Feasibility Study

Accelerating Inclusive Access to Climate Resilient Clean Water Supply using Small Scale Bundling Model in Siem Reap Province

Project:	Accelerating Inclusive Access to Climate Resilient Clean Water Supply Using Small Scale Bundling Model
Location:	Kantuot and Ta Siem Communes, Svay Leu District, Siem Reap Province

Authors

This publication is developed by Intervention Staffs of Cambodia Australia Partnership for Resilient Economic Development (CAPRED).

Disclaimer

This publication has been funded by the Australian Government through Cambodia Australia Partnership for Resilient Economic Development (CAPRED) in collaboration with the Ministry of Industry, Science, Technology & Innovation (MISTI). The views expressed in this publication are the author's own and are not necessarily the views of the Australian Government. The Australian Government neither endorses the views in this publication or vouches for the accuracy or completeness of the information contained within the publication. The Australian Government, its officers, employees, and agents, accept no liability for any loss, damage or, expense arising out of, or in connection with, any reliance on any omissions or inaccuracies in the material contained in this publication.

This publication is intended to provide general information only and before entering any particular transaction users should: rely on their own research, and care in using the information; check with primary sources; and seek independent advice.

Acknowledgment

This publication extends its deepest gratitude to the Ministry of Industry, Science, Technology & Innovation and the local authorities in the project location. Their invaluable insights, constructive comments, and professional input have significantly enriched our work, enhanced its quality, and ensured its accuracy. The collective wisdom and experience of these esteemed institutions have been indispensable in broadening our perspective and improving the quality of this publication. We are profoundly thankful for their support.

Contents

List of Figures

List of Tables

Abbreviation

CAPEX	Capital Expenditure
CAPRED	Cambodia Australia Partnership for Resilient Economic Development
PIC	Pasteur Institute of Cambodia
PWOs	Private Water Operators
MISTI	Ministry of Industry, Science, Technology & Innovation
MoP	Ministry of Planning

1. Project Overview

1.1 Purpose

This feasibility study aims to conduct the engineering design and financial viability analysis for a piped water infrastructure business to increase climate resilience and social inclusion in 6 villages in two communes of Svay Leu district, Siem Reap province.

This feasibility study will be used as part of the tendering package for a competitive permit approach of the Ministry of Industry, Science, Technology & Innovation (MISTI) to procure and select a competent investor. It will also determine the size of the investment grant to the selected bidder to supply piped treated water which is socially affordable and inclusive for the community and commercially sustainable for the operation.

1.2 Project objectives

The objectives of the project include the following:

- Enhancing climate resilience for 1,621 households (equivalently 6,300 people, of whom 51% are women) and 280 local enterprises in those far, remote villages through having secured access to clean water supply.
- Promoting gender, disability, and social inclusion (GEDSI) outcomes by providing reliable and affordable piped treated water access to the remaining far, remote villages which cannot attract investment on quality water infrastructure.
- Unlocking access to economic opportunities that potentially benefit the local people including women as a result of reliable and affordable piped treated water access.
- Contributing to the Royal Government of Cambodia (RGC)'s sustainable development goal to achieve universal and equitable access to safe and affordable drinking water for all.

1.3 Project Profile

1.3.1 Site Overview

The piped treated water supply project will cover two small scale piped water infrastructures that are in close proximity to each other and can be clustered under a single investment of one bundle.

The distance of all piped water systems in the cluster is close enough to allow less than half a day travel among sites. This is considered essential to allow the sharing of staff to manage various systems.

Looped financial model to determine the return on investment of the bundle and allow cross subsidy among systems will be also used to seek the opportunity to reduce the level of public subsidy in case it is required to make the investment attractive enough for private investment.

This site bundle consists of two small scale piped water supply systems to cover 6 villages in two communes of Svay Leu district, Siem Reap province. These two systems are located within 9 km radius to allow a half-day trip to reach each system from a main location which is supposed to be the main office.

These two systems are located in the Northeast of Siem Reap province. These systems can be accessed for about 361 km from Phnom Penh city via national roads 6 and 66.

Figure 1: Project site location

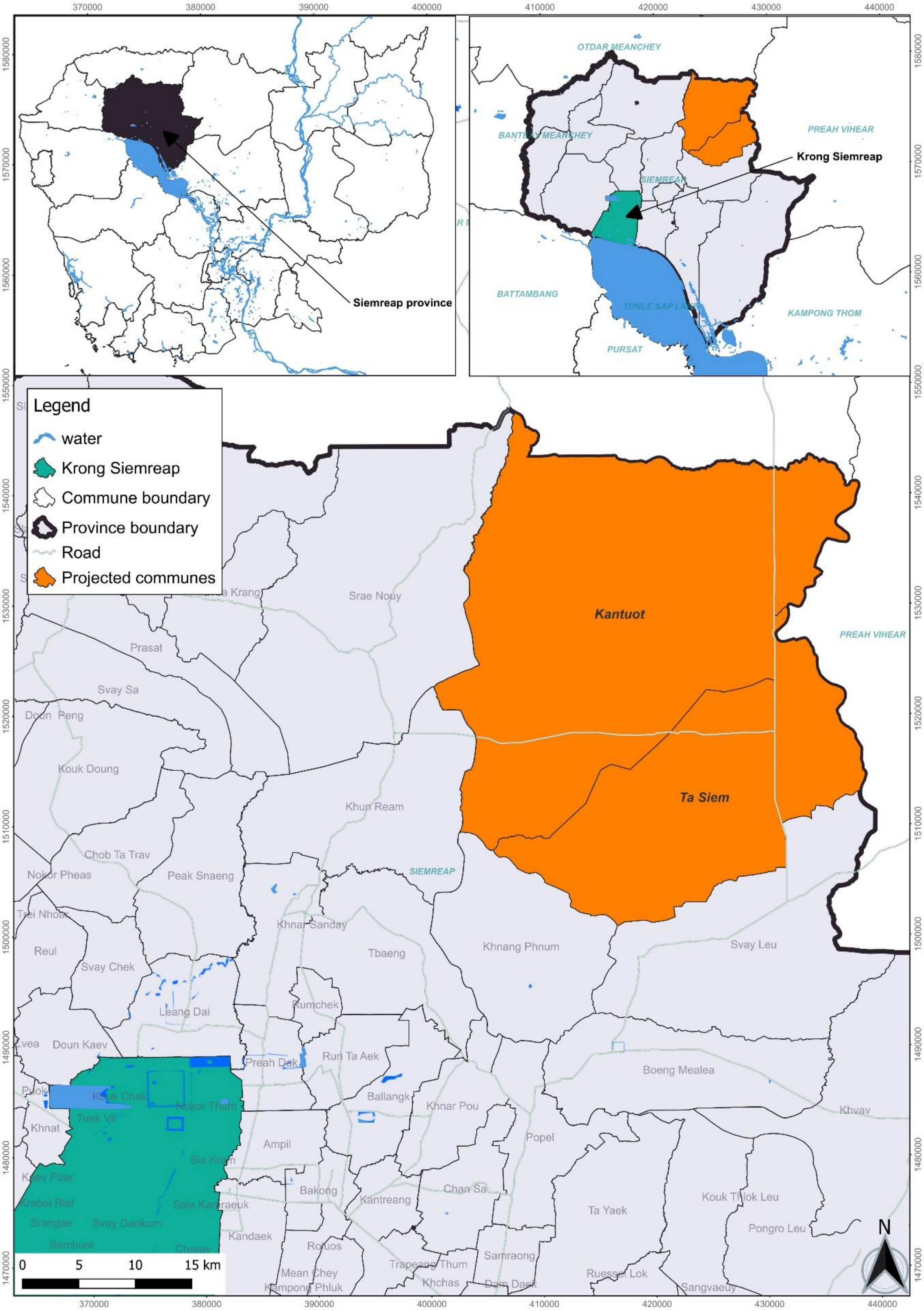
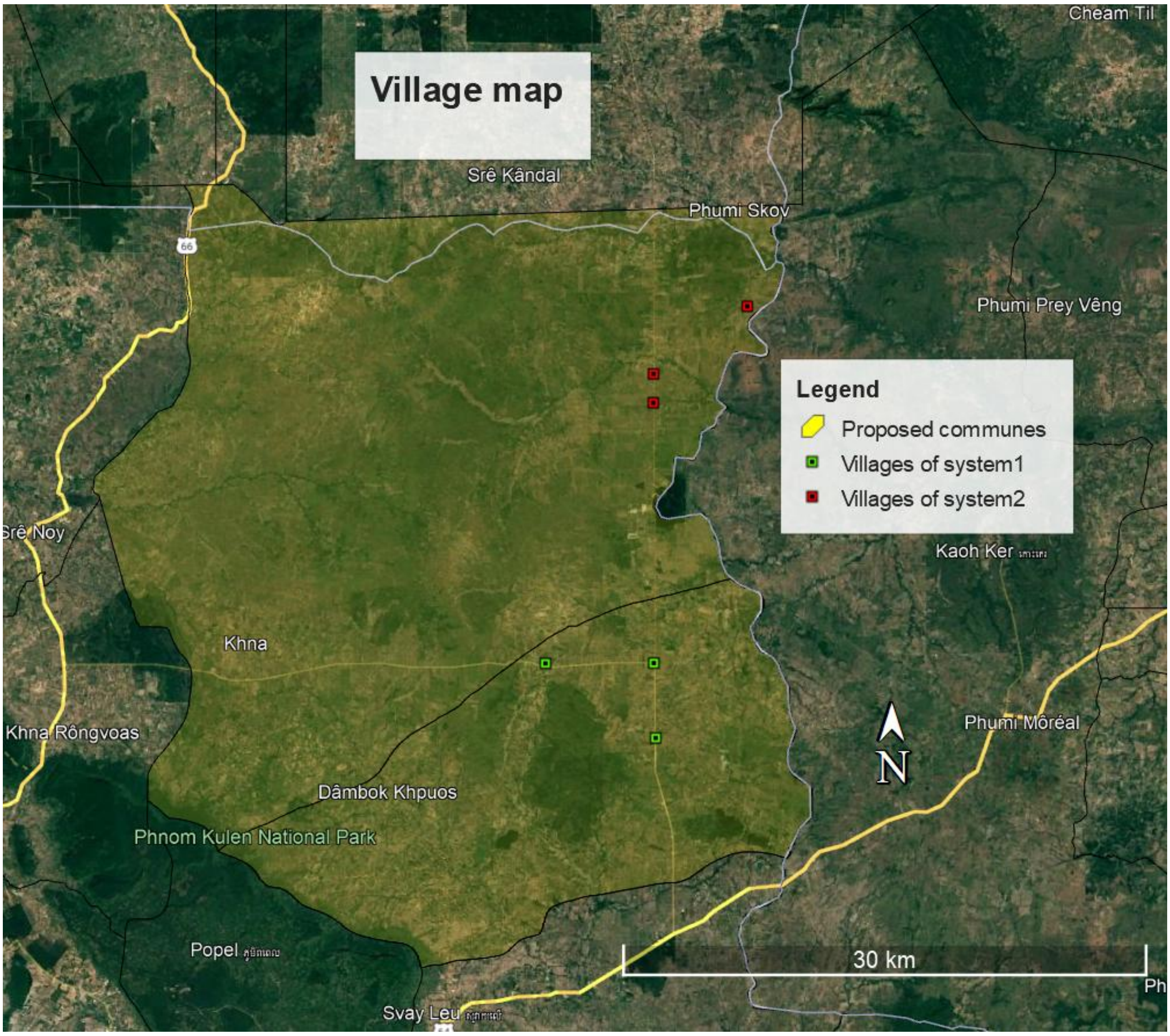


Figure 2: Village clusters in each water supply system



1.3.2 Households and the vulnerable, microenterprises, and public institutions

The beneficiaries are the households, microenterprises, and public institutions located in those villages in the service area of the small scale bundling piped water project.

1.3.2.1 Households, the poor, and people with disabilities

The site bundle will include 1,621 households or 6,300 people. Around 51.41% of the population are women and girls. The government's ID poor database shows that 40% are ID-poor households and the socioeconomic survey shows that of the households in the service area, 4% are those who have family members with disabilities.

The average annual population growth is 1.6%, calculated from the data of Commune Database between 2014 and 2023.

Table 1: Number of households, people, and women

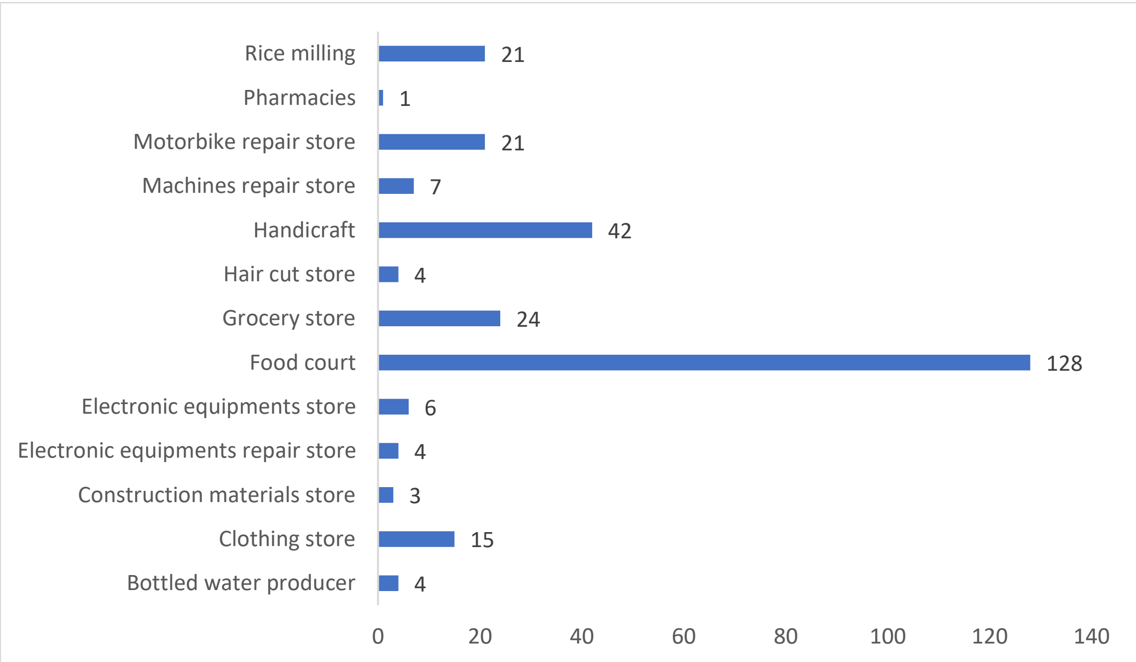
System	Communes	Villages		Number of Households	Number of People	Number of Women
1	Ta Siem	1	Trapeang Popel	211	970	548
		2	Trapeang Thmar	294	1,171	554
		3	Ou Roung	138	468	232
	Sub-Total			*643*	*2,609*	*1,334*
2	Kantuot	1	Akpiwat	405	1,421	708
		2	Rong Roeung	324	1,353	737
		3	Kramom Bol	249	917	460
	Sub-Total			*978*	*3,691*	*1,905*
	Total			**1,621**	**6,300**	**3,239**

Source: Commune data as of 2024

1.3.2.2 Microenterprises

According to the Commune database 2021 from the Ministry of Planning, there are in total 280 local enterprises in the site. The most common local enterprises include food courts (128 units), handicrafts (63 units), and grocery stores (46 units).

Figure 3: Number of local enterprises



Source: Commune database 2021

1.3.2.3 Public institutions

According to the data from the commune halls, this site bundle includes seven schools and four pagodas.

Table 2: List of public institutions

Public institutions	Number
School	7
Pagoda	4

1.4 Scope of climate resilient infrastructure

To supply clean water to all households and local enterprises in the community, the following facilities are needed:

Table 3: Water infrastructure facilities

Facility	System 1	System 2
Pond Excavation	48,111 m^3	72,751 m^3
Water treatment plant	10 m^3/h	15 m^3/h
Water storage tank	80 m^3	120 m^3
Raw water pumps	3 kW; 2 units (1 backup)	1.5 kW; 2 units (1 backup)
Booster pumps	2.2 kW; 2 units and inverter (1 backup)	3.7 kW; 2 units and inverter (1 backup)
Electricity connection	63 A	63 A
Distribution pipe network	46,518 m	32,481 m
Others	- A set of one pumping station, one motorbike and one phone for each system. - A set of one office, one warehouse, one test kit, one computer, one printer, and an inclusive toilet for the main office.	

2. GEDSI and Climate Resilience

2.1 Process for Integration

To effectively integrate GEDSI (Gender Equality, Disability, and Social Inclusion) and climate resilience into the project, a structured process has been developed:

- **Needs Assessment:** The process begins with a comprehensive needs assessment to evaluate the specific requirements of various groups, including women, people with disabilities, and other vulnerable populations. This assessment also identifies critical factors related to climate resilience, such as vulnerabilities to flooding, drought, and other climate-related challenges.
- **Project Design:** Based on the findings from the needs assessment, the project design incorporates GEDSI and climate resilience considerations at every stage. The goal is to create water infrastructure that is inclusive, equitable, and adaptive to environmental changes. For example, this includes providing connection subsidies for ID Poor households and designing climate-resilient water infrastructure system.
- **Project Implementation:** Once selected through the Competitive Permit Approach, the investor will implement the project with support from CAPRED. This ensures that inclusion and climate resilience are embedded throughout the implementation phase.

2.2 Inclusive consultation with stakeholders

The detailed proposal took the extensive and inclusive consultation approach to ensure that the project responds to the needs and concerns of the community, including women and people with disabilities and is in compliance with the technical engineering standards of Cambodia. There have been consultations as the following:

1. **Household and vulnerable group survey**: The socio-economic survey was conducted in the project location based on random sampling to ensure quality representation and a sample size of 99 respondents. The questionnaire addressed the need for piped clean water, affordability, willingness to connect, key challenges of current water sources concerning gender, and concerns and suggestions on piped clean water infrastructure development.
2. **Local authority consultation**: The proposal development team consulted with the local authority in the commune to understand the socio-economic status of the community, the potential disaster risks including flooding and drought, the mine and other explosive remnants of war, and other potential risks to the environment.
3. **Government**: The proposal development team had an ongoing extensive consultation with the Ministry of Industry, Science, Technology & Innovation (MISTI) to ensure that the project implementation aligns with the government's target and priority as well as the technical standards of Cambodia.

2.3 GEDSI and climate resilience

2.3.1 GEDSI

The socioeconomic survey findings illustrate critical insights that highlight gender and accessibility challenges, and opportunities to enhance inclusivity through this project. See Section 3 in further details.

Women are primarily responsible for water collection in 72% of households, facing significant challenges, particularly during the dry season, when 49% of women reported it to be challenging or very challenging.

This burden contributes to time usage, disproportionately affecting women and limiting their ability to engage in other productive activities. Additionally, health and hygiene concerns linked to alternative water sources—such as poor water quality (35%) and issues like skin and hair irritation (57%)—underscore the need for clean, safe water services that directly benefit vulnerable groups.

The high demand for piped water services, especially among women, reflects its perceived benefits in reducing hardship (53%), saving time (84%), saving money (63%) and improving health outcomes (58%).

Furthermore, the survey indicates that 71% of decisions to connect are made jointly within households, emphasizing the need to engage all members of the community, particularly women, during project consultations.

The connection fee remains a barrier for most households, as 42% of respondents are willing to pay the highest connection fee of 300,000 KHR, with the figure rising to 70% at a reduced fee of 150,000 KHR.

This demonstrates the necessity of connection subsidy to ensure accessibility for low-income and ID Poor households.

To address these needs and deliver GEDSI outcomes, the project will integrate targeted interventions for vulnerable groups. Subsidized connection fees for ID Poor households will make services more affordable, while infrastructure grant to stimulate quality investments will reduce the physical burden of water collection, benefiting women, the elderly, and persons with disabilities.

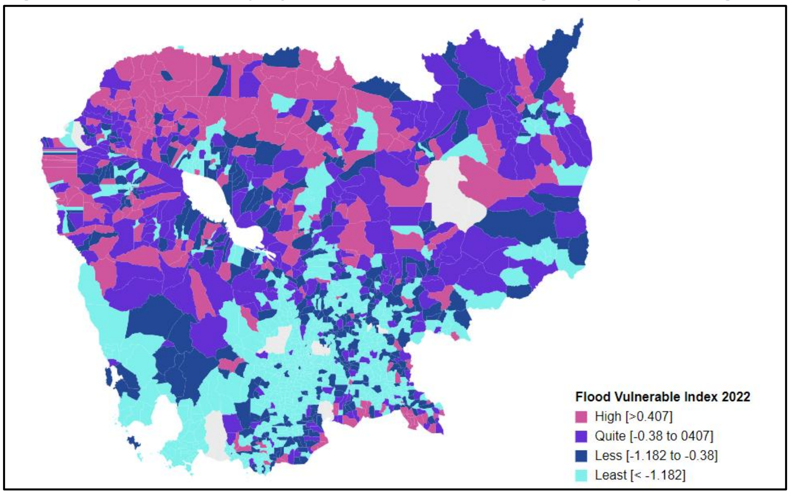
2.3.2 Climate and disaster risks

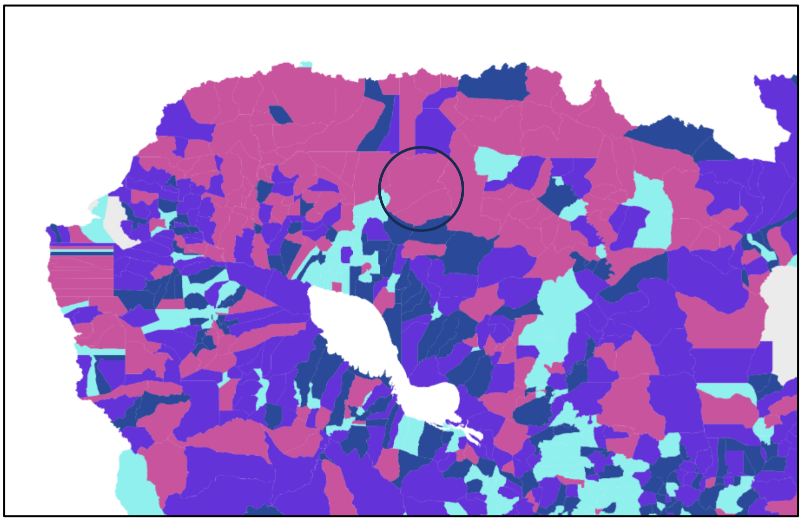
The bundle of small-scale piped clean water projects are located in the very remote villages, which are vulnerable to climate and disaster risks. These projects are situated in Kantuot and Ta Siem communes of Svay Leu District, Siem Reap Province.

According to the Climate Vulnerability Index from the National Council for Sustainable Development and the Ministry of Environment, these targeted communes are at significant risk from the impacts of climate change.

Figures 4 and 5 below show that these two communes are highly vulnerable to flooding and drought.

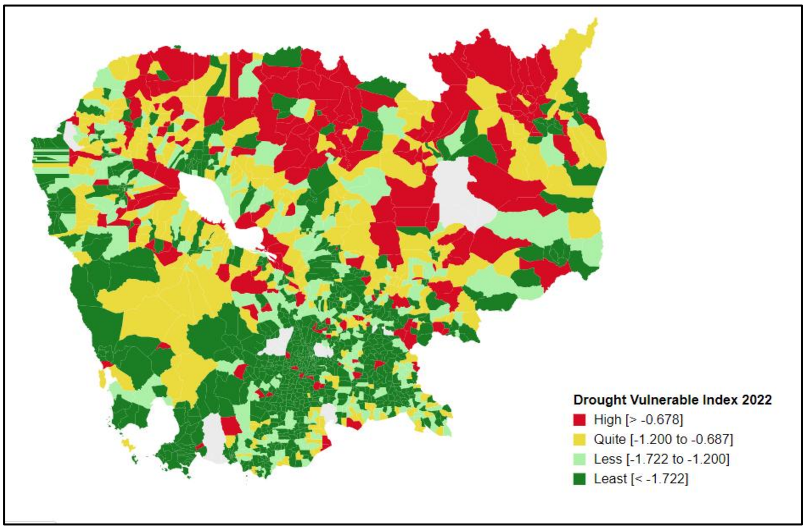
Figure 4: Vulnerability of small scaled bundling site to flooding

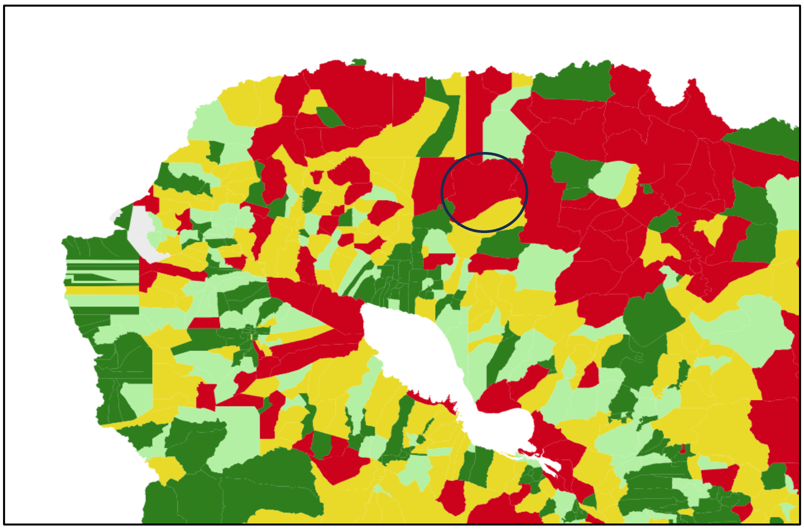




Source: Flood Vulnerability Index 2022

Figure 5: Vulnerability of small scaled bundling site to drought





Source: Drought Vulnerability Index 2022

These extreme weather events not only pose significant challenges to communities but also have the potential to disrupt water service delivery and damage infrastructure. To mitigate these risks, the project integrates climate resilience into every aspect of its water infrastructure design and operation, ensuring sustainability and reliability.

The design process begins with a thorough water source assessment, identifying the excavation of ponds with a duration of 7 months to store water for operation during both drought and flood conditions.

Water treatment plants will be constructed above flood level and reinforced to endure extreme weather events, ensuring continuous operation. The storage tank is designed to deliver water supply during peak demand in the dry season and elevated high enough to ensure sustainable operation during flood events.

3. Socio Economic Survey

3.1 Survey Methodology

The sampling of households for an interview goes through two stages. Firstly, the researcher used spatial sampling method on Google Earth to purposefully select 6 villages in 2 communes across various geographical locations of the project of 6 villages. This is to ensure representation of the diverse situation across villages. Secondly, the simple random sampling method was applied to randomly selected 4 to 10 houses within each village on the spot, considering different housing conditions (roof and walls) to also include diverse living standards. A respondent must be over 18 years old who is the head, spouse of the head, or a permanent family member in the household.

The survey set a quota for a large sample size of **100 respondents**. Of the respondents, 66% were women.

The survey questionnaire was designed with a focus on understanding the community's needs and perspectives regarding piped clean water usage. It sought to gather detailed information on various aspects such as current water sources, affordability, and willingness to connect to piped clean water. In addition, the questionnaire also aimed to identify the key challenges associated with current water sources. A unique aspect of this survey was its attention to gender-specific issues related to water usage, recognizing that men and women might face different challenges. Furthermore, the questionnaire also included sections for respondents to voice their concerns and provide suggestions on the development of piped clean water infrastructure.

This inclusive approach ensured that the survey gathered valuable insights that informed the technical engineering design and electrification project implementation.

As a result, the survey team interviewed **99 households** with diverse characteristics presented in Table 4. No business interviews were conducted.

Table 4: Household respondents participated in the interview

Respondent by gender	Number	% Percentage
Female	**65**	66%
Male	**34**	34%
Total household respondents	**99**	100%
Respondent by vulnerability characteristics		
Elderly (above 60 of age)	**2**	2%
Households characteristics		
Female-headed households	**13**	13%
Households with members having disabilities	**25**	25%
Households with elderly members	**6**	6%
ID Poor households	**21**	21%

Source: Socio-economic survey

3.2 Survey finding

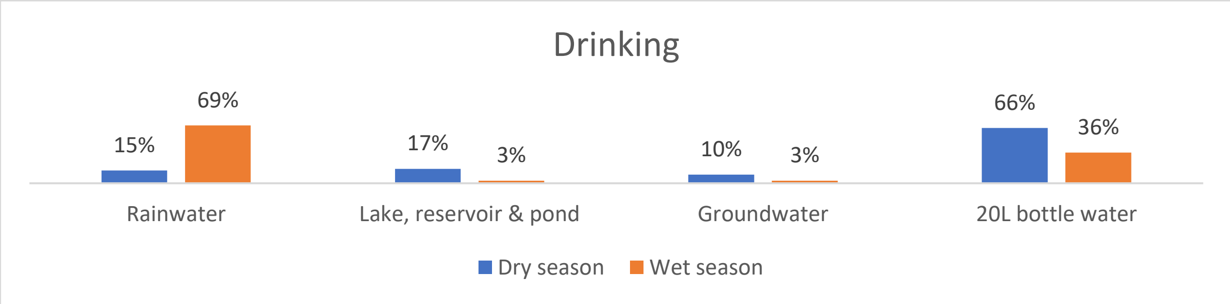
3.2.1 Current alternative water sources

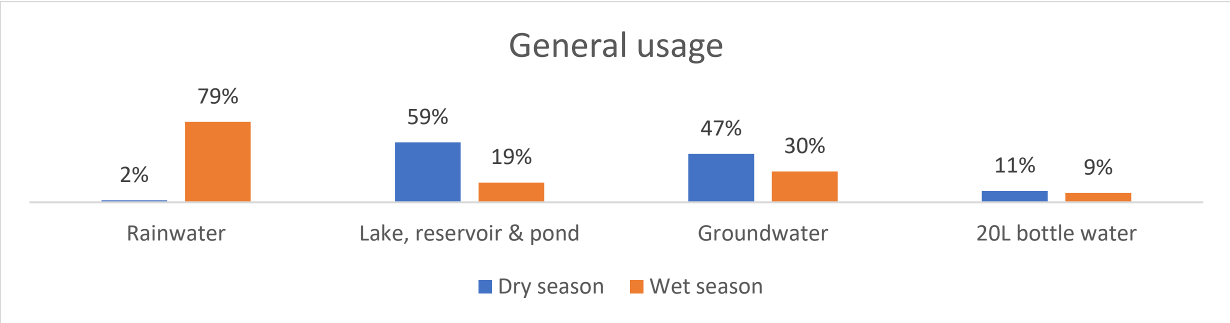
Villagers have been using various types of water sources in the dry and wet seasons.

For drinking, 20-liter bottled water is the primary source in the dry season (66%) and rainwater becomes the primary source in the wet season (69%). Other water sources such as surface water[1] and groundwater are the least water sources for both seasons.

For general usage, rainwater is the primary source during the wet season, with 79% of households using it. In the dry season, surface water becomes the main source, used by 59% of households, although this drops to 19% in the wet season.

Figure 6: Current water sources for drinking and general usage (bathing, washing, and cooking)

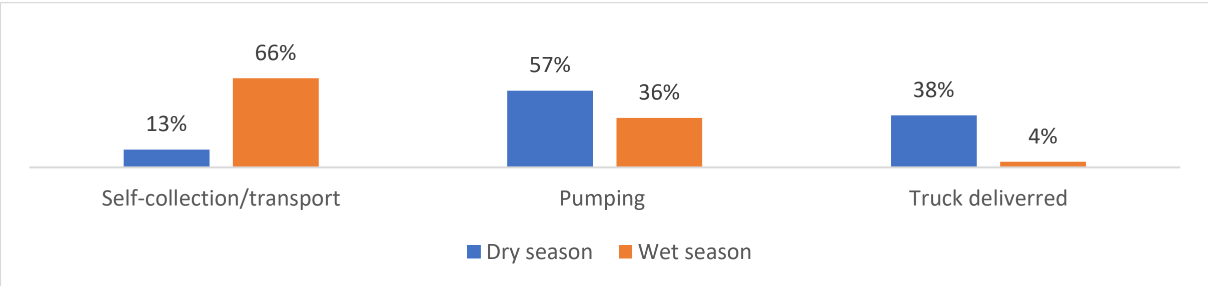




3.2.2 Water collection method

Pumping is the predominant method for water collection in the dry season, with 57% of households using it. In the wet season, self-collection and transport become the main method to collect water, used by 66% of households. Truck delivery becomes the important option for getting water during dry season, with 38% of households using it.

Figure 7: Water collection method

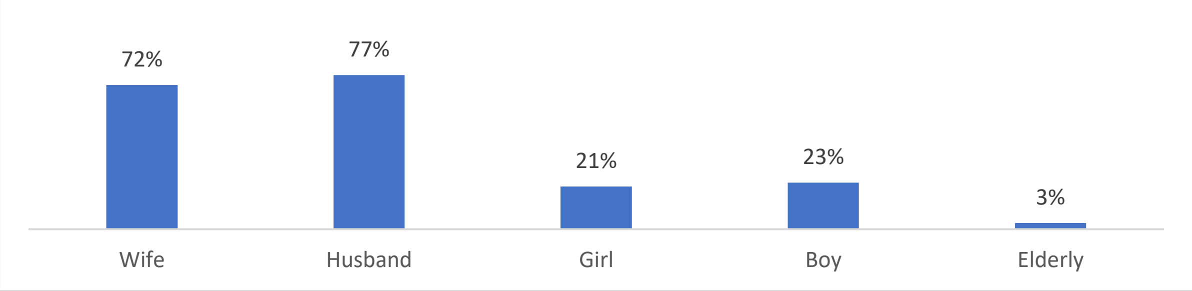


3.2.3 People responsible for Water collection

Husbands (77%) are the most responsible people to collect water for the households followed by the wives (72%).

[1] Surface water includes lake, reservoir & pond and canal, stream & river.

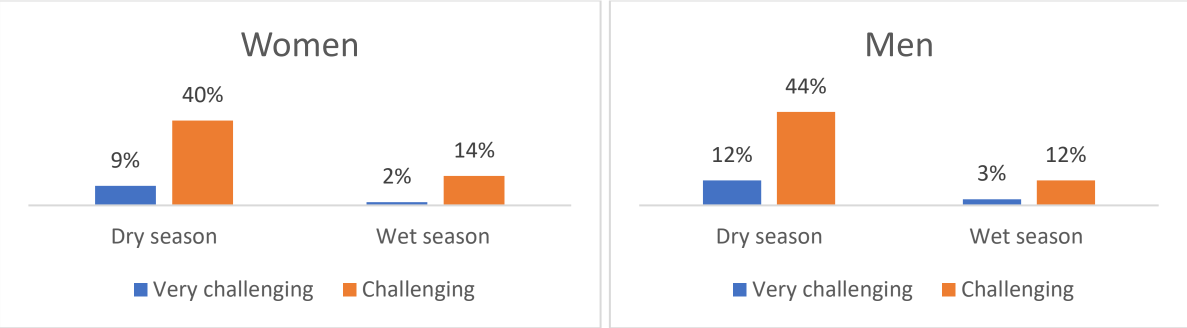
Figure 8: People responsible for water collection



3.2.4 Perception on challenges

When asked about the challenges on using the current alternative water sources, 49% of women explained that it was challenging or very challenging for them in the dry season. However, this figure decreased to only 16% in the wet season.

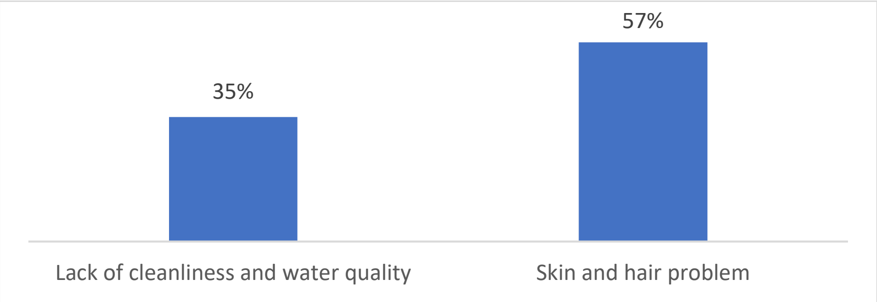
Figure 9: Perception on challenges



3.2.5 Perception on hygiene and health issues

There are hygiene and health concerns associated with using alternative water sources. These include issues such as skin and hair irritation (57%) and problems like lack of cleanliness and water quality (35%).

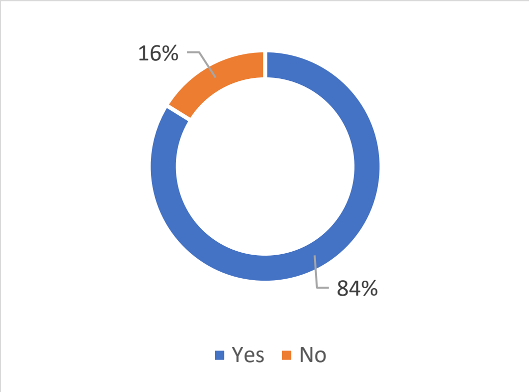
Figure 10: Perception on hygiene and health issues



3.2.6 Toilet

84% of respondents have the toilet.

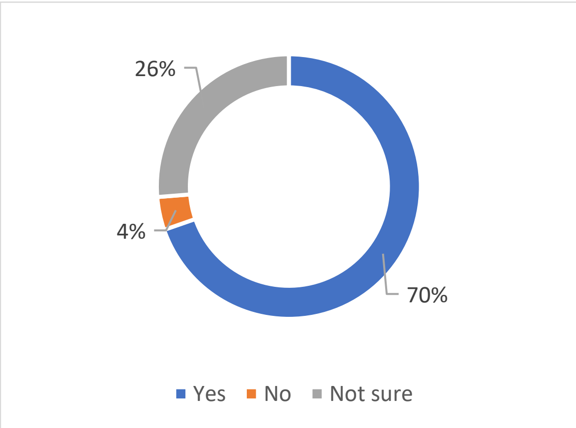
Figure 11: Toilet



3.2.7 Willingness to connect

The demand for piped clean water service is very high and most families value piped clean water. Majority of respondents (70%) mentioned they will connect once the piped water supply is available. Women respondents seemed to show a more apparent intention of connecting to piped water. Only 26% of respondents are still unsure of their decision.

Figure 12: Willingness to connect

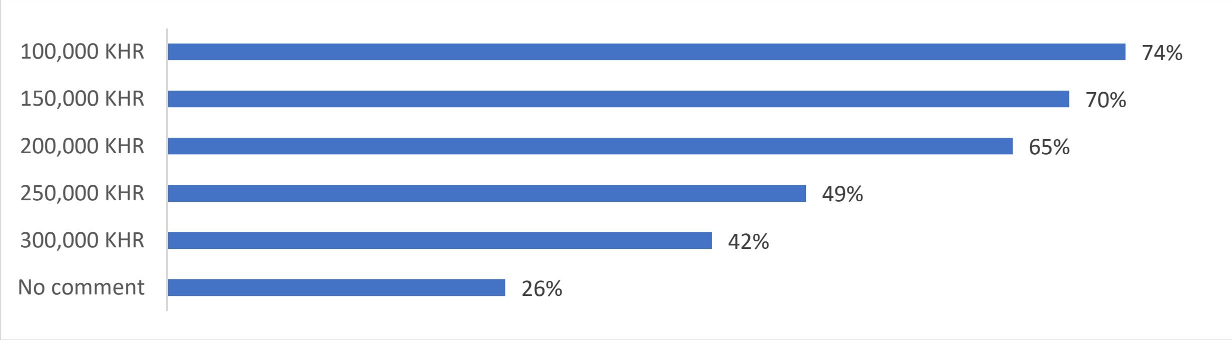


3.2.8 Willingness to pay for water connection fee

The survey asked about the willingness to pay for connection fees of villagers for those who intended to connect. The survey used the bid-down approach starting from 300,000 KHR—the highest connection fee on the list. If a respondent was not willing to pay for the connection fee level, he or she would be asked for the next lower connection fee which was 250,000 KHR. The cycle repeated until a respondent confirmed the connection fee that he or she was willing to pay. A respondent could choose not to comment, though.

Figure 13 shows that more than half of respondents (42%) reported that they were willing to pay for the connection fee of 300,000 KHR. The figure increased to 49% if the connection fee was at 250,000 KHR. This further increased to 70% if the connection fee was at 150,000 KHR. It is worth noting that 26% could not comment at all.

Figure 13: Willingness to pay for connection fee

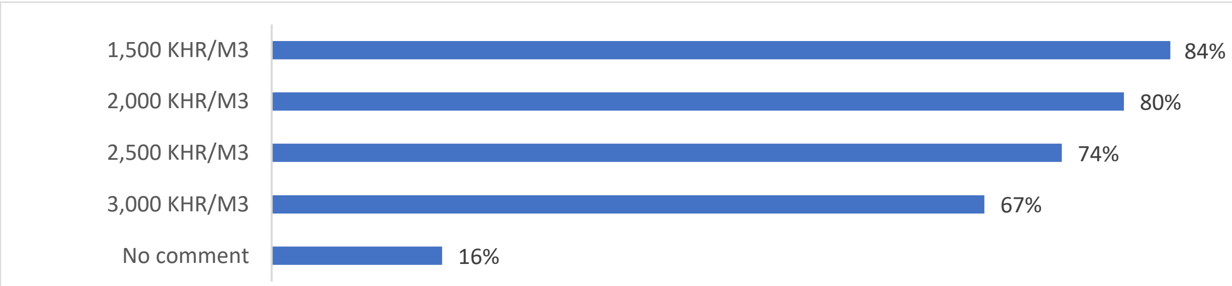


3.2.9 Willingness to pay for water tariff

The survey asked about the willingness to pay for clean water tariff of villagers for those who intended to connect. The survey used the bid-down approach starting from 3,000 KHR per m^3—the highest tariff on the list. If a respondent was not willing to pay for the tariff level, he or she would be asked for the next lower tariff which was 2,500 KHR per m^3. The cycle repeated until a respondent confirmed the tariff level that he or she was willing to pay for. A respondent could choose not to comment, though.

Figure 14 shows that 67% of respondents reported that they were willing to pay for the tariff at 3,000 KHR per m^3. The figure increased to 74% if the tariff was at 2,500 KHR per m^3. It is worth noting that 16% could not comment at all.

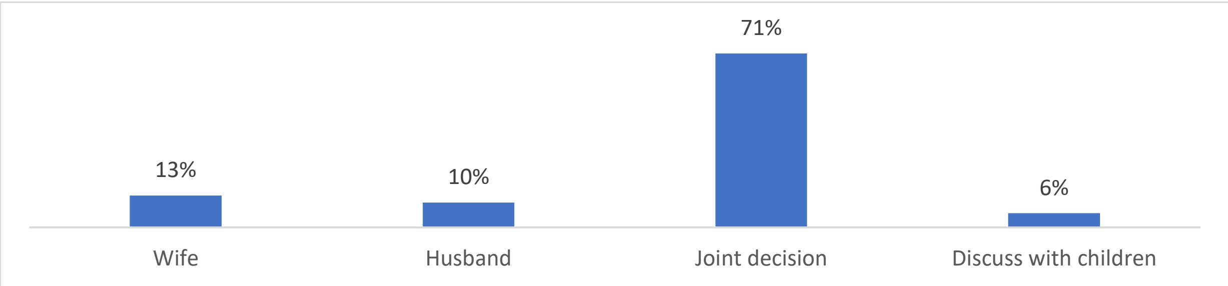
Figure 14: Willingness to pay for tariff



3.2.10 Decision makers to connect

71% of respondents who intended to connect reported the decision to connect is a joint decision in the family followed by the sole decision of wives (13%), the sole decision of husbands (10%), and discuss with children (6%).

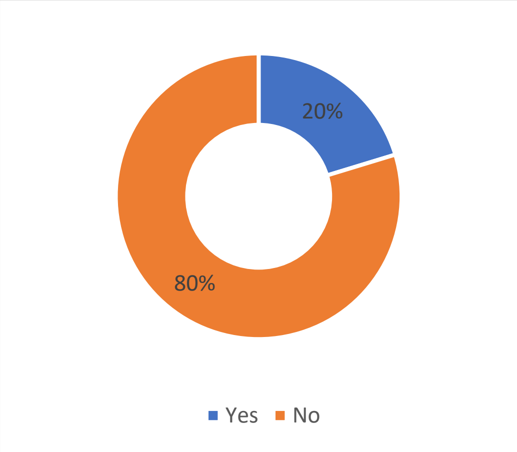
Figure 15: Decision makers to connect



3.2.11 Plan for new enterprises

20% of respondents who intended to connect reported they would create the new enterprises. Those include growing vegetable, grocery stores, food courts, raise pigs, and bottled water production.

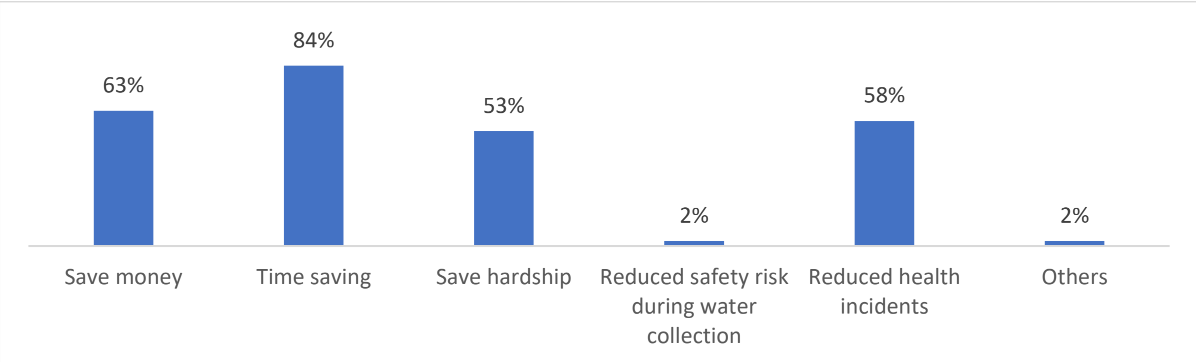
Figure 16: Plan for new enterprises



3.2.12 Perception on benefits

The women respondents who intended to connect anticipated that a clean water connection would provide the following benefits: saving time (84%), saving money (63%), reducing health incidents (58%) and reducing hardship (53%).

Figure 17: Perception on benefits



3.3 Estimated Water Consumption Level

3.3.1 Water Consumption of Household

Household consumption amount is a key factor in estimating revenue and in determining the designed capacity and sizes of infrastructure. The estimated consumption amount is based on the household's current water consumption of the 99 respondents in the dry season. The calculation will also exclude outliers which are unlikely to be household consumption but business consumption or abnormalities.

Based on the Australia funded Provincial Investment Plan Study for Piped Water Supply (2020), over 95% of households consumed less than 30 m^3 per month; This will be used as the cutoff figure for outliers.[2] The study also found a fluctuation in the water demand between the dry and wet seasons, with the demand in wet season being 25% lower than that in the dry season. For this calculation, the households that pump water directly from the boreholes and wells were excluded due to large amount of water usage for other purposes such as watering vegetable garden, washing livestock, and spraying water on the dusty road which is not likely to happen with the piped clean water.

The study uses two consumption estimates: 1) for revenue forecasting or financial modelling and 2) for infrastructure sizing or technical modelling. The former is the average monthly consumption per household for the whole year, while the latter is the monthly average of dry season consumption to ensure infrastructure can accommodate peak demand.

Table 5: Summary of water consumption based on the socio-economic survey

Average water consumption per person per month	2.37 m^3
Average household size in the service area	4.04 person
Dry season average consumption per household (for Technical Modelling)	9.57 (10) m^3/month
Yearly average consumption per household (for Viability Calculation)	8.37 (8.5) m^3/month

Source: Socio-economic survey

The PIP study also found that 28% of households use below 4 m^3 per month and the other 72% of households use above 4 m^3 per month.

3.3.2 Water Consumption of Businesses

Business consumption estimation depends on the likelihood of businesses connected to piped clean water and their current estimated consumption. Firstly, businesses in the project proposed area are identified based on interviews with commune chiefs. Secondly, the businesses which likely need clean water as business input will be interviewed for their intention to connect and their current demand. Water consumption considered as business input includes production purposes or daily use of personnel, which are separable from household consumption.

Based on the interviews with commune chiefs, there is no significant business requiring a high amount of water usage.

3.3.3 Water Consumption of Public Institutions

Public institutions are assumed to be connected in the first year, and their consumption level are based on rough estimate. There are a total of 11 public institutions in the proposed area: 7 schools, and 4 pagodas which have not been connected.

Based on consumption data of 30 public institutions from 8 service areas, the average consumption is 25 m^3 per month each.

3.4 Estimated Household Connection Speed

Household connection speed is another key factor in revenue projection and infrastructure design. The study bases connection speed projection on 3i's study[3]. The study showed that characteristics of alternative water sources are the main factors determining household connection speed. Particularly, in area where high prevalence of good quality groundwater, the connection speed was significantly

[2] 3i conducted Provincial Investment Plan (PIP) study to estimate the investment needed to make pipe clean water accessible countrywide, excluding areas where pipe solution is unsuitable. As part of the study, 1.52 million water consumption data points were collected from 59,619 connections made by 32 water stations supplying clean water in 45 communes in 15 provinces. The data covers both wet and dry seasons' consumption.

[3] 3i conducted a connection study in 2020 of 80 water projects supported by 3i having been operating between 1 and 4 years.

lower. In areas where households rely on surface water sources, which are usually with lower quality and less convenient, the connection tend to be relatively higher. 3i's analysis of its early completed water infrastructures shows that on average a water supply could reach 65% of connection at the end of year 5 and 100% by year 10.

Households in the studied area depend on pond water, groundwater, and rainwater, thus this location is not characterised as a good groundwater prevalent area. Therefore, the proposed project assumes a connection speed of 60% at the end of year 5 and a gradual increase to 90% in year 10. Table 6 summarises the projected connection speed.

Table 6: Assumed speed of connection

Year	1	2	3	4	5
Connection rate	20%	30%	40%	50%	60%

4. Climate Resilient Infrastructure Designing

4.1 Water Demand

4.1.1 Number of Connections

The number of projected connections is based on the assumed connection rate and annual population growth. The projected household beneficiary connection is summarised in Table 7.

Table 7: Number of connections from year 1 to year 5

Description	Year 1	Year 2	Year 3	Year 4	Year 5
Number of people	6,401	6,503	6,607	6,713	6,820
Connection rate	20%	30%	40%	50%	60%
Number of connected people	1,280	1,951	2,643	3,357	4,092
Number of connected households	**329**	**502**	**680**	**864**	**1,053**

4.1.2 Water Demand

Table 8 reports the average quantity of water demanded and produced per year after considering consumption growth and water losses. The quantity of water produced accounts for an assumed water loss of 15% from production and distribution.

Table 8: Quantity of water demanded and produced

Description	Unit	Year 1	Year 2	Year 3	Year 4	Year 5
Quantity of water demanded	m^3/year	18,613	46,599	65,509	85,375	106,222
Quantity of water produced	**m^3/year**	**21,898**	**54,823**	**77,069**	**100,442**	**124,968**

4.2 Water Source Overview

4.2.1 System 1

The water sources for this proposed clean water system are the Ou Roung stream and a supplementary pond for seven months during the dry season. The Ou Roung stream is approximately 10 km long from its upstream to the proposed intake point. It flows across Ou Roung village and down to the Steung Sen river. According to the Ou Roung village chief, the Ou Roung stream has water flowing during the rainy season from June to November. The stream receives water naturally from rainfall in its catchment area of about 4,500 hectares. The volume of water collected annually from the catchment is 17.86 million m^3, while the volume of water required for the system is 63,732 m^3 (see Box 1). Thus, there is plenty of water that can be extracted to meet the system's requirements.

Box 1:

A-Calculation of volume of rainfall that the catchment can collect.

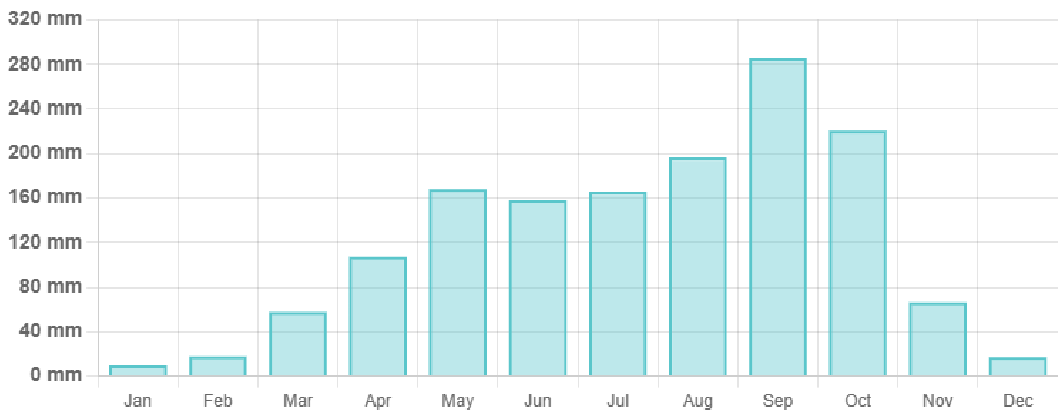
The runoff in the catchment can be estimated using the rational method of runoff formula, which considers the catchment area, runoff coefficient, and intensity of rainfall. Based on the rainfall data from a website named WEATHER & CLIMATE, the average annual rainfall in Siem Reap is 1,470 mm/year[4]. The land in this catchment area is mainly cultivated land and light forest, for which the runoff coefficient can be 0.27.

Siem Reap Rainfall & Precipitation: Monthly Averages and Year-Round Insights

This page shows the average amount of rainfall per month in Siem Reap. The numbers are calculated over a 30-year period to provide a reliable average. Now, let's break down all the details for a clearer picture.

Siem Reap experiences significant rainfall throughout the year, averaging **1470 mm** of precipitation annually.

Monthly Precipitation Levels



Therefore, the annual runoff can be estimated as follow:

Annual Runoff = $0.27 \times 1,470 \times 10^{-3} \times 4,500 \times 10^{4} = 17,860,500 \text{ m}^3$

The catchment can collect average annual rainfall of 17.86 million m^3 flowing through Ou Roung stream.

B-Water requirement for the system.

In section 4.4.1.1 (Water Treatment Plant Capacity) below, the monthly water required is 5,311 m^3. Therefore, the yearly water required would be $5,311 \times 12 = 63,732 \text{ m}^3$.

Based on the information provided above, water is available in the stream and can supply raw water to the system for six months each year during the rainy season. However, due to safety considerations and the impacts of climate change, the system is designed to extract water from the stream for only five months annually. For the remaining seven months, water will be sourced from a newly proposed pond.

[4] https://weather-and-climate.com/average-monthly-precipitation-Rainfall,siem-reap,Cambodia

The system requires 5,311 m³ of water per month. Therefore, during the seven months, the system requires 37,177 m³. Including a 15% water loss through evaporation and seepage, and a safety factor of 1.1, the pond needs to have a total storage capacity of up to 48,111 m³ to reserve for the seven-month period. The pond volume is 48,111 m³ and the capacity of water collection is 17.86 million m³, thus, there is plenty of water to refill the pond.

The maximum depth of the pond is limited to an 8-meter design with a bank slope of 1:1.5. Therefore, the pond requires a land size of 9,725 m². A detailed calculation of the pond volume and surface area is shown in (Box 2) below:

Box 2:

Pond area calculation:

Assuming pond shape is trapezoidal, surface area of the pond can be calculated using the below equation:

$$A = \left(\frac{\left(4 \times S \times D + \left((4 \times S \times D)^2 - 8\left((2 \times S \times D)^2 - \frac{2V}{D} \right) \right)^{\frac{1}{2}} \right)}{4} + 2 \times Dike \right)^2$$

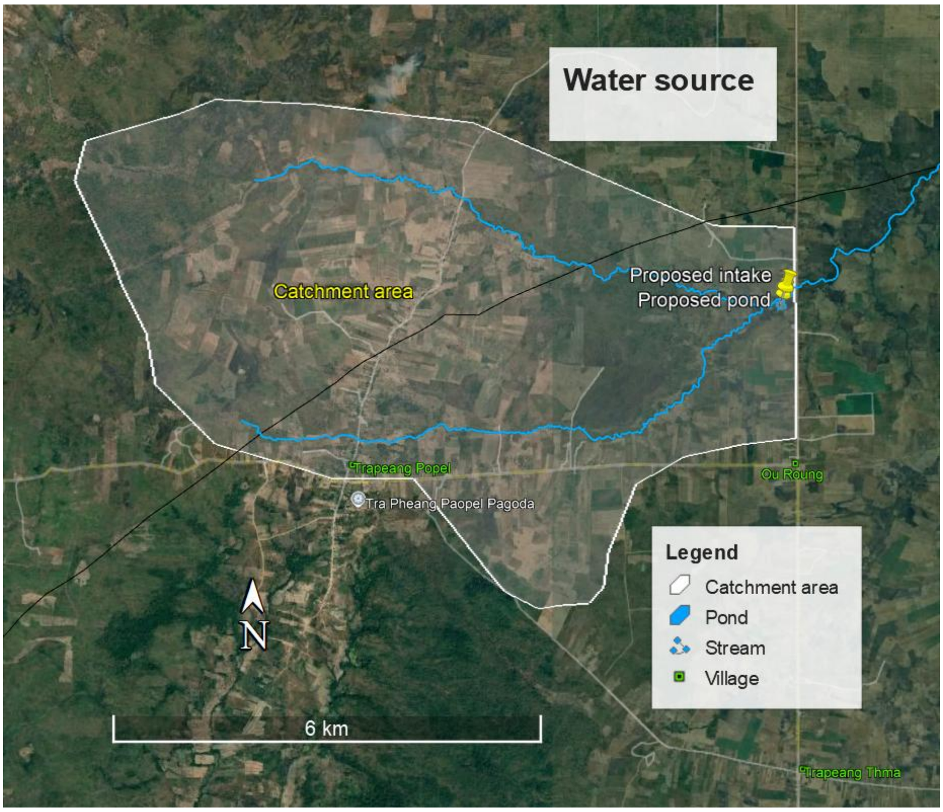
Where A = Surface area; m^2
S = Slope;
D = Depth, m
V = Volume, m^3

Based on feel method soil is silty clay, so slope is assumed to be 1.5 to ensure no bank erosion. Ponds need to have a safe length with a dike of at least 5 meters from the pond edge to ensure pond safety.

Given a depth of 8 meters, therefore, the surface area is:

$$A = \left(\frac{\left(4 \times 1.5 \times 8 + \left((4 \times 1.5 \times 8)^2 - 8\left((2 \times 1.5 \times 8)^2 - \frac{2 \times 48{,}111}{8} \right) \right)^{\frac{1}{2}} \right)}{4} + 2 \times 5 \right)^2 = 9{,}725\boldsymbol{m^2}$$

Figure 18: Ou Roung stream over view.



Source: Google Earth.

Figure 19: Ou Roung stream

Source: Author's own photo (date: 07 December 2023).

4.2.2 System 2

The water sources for this proposed clean water system are the Ou Ta Kok stream and a supplementary pond for seven months during the dry season. The Ta Kok stream is approximately 12 km long from its upstream to the proposed intake point. It flows across Akpiwat village and down to the Steung Sen river. According to the Akpiwat village chief, the Ou Ta Kok stream has water flowing during the rainy season from June to November. The stream receives water naturally from rainfall in its catchment area of about 14,000 hectares. The volume of water collected annually from the catchment is 55.57 million m^3, while the volume of water required for the system is 96,372 m^3 (see Box 1). Thus, there is plenty of water that can be extracted to meet the system's requirements.

Box 1:

A-Calculation of volume of rainfall that the catchment can collect.

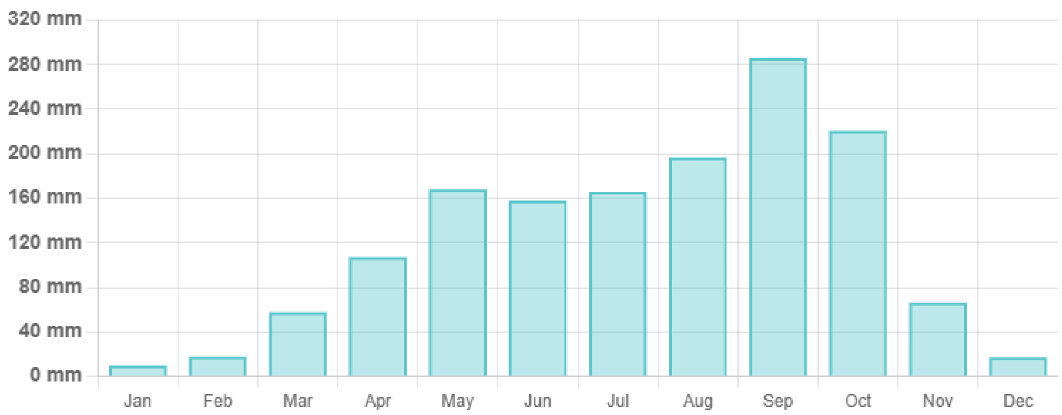
The runoff in the catchment can be estimated using the rational method of runoff formula, which considers the catchment area, runoff coefficient, and intensity of rainfall. Based on the rainfall data from a website named WEATHER & CLIMATE, the average annual rainfall is 1,470 mm/year[5]. The land in this catchment area is mainly cultivated land and light forest, for which the runoff coefficient can be 0.27.

Siem Reap Rainfall & Precipitation: Monthly Averages and Year-Round Insights

This page shows the average amount of rainfall per month in Siem Reap. The numbers are calculated over a 30-year period to provide a reliable average. Now, let's break down all the details for a clearer picture.

Siem Reap experiences significant rainfall throughout the year, averaging **1470 mm** of precipitation annually.

Monthly Precipitation Levels



Therefore, the annual runoff can be estimated as follow:

Annual Runoff = $0.27 \times 1{,}470 \times 10^{-3} \times 14{,}000 \times 10^{4} = 55{,}566{,}000\ m^3$

The catchment can collect average annual rainfall of 55.57 million m^3 flowing through Ou Ta Kok stream.

B-Water requirement for the system.

In section 4.4.1.1 (Water Treatment Plant Capacity) below, the monthly water required is 8,031 m^3. Therefore, the yearly water required would be $8{,}031 \times 12 = 96{,}372\ m^3$.

[5] https://weather-and-climate.com/average-monthly-precipitation-Rainfall,siem-reap,Cambodia

Based on the information provided above, water is available in the stream and can supply raw water to the system for six months each year during the rainy season. However, due to safety considerations and the impacts of climate change, the system is designed to extract water from the stream for only five months annually. For the remaining seven months, water will be sourced from a newly proposed pond.

The system requires 8,031 m³ of water per month. Therefore, during the seven months, the system requires 56,217 m³. Including a 15% water loss through evaporation and seepage, and a safety factor of 1.1, the pond needs to have a total storage capacity of up to 72,751 m³ to reserve for the seven-month period. The pond volume is 72,751 m³ and the capacity of water collection is 55.57 million m³, thus, there is plenty of water to refill the pond.

The maximum depth of the pond is limited to an 8-meter design with a bank slope of 1:1.5. Therefore, the pond requires a land size of 13,597 m². A detailed calculation of the pond volume and surface area is shown in (Box 2) below:

Box 2:

Pond area calculation:

Assuming pond shape is trapezoidal, surface area of the pond can be calculated using the below equation:

$$A = \left(\frac{\left(4 \times S \times D + \left((4 \times S \times D)^2 - 8\left((2 \times S \times D)^2 - \frac{2V}{D} \right) \right)^{\frac{1}{2}} \right)}{4} + 2 \times Dike \right)^2$$

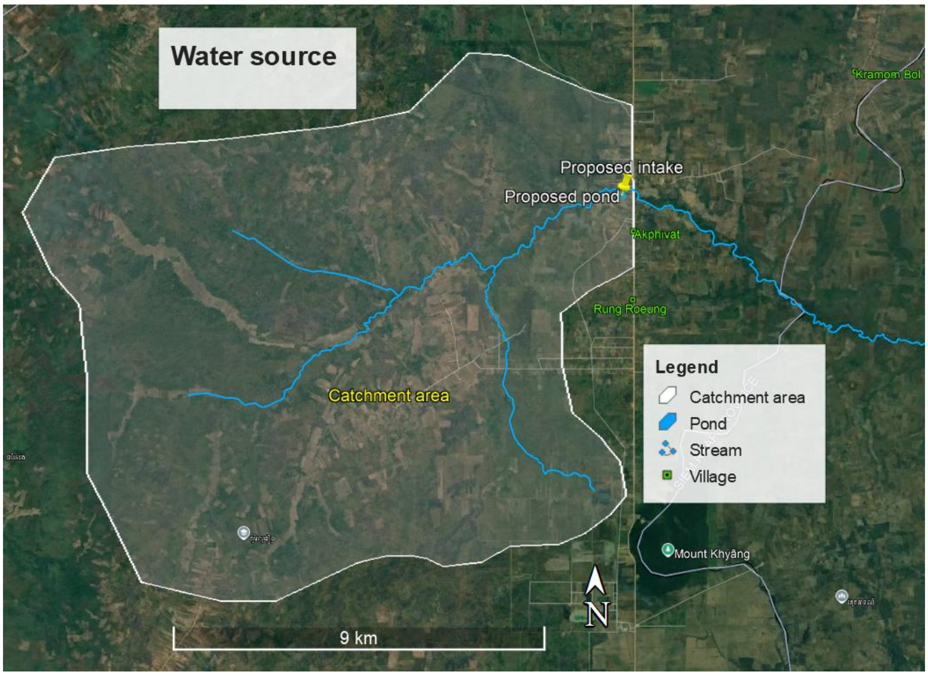
Where A = Surface area; m^2
S = Slope;
D = Depth, m
V = Volume, m^3

Based on feel method soil is silty clay, so slope is assumed to be 1.5 to ensure no bank erosion. Ponds need to have a safe length with a dike of at least 5 meters from the pond edge to ensure pond safety.

Given a depth of 8 meters, therefore, the surface area is:

$$A = \left(\frac{\left(4 \times 1.5 \times 8 + \left((4 \times 1.5 \times 8)^2 - 8\left((2 \times 1.5 \times 8)^2 - \frac{2 \times 72{,}751}{8} \right) \right)^{\frac{1}{2}} \right)}{4} + 2 \times 5 \right)^2 = 13{,}597 \boldsymbol{m^2}$$

Figure 20: Ou Ta Kok stream over view.



Source: Google Earth.

Figure 21: Ou Ta Kok stream

Source: Author's own photo (date: 07 December 2023).

4.3 Water Quality

Around the water source are agricultural plantations where people use pesticides and fertilizers. According to the experience of 3i and CAPRED, pollution caused by pesticides and fertilizers has never been found in such a type of water source. A water sample was taken from each water source to be tested by the Pasteur Institute of Cambodia against MISTI's water quality standards. According to the results detailed in Table 9 below, the raw water source is chemically clean, except for manganese in systems 1. However, the physical and microbiological parameters, as well as manganese levels that exceed permissible values, can be treated by a conventional treatment plant. CAPRED will require all grant recipient PWOs to join technical training to ensure proper operation of the supported infrastructure.

Table 9: Quality of water sources of the two systems

Parameters	Results of system1	Results of system2	Permissible values[6]
Total coliforms	**2.1×10^3**	**1.6×10^2**	0
Escherichia coli	**4.6×10^1**	**2**	0
Turbidity	**55 NTU**	**15 NTU**	<5
pH	6.7	8.1	6.5-8.5
Nitrite	0.14 mg/l	0.09 mg/l	<3
Nitrate	1.09 mg/l	0.65 mg/l	<50
Iron	0.00 mg/l	0.00 mg/l	<0.3
Arsenic	0.00 mg/l	0.00 mg/l	<0.05
Manganese	**1.09 mg/l**	0.05 mg/l	<0.1
TDS (Total Dissolved Solid)	81.00 mg/l	60.00 mg/l	<800
Color	**7.60 TCU**	4.60 TCU	<5

Source: Quality test report; Date of sampling: 07/12/2023; Date of analysis: 08/12/2023

4.4 Clean Water Production System

4.4.1 Water Treatment Plant

A water treatment plant removes contaminants that are unhealthy and undesirable for consumption. The water treatment plant is designed based on two factors. One is the capacity of the plant to ensure that enough clean water will be produced to meet the water demand. The other factor is characteristics of the source water.

4.4.1.1 Water Treatment Plant Capacity

The water treatment plant's capacity is simply the multiplication of the total number of consumers and water consumption per consumer during the design period divided by the operational time. The average household consumption per month is used to calculate the water treatment plant's capacity. A safety factor of 1.1 is integrated to ensure that the capacity of the plant is big enough to supply water during the driest month. Table 10 illustrates the calculation of the capacity of the water treatment plants.

Table 10: The calculation of the size of the treatment plants of the two systems

Items accounted for calculation	System 1	System 2
Total number of households in 2023	643 Households	978 Households
Total number of households in year 5	Population growth rate is 1.6% per year = 643 x $(1+ 0.016)^5$ =696 Households	Population growth rate is 1.6% per year = 978 x $(1+ 0.016)^5$ =1,059 Households
Number of households to supply treated water to	60% of total households is supplied with treated water = 0.6 x 696 = 418Households	60% of total households is supplied with treated water = 0.6 x 1,059 = 635Households

[6] Based on MISTI's standard

Amount of treated water to supply per month to households	A household consumption is 10 m^3 per month. Consumption growth rate is 1% per year[7]. = 418 x 10 x $(1.01)^5$=4,390 m^3/month	A household consumption is 10 m^3 per month. Consumption growth rate is 1% per year. = 635 x 10 x $(1.01)^5$=6,677 m^3/month
Amount of treated water to supply per month to the public institutions and large consumer	There are 3 schools and 2 pagodas in the service area, and each consumes 25m^3 per month. =25 x 5 = 125 m^3/month	There are 4 schools and 2 pagodas in the service area, and each consumes 25m^3 per month. =6 x 25 = 150 m^3/month
Amount of treated water to supply per month to all users	= 4,390 + 125= 4,515m^3/month	= 6,677 + 150= 6,827m^3/month
Amount of treated water to be produced per month	15% of treated water produced is lost = 4,515 / 0.85= 5,311m^3/month	15% of treated water produced is lost = 6,827 / 0.85= 8,031m^3/month
Daily water to be produced	One month has 30 days. The safety factor is 1.1 = 1.1 x 5,311 / 30=195 m^3/day	One month has 30 days. The safety factor is 1.1 = 1.1 x 8,031 / 30=294 m^3/day
Treatment plant capacity	The treatment plant is operated 20 hours per day = 195 / 20= 9.74 m^3/hour	The treatment plant is operated 20 hours per day = 294 / 20= 14.72 m^3/hour

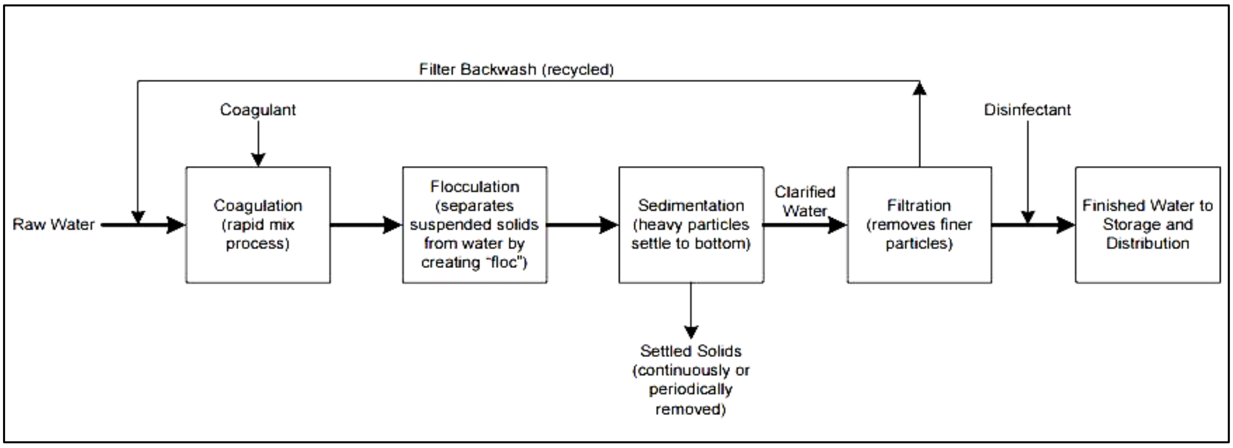
For design simplicity, the capacity of the treatment plant of the system1 and system 2 are rounded up to **10m^3 /hour and 15 m^3/hour** respectively.

4.4.1.2 Water Treatment Plant Component

Based on the drinking water quality test results, no major contaminants or toxins are found. Therefore, conventional filtration, the most common treatment plant, will be good enough to remove water contaminants and to produce clean water that meets the national drinking water standard. It is a series of processes, including coagulation, flocculation, sedimentation, and filtration, that result in turbidity removal from the raw water. Figure 22 shows a flow diagram of a conventional filtration treatment plant.

[7] Note that the assumption of 1% annual consumption growth rate is not incorporated with the business and public institutions consumptions. While it is expected that households will try to save piped water initially and increase their usage over time after getting used to the convenience of the piped treated water, the consumption behaviour of the people in businesses and institutions is unknown. In case there is actually consumption growth for them, which is not unlikely, the safety factors used in the study is expected to be able to account for such increase.

Figure 22: Typical conventional treatment plant flow diagram



- The coagulation chamber is to homogeneously disperse the solution of Alum and Lime or PAC with the raw water. Alum is used to coagulate scattered particles to form flocs which settle down in the next tanks. Lime may need to be used to maintain the pH of the water within the standard level.
- In the flocculation chamber, the water is in a turbulent state to enhance the bonding between scattered particles and flocs. Heavy flocs can settle in the next treatment step through sedimentation and filtration.
- In the sedimentation chamber, agitation of the water causes collisions between suspended particles, forming agglomerated flocs. The flocs settle to the bottom of the basin and are removed via an underflow pipe.
- After flocs settle, the water passes through filters to remove finer particles and metals. The fine flocs that did not settle in the sedimentation chamber are removed at this stage. Water passes through pores of sand layers where the fine flocs are trapped. Some bacteria and virus are also removed at this stage.
- After the filtration process, the disinfection step is used to maintain a disinfectant residual in the finished drinking water to prevent growth of microorganisms in the reservoir and in the pipelines. A disinfectant commonly applied is chlorination since this disinfectant is effective and locally available. A chlorine solution needs to be injected at the end of treatment process before supplying the water to the consumers to ensure that the amount of chlorine residual meets the national standard.
- Over time the treatment plant results in a sludge build up. Therefore, backwash has to be done frequently to ensure the proper functioning of the filter. A sludge sedimentation tank needs to be installed nearby the plant to collect the sludge.

4.4.2 Clean Water Storage Tank

The capacity of the clean water storage tank is designed to store the clean water which can meet the high demand of 16 hours a day. As suggested by MISTI, the formula below is used to determine the size of the tank:

$$V = a(\frac{Q}{T_1} - \frac{Q}{T_2}) \times T_1$$

Where: *Q = Maximum daily water produced, m^3/h*

T_1 = Duration of high demand, h

T_2 = Duration of production

a = Peak hour coefficient

The peak hour coefficient is estimated to be 2 based on engineering practices. Based on the above equation the capacity of the clean water storage tank is estimated as shown in the table below. A detailed calculation is found in Table 11.

Table 11: The calculation of the size of the clean water storage tanks of the two systems

Determinants	System 1	System 2
Maximum daily water produced	195 m^3	294 m^3
Duration of high demand	16 hours	16 hours
Duration of production	20 hours	20 hours
Peak hour coefficient	2	2
Calculated capacity of the storage tank	$V = 2\left(\frac{195}{16} - \frac{195}{20}\right) \times 16 = 77.90\ m^3$	$V = 2\left(\frac{294}{16} - \frac{294}{20}\right) \times 16 = 117.80\ m^3$
Capacity of a storage tank	**80 m^3**	**120 m^3**

The clean water storage tank will be built under or near the treatment plant. The clean water from the treatment plant flows into the storage tank by gravity.

4.5 Distribution Pipe Network

4.5.1 Topographical Condition

According to data from Google Earth:

System1

The highest altitude in the service area is 123 meters above sea level in Trapeang Thma village, while the lowest altitude is 115 meters above sea level in the same village. The water station is located at an altitude of 120 meters above sea level. The location is deemed conducive as it is in the middle and at a high altitude. Google Earth also shows that the distance between the centers of each village is between 4.3 and 6.2 kilometers.

System2

The highest altitude in the service area is 99 meters above sea level in Rung Roeung village, while the lowest altitude is 85 meters above sea level in Kramom Bol village. The water station is located at an altitude of 89 meters above sea level. The location is deemed conducive as it is in the middle and at a high altitude. Google Earth also shows that the distance between the centers of each village is between 3.0 and 7.4 kilometers.

4.5.2 Distribution Pipe Network Design

The Hazen-Williams formula is used to determine the pipe sizes and the correspondent friction losses for the distribution networks. The design of the distribution network is based on the drivers and criteria listed in Table 12.

Table 12: Key design criteria used to compute the complete sizes of main pipes

Key calculation driver	Design criteria
Design period	The design period for the main pipe network is 10 years.
The hourly peak demand coefficient	It is estimated to be 2 based on engineering practices.
Water loss in the network	The water loss of the new system is estimated to be 10 % of the estimated consumption based on engineering practice.
Water velocity	The water velocity in the pipes ranges from 0.3 to 1.5 m/s to prevent particles clogging in the pipe and sedimentation building up.
Total pressure loss at year 10	The total pressure loss ranges from 2.0 to 4.0 bars.
Minimum residual pressure	It is designed to be 0.5 bar based on engineering practices.
The roughness of the pipe coefficient	140

Initially the pipe size is calculated using the pipe diameter equation below. Once the diameter of a section is found, the Hazen-Williams formula is used to verify the associated friction losses to ensure the safety of the pipe such that the friction loss of the main pipe ranges between 1 and 10 meters per kilometer or less than 40 meters for the whole length of the pipe. If the friction loss is outside this range, the pipe size is adjusted to a size that can dictate a friction loss which would be in the safety range. Iteration is needed. The pipe diameter equation is as follows:

$$D = \sqrt{\frac{4Q}{3600\ x\ \pi v}} \times 1000$$

$where: \ D = Inner\ pipe\ diameter, mm$

$Q = Flow\ rate, m^3/h$

$v = Velocit, {}^{m}/_{s}$

The total friction losses are calculated by the formula of Hazen-Williams which stipulates that:

$$H_f = \frac{1.21 \times 10^{10} \times L \times \left(\frac{q}{C}\right)^{1.852}}{D^{4.87}}$$

where:

L = Distance between section 1 and section 2, m

D = Inner pipe diameter, mm

q = Flow rate, m^3/h

c = Roughness coefficient

Since the raw water pipe is connected from the source water to the treatment plant and the treatment plant is designed for 5 years, the raw water pipe is also designed for 5 years. Using the equation stipulated above, the raw water pipe size is calculated in the table below. Table 13 illustrates the calculation of the raw water pipe size.

Table 13: Calculation of the raw water pipe size and its correspondent friction loss

1-Calculate raw water pipe diameter, mm		
Description	**System 1**	**System 2**
Flow rate	9.74 m^3/hour	14.72 m^3/hour
Velocity	1 m/s	1 m/s
Calculated Pipe diameter	$\sqrt{\frac{4 \times 9.74}{\pi \times 1 \times 3600}} \times 1000 = 58.69\ mm$	$\sqrt{\frac{4 \times 14.72}{\pi \times 1 \times 3600}} \times 1000 = 72.16\ mm$
Selected pipe diameter	90 mm with inside diameter of 81.4 mm (to ensure design safety and cost efficiency for high elevation topography and length)	90 mm with inside diameter of 81.4 mm (to ensure design safety and cost efficiency for high elevation topography and length)
2- Calculate its correspondent fiction loss, m		
Flow rate	9.74 m^3/hour	14.72 m^3/hour
Length	2638 m	318 m
Calculated friction loss	$\frac{1.21 \times 10^{10} \times 2638}{81.4^{4.87}} \times \left(\frac{9.74 \times 1000}{140 \times 3600}\right)^{1.852} = 10.59m$	$\frac{1.21 \times 10^{10} \times 318}{81.4^{4.87}} \times \left(\frac{14.72 \times 1000}{140 \times 3600}\right)^{1.852} = 2.75\ m$
Judgment	Checked and acceptable as 10.59 m is in the safety range.	Checked and acceptable as 2.75 m is in the safety range.

High Density Polyethylene (HDPE) PE100 is selected as pipe material because it lasts longer than Polyvinyl Chloride (PVC). It is easy to install, maintain, and less vulnerable to damage and corrosion. Pipes are aligned along each side of the road to minimize pipes crossing the roads too often. Cross connections are done at bridges or culvert boxes to avoid cutting across the roads. On small roads where houses are sparsely aligned, a pipeline at only one side of the road is planned. The designed pipe network is shown in figure 23 and figure 24.

Figure 23: Distribution network of the service area for system1

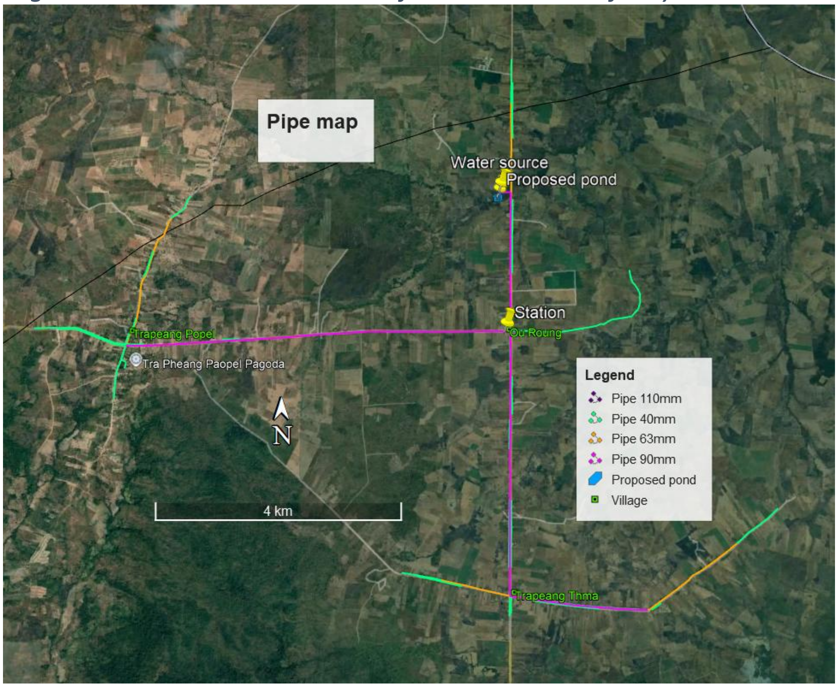
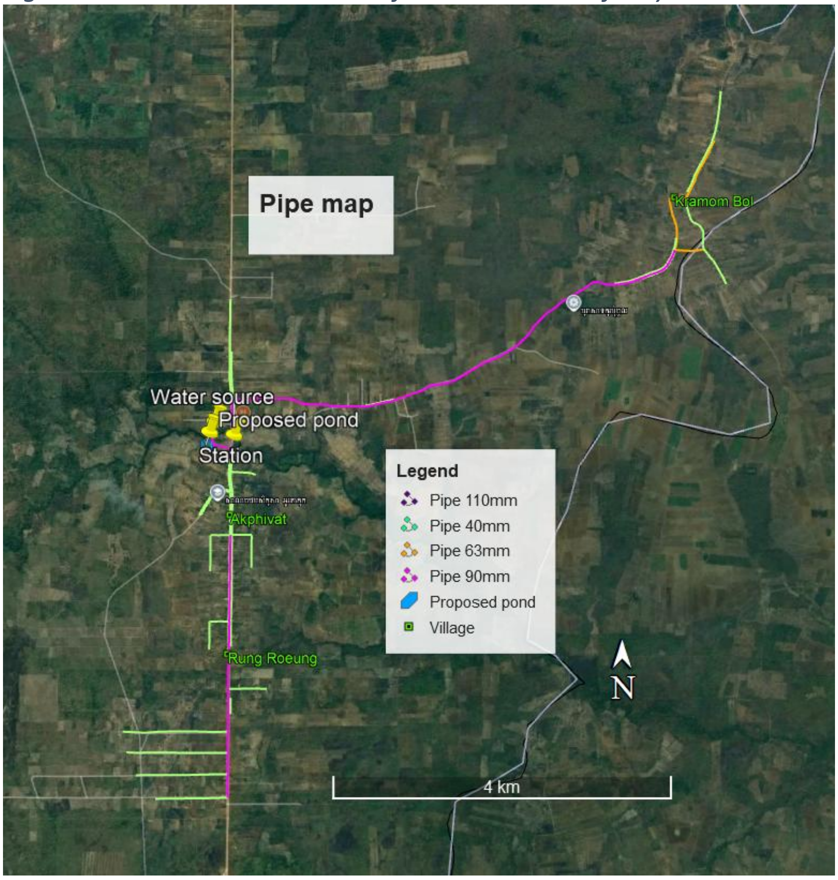


Figure 24: Distribution network of the service area for system2



All pipe sections in the network are modelled to calculate the total friction losses. The pipeline with the highest total head loss determines the pipe size and pump selection. The above-stipulated Hazen-Williams formula shows the highest friction loss as follows:

For system1

- Year 5: 10.28 meters water column (for pump head design)
- Year 10: 27.67 meters water column (for pipe size design)

For system2

- Year 5: 7.67 meters water column (for pump head design)
- Year 10: 34.93 meters water column (for pipe size design)

Detailed pipe sizes and lengths are shown in Table 14. The distribution network and mapping can be found in the Appendix section.

Table 14: Length of pipe network by village in the service area of the two systems

System	Commune	Village	Ø40	Ø63	Ø90	Ø110	Sub-Total
System1	Ta Siem	Raw Water	-	-	2,638	-	**2,638**
		Trapeang Popel	3,957	2,263	6,213	-	**12,433**
		Trapeang Thmar	8,343	2,942	6,499	-	**17,784**
		Ou Roung	9,719	3,823	-	121	**13,663**
System2	Kantuot	Raw Water	-	-	318	-	**318**
		Akphivath	9,760	-	2,374	1,064	**13,198**
		Rong Roeung	5,579	-	3,078	-	**8,657**
		Kramom Bol	4,115	1,989	4,204	-	**10,308**
Total			**41,473**	**11,017**	**25,324**	**1,185**	**78,999**

4.6 Pump System and Electricity Consumption

In the water supply system, two types of pumps are required:

- Raw water pumps: used for pumping raw water from the source water to the treatment plant.
- Clean water pumps and/or booster pumps: A clean water pump is used for pumping clean water from the clean water storage to a water tower. If a booster pump is used instead of a water tower a clean water pump is unnecessary. The booster pump is used to distribute water from the clean water storage tank to consumers.

The capacity of pumps is computed with the below equation:

$$PP = \frac{\rho \times g \times Q \times H}{h}$$

$where:$

$$PP = Pump\ capacity, W$$
$$\rho = Water\ density, kg/m^3$$
$$g = Gravity\ force, m/s^2$$
$$Q = Designed\ flow, m^3/s$$
$$H = Total\ head, m$$
$$h = Total\ efficiency, \%$$

To estimate the capacity of the pumps, the following data are needed:

- Pump designed flow
- Total pump dynamic head
- Total pump efficiency

4.6.1 Booster Pump

In these projects, booster pumps are used. The pumps are designed to meet water demand during peak hours in year 5. It is decided that three booster pumps are used to optimize operation and investment costs and ensure reliability. The two booster pumps will be routinely interchanged while one is for operation and another one is used as a backup. However, it is difficult to find a booster pump with a very small capacity in the market. Therefore, for a small system, only two booster pumps are used due to the increased capacity of the pump. The two booster pumps will be routinely interchanged, with one in operation and one as a backup.

System1

As stipulated in the pipe network design section, the total friction loss of the longest pipe network at year 5 is 10.28 meters. Added to this are minor losses of 10% (1.03 meters), elevation head of 3 meters, and residual pressure of 5 meters. An additional safety factor of 1.2 is added. The calculation of the total pressure head for the booster pump is shown below:

$$Total\ pump\ head = (10.28\ m + 1.03\ m + 3\ m + 5\ m) \times 1.2 = 23.17\ \boldsymbol{m}$$

Therefore, a total pump head of 23.17 meters is required at a volume of 14.90 m^3/hour. Since the system uses one pump, the flow rate for the pump is 14.90 m^3/hour. Table 15 illustrates the calculation of the capacity of a booster pump.

Table 15: Calculation of the capacity of a booster pump

Water density	Gravity force	Total head	Designed flow rate	Efficiency	Pump capacity
1,000 kg/m^3	9.81 m/s^2	23.17 m	14.90 m^3/h	50%	$=\frac{23.17\times14.90\times1000\times9.8}{0.5\times3600000} = 1.88\ kW$

The next size available on the market is 2.2 kW. Hence, two booster pumps with the power of **2.2 kW** each are required for the entire system, and an inverter is also needed to save electricity cost.

System2

As stipulated in the pipe network design section, the total friction loss of the longest pipe network at year 5 is 7.67 meters. Added to this are minor losses of 10% (0.77 meters), elevation head of 10 meters, and residual pressure of 5 meters. An additional safety factor of 1.2 is added. The calculation of the total pressure head for the booster pump is shown below:

$$Total\ pump\ head = (7.67\ m + 0.77\ m + 10\ m + 5\ m) \times 1.2 = 28.12\ \boldsymbol{m}$$

Therefore, a total pump head of 28.12 meters is required at a volume of 22.67 m^3/hour. Since the system uses one pump, the flow rate for the pump is 22.67 m^3/hour. Table 16 illustrates the calculation of the capacity of a booster pump.

Table 16: Calculation of the capacity of a booster pump

Water density	Gravity force	Total head	Designed flow rate	Efficiency	Pump capacity
1,000 kg/m^3	9.81 m/s^2	28.12 m	22.67 m^3/h	50%	$=\frac{28.12\times22.67\times1000\times9.8}{0.5\times3600000} = 3.47\ kW$

The next size available on the market is 3.7 kW. Hence, two booster pumps with the power of **3.7 kW** each are required for the entire system, and an inverter is also needed to save electricity cost.

4.6.2 Raw Water Pump

The raw water pump is designed to meet the water demand in year 5 and to be able to pump raw water from the water source to the top level of the treatment plant. Two raw water pumps are required. One is used in the operation while another one is used as a backup. The calculation of the raw water pump capacity is shown table 17 below.

Table 17: Calculation of the capacity of the raw water pumps

System1	System2
The designed flow rate of the raw water pump is 9.74 m^3/hour.	The designed flow rate of the raw water pump is 14.72 m^3/hour.
The raw water pump head is the addition of the raw pipe friction loss of 10.59 meters, minor loss (10%), elevation head of 24 meters, and the top level of the treatment plant of 4 meters with a safety factor of 1.2. $Pump\ head = (10.59 + 1.06 + 24 + 4) \times 1.2 = 47.58\ m$	The raw water pump head is the addition of the raw pipe friction loss of 2.75 meters, minor loss (10%), elevation head of 6 meters, and the top level of the treatment plant of 4 meters with a safety factor of 1.2. $Pump\ head = (2.75 + 0.28 + 6 + 4) \times 1.2 = 15.63\ m$
The capacity of the raw water pump is $PP = \frac{9.74 \times 47.58}{0.5 \times 3600000} \times 1000 \times 9.81 = 2.53\ kW$	The capacity of the raw water pump is $PP = \frac{14.72 \times 15.63}{0.5 \times 3600000} \times 1000 \times 9.81 = 1.25\ kW$
The next size available in the market is **3.0 kW**.	The next size available in the market is **1.5 kW**.

4.6.3 Pump summaries

The summary of characteristics of the booster pumps and the raw water pump are found in Table 18 and Table 19 below.

Table 18: Summary of characteristics of booster pumps

Description	System 1	System 2
Number of pumps	One pump in operation + one backup	One pump in operation + one backup
Flow rate	14.90 m^3/h	22.67 m^3/h
Total pump head	23.17 m	28.12 m
Pump efficiency	50 %	50 %
Pump capacity	2.2 kW	3.7 kW
Inverter	Yes	Yes
Control panel	Yes	Yes
Pump accessories	Wiring cable, pressure gauge, fitting, supports, and pumps base plate	Wiring cable, pressure gauge, fitting, supports, and pumps base plate

Table 19: Summary of characteristics of raw water pumps

Description	System 1	System 4
Number of pumps	One pump in operation + one backup	One pump in operation + one backup
Flow rate	9.74 m^3/h	14.72 m^3/h
Total pump head	47.58 m	15.63 m
Pump efficiency	50 %	50 %
Pump capacity	3.0 kW	1.5 kW
Inverter	No	No

Control panel	Yes	Yes
Pump accessories	Wiring cable, pressure gauge, fitting, supports, and pumps base plate	Wiring cable, pressure gauge, fitting, supports, and pumps base plate

4.6.4 Electricity Consumption

Electricity cost is one of the crucial costs that affect the cash flow. For simplicity, the electricity cost is estimated per cubic meter of water.

The electricity consumption of a raw water pump is simply the multiplication of pump power and pumping duration.

The booster pump is attached with an inverter that can save energy usage. If the actual power consumption is lower than the pump power, the inverter will save electricity up to 30% based on the pump expert's opinion. Since the actual power consumption is varied hourly depending on the water consumption, power consumption by booster pumps is estimated every hour, the sum of which results in the total power consumption per day.

System1

The electricity consumption of a raw water pump is estimated at 50.50 kWh/day.

The electricity consumption of a booster pump is estimated at 33.11 kWh/day.

The electricity consumption per m^3 of water is the ratio of total power consumption (of raw and booster pump) and water produced per day. The electricity consumption is estimated to be **0.429 kWh/m^3**. A detailed calculation can be found in Table 20:

Table 20: Electricity consumption calculation

Pump type	Pump power (kW)	Total power used per day (kWh/day)
Raw water pump	2.53	$2.53 \times 20 = 50.50\ kWh/day$
Booster pump	1.88	33.11 kWh/day
Total		83.61 kWh/day
Water produced per day (m^3)	$9.74 \times 20 = 195m^3$	
Power consumption per m^3	$= \frac{83.61\ kW/day}{195\ m^3/day} = 0.429\ kWh/m^3$	

System2

The electricity consumption of a raw water pump is estimated at 25.09 kWh/day.

The electricity consumption of two booster pumps is estimated at 61.05 kWh/day.

The electricity consumption per m^3 of water is the ratio of total power consumption (of raw and booster pump) and water produced per day. The electricity consumption is estimated to be **0.292 kWh/m^3**. A detailed calculation can be found in Table 26:

Table 21: Electricity consumption calculation

Pump type	Pump power (kW)	Total power used per day (kWh/day)
Raw water pump	1.25	$1.25 \times 20 = 25.09\ kWh/day$
Booster pump	3.47	61.05 kWh/day
Total		86.13 kWh/day
Water produced per day (m^3)	$14.72 \times 20 = 294\ m^3$	

Power consumption per m^3	$= \frac{85.13\ kW/day}{294\ m^3/day} = 0.292\ kWh/m^3$

5. Investment Cost

Table 22 and 23 list all majority additional investments required to operate a piped-treated water business in this service area. The total cost of the 2 systems is estimated to be **433,889 USD.**

Table 22: Total investment cost of system1

Water Production System	Description	Cost (USD)
Electricity connection	63A	1,500
Pond Excavation	48,111 m^3	40,895
Pumping Station	1 unit	1,000
Water Treatment Plant	10 m^3/h	21,870
Water Storage Tank	80 m^3	13,747
Raw Water Pumps (one backup)	3 kW; 2 units	2,090
Booster Pumps (one backup)	2.2 kW; 2 units and inverter	3,530
Office building	1 unit	4,000
Warehouse	1 unit	4,000
Toilet	1 unit	3,000
Sub-Total		**95,632**

Distribution Pipe Network	Length (m)	Cost (USD)
HDPE Pipe 40 mm	22,019	35,891
HDPE Pipe 63 mm	9,028	26,091
HDPE Pipe 90 mm	15,350	68,922
HDPE Pipe 110 mm	121	756
Sub-Total	**46,518**	**131,660**

Others	Description	Cost (USD)
Test Kits	1 unit	700
Motorbike	1 unit	1,000
Computer	1 unit	500
Printer	1 unit	350
Phone	1 unit	150
Sub-Total		**2,700**

Total Investment Cost of System1		**229,992**

Table 23: Total investment cost of system2

Water Production System	Description	Cost (USD)
Electricity connection	63A	1,500
Pond Excavation	72,751 m^3	61,839
Pumping Station	1 unit	1,000
Water Treatment Plant	15 m^3/h	26,341
Water Storage Tank	120 m3	17,380
Raw Water Pumps (one backup)	1.5 kW; 2 units	1,695

Booster Pumps (one backup)	3.7 kW; 2 units and inverter	5,101
Sub-Total	**-**	**114,856**

Distribution Pipe Network	Length (m)	Cost (USD)
HDPE Pipe 40 mm	19,454	31,710
HDPE Pipe 63 mm	1,989	5,748
HDPE Pipe 90 mm	9,974	44,783
HDPE Pipe 110 mm	1,064	6,650
Sub-Total	**32,481**	**88,891**

Others	Description	Cost (USD)
Phone	1 unit	150
Sub-Total		**150**

Total Investment Cost of System2		**203,897**

Note: The cost of infrastructure facilities above does not include the cost of land, the structural design drawing and supervision cost for construction.

6. Business Plan Over 5 Years

This section explains the projected expenses of the water business over 5 years based on the following key drivers:

Table 24: Total investment cost

Key drivers	Value	Reference
Number of standby staff at each system	1 staff per system	Assumption
Wage of standby staff	250 USD/staff/month	Assumption
Number of additional staff at the central office	1 supervisor staff	Assumption
Wage of additional staff at the central office	400 USD/month	Assumption
Electricity Consumption	0.292 – 0.429kWh/m^3	Technical calculation
Price of electricity	730 KHR/kWh	The commune chiefs
Chemicals	0.02412 USD/m^3	Engineer's common practice
Inflation rate	3%	Institute of Statistics of Cambodia
Maintenance	1 % of Plant, Property, and Equipment	Assumption
Billing and Collection	100 KHR/connection	Assumption
Communication and travel	250 USD/month	Assumption
Supplies	50 USD/month	Assumption

6.1 Expenses

6.1.1 Direct Expenses

Most direct expenses are variable. They are directly correlated with the volume of water produced. The exception is the maintenance cost which is modelled as a fixed cost. Table 25 below reports the projected direct expenses of the business over 5 years based on the projected number of connections in 4.1.1..

Table 25: Direct expenses over 5 years

Description	Unit	Year 1	Year 2	Year 3	Year 4	Year 5
Connection rate	%	20%	30%	40%	50%	60%
Quantity of water produced	m^3/year	21,898	54,823	77,069	100,442	124,968
Chemical expense	USD	528	1,362	1,972	2,647	3,393
Electricity expense	USD	1,384	3,465	4,871	6,349	7,899
Maintenance and Repair	USD	3,312	3,312	3,312	3,312	3,312
Total Direct Expenses	**USD**	**5,224**	**8,139**	**10,155**	**12,308**	**14,603**

Note: Chemical expense/m^3 is being adjusted for inflation of 3% per year.

6.1.2 Overhead Expenses

Table 26 reports the projected overhead expenses of the business over 5 years. Overhead costs are all fixed expenses and remain stable even if water production grows. It is only being adjusted for inflation.

Table 26: Overhead expenses over 5 years, in USD

Description	Unit	Year 1	Year 2	Year 3	Year 4	Year 5
Salaries	USD	10,800	11,124	11,458	11,801	12,155
Billing and collection	USD	102	154	207	263	319
Communications	USD	3,000	3,000	3,000	3,000	3,000
Supplies	USD	600	600	600	600	600
Patent fee	USD	100	100	100	100	100
Total Overhead Expenses	**USD**	**14,602**	**14,978**	**15,365**	**15,764**	**16,175**

Note: Only salary and billing and collection are being adjusted for inflation of 3% per year.

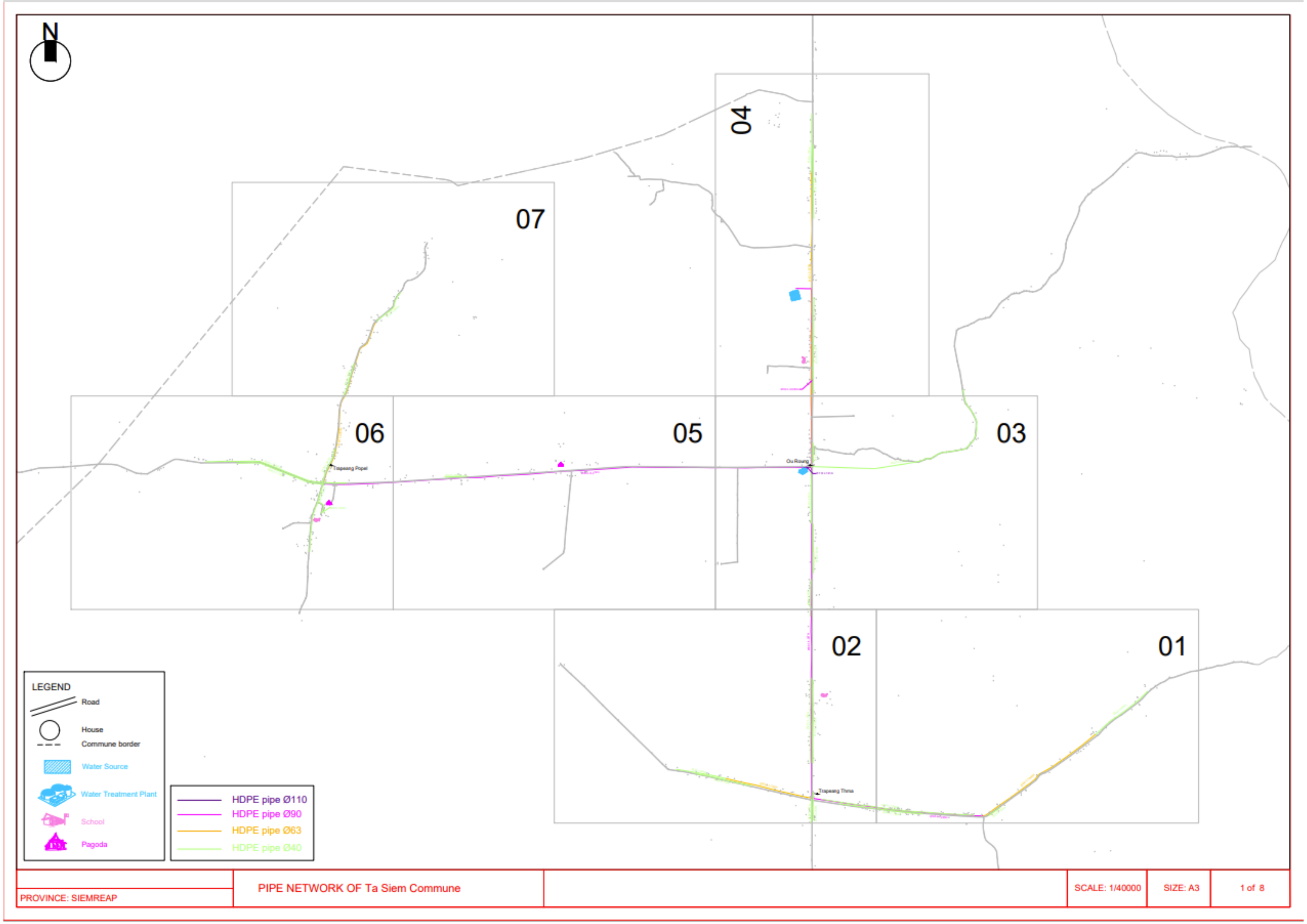
6.1.3 Direct and Overhead Expenses

Table 27 shows all projected expenses of the business over 5 years.

Table 27: Total expenses over 5 years, in USD

Description	Unit	Year 1	Year 2	Year 3	Year 4	Year 5
Total Direct Expenses	USD	5,224	8,139	10,155	12,308	14,603
Total Overhead Expenses	USD	14,602	14,978	15,365	15,764	16,175
Direct and Overhead Expenses	**USD**	**19,826**	**23,117**	**25,520**	**28,071**	**30,778**

Appendix 1: Distribution pipe network of the service area for system1



Appendix 2: Distribution pipe network of the service area for system2