drilling program (drilling and test pumping, contract management and supervision), whereas smaller size water supply systems typically do not.

The first step is to ensure permission to drill from the owners for all recommended and alternative drill sites mentioned in the decision tree and/or list of possible drill sites.

The Consultant involved in the earlier phases should also be responsible to prepare the tender documents and drilling contracts. He can best give the specifications of the drilling programme in terms of equipment needed, number of boreholes to be drilled (Were the budgeted number of boreholes to be drilled sufficient to achieve the required volumes? What can be achieved within the planned budget?), drilling depths, borehole and drilling diameter, etc. Some indications on the borehole casing and drilling diameters are given in for the drilling and casing diameter are given in Table 5 for the three types of systems.

Contracts between consultants / contractors and the implementing agency must clearly specify the required activities of consultants and contractors in the various steps. It is recommended that both the consultant and the contractor have BOQ-based contracts, rather than lump sum (no water, no payment contracts).

Figure 4. Example of a decision tree for the drilling of a borehole based on results of geophysical surveys

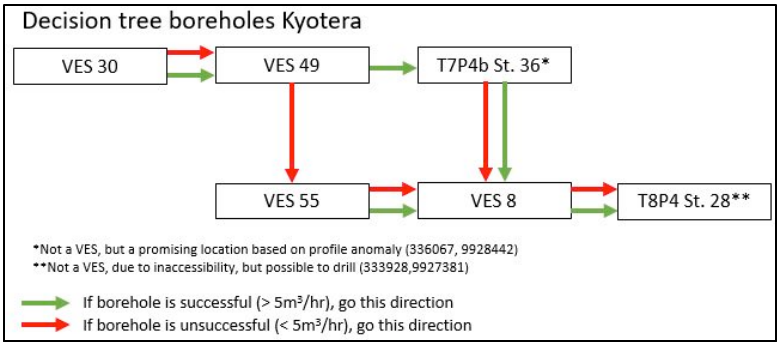


Table 5. Guidelines on drilling and casing diameters for three types of water supply systems

System type	Drill diameter in loose rock	Drill diameter in hard rock	Casing diameter
Hand-pump supply system (Type A)	10-inch	7-inch	4-5 -inch
Medium water supply system (Type B)	10-inch	6-8 -inch	5-6 -inch
Large production well system (Type C)	10-14 -inch	8 -10 -inch	6-8 -inch

6. Test pumping

Following the drilling of borehole, a pumping test is performed. A pumping test is a practical method of estimating the performance of the well, such as yield, capacity, as well as the zone of influence of the well and aquifer characteristics (e.g., the aquifer's ability to store and transmit water, anisotropy, aquifer extent, presence of boundary conditions and possible hydraulic connection to surface water).

A pumping test consists of pumping groundwater from a well, usually at a constant rate, and measuring the change in water level (drawdown) in the pumping well and any nearby wells (observation wells) or surface water bodies during and after pumping. Pumping tests can last from hours to days or even weeks, depending on the size of the system.

Three different tests are recommended. The extended step test, the constant rate test and the recovery test. The yield at which the test is carried out depends on the capacity of the well the duration of the test depends on the purpose of the well (the type of water supply).

Additionally, the water quality of the borehole needs to be tested at this stage of development to determine if the water is potable or has any constituent or water chemistry that needs to be remedied.

Table 6 below provides guidelines on planning test pumping programmes for each of the water supply types.

7. Supervision

The drilling and test pumping programme shall be supervised by a specialized, professional consultant. This consultant also has to produce a borehole completion report. A borehole completion report should contain the results of the drilling and recommendations on the yield at which the production wells can be best pumped. Recommendations with regards to pump type, pump installation depth and recommendations for borehole and water resource monitoring has to be included.

Usually, the consultant that performs the hydrogeological survey also provides management and supervision of the drilling contract. The supervisor will be in charge of drafting the Terms of Reference and the contract tendered with appropriate borehole specifications.

The qualification for the supervising hydrogeologist depends on the type of borehole to be drilled.

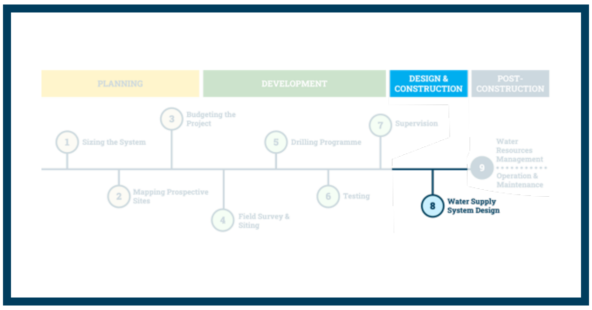
Table 6. Guidelines for test pumping programmes, by water supply system

System type	Duration step test (hrs)	Duration and yield constant rate (hrs)
Handpump supply system (Type A)	NA (or extend first step to constant rate)	3 hrs, at Q=1.0 m^3/hr then extend to Qair
Medium sized water supply system (Type B)	4 x 1-hr step,	12-24 hr
Large production well system (Type C)	4-6 x 1-1.5 hr step,	with 72 hr CR

WATER SUPPLY DESIGN PHASE

After the drilling and test pumping programme the sustainable yields of the boreholes are known. With that information the **water supply can be designed**.

The complexity and costs of the systems depend on the size of the system. Typical water supply components are borehole, pumping system, transmission main, reservoir, distribution system. In the case of handpump system (Type A), the supply system is the handpump only.



8. Water Supply System Design

The design of the water supply system comes at the end of the implementation phase. The components of the system that will pump water out of the ground, convey it to storage tanks, and distribute it to collection points will have to be sized and specified by an engineering consultant. This is usually another consultant then the groundwater consultant involved in the earlier phases. The general conceptual design for a piped system is given in Figure 5.

The smallest piped system consists of a borehole, solar powered pump, a small tank and a tank stand. Larger systems generally distribute water to houses, kiosk and tap stand.

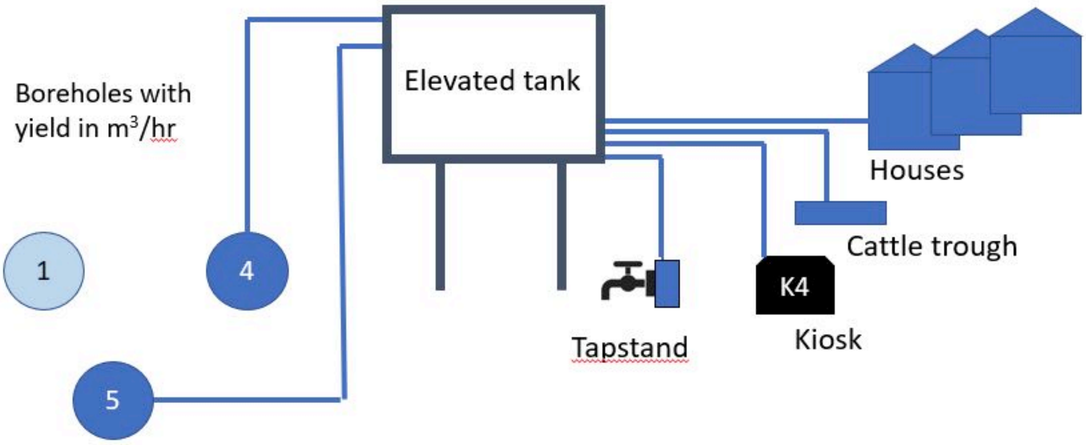
After the borehole yields are know the engineers can make the optimum design for the piped systems.

A groundwater system with a wellfield in Rwanda is likely to have numerous boreholes in a valley, and a reservoir high above on a hilltop, so a collector sump in the valley (a component that collects water from multiple boreholes) is often the best option (see Box 4). For new systems (or system extensions), the design of the system from the reservoir to the draw-off points is required, and it should also be designed and costed.

A schematic overview of the planning and development stages is given in. More details on the activities of the stages are given in the following sections for each system type. Groundwater development needs to be integrated in every phase of a water supply project.

Based on the groundwater potential map, one should already know what activities are required to develop the groundwater at the planning / budgeting stage. A form for designing the water supply system is provided in Box 2 above.

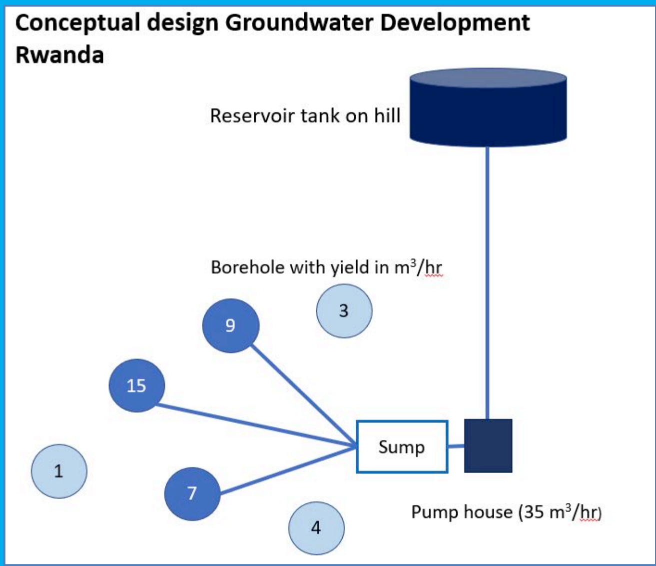
Figure 5. General conceptual design schematic for a piped system



Box 4. Case study: Designing groundwater supply system in a hilly location (valley groundwater to hilltop reservoir)

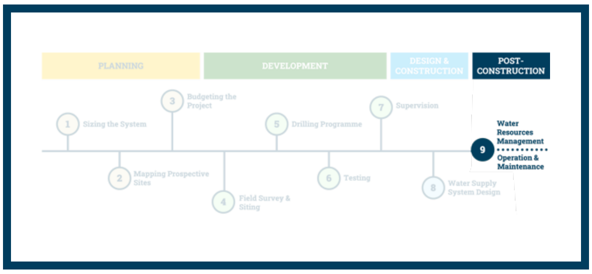
Rwanda's topography is quite rugged in many places. In the southeastern region, the elevation difference between valley floors and hilltops is frequently around 200 m. The valleys are expected to have good groundwater potential in shallower alluvial deposits, but the water must eventually be pumped to reservoirs on the hills where the water users need it. The cost of a pumping station and transmission line are only justified if the line can pump a significant amount of water. The minimum size of such a system is generally expected to be around 40 m³/hr, depending on the exact elevation differences and distances between the boreholes and the reservoir.

For this valley-hilltop scenario, it is recommended to come up with a design whereby several boreholes are drilled in the valleys. The water from the successful production wells is then collected in a sump next to a pumping station, from which the water is then pumped to the reservoirs on top of the hill. The threshold yield depends on distance from wells to the sump. The schematic illustrates this case design.



POST-CONSTRUCTION PHASE

The water supply system needs to be handed over to an operator. The operator is responsible for the effective operation and maintenance of the system phase in the typical groundwater development process entails planning for long-term operation and maintenance (O&M), critical for sustainability of the system and ensuring the investment continues to serve the end-users.



9. Operation & Maintenance

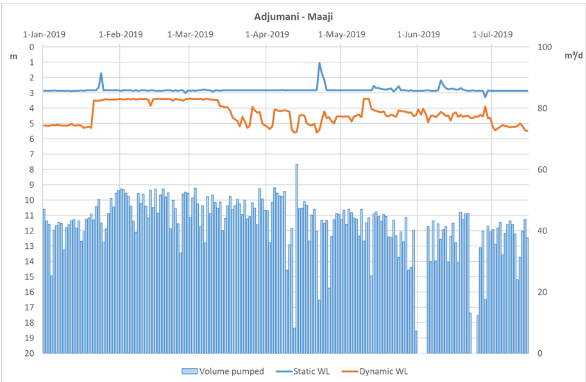
Planning new water supply systems, including small handpump boreholes and medium solar pump systems will need to include long-term operation and maintenance plans. Rural boreholes equipped with handpumps are often operated and maintained by communities, sometimes supported by a water company (some of them by WASAC in Rwanda). The costs for small repairs are usually covered by the communities. Details for O&M are provided for each type of water supply system in the sections that follow.

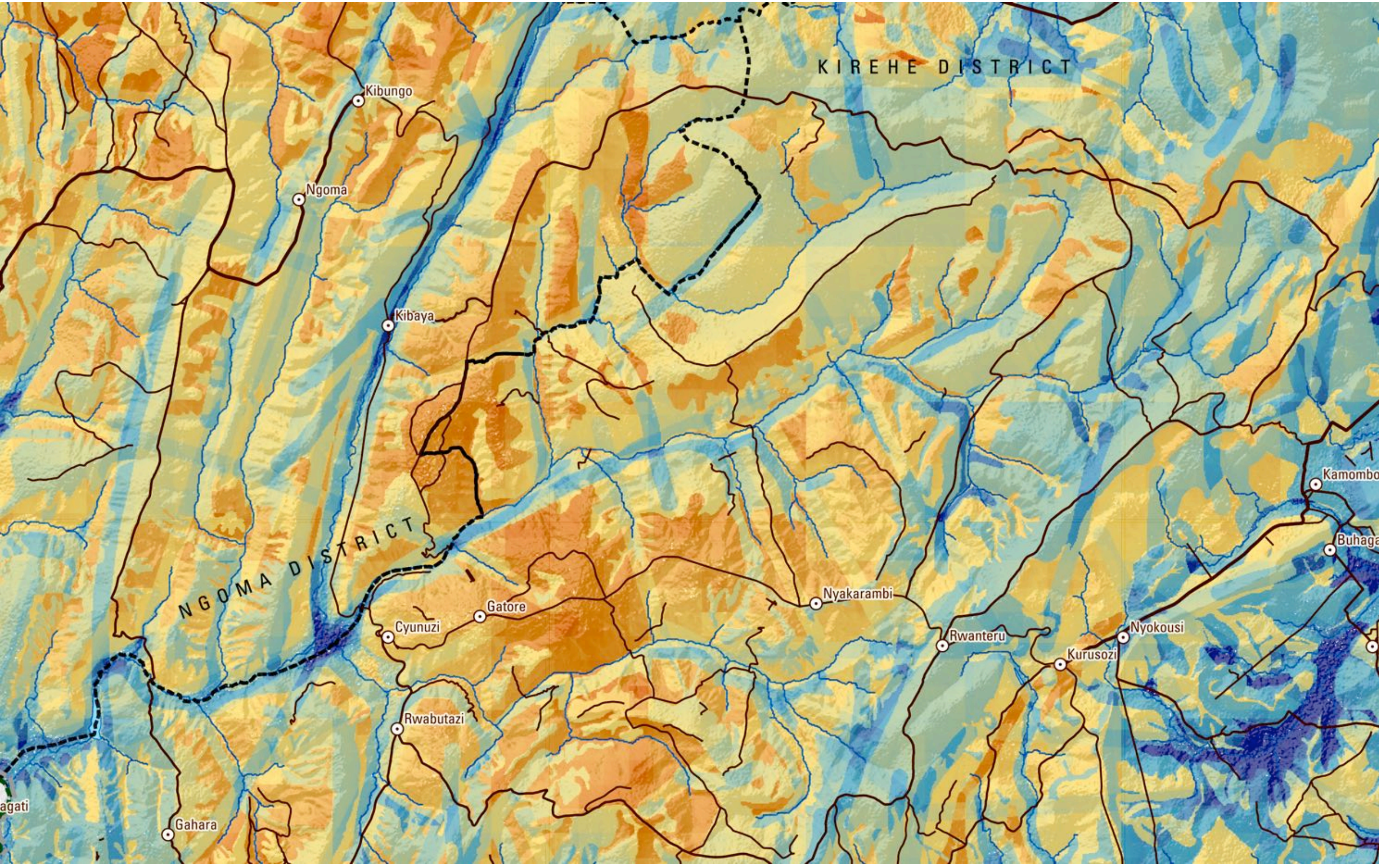
Water Resources Management

The system should not only be operated properly but the operator should also ensure that the water resources are managed properly meaning that the borehole will not be over pumped, hence damaging the aquifer and undermining the sustainability of the investments.

The operation of the new water supply system should be done in such a way that the aquifers are not drained. The operator should be instructed by the regulatory authority (RWB), and laws need to be put in place to ensure monitoring of water levels in the boreholes, abstracted amounts and pumping hours. There also should be monthly and quarterly recording in pre-defined formats submitted to RWB. RWB can assign a hydrogeologist (or consultant) to analyze the data and take action if the water resources are endangered.

Figure 6. Example of a pump test results in a borehole



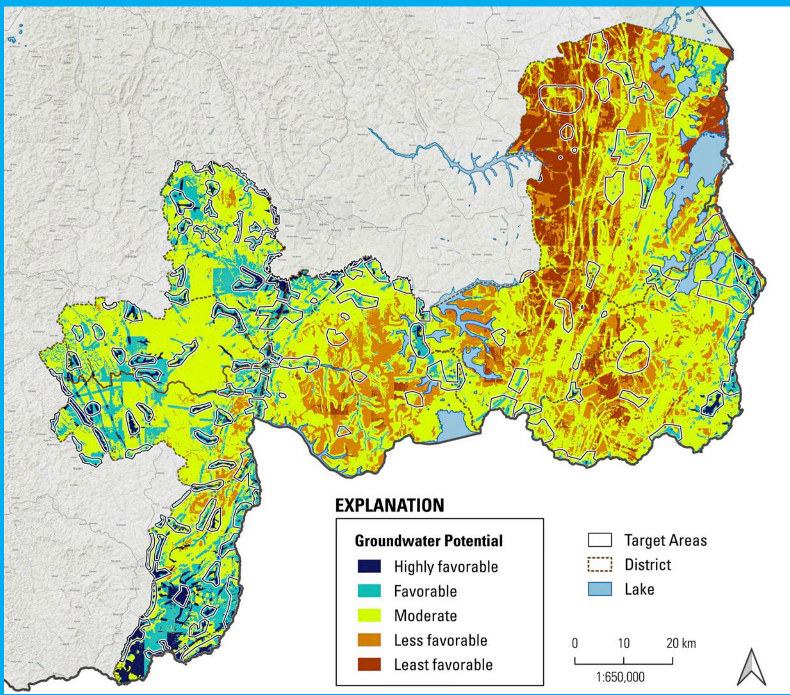


4. Application of the Groundwater Potential Map

The GWP map can help planners confirm the best location for the proposed water supply project and predict the amount of water that reasonably be obtained from the new project once in operation. With this information, the next step of conducting detailed field investigation and siting can go ahead, and the project can be budgeted.

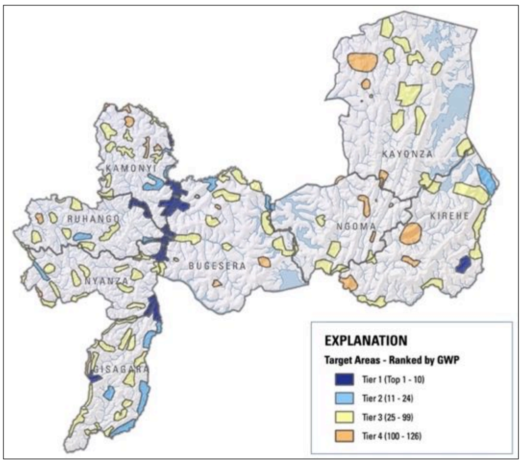
Box 5. The Groundwater Potential Map of Southeastern Rwanda

The groundwater potential map is defined as a spatially distributed estimate of the physical capacity of the terrain to yield enough groundwater for a given use. Over a regional scale, like southeastern Rwanda, the primary purpose of the groundwater potential map is to make exploration as efficient as possible. As a tool for pre-feasibility analysis of options for developing water supply, the groundwater potential map is a first-level approximation of conditions favorable for a water supply system to be built and operated. It tells the hydrogeologist where to go to focus field exploration. Within the process of regional groundwater exploration, the groundwater potential map is an expert best estimate of optimal zones for groundwater development.

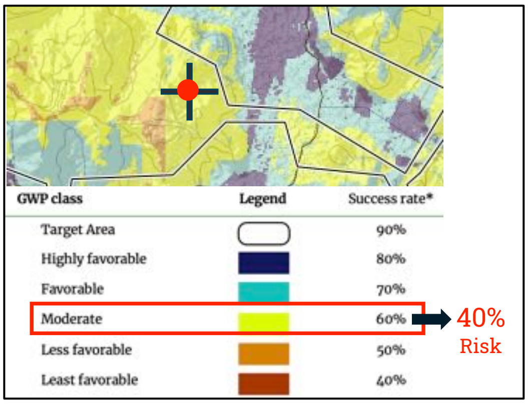


Here are guidelines for using the GWP for prospecting:

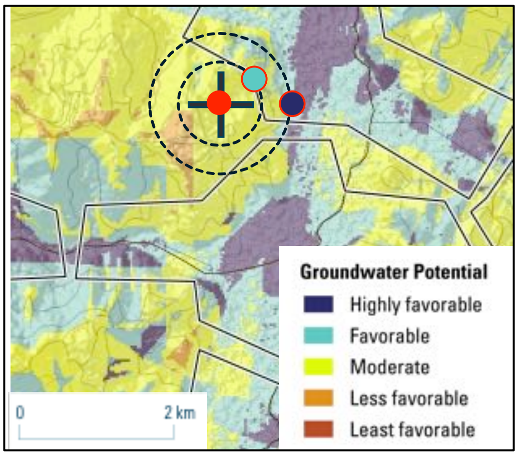
1. **Check for pre-selected Target Areas**: Does the area where a new system is proposed fall within a pre-selected Target Area? The GWP map contains 126 pre-selected Target Areas. These areas are generally rated higher for siting new boreholes and wells.



2. **Check the GWP zone of the location**: What GWP class does the area where a new water system is proposed have? – What is the estimated success rating for a project in that GWP class (% success rate)? Is the level of risk acceptable for the project investment?



3. **Check the distance to the nearest GWP zone of 'highly favorable' or 'favorable' class**: What is the distance to the nearest zone with 'highly favorable' or 'favorable' class? Is it an acceptable location for the project?



4. **Check the topography / elevation**: Is the location in a valley, or at higher elevation that is greater than (>) 100 m above the valley floor? The areas with elevations of more than 100 m above the valleys are generally too high for groundwater development and geophysical methods are usually not able to identify aquifers at those depths.

5. **Check the static water levels (SWL) in the targeted area**: Areas with static water levels between 50 and 100 m should only be considered when one is planning for a small system and there is no alternative location available at a lower elevation (shallower groundwater table).

	Small handpump supply system	Medium sized water supply system
SWL, 50-100m bgl	35%	15%
SWL > 100 bgl	-	-

6. **Check the performance of other existing boreholes nearby**: If possible, check the success rate and average yield of boreholes operating in the same vicinity. For small and medium-sized systems, information on nearby boreholes can provide good indication for the groundwater potential in the area and the range of possible yields that a new project can achieve (see Box 8 in Annex 1 for a map of borehole average yields in the region). If no information on yields and success rates of existing boreholes is available, then the probability estimates of exceedence from Box 9, Annex 1 can be used to identify the expected success rate and average.

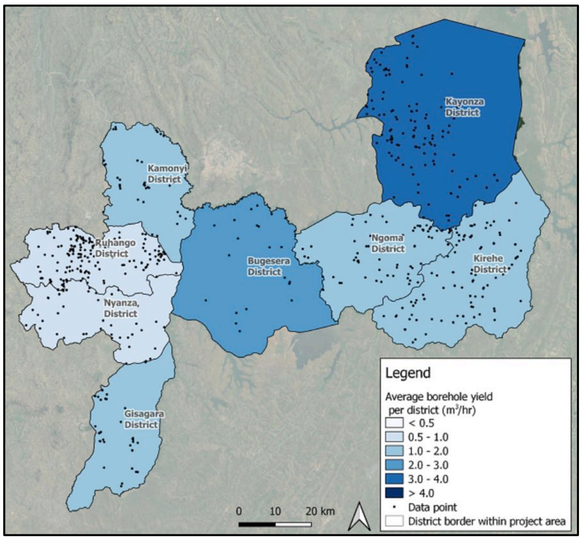


Table 7 shows the estimated success rate of boreholes drilled for the three system types / yields [handpump = 0.5 m3/hr , solar pump 2.5 m3/hr, production well 10 m3/hr] in the various groundwater potential classes. The estimates are indicative. Not indicated on the GWP map are zones 5 and 6, which relate to the estimated static water level (SWL) at a given location, which are also important factors unique to the Rwanda environment for planning the project and/or the fieldwork. SWL is important since

Table 8 provides a list of guidelines for using the GWP map to prospect for sites for three types of groundwater supply systems.

Box 6 demonstrates a mapping of potential sites for new boreholes using the guidelines for GWP map usage described above.

Table 7. Chart of GWP map classes, estimated success rates and yields, by system type

			Type A	Type B	Type C
			Handpump supply system	Small-medium sized piped water supply system	Large production well piped system
		Yield (m³/hr)*	0.5	2-10	10-50
Zone	GWP class	Legend	Success rate*	Success rate*	Success rate*
0	Target Area		90%	75%	35%
1	Highly favorable		80%	60%	25%
2	Favorable		70%	50%	20%
3	Moderate		60%	40%	15%
4	Less favorable		50%	30%	–
5	Least favorable		40%	20%	–
	Other classes				
6	SWL, 50-100m bgl		35%	15%	–
7	SWL > 100 bgl		–	–	–

*Yield and success rate figures are indicative.

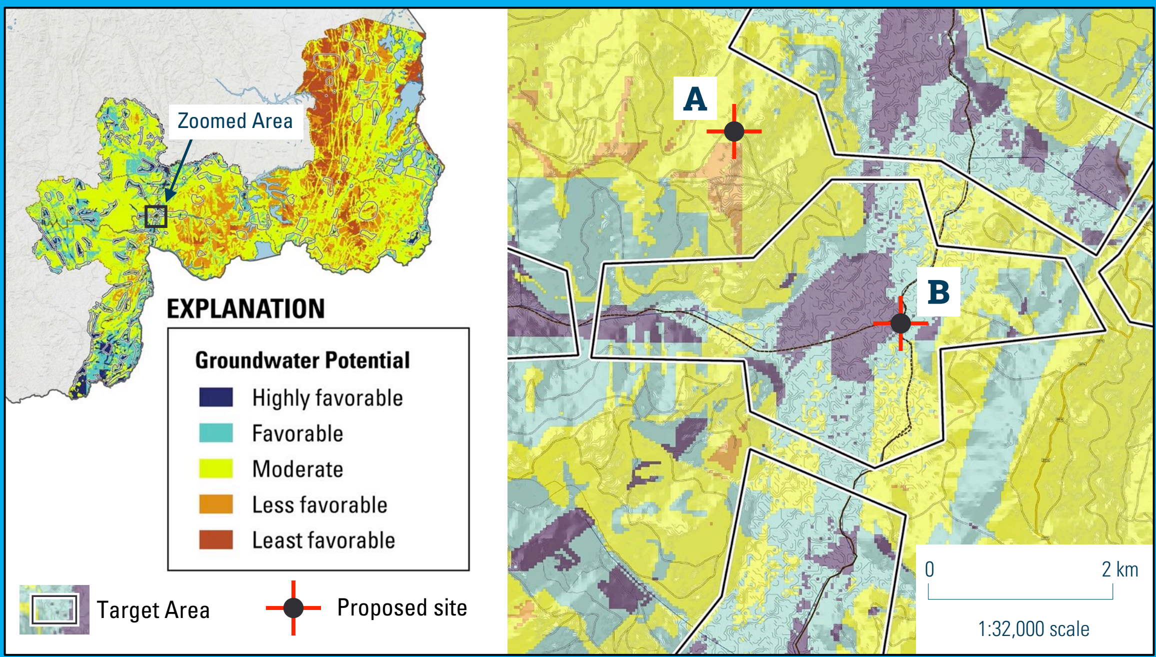
Table 8. Prospecting guidelines for use of the GWP map for three types of system

System type	GWP class	Prospecting guidelines
Handpump supply system (Type A)	Highly favorable Favorable Moderate Less favorable Least favorable	All areas, except high elevation areas (areas likely to have shallow water table, SWL <50)
Medium water supply system (Type B)	Highly favorable Favorable Moderate Less favorable	All areas, except those with 'least favorable' GWP. Also some areas close to valleys.
Large production well system (Type C)	Highly favorable Favorable	Areas with highly favorable and favorable GWP. Also some areas close to valleys.

Figure 7. More elevated areas (>100 m above valley floors) are generally less favorable for shallow groundwater development (Type A systems)

Box 6. Case study: Mapping prospective sites with the use of the GWP map

A practical example of selecting a prospective site is illustrated in the map below. The proposed site 'A' is located in a zone with less favorable GWP. Site 'B' is located within a pre-selected Target Area and sits in a zone with highly favorable GWP. Deciding on which prospective site to select will be based on an assessment of the estimated cost of effective to conduct investigations Is it cost effective to move and investigate in that zone rather than developing groundwater nearby but in a less favorable zone?



Disclaimer / updates on the GWP map

1. The GWP map is a tool that is based on the data available at the time of the Project. New borehole data will give more information that can lead to a better understanding of the hydrogeology and better / more realistic assumptions for the success rates and average borehole yields that can be obtained in the various groundwater potential zones in the different areas of Rwanda.
2. The GWP map is mainly based on groundwater quantity indicators. Groundwater quality is inferred from geology and runoff. Water quality should be tested in the testing phase (discussed below under 'Testing' step.) In some locations high concentrations of iron and manganese have been reported. At the planning stage, one is advised to check with local water authorities on what is known about groundwater quality in the area.
3. Locations outside of the 126 Target Areas should be investigated with detailed desk study and field surveys to determine local aquifers and alluvial aquifers[1].
4. The high priority areas are usually based on the presence of many favourable hydrogeological indicators. Outside the highly favorable zones, other places with single, or fewer favourable indicators may still be of interest for groundwater development.
5. The map is a tool and the values for success rates and average yields are indicative only. The actual results will only be known after the drilling, since even the geophysical results are not 100% conclusive. Nevertheless, it is of utmost importance that the hydrogeological and geophysical investigations are carried out since the more we measure the more we know.
6. Boreholes drilled in areas more than 50 m above the valleys may still produce water, but the success rates are believed to be low, and it is often more economical to move to the valleys and pump the water up to the place where the water is needed.

[1] During the Project some of these areas have been identified (Target 15 alluvial aquifers near the refugee camp / fracture valleys through the quartzite ridges and Target 34 where alluvial aquifers are expected to be well developed in the main valleys) but they could not be included in the geophysical investigation programme because of budget constraints (only 4 days of survey per target area).

5. Handpump Supply Systems (Type A)

Planning

Already at the planning stage of a Type A system, the funding agency and the implementing agency should go through the various stages of such a project. The groundwater potential and the design of a borehole determine the costs of the boreholes in the project. Often groundwater potential and designs are only discussed at the implementation stage, which then may lead to some serious challenges. The Rural Water Supply Network (RWSN) has published several manuals / guides on how to plan and implement rural water supply projects (https://www.rural-water-supply.net).

Type A handpump systems can be comprised of a single borehole or a network of multiple boreholes. The boreholes require a minimum yield of 500 liters per hour, which is roughly the rate at which a handpump borehole can be pumped. Boreholes with yields of 300 l/hr can also be accepted in some water stressed areas of Rwanda (areas where there are low success rates) if there is a quick recovery and the users are well informed and aware of the water stressed situation and are willing to operate the borehole less intensively. Boreholes are dug for rural communities, schools, and health centers that are far from piped systems.

The costs of dry boreholes should be budgeted for in the project. The success rates for getting enough water for a handpump (set at 500-1,000 l/hour) are an important guide in budgeting for a rural water project that includes boreholes with hand pumps. Preparing maps with success rates for handpump boreholes per district or region are useful planning / budgeting tools. It should be noted that most boreholes in Rwanda have been drilled without proper surveys and by implementing the steps recommend in this document higher success rates can be expected.

A consultant should be hired to assess the groundwater potential (quantity / quality) in an area that is already in the planning stage (budgets for all components are determined by these) but before the siting / drilling begins. The expenses associated with

Many projects require drilling companies to cover the risk of dry boreholes (no-water-no-payment), which sounds good from the donor and implementer's perspective, but in practice this can lead to unhappy contractors leaving the project, causing significant delays in project implementation. It is preferable to implement the project professionally for good results. The RWSN has created a document outlining how this can be accomplished while taking into account the interests of all stakeholders. (A guide for project managers on the location of drilled water wells can be found at https://rural-water-supply.net/en/resources/details/187). The greater the success rate of handpump boreholes in a given area, the fewer challenges will arise with dry boreholes.

The client should hire a specialized consultant to conduct the hydrogeological survey as well as oversee the drilling and test pumping. The client should also make certain that the contracted consultant follows the specifications outlined below.

In an ideal world, there would be a national standard for drilling handpump boreholes that could be slightly modified to suit local conditions if necessary. The borehole specifications determine the final cost of the borehole. Unrealistic specifications result in extra costs. The consultant preparing the contract documents should preferably be the same person who did the siting; he is most familiar with the hydrogeological environment of the project area.

Mapping Prospective Sites

Mapping of prospective sites for Type A systems should follow the guidelines set out in Chapter 3, section ‘2. Mapping Prospective Sites’). As discussed in the approach above, the GWP map in Figure 17 can be used to identify areas where there is a higher chance of getting higher yields.

Chapter 2 shows the anticipated success rates for Type A systems according to GWP class. Also, Table 7 provides a list of guidelines for using the GWP map to prospect for sites for Type A systems. Each potential class on the GWP map has an expected success rate, but these success rates can be different from area to area.

Type A handpump boreholes can be drilled in all the GWP classes. Handpump boreholes should not be drilled in areas where water tables are deeper than 45 meters because handpumps usually cannot be used in a sustainable way with water levels around those depths.

Based on the information available on existing borehole data in the region (Box 8 in Annex 1), Type A systems with handpumps installed in the region have had mixed success rates in the region. In Ruhango District, Type A systems with hand pumps have a low success rate of around 20%. This rate of success can be improved by carrying out more detailed surveys, profiling instead of VES only, as discussed below.

The success rate determines the activities required and the number of boreholes to be drilled. This information is needed when planning and budgeting the project.

Budgeting the Project

Budgeting for Type A systems should consider field surveying and siting costs, drilling contracting, and supervision.

Hydrogeological survey

The success rates for a rural water supply programme can be increased by carrying out more detailed investigations. The costs for the investigations should not be more than the costs for drilling a dry borehole. In areas known to have low success rates a professional consultant could be hired to make an inventory of the hydrogeological conditions of the area and to recommend on the best development procedure.

Generally, the scope of the hydrogeological study for one borehole should comprise the following:

1. 0.5 day of a desk study (plot the village preferred sites, make an analysis of topography and geology, collect all borehole data and borehole locations, get the results of earlier studies and drilling programmes [they are the reference for the new investigation].
2. 1 day of geophysical surveying comprising resistivity profiling and VES soundings (500-1,000 m of profiling with 2-3 VES)
3. 0.25 day of reporting

The costs for such a survey with good reporting following national standards and guidelines (not yet available in Rwanda) should cost between USD $300 and $500, depending on the travel distances and the number of boreholes in the drilling programme.

Mobilization and demobilization should be quoted separately from the survey days. In more difficult areas more surveying days will help while in easy areas less surveying may be needed.

Drilling

DRILLING CONTRACT PREPARATION

The drilling of a handpump borehole must be done according to national guidelines. Standard contracts and tender documents need to be used. A consultant needs to be engaged to prepare the documents and in case they are already there a consultant needs to make customize the documents for the planned project.

The costs involved are between USD $500 and $1,000.

DRILLING AND TEST PUMP SUPERVISION

The costs involved for the hydrogeologist supervising the drilling and the technician supervising the test pumping are approximately USD $500 for supervision of the drilling and USD $150 for the supervision of a pumping test.

The drilling of a borehole cased and screened with a 5” ID lining will cost approximately USD $130 per m. The cost for a 5” ID lining will be USD $125 per m. The 3-hour pumping test will cost approximately USD $500, excluding VAT and mobilization.

Hydrogeological survey

A hydrogeological survey for siting should consist of a desk study and a geophysical survey. During the desk study the data of existing boreholes is collected and analysed in conjunction with the geological map, the Google Earth map and the topographic maps. The geology and earlier drilling results determine the details of the hydrogeological survey required. Target areas for the village can now be identified.

It is recommended to spend one day on the survey for a handpump. This allows the hydrogeologist to carry out between 500-1,000 m of resistivity profiling and 3 VES. In some areas it is known that groundwater occurs everywhere in quantities that are sufficient for handpumps. In such areas the survey can be limited to one VES or no measurements at all.

The recommended site is based on the best anomaly / best VES / best hydrogeological location. If the first borehole is dry, then a second borehole may be drilled at an alternative site. This should not be done if the recommended and alternative site have similar characteristics.

Drilling Programme

Planning a drilling programme for a Type A system requires well-prepared drilling contracts / tender documents with realistic specifications adapted to the needs of the stakeholder. These documents should be readily available at national level. There should be standard implementation guideline that has to be adhered to not only by the contractors and consults but also by the implementing agencies (NGOs, UNICEF, etc.) to avoid that each organization uses its own standards.

The funding / implementing agency should decide on two things that determine the borehole cost:

1. Borehole design: open hole or cased to the bottom hole. The open hole is a cheaper option but requires more skills from the consultant and the driller and should only be adapted if one of them has proven experience with it.
2. Casing diameter (and hence the diameter of the borehole): 4", 5" or 6" ID casings. The larger the diameter the easier it is to install pumps and data loggers. The costs for a borehole however will increase with increased diameter. The most common design is a 5" cased borehole down to the bottom. A 5" casing will still allow for the installation of a 4" submersible pump which can pump up to 15 m^3/hr. A 4" hole can accommodate a 3" pump which will still be able to pump up to 7m^3/hr. It should be noted however that these dimensions do not allow for the installation of a datalogger within a guiding pipe. There is usually enough space to enter the borehole with a water level dipper to measure the water level in the boreholes.

Test pumping

The pumping test of Type A systems with handpump boreholes should be done for 3 hours, followed by a 1-3 hour recovery. The yield of the test should initially be 500-1,000 l/hr because that information (the actual pumping rate of a handpump) will be used to determine the installation depth of the handpump. If the capacity of the borehole is much higher than the yield, then pumping can be increased after the first hour (the water level then will have stabilized – no more increase of the drawdown), and the borehole can be pumped at the maximum yield of the pump brought on site or to a yield close to the airlift yield of the borehole.

For the handpump borehole one is interested at what depth to install the handpump (for which we have to do a constant rate test at the yield of a handpump [500-1,000 l/hr]) and the specific capacity after 3 hours of pumping (for which we can increase the yield to the airlift yield after the water level stabilized [after 1 hour or 2 hours] till the end of the test.

Supervision

The drilling and test pumping supervision ideally needs to be done on a permanent basis by an independent supervisor who is able to guide the drilling contractor in constructing the borehole according the specifications and procedures stipulated in the contract. Full time supervision is a must for BoQ-based contracts. The supervisor needs to certify the payable quantities used by the contractor.

For lump-sum contracts, some organizations only carry out checks at milestone moments in the drilling process. This is then best done at the test pumping stage where the borehole is pumped for three hours (check the water level) and the borehole is sampled (check the turbidity). The borehole water needs to be sampled and analysed. Please note that the contractors cannot be held responsible for high concentrations of certain chemical parameters[2]).

The drilling supervision of handpump boreholes can be carried out by a hydrogeologist with

[2] The water quality challenges that may be present in an area should be identified by a consultant who has to prepare the groundwater assessment report for a project area.

at least 2 years' experience (drilling) and a technician (test pumping).

Water supply

Rural boreholes with handpumps are frequently operated and maintained by communities, with some assistance from a water company (some of them by WASAC in Rwanda). Small repairs are typically covered by the communities. In general, the district and/or WASAC should assist in cases where major repairs are required.

Water resources management

The abstracted volumes of Type A systems with handpump boreholes do not have a significant impact on the groundwater resources. A handpump can abstract approximately 5,000 l/d, which is approximately equal to the recharge of 1/20 km^2 in Rwanda (using 5% recharge, 1,000 mm rainfall). This means that up to 20 handpump boreholes could presumably be installed per 1 km^2 without lowering the water table.

6. Planning small - medium-sized piped Systems (Type B)

Planning and sizing the system

More and more the water sector moves from boreholes equipped with handpumps towards small piped system. One single borehole can often produce more water than the amount that can be abstracted with a handpump. A handpump borehole can only serve 250 people with 20 l/d. A submersible pump in a borehole can be used to abstract more water and serve more people. The number of people served depends on the yield of the borehole. The number of people served (size of the system) should be in line with the costs of the system (per capita cost).

Small systems are systems that are based on a single borehole equipped with a small submersible pump powered by solar power that will pump water to a raised water tank from where the water is lead to one or more tap stands. The solar power can only be generated for 8 hours and as such limits the daily capacity of such a system. A power supply by a generator is more expensive in the operation. The power from the grid is less expensive and allows the borehole to be pumped for 20 hours.

The minimum capacity for such a system based on investment cost is 2-3 m^3/hr. If the yield is less the investment costs are not outweighing the additional benefits. The maximum capacity of these systems is limited.

Mapping Prospective Sites

Mapping of prospective sites for Type B systems should follow the guidelines set out in Chapter 3, section '2. Mapping Prospective Sites'). The goal of mapping prospective sites for Type B systems is to identify sites where the boreholes is expected to achieve a yield of at least 2-3 m^3/hr. As discussed in the roadmap approach above, the GWP map in Figure 17 in Chapter 2 can be used to identify areas where there is a higher chance of getting higher yields.

The GWP map has five classes. The lowest GWP class has the least favorable conditions for Type B system boreholes, although it may still be possible if more detailed hydrogeological surveys (ie. more measurements) are carried out. However, planning Type B systems in low favorability zones carry higher risk of lower success and thus, higher costs. It is recommended to site a borehole slightly further away from the demand area in a better GWP class zone where there is a better GWP and transmit the water to a reservoir via a transmission line.

Chapter 4 provides the anticipated success rates for Type B systems according to GWP class. Also, a list of guidelines is given for using the GWP map to prospect for sites for Type B systems (Table 7). The success rates for a borehole with a yield of 2.5 m^3/hr can also be inferred from information regarding other boreholes in the same area. The data in a borehole database are usually from boreholes that have not been drilled based on the results of detailed geophysical measurements, therefore the success rates can be higher, if combined with detailed field surveys. Recommendations for such surveys are given below.

Budgeting the Project

The cost for the implementation of small system depends on a couple of factors. The details of the costs are given in the following sections. The main variable costing is the drilling of the boreholes and the distance between the borehole and the storage tank.

The success rate for boreholes suitable for small to medium sized piped systems depend on the area where the borehole is to be drilled and/or the amount of water required. To estimate the success rate at the start of a project one could consult a database and use the information there to assess the success rate for boreholes with a specific yield. It should be noted that most of the boreholes in the Rwanda database have been sited without proper investigations. If the guidelines given in this document are followed higher success rates can be expected.

In many cases funding / implementing agencies will make use of existing boreholes with known high yields. This will eliminate the variable cost from the project. The targeted existing boreholes will need to be subjected to a pumping test to confirm the sustainable yield.

Hydrogeological study

The siting comprises a desk study and a hydrogeological fieldwork. The hydrogeologist involved should have a minimum experience of three years. The number of measurements and the details of the study depend on the complexity of the target areas. Generally, the work during the desk study should comprise the following:

1. 1 day of a desk study (plot the village preferred sites, make an analysis of topography and geology, collect all borehole data and borehole locations, get the results of earlier studies and drilling programmes [they are the reference for the new investigation].
2. 2 day of surveying comprising resistivity profiling and VES soundings (1,000-1,500 m of profiling with 4-6 VES)
3. 1 day of reporting per site

The costs for such a survey with good reporting following national standards and guidelines (not yet available in Rwanda) should cost between USD $1,000 and $1,500, depending on the travel distances and the number of boreholes in the drilling programme.

Mobilization and demobilization should be quoted separately from the survey days. In more difficult areas more surveying days will help while in easy areas less surveying may be needed

Drilling programme

DRILLING CONTRACT PREPARATION AND SUPERVISION

The drilling of a borehole has to be done according to national guidelines. Standard contracts and tender documents need to be used. A consultant needs to be engaged to prepare the documents and in case they are available the consultant needs to customize the documents for the planned project. The costs involved for preparing tender documents are between USD $500 and $1,000.

The costs involved for the hydrogeologist supervising the drilling and the technician supervising the test pumping are approximately USD $600 for supervision of the drilling and USD $250 for the supervision of a pumping test.

DRILLING AND TEST PUMP SUPERVISION

The drilling of a borehole cased and screened with a 5" ID lining will cost approximately USD $125 per m. The cost for a 6" ID lining will be USD $150/m. The pumping test up to a yield of 7 m^3/hr will cost approximately USD $40 per hour excluding VAT and mobilization.

Dry or low yielding boreholes should be backfilled to save costs.

The drilling contractor should be experienced in drilling under difficult conditions and the equipment should be able to drill in these formations.

Water supply system

The investment cost of a Type B system is determined by the capacity of the pump, the size of the storage reservoir, the type of water supply, and the distance and elevation difference between the source and the draw off points. The system will typically cost between $20,000 and $200,000.

The small water supply systems in Rwanda usually consist of a borehole, a solar powered submersible pump, and a reservoir tank of 2-3,000 liters at a tank stand of 2.5-5 m with one or two tap stands and sometimes a cattle trough within 50 meters of the boreholes. For the larger systems a pump house with control panel, and in some case even a guard house needs to be included and solar panels may need be in a fenced area.

Water supply and resources monitoring

Rural boreholes equipped with solar pumps are often operated and maintained by communities, sometimes supported by a water company, e.g. WASAC in Rwanda. The costs involved are usually covered by the communities for small repairs. The larger repairs are to be covered by the water company or the government.

The cost of a pump attendant for regular monitoring once the system is operating will be in the range of USD $200 per month. If the borehole has enough space (space between the permanent casing and the rising main), then a permanent data logger could be installed. A datalogger will cost approximately USD $1,000.

Hydrogeological study

The field survey and siting works for a Type B system comprises of a more detailed desk study covering a larger area. The study has the following components:

1. **Desk study** for an area within 1-3 km from the demand area. The distance depends on the demand amount. The higher the demand the further away the borehole can be (for the project to be able to make a cost-effective investment). During the desk study the data of existing boreholes is collected and analysed in conjunction with the geological map, the Google Earth map, and the topographic maps. The geology and earlier drilling results determine the details of the hydrogeological survey required. Target areas for the village can now be identified. Usually, the valleys near the demand area form the target areas. A detailed lineament analysis is part of the desk study and will be the main output for the identification of target areas.
2. **Geophysical surveys** will be carried out in the target areas. It is recommended to carry out at least 2 days of resistivity surveying (1,500 m of profiling with 3-6 VES).

The field surveying works results in one recommended site and an alternative drill site. If the first borehole is dry, then a second borehole may be drilled at an alternative site. This should not be done if the recommended and alternative site have similar characteristics in terms of geophysical responses.

Drilling

Planning a drilling programme for a Type B system requires well-prepared drilling contracts / tender documents with realistic specifications adapted to the needs of the stakeholder. These documents should be readily available at national level that will be adapted according to the project details that were reported in the hydrogeological study.

The Consultant who carries out the hydrogeological study should ideally also be in charge of managing the drilling contract.

The drilling and test pumping programme for a Type B system needs to be designed based on the demand. Generally, a 3" pump can provide up to 7 m^3/hr against 40 m of head but more commonly 5" ID boreholes are installed. These boreholes can accommodate 3" pumps more easily (leaving space for monitoring devices as well) and even allow 4" diameter pumps that can pump more water against larger heads.

Type B system boreholes are generally cased down to the bottom meaning the borehole ideally is to be drilled at 8" in the overburden and 6 7/8" in the hard rock.

Test pumping

The pumping test for a Type B system should consist of a step test with 3-4 steps of 1 hour, followed by a constant rate test of 12-24 hours. If a solar pump is installed the borehole will only pump for 8 hours per day and a 12-hour test will suffice. If the pump is supplied by the grid or by a generator the longer test of 24 hours should be applied.

Supervision

For Type B systems, drilling and test pumping must be permanently supervised by an independent supervisor who can guide the drilling contractor in constructing the borehole in accordance with the specifications and procedures specified in the contract. BoQ contracts call for full-time supervision. The contractor's payable quantities must be certified by the supervisor.

Some organizations only check lump-sum contracts at critical points in the drilling process. This is best accomplished during the test pumping stage, which involves pumping the borehole for three hours (to check the water level) and sampling the borehole (check the turbidity, please note that the contractors cannot be held responsible for high concentrations of certain chemical parameters).

Handpump borehole drilling can be supervised by a hydrogeologist with at least two years of drilling experience and a technician (test pumping).

Water Supply

In Rwanda, Type B medium water supply systems typically include a borehole, a solar-powered submersible pump, and a reservoir tank of 2-3,000 liters at a tank stand of 3-5 m, with one or two tap stands and, in some cases, a cattle trough within 50 meters of the boreholes. For larger systems, a pump house with control panel and, in some cases, a guard house is required, and solar panels may need to be installed in a fenced area.

The most critical design challenge is the specification of the appropriate pump which depends on the sustainable yield and the head between the DWL and the storage tank (determined by elevation difference and rising main and transmission main diameter. An experienced hydrogeologist should analyze the pumping test and recommend the best pump and pipe diameters for the borehole. The smaller Type B systems like depicted in Figure 9, can be easily designed because the hydraulics of the system are simple. When transmission and distribution lines are involved, an engineer should be involved to carry out the hydraulic calculations for the system and recommend the optimum diameters of the pipes.

The boreholes should be equipped with flow meters to allow the monitoring of the pumped volumes of water.

Figure 8. Small (Type B) sized piped systems with storage tanks

Figure 9. Medium sized piped systems

District offices, NGOs or community user associations will typically manage the small Type B systems. The medium sized systems may be given for operation to small companies that operate and manage the system on behalf of WASAC or the District.

Water resources management

The operational yield of the small to medium sized systems is approximately 2.5-10 m^3/hr for 8 hours per day which is approximately 10-40 m^3/day. Boreholes that pump such quantities do not have a significant impact on the groundwater resources. The production of such a system is approximately equal to the recharge of 1/3 km^2 in Rwanda (using 5% recharge, 1,000 mm rainfall), meaning that the recharge in 1 km^2 is equal to three boreholes with such a production.

The larger Type B systems should ideally be monitored by reading water levels and flow meters. The information will help to monitor the performance of the borehole and /or the pump. The system could be visited on a monthly basis to measure the water level and read the pumped amounts in that month from the flow meter. s should be taken before the pump is switched on and the SWL is measured rather than taking the reading of a dynamic water level. These measurements could be daily readings if there is a permanent pump attendant present on site. Before turning back on the pump, the water level should be measured (SWL) to avoid measuring the dynamic water level (DWL) while the pump is operating.

7. Planning Large Supply Systems (Type C)

Developing groundwater supply with the use of large-scale abstraction systems (production wells / well fields) is a comprehensive, complex, and costly process that requires timely and committed input from a wide range of stakeholders. Engineers and/or hydrogeologists frequently work solely from their own perspective, resulting in less cost-effective outputs and operations. Intensive collaboration is required from the planning to the management stages. The recommended groundwater development process for high volume piped systems in Rwanda follows the approach laid out in Chapter 3. This section provides guidance on those steps as they pertain to the Type C systems.

In Rwanda there are no large-scale groundwater-based systems with boreholes drilled in the hard Basement rocks. The only large groundwater-based systems are getting water from riverbank aquifers.

Planning and sizing the system

Sizing the large production well system involves two key steps: (1) **identifying the demand area** (service area) of the system, and (2) conducting a **baseline survey** of water requirements in the project area.

Identify the demand area

The first step in groundwater development is to locate the demand area and calculate the amount of water needed to meet the demand. The demand area can be a town or a city. The project's overarching goal is to locate water for either an existing or new water supply system. The costs are obviously much higher in the latter case but both must be carefully planned for in order to realize a delivery system as well.

Baseline survey

The first step in the baseline survey is a demand assessment with the to know how much water is needed in which area The baseline survey is also carried out to identify the status of the existing system in terms of production, storage, and distribution. The study should address the source (boreholes, springs, lakes), the transmission lines, the treatment plant, the storage tanks and the distribution network as well as the availability of power supplies.

The exact locations where the water is needed are determined by the locations of the existing or planned reservoir tanks for the existing or new water supply system. In general, the closer the water is to these reservoir tanks, the less expensive the future water supply system will be. Other cost determinants include electricity availability, elevation difference, and so on.

The information gathered during the baseline survey will result in a planning map that shows the locations of demand areas as well as the amount of water required in those areas. The map should also include existing and planned infrastructure locations (reservoirs, transmission lines, power lines, transformers).

Mapping Prospective Sites

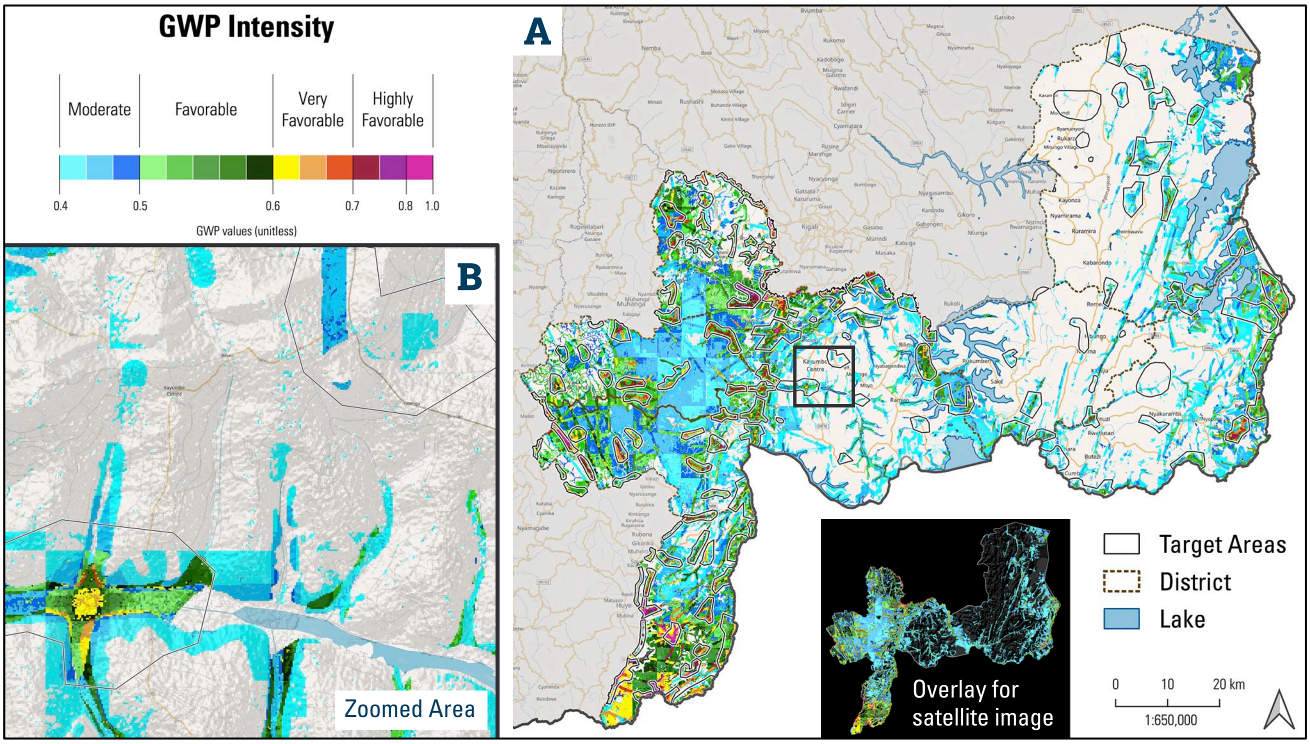
Mapping prospective sites for Type C production well systems utilizes the GWP map (Figure 17 in Annex 1) to identify areas with the highest groundwater potential (GWP class 'highly favorable'), thus increasing the chance of obtaining higher yield that production well systems require. The primary function of the GWP map is to determine the distance, success rates, and amount of water to be expected in the area surrounding the demand area. This is the foundation for calculating the indicative cost of the proposed system.

The GWP map should also be used to identify possible highly favorable areas in the flood plains of larger rivers. The existing and planned riverbank wellfields west and south of Kigali have shallow boreholes with capacities ranging from 40 to 80 m^3/hr, drilled in the shallow alluvial aquifers. These sediments form some of Rwanda's most productive aquifers and are relatively easy to explore and exploit.

GWP Intensity tool

As a secondary tool for "fine-tuning" the mapping of prospective sites for production wells, a second version of the GWP map has been developed—the GWP Intensity map (Figure 10). GWP Intensity map gives more discrete grades of GWP classes for 'moderate', 'favorable', 'very favorable', and 'highly favorable', allowing planners a more controlled prospection at the local level. For prospecting sites for Type C systems, the GWP classes for 'very favorable' and 'highly favorable' should be targeted.

Figure 10. GWP Intensity map (A) for detailed site prospecting for production well systems, with zoomed-in closeup view (B)



Budgeting the Project

Costing the Type C water supply system

The information from the baseline survey will lead to the scope of the water supply project. At this stage the cost of the individual components of the new water supply or water supply extension needs to be known.

For an existing system the client needs to identify the locations of existing tanks / treatment plants that can receive additional water. The location of existing infrastructure is often known by the people initiating the projects but WASAC also has a database with all the existing infrastructure in the country.

For a new system the planned location for the reservoir tank will need to be known. The locations of the existing / new reservoirs / treatment plants now determine the location of where the water is needed.

For both type of systems preliminary costs estimates needs to be made at this early stage, not only for the development of the source (siting, drilling and test pumping, borehole installation [pump, pump house, electricity, etc.] but also for the transmission, storage and distribution components. When the required funds have been identified and/or secured for the various phase, then the groundwater development can start.

Overall investment planning

The siting activity for planning Type C systems comprises a desk study, a reconnaissance survey and a geophysical survey. The costs for these components depend on the size of the project. The same applies to the drilling and test pumping phase. The costs for the development of groundwater usually is a fraction of the overall costs for the construction of the water supply scheme.

The reliability of a cost estimate for the groundwater development phase of a project depends on the availability of borehole data. The database in Rwanda is not yet well developed. Nevertheless some tools can be used to come up with some cost estimates.

Table 9 shows an example of a budget calculation for a Type C project proposed for a town. It is based on a requirement of 800 m^3/day. It is assumed that the success rate for boreholes with more than 10 m^3/hr is 40% and the average rate of the successful boreholes is 20 m^3/hr.

The overview then is used to calculate the groundwater development unit rates that can be used for budgeting (Table 10). Please note that:

1. The costs do not include project management costs for the client, only costs for external services by consultants and contractors.
2. No costs for water supply designs, construction, construction supervision, pumps etc. are included.
3. No costs for contract / project management by the clients themselves is included.
4. The inputs are by regional senior hydrogeologists. The costs can be higher when international consultants are used and cheaper when national consultants are used. The success of the project mainly depends on the quality of the hydrogeologists engaged. The investment in better consultants will pay itself back during the operational period of the water supply system if they can realize higher yields (better sited boreholes and better designed hence more efficient boreholes) in areas closer to the demand areas.
5. The unit costs can be adapted as soon as more information on groundwater development project becomes available (Table 10).

Table 9. Example of a budget calculation for Type C project for a town

Estimated costs for groundwater development for one town for 5 test holes and 2 production wells

No.	Phase	No.	Activity Week	Input	Unit 2	Qty total	Rate	Amount	Total
1	Inception	1.1	Meetings	Sr.Hydrogeologist	days	1	$ 600	$ 600	
		1.2	Report	Sr.Hydrogeologist	days	1	$ 600	$ 600	$ 1,200
2	Desk Study	2.1	Data collection	Sr. Hydrogeologist	days	1	$ 600	$ 600	
				Hydrogeologist	days	2	$ 300	$ 600	
	and Reconnaissance	2.2	Data analysis and reporting	Sr. Hydrogeologist	days	3	$ 500	$ 1,500	
				Hydrogeologist	days	5	$ 300	$ 1,500	
				GIS	days	3	$ 350	$ 1,050	$ 5,250
		2.3	Reconnaissance travel	Sr.Hydrogeologist	days	2	$ 600	$ 1,200	
				Hydrogeolgogist	days	2	$ 300	$ 600	
		2.4	Reconnaissance Meetings / visit target sites	Sr.Hydrogeologist	days	3	$ 600	$ 1,800	
				Hydrogeologist	days	3	$ 300	$ 900	
				Car days plus driver	days	3	$ 150	$ 450	
				Allowances	nr.	10	$ 100	$ 1,000	$ 5,950
		2.5	Data analysis and reporting	Sr. Hydrogeologist	days	2	$ 600	$ 1,200	
				Hydrogeologist	days	2	$ 300	$ 600	
				GIS	days	2	$ 350	$ 700	$ 2,500
3	Fieldwork	3.1	Geophysical field work	fees, transport, equipment	days	10	$ 1,500	$ 15,000	
		3.2	Fieldwork mob and demob		days	2	$ 1,500	$ 3,000	$ 18,000
4	Reporting	4.1	Groundwater assessment report	included in daily fees geophysical fieldwork					
								Total ex VAT	$ 32,900
5	Drilling and	7.1	Drilling testholes	per borehole	BH	5	$ 5,000	$ 25,000	
		7.2	Drilling production holes / reaming	per borehole	BH	2	$ 7,500	$ 15,000	
	Testpumping	7.3	Drilling	supervision	BH	7	$ 2,000	$ 14,000	$ 54,000
		7.4	Test pumping	per borehole	Test	2	$ 3,000	$ 6,000	
		7.5	Test pumping	supervision	Test	2	$ 1,500	$ 3,000	$ 9,000
								Total ex VAT	$ 63,000
6	Groundwater development	8.1	Groundwater development report	Sr. Hydrogeologist	days	2	$ 600	$ 1,200	
				Hydrogeologist	days	4	$ 300	$ 1,200	
				GIS	days	2	$ 350	$ 700	
								Total ex VAT	$ 3,100
								GRAND TOTAL ex VAT	$ 99,000

Table 10. Unit cost calculation for Type C production well supply systems

Unit	Assumption	Value example		Generalised	
Average yield of BH > 10 m3/hr		20	m3/hr	20	m3/hr
Number of boreholes		2			
Total yield per hour		40	m3/hr	40	m3/hr
Total yield per day	20 hrs pumping	800	m3/day	800	m3/day
Total cost		$ 99,000		$ 100,000	
cost per m3 per hour		$ 2,475	per m3/hr	$ 2,500	per m3/hr
cost per m3 per day (20 hr pumping)		$ 124	per m3/day	$ 125	per m3/day
Feasibility study area (deskstudy plus reconnaissance plus report)		$ 14,900			

Water resources management

All boreholes drilled as production wells in Rwanda shall be equipped with access tubes for water level dippers or access tubes for data loggers. The latter have a larger diameter and costs may increase for the borehole designs but monitoring the water levels and production rates could be automatic. A water level dipper costs approximately 750 US$ while simple data loggers are 1,000 US$ and telemetric data loggers can costs 2,500 US$

Hydrogeological study

The siting activity comprises a desk study, a reconnaissance survey and a geophysical survey.

Staffing

A hydrogeological study for production well drilling should be led by a senior hydrogeologist with at least 5 years' experience but preferably 10 years The hydrogeologist should be well educated in the theoretical background of hydrogeology and geophysical surveys. The experience is mainly gained during the execution of similar projects and as such the more projects the hydrogeologist has been involved in the more knowledge he has. Examples of earlier studies carried out by the hydrogeologist will give a good indication on the professional level of the hydrogeologist.

The execution of the fieldwork can be done by a junior hydrogeologist with 3-5 years' experience. The Junior and Senior hydrogeologist work hand in hand through the phase.

One of the two hydrogeologists should be experienced in using GIS systems (ArcGIS or QGIS) as well.

Desk study

The hydrogeologist will start with a hydrogeological survey focused on the general groundwater conditions in the selected area. The results of the desk study will be a detailed report describing the groundwater potential and the scope of the geophysical survey clearly indicating the locations of the start and end of survey lines. The desk study report will contain all relevant information and analyses and should include the information as indicated in Table 11.

Table 11. List of desk study datasets for Type C systems

Item	Dataset
1	Location data
2	Demand area
3	Topography, elevation
4	Hydrogeological and geological map
5	Existing borehole / spring data
6	Existing geophysical survey data
7	Lineament analysis
8	Conceptual model
9	Recommended areas for the geophysical survey

After carrying out the desk study the consultant will have to do a reconnaissance survey to the area. During the visit the identified target sites for geophysical measurements will need to be confirmed and additional targets could be identified. The Consultant will liaise with local communities, authorities and the RWB local team to ensure a smooth execution of the geophysical measurements. Since RWB is only interested in high yielding boreholes, the targets for the geophysical surveys are usually formed by valleys. The valleys can be either structurally controlled or lithologically controlled, meaning that either they are formed/underlain by fractures, or they are formed by softer layers found in the geological formation.

Fractures can run over long distances and even cross from one topographic catchment to another. These features can be identified on aerial photographs, topographical maps and hill shade maps where they form lines. These lines are called lineaments. The GWP map has already taken into account a regional mapping of lineaments and important structural conditions for groundwater. Localized surveying of lineaments in a target area should be conducted to confirm the specific local lineament conditions.

The main aim of the desk study is to confirm these lineaments and find additional smaller / local ones that only show up when zooming in to one particular Target Area. In some areas intrusive dykes are found in higher areas, and these are often visible at the aerial photos or google earth images.

The locations with the highest groundwater potential are often formed by the intersection of two or more valleys / local / regional lineaments.

Ideally the lineaments, valleys and dykes are to be traversed with geophysical profiles to locate anomalies that could indicate the exact location of the fracture aquifer. On the spot of an anomaly, a VES should be carried out to assess the vertical built up at these locations.

Reconnaissance visit

It should be noted however that very often these favorable locations as identified through a geological / topographical analysis cannot always be accessed or lack the space to carry out geophysical measurements. Therefore, a reconnaissance visit is made to the target areas to confirm the accessibility of locations for the profiles.

The information of the reconnaissance visit is evaluated and the priority profiles are determined. All information is included in the desk study report (in this project the Site-specific Investigation Report). The number of profiles to be done depends on the available budget for siting.

Geophysical survey

Geophysical measurements should be planned in areas where hydrogeological features have been identified. The presence of these features can be confirmed using geophysical data. However, there is no direct relationship between the geophysical measurements and the amount of water present in a borehole drilled at the site. Some boreholes drilled in areas with good geophysical data yield low yields, while others drilled in areas with low groundwater potential yield high yields. The more data we have from existing surveys and boreholes, the more reliably we can find a relationship between geophysical responses and borehole yields.

The resistivity method was used in the project's geophysical survey. 1D profiles, ERT lines, and VES measurements have all been performed. This method is well documented and should be used (especially for production well siting) rather than newly introduced methods using low-cost equipment that produce undocumented results.

The 1D profiles are quick and effective in granitic rock areas where the contrast between water bearing sections and dry areas is usually very sharp. The more detailed information that can be obtained with ERT profiles will help to get a better understanding of the geological built up in areas with hard rock formations where lithological differences are more common and in sedimentary areas.

Geophysical profiles are used to locate anomalous sections that may be related to fractures that form aquifers in the rocks. These fractures may appear as lineaments on maps and satellite images.

To identify the same anomaly on two different profiles, parallel profiles are performed. When these points are connected on a map, the orientation of the line is compared to lineaments derived from remote sensing and other analyses. If the orientations coincide, the fracture location has most likely been confirmed in the field and the location is one of the preferred drill sites.

In valley areas where the river cannot be easily crossed, 3-5 VES can be performed parallel to the valley to observe any differences in point depth to bedrock / vertical build-up. Where there is insufficient space to conduct geophysical measurements but lineaments and/or field observations indicate favorable hydrogeological conditions, a preferred drill site can be chosen without conducting geophysical measurements.

Analysis and reporting

The geophysical data will be processed and analyzed using geophysical data from previous studies, if available, and information from the desk study, which will lead the planner to select multiple potential drilling sites. These sites will be ranked according to their potential. The outcomes of similar drilling programs that have been carried out It demonstrates in Uganda that there is no strong relationship between site ranking and borehole yields, implying that the first ranked borehole is not always the highest yielding one.

Drilling Programme

The drilling programme for Type C systems should be well planned from the start as explained in Box 5 in Chapter 2. The consultant in charge of the hydrogeological study should also be involved in the preparation and management of the drilling contract.

Planners of Type C systems should expect to plan 2-3 test holes and a final production borehole (typical ratio of test holes-production boreholes is 2:1 or 3:1). The costs involved in the drilling is determined by the borehole design and the success rate for a production borehole. The anticipated success rates and yields for Type C systems are given in Table 7.

Before the drilling starts the client should ensure that all locations as marked during the hydrogeological survey can be found in the field. Some of the locations may need to be reconfirmed through a short resurvey. After confirming the sites, the permission to drill on each of the sites need to be arranged from the landowners. All drill locations appearing in the decision tree should be considered.

The drilling specifications should be flexible to be cost effective. This means that the programme should allow the driller to drill boreholes with different designs. The boreholes will be designed with casings down to the bottom or with open holes in the hard rock if the hard rock is stable enough.

A drilling contractor will get paid for the actual work he has done. The following set up of a drilling programme in the basement hard rock environment is suggested:

1. Start drilling the borehole with 6" in the hard rock which allows the installation of a 5" ID casing. However, if the yield of a borehole is less than 3 m3/hr the borehole will be backfilled, no casing installed. Unless the location would be good for a monitoring well in which case the borehole will be installed with a 2-5" lining.
2. If the yield is between 3 and 10 m3/hr the borehole will be installed with a 5"ID, allowing a 4" pump to enter with a 2 "rising main
3. If the yield is between 10 and 15 m3/hr the borehole will be installed with 6" casing allowing a 4" pump to be installed with a 3" rising main. The borehole needs to be reamed to 8-9"
4. If the yield is above 15 m3/hr the minimum diameter is supposed to 7" ID allowing the borehole to be installed with a 6" pump and a 3-4 inch rising main. If the borehole is to be equipped with a permanent data logger, then it is better the borehole is installed with an 8" ID casing and the borehole be reamed to 10-11"

An alternative option is to drill test holes and install 5" casing always. Then for the boreholes that are of interest for the future supply (depending on yield and location= distance from tank / elevation difference between borehole and tank) production boreholes will be drilled at a distance of 2-3 m.

The contractor should bring on site all necessary bits and hammers, casings and screens and temporary casings to drill the different diameter boreholes and install them with the variable designs. Each type of boreholes comes with its own costs. The costs increase from design 1 to 5.

Alternatively, the client can decide to provide one or more of the various sizes of casings and screens.

The drilling contract and tender documents should be well prepared by an experienced hydrogeologist preferably the one who was in charge of the siting and as such is well conversant with the local groundwater environment. It is clear that the design of a borehole depends on quite a number of factors and it is difficult to recommend a standard design. Therefore, it is important to have a senior hydrogeologist with more than 10 years' experience involved in the drilling supervision; preferably permanently in the field but at least in tandem with a hydrogeologist with 5 years' experience in the field. The costs incurred now for the experience will pay itself back in better designed boreholes that will have lower operational costs during their whole lifespan.

Test pumping

Pumping tests for Type C systems should consist of a standard step-drawdown test, with 4-6 steps of 96-90 minutes each until the water level drops sharply, followed by a constant discharge test for a period of 72 hours.

It is very important that the tests are analyzed by an experienced hydrogeologist. The results of the tests are used for the pumping scenario's (which borehole can pump how much water for how many hours), the pump specifications and the pump settings. Too often the results are wrongly interpreted, and the wrong pumps are acquired and installed. The procurement of the wrong pump may also lead to unnecessary costs during operation.

Supervision

For Type C systems, it is critical that drilling and test pumping are permanently supervised by an independent supervisor who can guide the drilling contractor in constructing the borehole in accordance with the specifications and procedures specified in the contract. BoQ-based contracts require full-time supervision. The supervisor must certify the contractor's payable quantities.

Drilling supervision of production wells and pump boreholes can be performed by a hydrogeologist with at least 2 years of drilling experience and a technician (test pumping).

Water Supply System

For new water supply systems, the groundwater consultants usually work under the overall water supply consultant. This consultant will design the system and will consult with the groundwater consultant on the specifications of the groundwater related components of the project.

For an existing Type C system, the client must identify the locations of existing tanks / treatment plants that can receive additional water. Although the location of existing infrastructure is frequently known by those initiating projects, WASAC also maintains a database of all existing infrastructure in the country.

For a new Type C system, the reservoir tank's planned location must be known. The locations of existing / new reservoirs / treatment plants are the determinants of where the water is required.

There are no large-scale systems yet in Rwanda apart from the PPP run wellfield system in Bugesera south of Kigali operated by WASAC. For new systems and extension of systems in the Basement rock areas it will be typically WASAC to manage the Type C production well systems. The Type C system borehole should ideally be monitored by reading water levels and flow meters. Before turning back on the pump, the well should be visited monthly, and the water levels measured and logged. In addition, the SWL is measured rather than the dynamic water level (DWL). If there is a permanent pump attendant on site, these daily readings could be taken. A pump attendant will cost approximately USD $200 per month.

If the borehole has enough space between the permanent casing and the rising main, a permanent data logger, estimated to cost US $1,000/unit, could be installed.

Water supply and resources monitoring

The large abstraction volumes from the production wells require close monitoring of the water levels. Huge investments are linked to these boreholes and the sustainability of the boreholes should be well monitored. It is highly unlikely that the boreholes fail at once but lowering groundwater level trends can be easily detected if regular water level monitoring is done. This information combined with known production (abstraction) rates can be sued to design optimum pumping scenarios.

All production wells should be installed with data logger access tubes and flow meters and the operators would be obliged to take the required readings.

The information has to be submitted to RWB and RWB shall monitor the water resources and take appropriate action when necessary.

8. Recommendations

This Roadmap document has given a situation analysis for the groundwater sector in Rwanda. It has described the procedure for the most cost efficient and effective way to develop groundwater in Rwanda using the newly developed groundwater potential map and carious other tools.

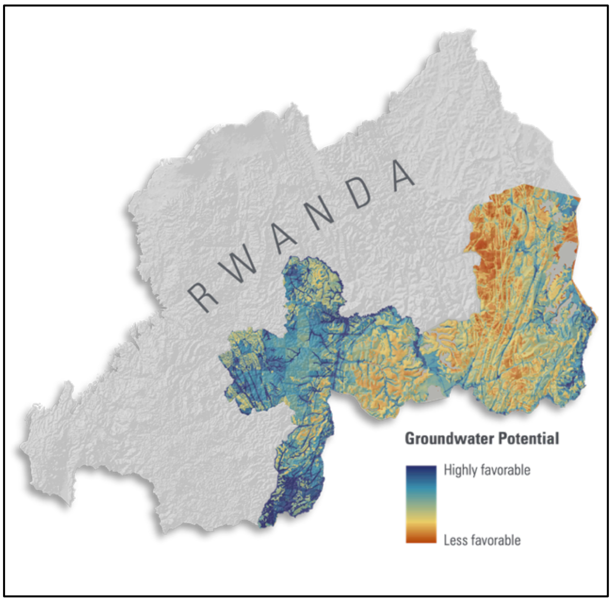
The groundwater sector in Rwanda is still young and underdeveloped but the GoR and donors have acknowledged the opportunities that are there for groundwater development. The UNICEF supported project carried out by Hydro Nova and WE Consult is a good start to professionalize the groundwater sector.

In order to make the sector grow and make efficient use of this momentum some of the activities for further growth should be implemented as soon as possible.

Plan large production wells for scaling up public water supply networks where additional water supply is needed

WASAC, as the agency in charge of managing Rwanda's water supply piped systems, can plan for new production wells to increase water supply for existing and new supply piped systems. WASAC is able to lobby for funds from donors or use own funds to execute pilot projects focused on getting additional water from boreholes for systems that have a shortage of water. WASAC after identifying and prioritizing possible systems (reservoirs) should consult with Hydro Nova / WE Consult on the approach to follow to realize the extensions. With the aid of the project exploration experts and the GWP map, the approach would begin with a review of the map of TAs to determine their proximity to existing networks, particularly in the case of city or secondary town systems. Projects for existing water supply piped systems located in or near a TA can be prioritized. Exploration at the feasibility level should be carried out in those Target Areas to determine the viability of developing new wells. New systems can be budgeted and designed, including designs for additional infrastructure and connectivity. Sites of large production wells will require a detailed field investigation and siting works focused in the selected TAs. The project budget and designs should be reassessed before proceeding with drilling, testing, and supervision. WASAC can use the same approach to build a new public water supply piped system in an unserved area.

Figure 11. GWP map at national scale



Expand the Groundwater Potential Map to cover all of Rwanda

The GWP map for southeastern Rwanda produced by the Project is a useful tool for water planners to prospect sites and planning new groundwater-based water supply projects, including small scale handpump boreholes, small-medium solar pump systems and larger production wells. The map gives guidance on what level of success can be expected from pursuing groundwater development in a specific location, and points planners of water supply projects in the right direction to plan investigations and drilling.

The current GWP map covers 8 districts in the Southern and Eastern Provinces, about 30% of Rwanda3. Expanding the GWP map to cover the national scale could provide a useful national tool in improving planning and success of groundwater development for all of Rwanda. The remaining areas of Rwanda to be mapped include Kigali, Northern and Western Provinces, as well as the remaining portions of Eastern and Southern Provinces.

Expand investigation of alluvial aquifers, a resource with great development potential.

The shallow alluvial aquifers situated predominantly in the valleys along rivers in Rwanda are proven to be highly productive and could hold the key to developing additional sustainable water supply. The boreholes are shallow, the yields are high and many can be drilled close to each other to form a wellfield. For example, the area south of Kigali has been developed by the Government as a large capacity wellfield for municipal water supply. However, other productive alluvial aquifers throughout Rwanda could also hold good potential, but still need to be confirmed with geophysical surveys and test drilling.

In some areas where coarse grained granites have weathered, some sandy deposits may also form reasonable to good aquifers. Indications for these aquifers were found by the Consultants during the UNICEF supported project, but they could not be subjected to intensive investigations.

[3] District areas in km2: Kamonyi (655.4 km^2), Ruhango (626.5 km^2), Nyanza (672.3 km^2), Gisagara (679.6 km^2), Bugesera (1,288 km^2), Ngoma (874.3 km^2), Kirehe (1,176 km^2), Kayonza (1,937 km^2), a combined area of 7,909 km2 (30% of Rwanda).

Strengthen compliance and professionalism in the professional drilling and consulting sector

LICENSING PROGRAMME

A programme of licensing for professional drilling contractors and consultants in Rwanda could help improve quality standards of services related to the borehole drilling and construction services. More specifically, these facets of licensing programme are recommended:

a) **Drilling contractors license**: drilling companies require a license to operate in Rwanda, issued by the Rwanda Water and Forestry Authority (RWFA). The issuance and renewal of the license are subject to the compliance of the contractor. The performance will be linked to the procedures set out in standard procedures. This license is normally issued by Rwanda Development Board (RDB).

b) **Groundwater consultants license**: a licensing system for groundwater consultants could assist the RWFA to regulate the drilling sector. Groundwater consultants, including hydrogeologists, geologists, and geophysicists, need to be trained, utilized, and be involved in groundwater development projects, from the designing of contract documents to the certifying of final products (water supplies). The professionals should ensure that borehole siting projects are carried out according to standard procedure and that contractors follow standard procedures during drilling. Licensing the consultants will enable RWFA to know which professionals are operating in the country and their performance.

c) **Groundwater abstraction permit**: A system of abstraction permitting needs to be developed to ensure that water resources are used in a sustainable way. Abstraction permits shall be required for all boreholes and wells intending to produce water for supply (production boreholes or wells). However, abstraction impact monitoring boreholes should be a condition to give permit for above a certain threshold abstraction volume (e.g., larger than 50 m^3/day) and shall be linked to self-regulatory requirements (collection and submission of production and water level data).

d) **Drilling permit**: The licensing permit system could also have a borehole drilling permit component for production boreholes, ie. boreholes that are to be equipped with submersible pumps. The permits need to be requested before drilling starts. Drillers should not be permitted to commence drilling without such a permit. This permitting method would enable RWFA to monitor any production and over abstraction.

STANDARDIZED TENDER DOCUMENTS FOR GROUNDWATER PROJECTS

Further to licensing, standards for groundwater project services could be developed to improve professionalism and ultimately the overall success of groundwater projects. Standard tender documents for borehole siting, drilling, and drilling supervision could be drawn and enforced for compliance. Related to the above, RWB's role in developing and enforcing procedures could be more widely communicated to the sector to improve uptake and awareness.

CAPACITY BUILDING

Expand training of private drilling and consultants working in Rwanda on optimal procedures for siting and planning boreholes and supervising projects.

Expand training of government staff / consultants / private drilling companies in the use of standardized procedures for data collection and tendering documents.

Standardize procedures for groundwater data compliance

Standard data collection procedures are needed to monitor quality in the sector, but also for monitoring the status of groundwater resources in Rwanda. This should include the development of borehole data collection procedures and tools, such as design sheets, databases, data processing and storage.

Further, a comprehensive system of borehole logging and numbering should be established and implemented by the RWB. Such a system is not only required to facilitate the various licensing / permits system, but also required for the implementation of a modern national groundwater database.

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Annex 1 - Background and summary UNICEF supported project

Summary

With the southeastern region of Rwanda facing persistent drought and water, the Rwanda government has sought to expand water supplies with groundwater to make it easier for people to get clean water. But many boreholes have failed or producing too little water, and planners haven't had enough good information about how locate and design successful wells. From May 2022 to July 2023, the Rwanda Water Resources Board, with support by UNICEF, commissioned a consultant team comprised of Hydro Nova and WE Consult to study and map the groundwater in eight districts in the Eastern Province and Amayaga Region and find out more about how and where to set up new water supplies in the region.

The assignment aimed to contribute to sustainable management of groundwater resources in Rwanda, particularly in the Eastern Province and Amayaga Region of Rwanda.

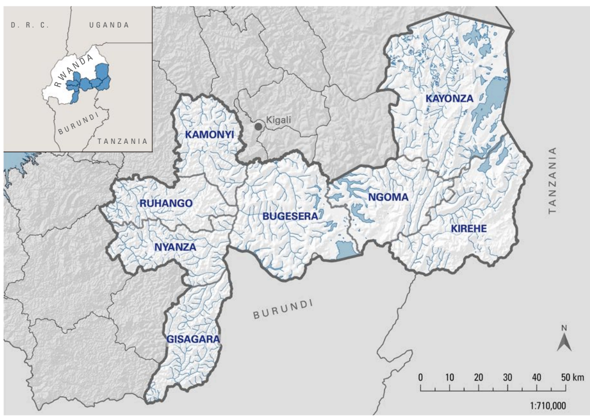
The study had three specific objectives:

1. To achieve an assessment and mapping of groundwater potential and vulnerability in the Eastern Province and Amayaga Region of the Southern Province;
2. To create an inventory of aquifers by location; geometric, lithological and stratigraphic characteristics;
3. To build the capacity of Rwanda Water Resources Board and key stakeholders on the use of geospatial approach to map groundwater.

This project used a selection of target areas (TAs), which was done with multicriteria analysis that included GWP map plus other socio-economic and political factors. This is not necessarily a standard step of the technical approach of developing groundwater but does provide a starting point for prioritization of additional boreholes and water supply projects.

One of the main outputs of the project is in line with the expectation of the client, that is: to locate the spots in the districts where we can get most water out of the ground. This requirement is fulfilled with the map with 126 target areas and the list with sites ranked based on their groundwater potential. Initially, 10 TAs were pre-selected, and out of these, 8 TAs (initially 5, then an additional 3) were selected for detailed investigations and siting works. This selection was done without knowledge of the water demand in those areas and without a plan for the drilling programme and future water supply infrastructure to connect the new boreholes to existing systems or make new systems. These missing tasks were the reason why the Roadmap was prepared—to combine a comprehensive approach for planning that can be followed step-by-step from deciding the size and budget, to determining the target community, through to developing the full water system and to long-term operation and maintenance.

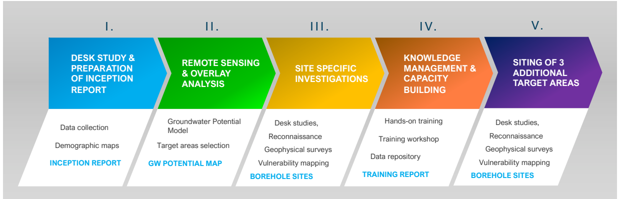
Figure 12. Project area map



Method

The overall approach to regional groundwater development of the Project is summarized in the figure below. The project started with a detailed **desk study** of the available information and a development of a conceptual hydrogeological model. A regional **groundwater potential map** (GWP) was developed for southeastern Rwanda by combining remote sensing techniques with hydrogeological, meteorological and geophysical data. The GWP map for southeastern Rwanda predicts the prospective areas where additional field siting can be focused and helps site new water supply systems more effectively. The exploration team used the GWP map and expert knowledge to identify Target Areas across the region where conditions are considered favorable for developing groundwater. A limited selection of the most favorable target areas was made for the purpose of the Project, where the team conducted **site specific field surveys** in order to select a number of potential sites for drilling new water supply boreholes. The data and maps developed by the Project were compiled into a **knowledge management** tool for use by stakeholders, and experts from RWB and other stakeholders were trained on groundwater exploration and planning (**capacity building**).

Figure 13. Project methodology



Key Outputs

The main outputs of the Project that relate to a groundwater planning approach are summarized in the table below. Details of each output are given in the following section.

Table 12. Project main outputs for groundwater development

Output	Description
Groundwater Potential Map of Southeastern Rwanda (2022)	A regional map of southeastern Rwanda that predicts degrees of groundwater potential ("favorability"), published at 30-m digital resolution (1:100,000 scale). The GWP map determines optimal zones for field surveying, targeting locations for new water supply sources, designing boreholes and wells and designing monitoring programmes to protect groundwater resources.
Vulnerability Maps (2022)	Groundwater suitability maps for five target areas have been developed, which gives information on the stress of groundwater resources in the area and can be used to guide UNICEF and other agencies in planning effective WASH projects.
Target Areas (x 126)	A set of 126 specific areas across the region have been identified and analyzed where groundwater potential is considered to be favorable for additional detailed field investigation and new boreholes to be sited. These are areas where agencies and other stakeholders can invest in focused investigations and prospect for more successful boreholes.
Detailed field investigation and siting works	8 Target Areas surveyed and studied by detailed field investigation
Sites for new groundwater-based water supply systems	A set of twelve (12) top priority sites have been staked and made ready for drilling and installation of new boreholes. These are immediately actionable for UNICEF and/or other agencies to plan. An additional 60 potential sites with less confidence were staked and identified, where success for drilling is less confident, final yields could be less sustainable, and would likely require additional investigation to decide on drilling or not.
Roadmap for scaling up sustainable groundwater development	This document.

GROUNDWATER POTENTIAL MAP

A regional groundwater potential map was developed for the southeastern part of Rwanda. Mapping groundwater potential requires the ability to combine a series of indirect indicators into a single measurement of suitability—hydrogeologic and recharge favorability. The method of analysis used to map groundwater potential in southeastern Rwanda relied on a model that predicts groundwater potential developed from processing of remotely sensed and ancillary datasets (Hardcastle and Walther, 2022).

The groundwater potential map, therefore, is defined as a spatially distributed estimate of the physical capacity of the terrain to yield enough groundwater for a given use. Over a regional scale, like southeastern Rwanda, the primary purpose of the groundwater potential map is to make exploration as efficient as possible. As a tool for pre-feasibility analysis of options for developing water supply, the groundwater potential map is a first-level approximation of conditions favorable for a water supply system to be built and operated. It tells the hydrogeologist where to go to focus field exploration. Within the process of regional groundwater exploration, the groundwater potential map is an expert best estimate of optimal zones for groundwater development.

The groundwater potential map was made using remote sensing data (elevation, rainfall), geological maps, soil maps and borehole and spring data. The data was organized in various thematic layers and overlain using various weights which resulted in a recharge favorability map and a hydrogeological favorability map.

The Figure 15 shows the layers that were produced and combined. The overlay of the latter two maps resulted in the groundwater potential map (Figure 16). The combined Groundwater Potential Map (Fig. 17) reveals the nature and spatial distribution of both shallow and deep aquifers, subsurface conditions and recharge conditions that impact groundwater resource availability, quality and sustainability. The map can be used for: Groundwater management, groundwater resource development, aquifer science. Variations of the map have been produced to assist in these different applications (Figure 18).

The map can help in identifying the amount of water that can be obtained from boreholes and success rates for drilling programmes (for handpump, solar pumped and production wells). The map is an indicative tool and is only useful if it is used hand in hand with detailed hydrogeological and geophysical investigations.

Figure 14 Compilation or regional groundwater potential map

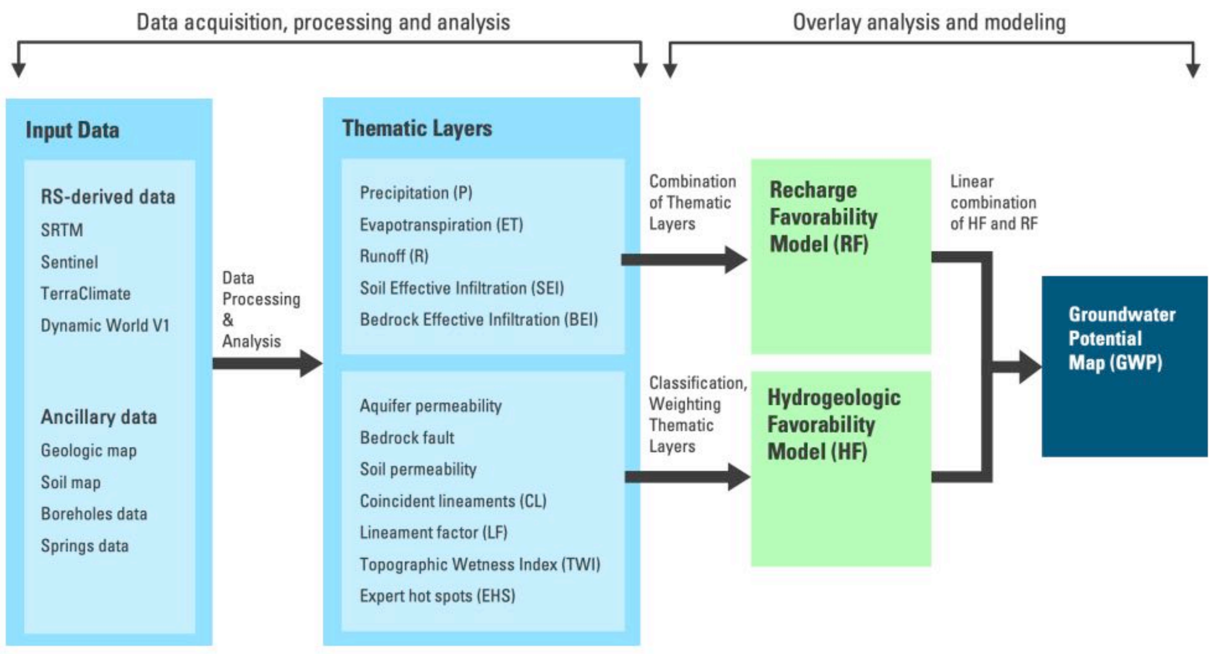


Figure 15. Layers of the HF and RF sub-models

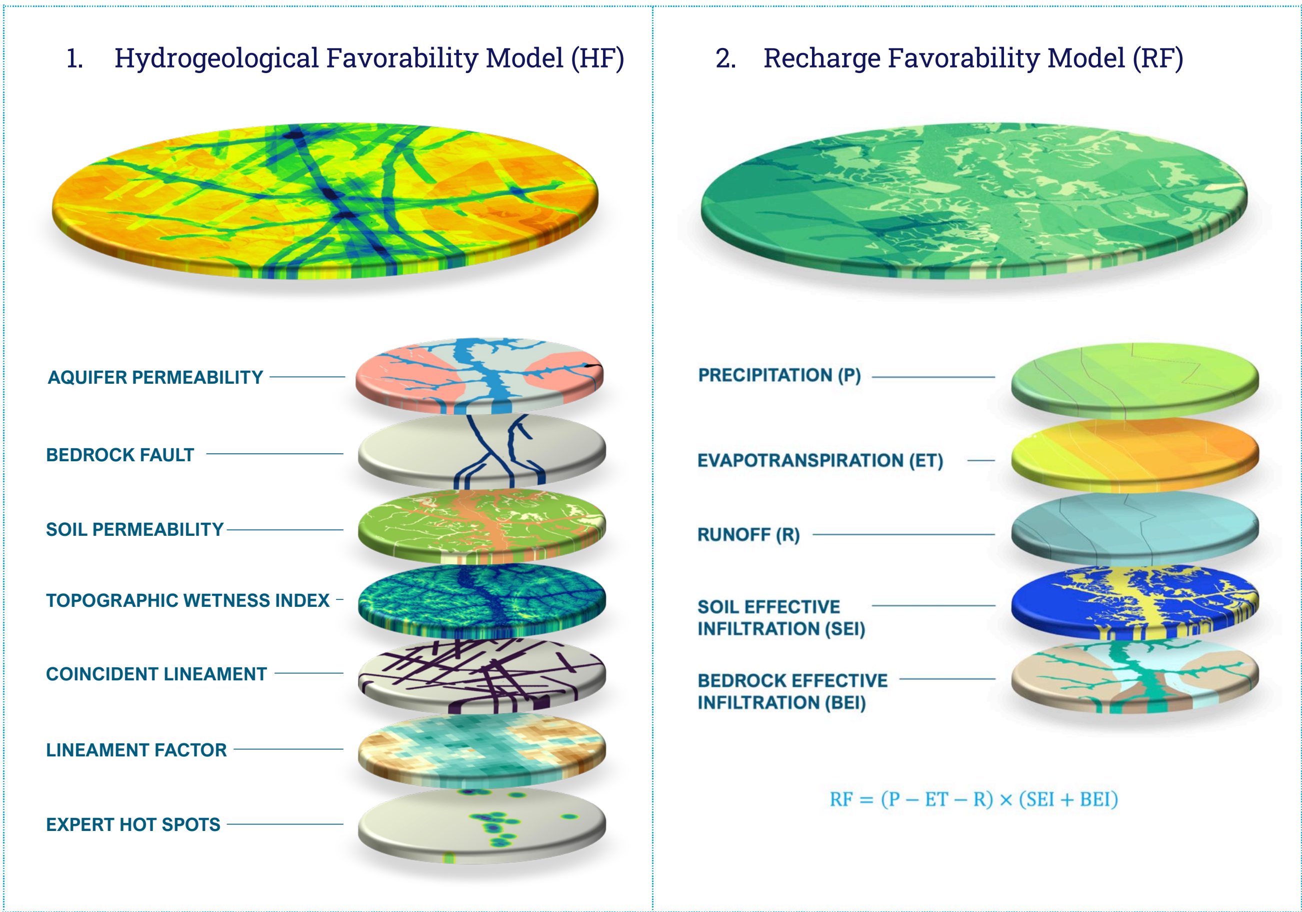


Figure 16. Combination of layers to generate the GWP model

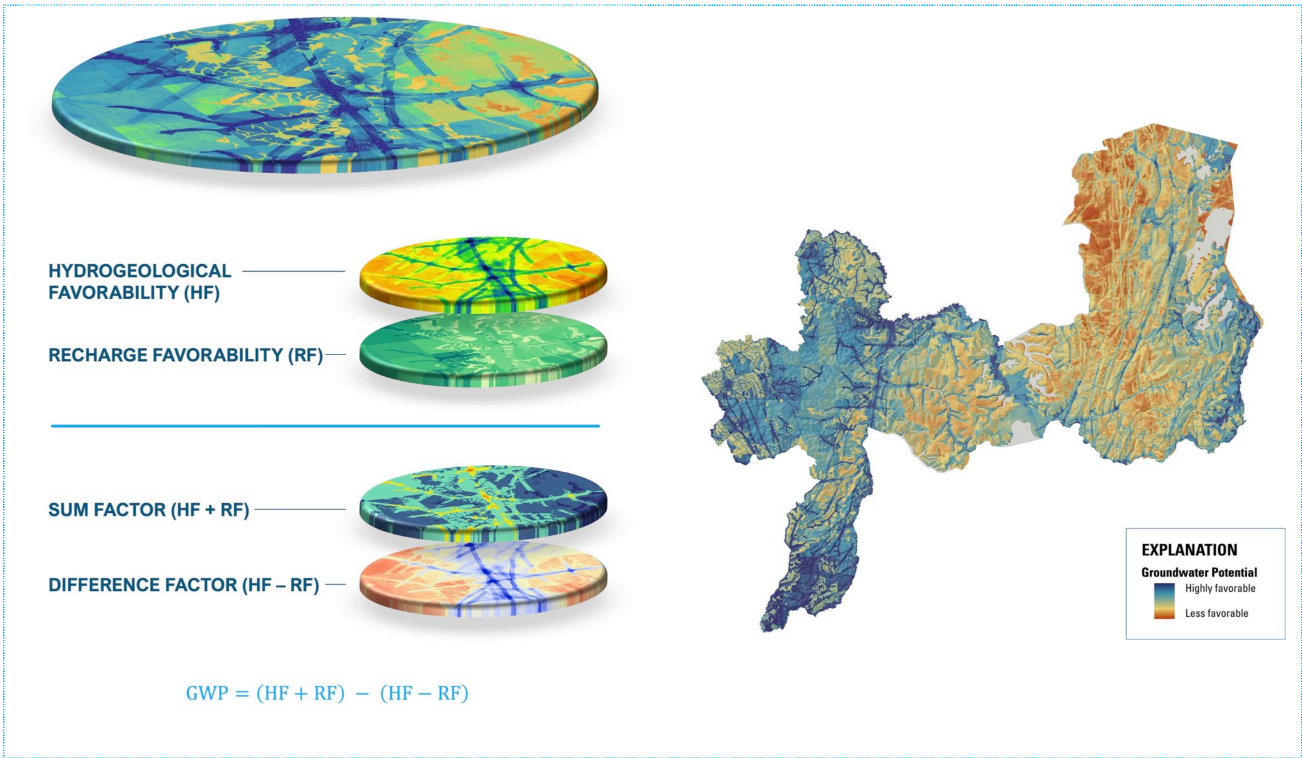
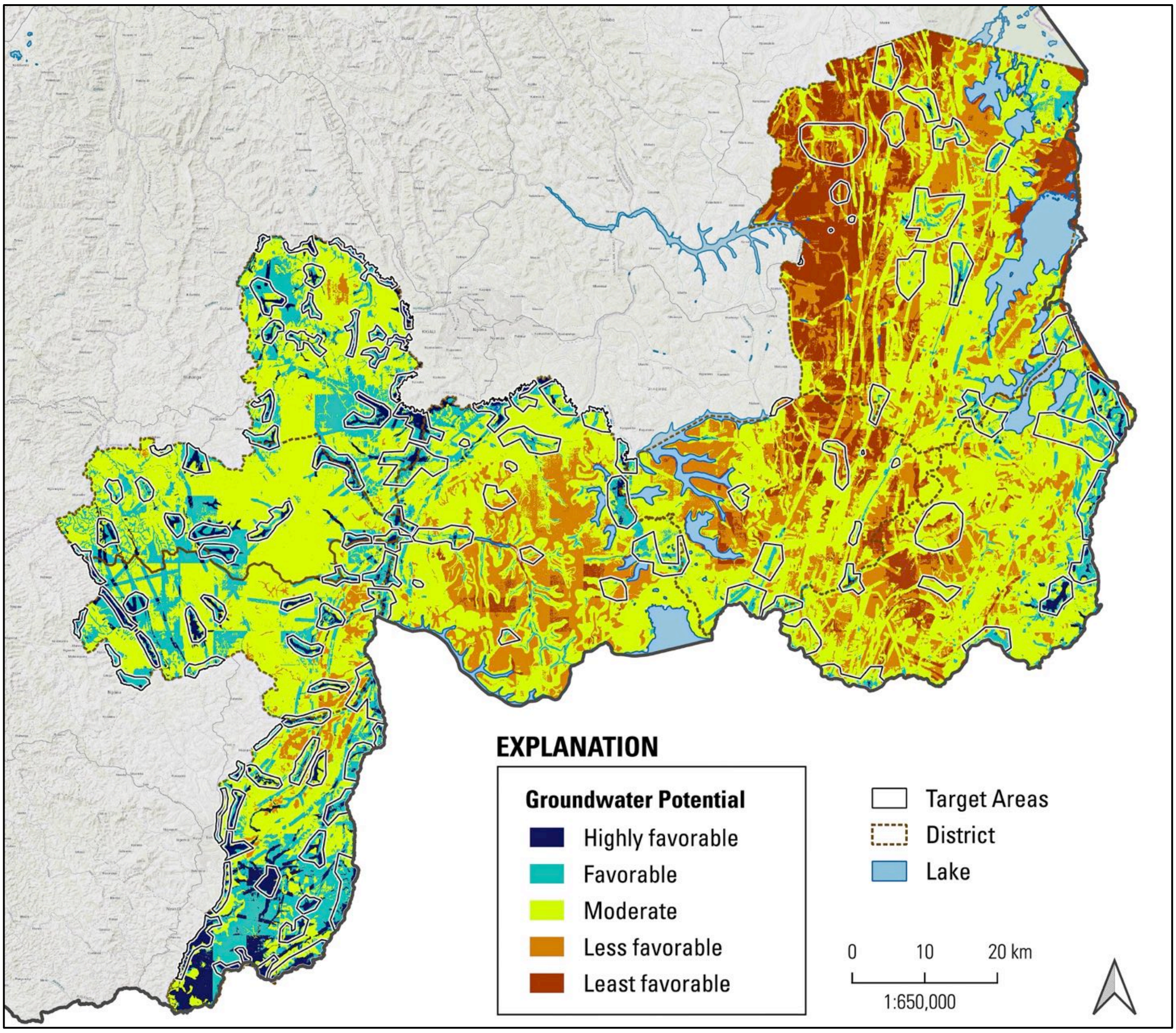


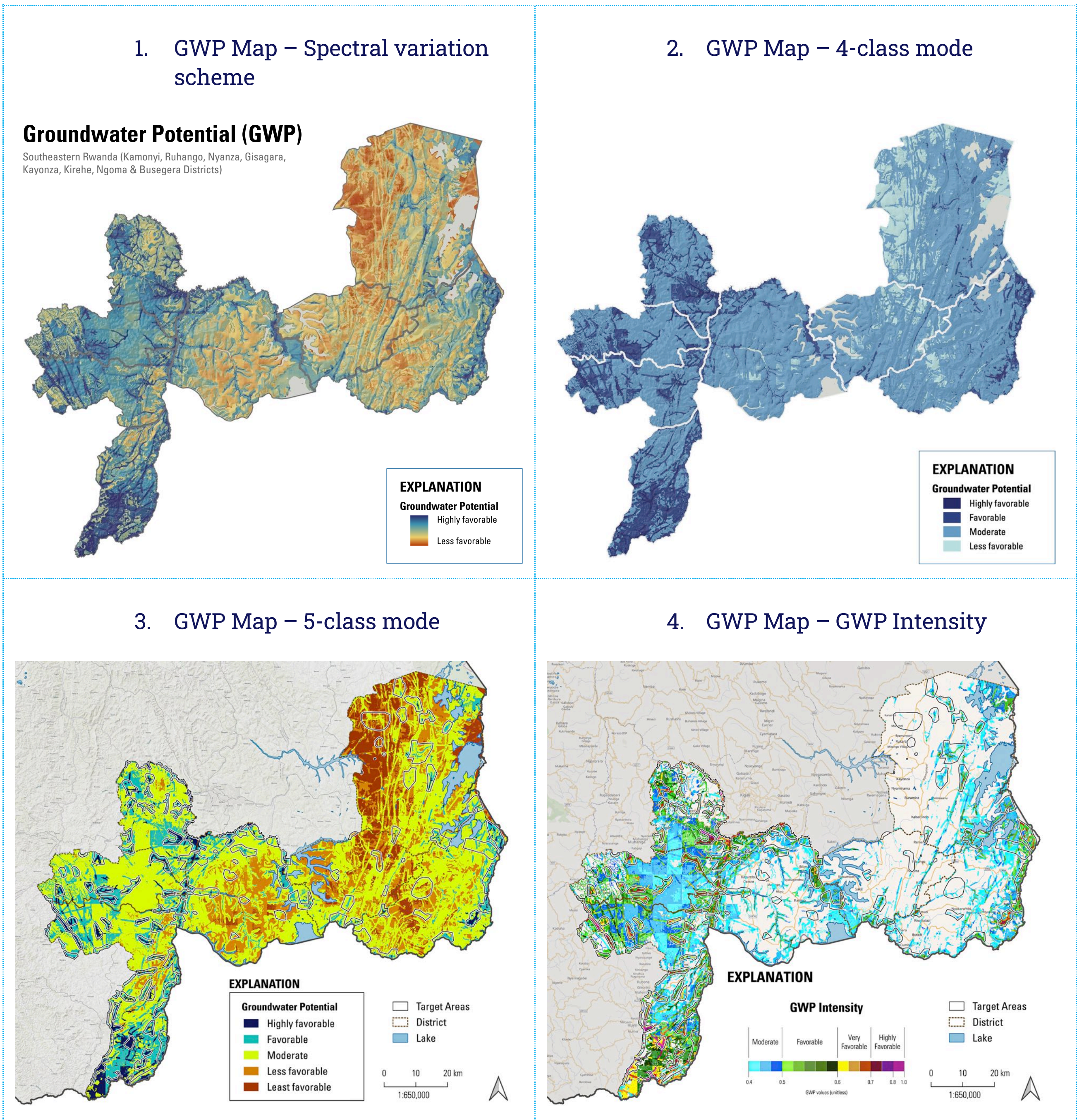
Figure 17. Groundwater potential map of southeastern Rwanda (UNICEF, 2022)



Variations of the GWP map

Guidance on how to use the GWP map for planning groundwater development is covered in the roadmap document.

Figure 18. Variations of the GWP Map: (1) Spectral variation, (2) 4-class mode, (3) 5-class mode, (4) GWP Intensity



VULNERABILITY MAPS

A method for calculating groundwater suitability and presenting vulnerability as a groundwater suitability map has been developed for Rwanda. Under the Project, maps for five priority Target Areas were demonstrated (Fig. 19). The maps aim to predict groundwater suitability that will guide stakeholders in planning effective WASH projects. The goals are to improve project impact and reduce population vulnerability where the use of groundwater resources is concerned. The method of analysis used to map groundwater suitability in southeastern Rwanda relied on an indexed model that predicts groundwater suitability developed from processing of publicly available remotely sensed and ancillary datasets. The composite vulnerability model was generated through weighted and mathematical processes to discern the conditions for groundwater suitability in the Rwanda setting, including higher yielding zones (GWP), water quality, adjacent water infrastructure, poverty and climate change.

TARGET AREAS

A total of 126 areas of approximately 10 km^2 with favorable groundwater potential and minimal undesirable conditions for drilling new boreholes, "Target Areas" (TA), have been identified as candidates across the project region (Fig. 20-A). The method of analysis used to determine the location of TAs relied on the use of the regional GWP map and expert analysis of favorable conditions. Ranking and evaluating the most suitable TAs for this project relied on an overlay analysis of GWP and socio-economic parameters.

This initial set of 126 Target Areas is a significant milestone for exploration in southeastern Rwanda, showing the first-level analysis of where groundwater development efforts can be pursued across the region with higher probability of success and lower risk. TAs enable resources and investment to be focused where the conditions for groundwater development are best and risk for project failure are most mitigated. Without identifying TAs, efforts to study and investigate prospects for installing new boreholes, and certainly drilling, would carry significant risk of failure and unsatisfactory results.

The map of 126 Target Areas can be used as the starting point for stakeholders to plan future investigations and drilling projects in Bugesera, Ngoma, Kirehe, Kayonza, Kamonyi, Ruhango, Nyanza, Gisagara Districts.[4]

The UNICEF project called for the selection of eight (8) Target Areas in which to prospect for potential drilling sites that would be subsequently planned for drilling. The 126 candidate Target Areas were ranked and analyzed based on a set of socio-economic criteria, and through a consultative process with stakeholders, a shortlist of ten (10) Target Areas were agreed upon for the Project to concentrate a limited amount of field siting work (Fig. 20-B). Out of this shortlist, eight were contracted for siting works during the project. However, this process of selecting Target Areas carried out for this Project did not take into account the local demand or the feasibility of connecting water supply infrastructure, which are important factors for designing and planning new supply systems. A practical example of this consideration is illustrated in Box 7.

Going forward, the 126 Target Areas will be subjected to detailed investigations in case there is a town or water supply system that requires a lot of water. But what should be done if water needs to be developed for a community outside of these Target Areas? The high potential target areas maybe too remote from the demand area, making the cost for the water supply system too high. The recommended approaches for groundwater development for handpump borehole programmes, small water supply systems and production well (fields) are given in this report.

[4] The selection of the target areas for the current project was done without a detailed planning based on accurate demand requirements, such as where exactly is water needed and how much water is needed at specific locations. The selection was based on district shortages rather than shortages at the system or village level, or infrastructure already available.

Figure 19. Vulnerability maps (GSI)

A – Location of vulnerability mapping of five Target Areas

B – Vulnerability map of Target Area 33

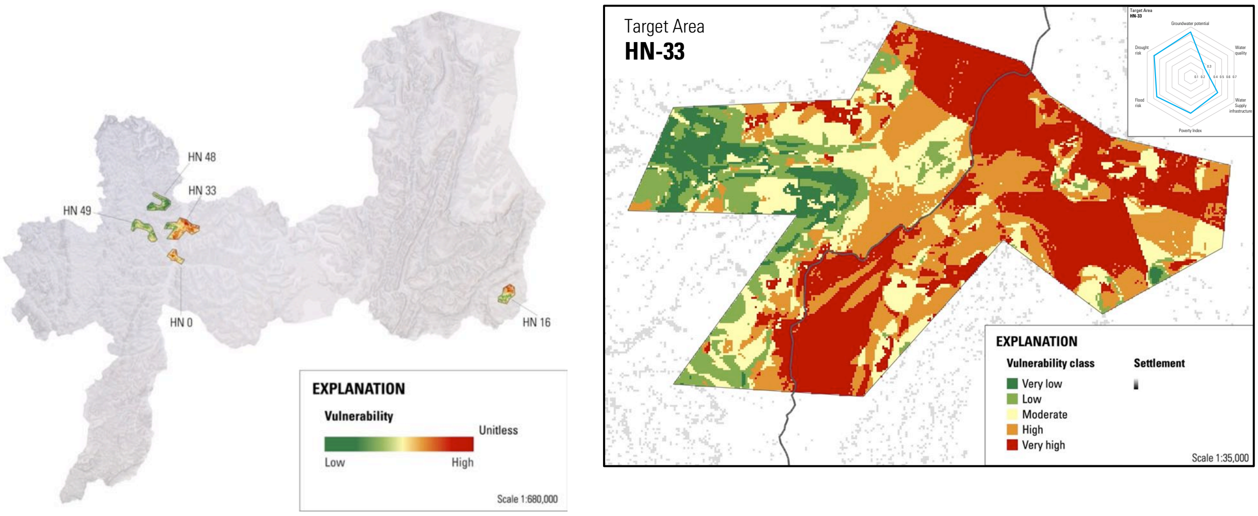
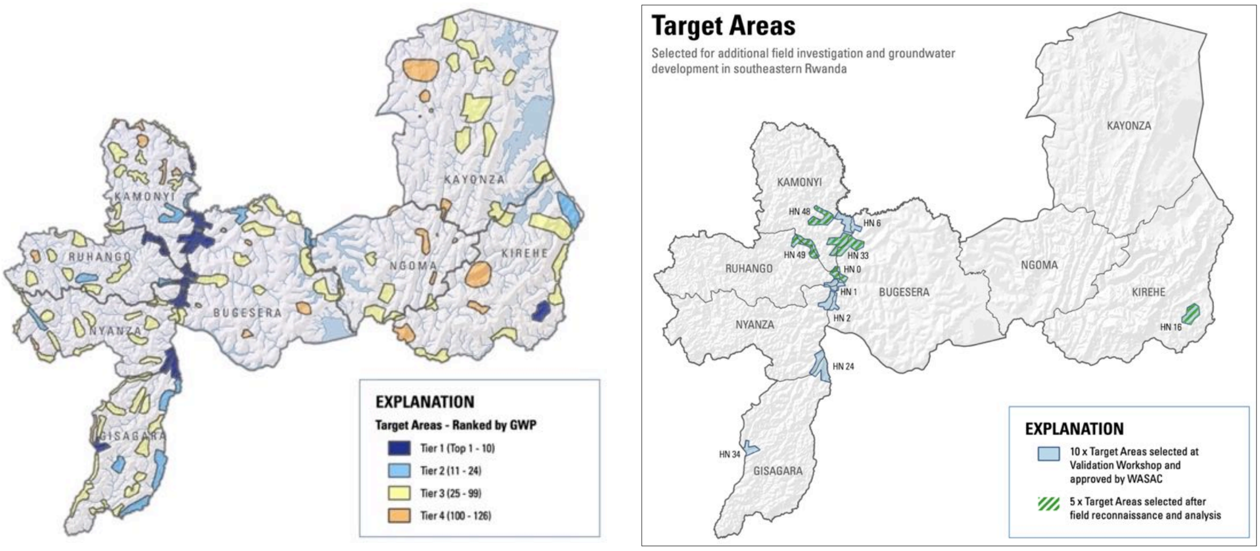


Figure 20. Target Areas identified, ranked by GWP score (A) and selected for project exploration (B)

A – All Target Areas identified in southeastern Rwanda

B – Target Areas selected for additional siting work under the Project



Box 7. Case study: Kirehe Town groundwater supply planning

WASAC stated during the current Project that it intended to expand water supply for Kirehe town in Kirehe District, citing an urgent need for additional water supplies there. The Kirehe town water supply system has a total shortage of 4,000 m^3/day, which would necessitate the installation of about ten (10) new boreholes each with a minimum output of 20 m^3/hr. Groundwater alone is unlikely to be able to fill this demand gap. An addendum to the project called for a four-day survey in Kirehe Town. The results of four days of surveying will yield 2-4 drill sites, one of which may be high yielding (yielding 5-10 m^3/hr or more), but this does not justify the investment required to pump the water uphill to Kirehe town. It would be more cost effective to design a groundwater development program for a system of 30-50 m^3/hr, which would necessitate additional siting and drilling. The additional work proposed for Kirehe must now be viewed as a first step (pilot) of a larger plan.

DETAILED FIELD INVESTIGATION AND SITING WORKS

The scope of the project was to identify drilling locations for production wells in 5 target areas (later extended to 8 areas). The target areas with high groundwater potential were ranked using socio-economic criteria as well. The final 10 target areas were selected during a workshop with the main stakeholders in the groundwater sector (WASAC, RWB, UNICEF, NGOs). The consultant selected 5 (later 3 were added) out of the 10 areas for further geophysical investigations based on a field reconnaissance survey.

Detailed field investigation and siting works were conducted in eight (8) selected Target Areas in the Project area. The sub-phases of this component included a desk study, reconnaissance visit, geophysical surveying and analysis and reporting. The main activities and outputs of this component are summarized in Table 13.

Project budget permitted only four (4) days of siting work per Target Area, which is less than ideal and limited the number of potential sites that could be identified and assessed. Had the project been able to finance more field survey work, the Consultant would have been able to carry out more measurements and achieve a much better understanding of groundwater potential in each of the selected Target Areas, and thus, a higher number of sites with good geophysical responses and a higher chance of getting higher yielding boreholes. Investment in water resources assessments and drilling programs are often under-budgeted, while the bulk of investment is typically reserved for infrastructure and construction.

SITES FOR NEW GROUNDWATER-BASED WATER SUPPLY SYSTEMS

The original scope of the Project requested 10 boreholes to be sited for drilling. Under the Project, a total of 72 potential drilling sites have been identified in eight Target Areas. Among these, a set of twelve (12) top priority sites have been staked and made ready for drilling and installation of new boreholes (Table 14). These sites are immediately actionable for UNICEF and/or other agencies to plan (Fig. 21). An additional 60 potential sites with less confidence were staked and identified, where success for drilling is less confident, final yields could be less sustainable, and would likely require additional investigation to decide on drilling or not.

The approach for the drilling program depends on which sites boreholes UNICEF and other stakeholders will select to be drilled. We offer three planning scenarios for the Client to consider:

- **Scenario 1**: Drill two (2) priority sites across all 8 Target Areas with fewer sites in each area
- **Scenario 2**: Drill four (4) priority sites in the three (3) best Target Areas
- **Scenario 3**: Drill ten (10) or more sites concentrated in one (1) Target Area.

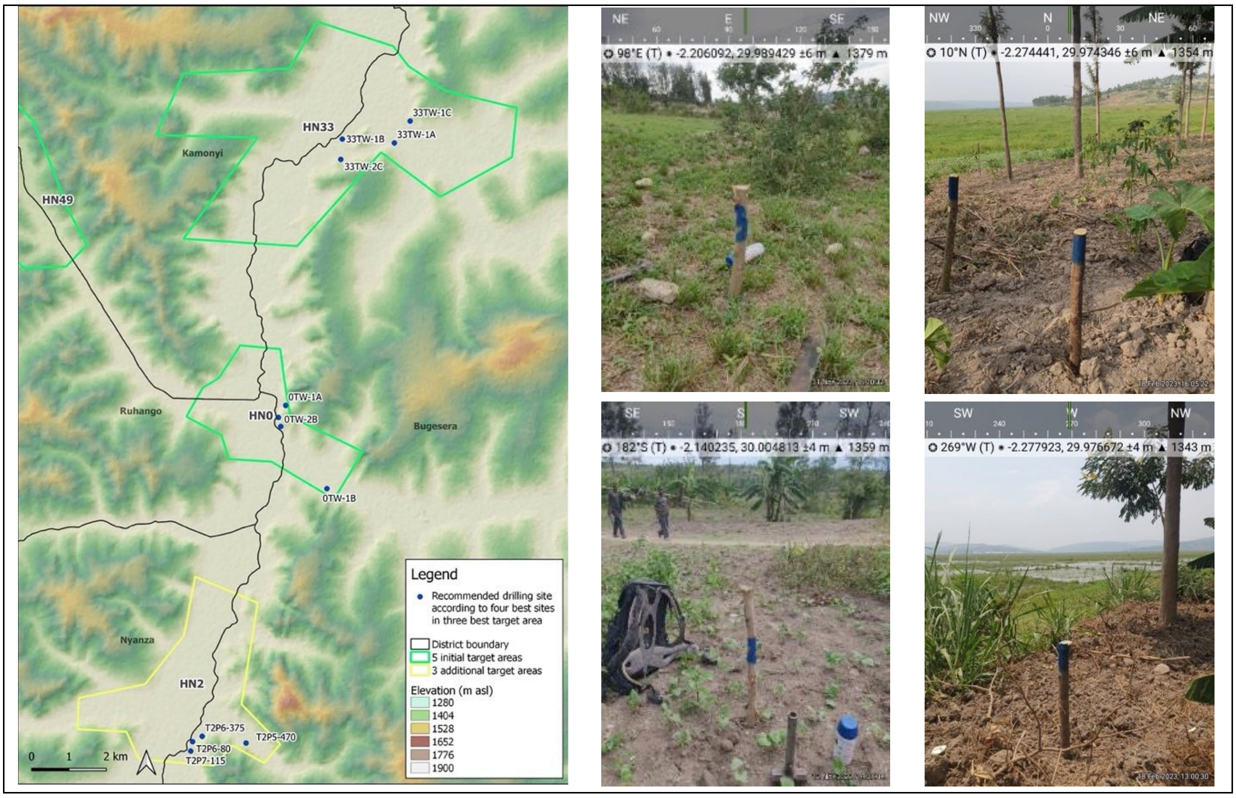
Table 13. Activities and outputs of site-specific investigation in eight 8 Target Areas

Project Phase	Sub-phase	Description of activities	Output
Site specific hydrogeological investigations	(1) Desk study	Assess the local hydrogeological situation in eight (x8) Target Areas	Overview of the hydrogeological situation in the 8 Target Areas
	(2) Reconnaissance visit	Visit to the eight (8) Target Areas to observe GWP conditions and confirm locations for geophysical surveys	Locations for geophysical measurements
	(3) Geophysical surveying	In each of the eight (8) Target Areas, conduct four (4) days of geophysical survey lines (1D, ERT, VES).	Geophysical measurements and data conducted in the 8 Target Areas
	(4) Analysis and reporting	Identified and staked 16 priority potential drilling sites in the 8 Target Areas, based on data collected and analysis (Project called for 10 sites)	12 top priority sites for potential boreholes in 3 Target Areas. Also, a selection of 16 priority sites, two in each of the 8 Target Areas. An additional 60 sites for potential boreholes in 8 Target Areas

Table 14. Location of 12 sites: four of the highest priority potential sites in three most favorable Target Areas

No.	Target Area ID	Location ID	Profile No.	Length, m	X-coord.	Y-coord.
1	TA 0	0TW-2D	T0P5b	350	29.98918	-2.20677
2	TA 0	0TW-2B	T0P5b	100	29.98972	-2.20896
3	TA 0	0TW-1A	T0P7	200	29.99092	-2.20387
4	TA 0	0TW-1B	T0P9	320	30.00080	-2.22404
5	TA 33	33TW-2C	T33P10	720	30.00429	-2.14432
6	TA 33	33TW-1B	T33P3b	70	30.00466	-2.13938
7	TA 33	33TW-1A	T33P8	425	30.01719	-2.14035
8	TA 33	33TW-1C	T33P8	25	30.02098	-2.13506
9	TA 2	T2P5-470	T2P5	470	29.98122	-2.28562
10	TA 2	T2P6-80	T2P6	80	29.96836	-2.28523
11	TA 2	T2P6-375	T2P6	375	29.97068	-2.28395
12	TA 2	T2P7-115	T2P7	115	29.96792	-2.28751

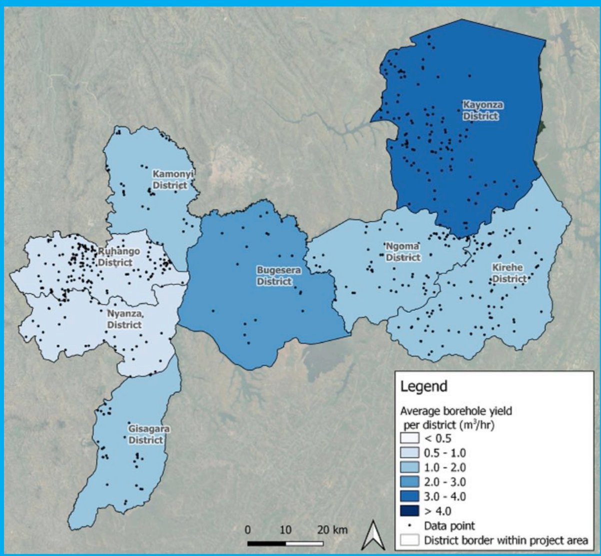
Figure 21. Location map (left) of 12 priority sites, and example images (right) referencing the precise location of 4 potential drilling sites

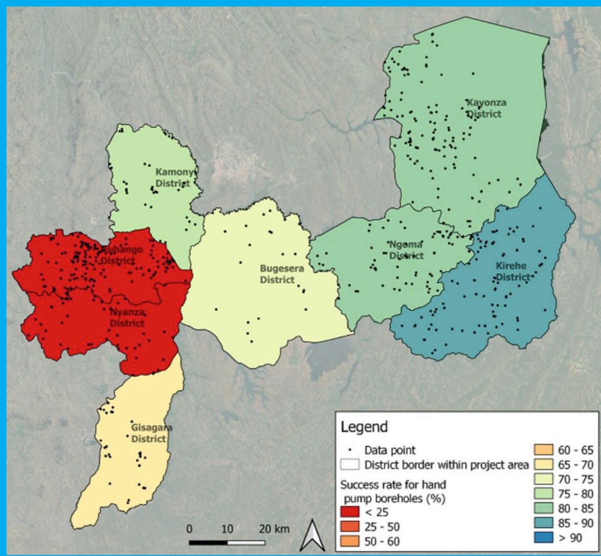


OTHER PLANNING TOOLS

For the areas where more data is available more detailed cost estimates can be made because the borehole data can be used to prepare average yield maps, the success rate maps and probability of exceedance graphs. These tools are described in Box 8 and Box 9 below. It should be noted that the resulting average yields and success rates are based on a data set of boreholes that often have not been properly sited. If one follows the hydrogeological survey guidelines stipulated in Chapters 5-7, one is likely able to get success rates and average yields of borehole drilling programmes in line with the numbers indicated in Table 7.

Box 8: Success rate maps and average yield map

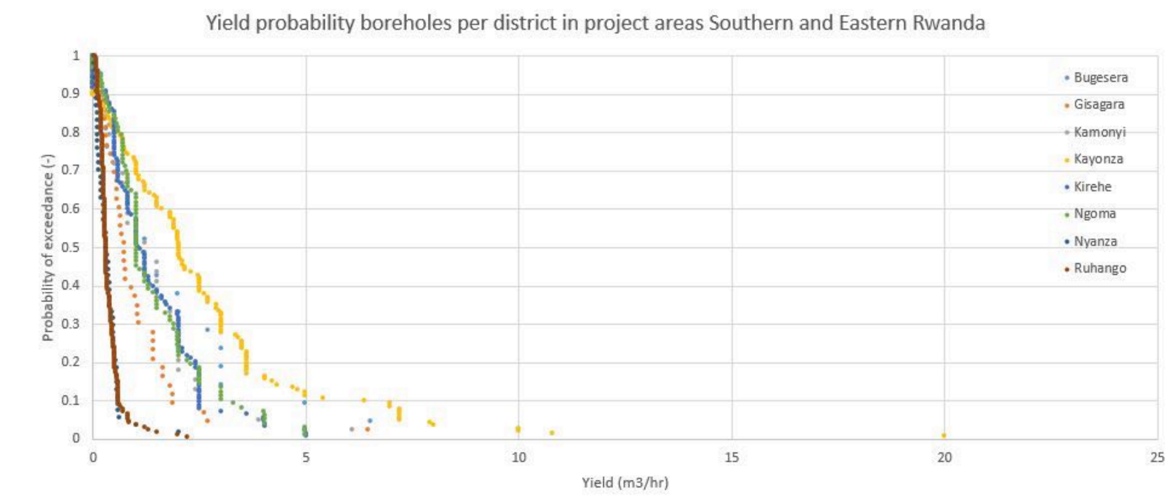


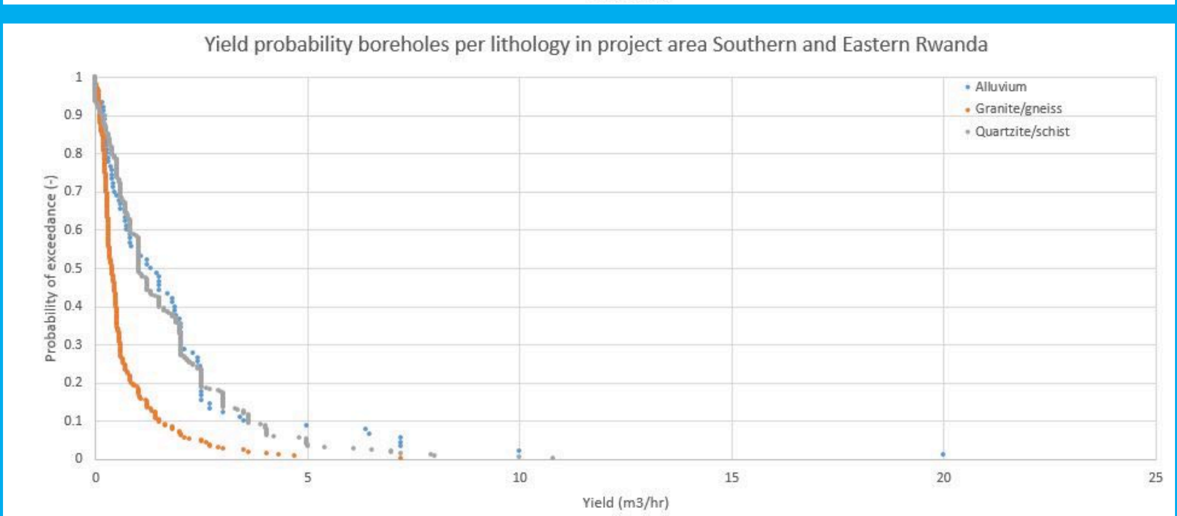


The maps show the success rate for a handpump and the average yield per district. The existing database has been used to calculate the success rates for hand pump boreholes in the 8 districts. A borehole is considered to be successful if it has a capacity of 500 l/hr or more. The success rate for the handpump borehole programs in Nyanza and Kuhango is low and siting methodologies may need to be improved to get higher success rates. If the success rates remain low then it is more economical probably to plan for piped systems. When these programs are designed the budget should include the costs for dry boreholes.

It is a good indication for the groundwater potential for handpump boreholes and small systems and one can see what kind of yields are obtained with no siting or with limited siting activities (usually only VES measurements are used to identify drilling locations for handpump boreholes.

Box 9: Probability of exceedance graphs





The two graphs give the probability of drilling a borehole with a certain yield in the districts (first graph) and in various lithological formations. It should be noted again that the boreholes drilled have not been drilled based on the results of detailed geophysical surveys. In the current project more measurements have been carried out which should also result in higher chances of getting boreholes with high yields.

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