Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY FOR SABRANG AND NAF TOURISM PARK

Final Report (Phase-1)

November, 2020

INSTITUTE OF WATER MODELLING (IWM)

Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY FOR SABRANG AND NAF TOURISM PARK

Final Report (Phase-1)

November 2020

INSTITUTE OF WATER MODELLING

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AE	Assistant Engineer
APHA	American Public Health Association
BEZA	Bangladesh Economic Zone Authority
BIWTA	Bangladesh Inland Water Transport Authority
BM	Bench Mark
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BOD	Biological Oxygen Demand
BOD_5	5 Day BOD
BOQ	Bill of Quantities
BOT	Build-operate-transfer
BTM	Bangladesh Transverse Mercator projection
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
BWRO	Brackish Water Reverse Osmosis
CIP	Clean-In-Place
COD	Chemical Oxygen Demand
CTFB	Chittagong Tripura Fold Belt
DAF	Dissolved Air Flotation
DBO	Design-build-operate
DEM	Digital Elevation Model
DFR	Draft Final Report
DHI	Danish Hydraulic Institute
DO	Dissolved Oxygen
DPHE	Department of Public Health Engineering
EC	Electrical Conductivity
EZ	Economic Zone
FAP	Flood Action Plan
FC	Fecal Coliform
GoB	Government of Bangladesh
GPS	Global Positioning System
GIS	Geographic information system
GDEM	Global Digital Elevation Model
GNSS	Global Navigation Satellite System
GSB	Geological Survey of Bangladesh
GW	Groundwater
HD	Hydrodynamic
HDPE	High density polyethylene
IBR	Indo-Burman Ranges
IRP	Iron Removal Plant
IWM	Institute of Water Modelling
Km	Kilometre
m	Metre
lcpd	Litre per Capita per Day
MED	Multi-effect Distillation
MF	Microfiltration
MGD	Million Gallon per Day

MLD	Million Litter Per Day
MSF	Multi-stage Flash Evaporation
MSL	Mean Sea Level
O&M	Operation and Maintenance
PTW	Production Tube Well
PwC	PricewaterhouseCoopers Pvt Ltd
PWD	Public Works Department
PWL	Piezometric Water Level
Q	Discharge
RO	Reverse Osmosis
RR	Rainfall-Runoff
RTK	Real Time Kinematic
RWHS	Rainwater harvesting System
RWH	Rainwater harvesting
SE	Superintendent Engineer
SoB	Survey of Bangladesh
SPV	Special Purpose Vehicle
SW	Surface Water
SWL	Shallow Water Level
SWRO	Sea Water Reverse Osmosis
SWTP	Surface Water Treatment Plant
TBM	Temporary Bench Mark
TC	Total Coliform
TDS	Total dissolved solids
TP	Tourism Park
TSS	Total suspended solids
TTW	Test Tube Well
TRDI	Teledyne RD Instruments
UTM	Universal Transverse Mercator
UF	Ultrafiltration
UWF	Unaccounted For Water
VES	Vertical Electrical Sounding
WL	Water Level
WMP	Water Management Plan
WS	Water Supply
WQ	Water Quality
WRP	Water Recourses Planning
WTP	Water Treatment Plant

EXECUTIVE SUMMARY

E.1 Introduction

With a view to encourage rapid economic development Bangladesh Economic Zones Authority (BEZA) has selected Naf and Sabrang area in Teknaf upazila of Cox's Bazar district to develop as economic zones for recreational and tourism purposes. The proposed Sabrang Tourism Park comprise an area of 1048 acres (424 hectares), 96km away from Cox's Bazar town and runs parallel to Teknaf-Shahparirdwip highway (Z1099). The proposed Naf Tourism Park is an Island to be designated as economic zone with covering an area of 271.93 acres (110 hectares) approximately 80 kms from the Cox's Bazar and besides Cox's Bazar-Teknaf National Highway (N1). The study area is shown in **Figure E.1**.

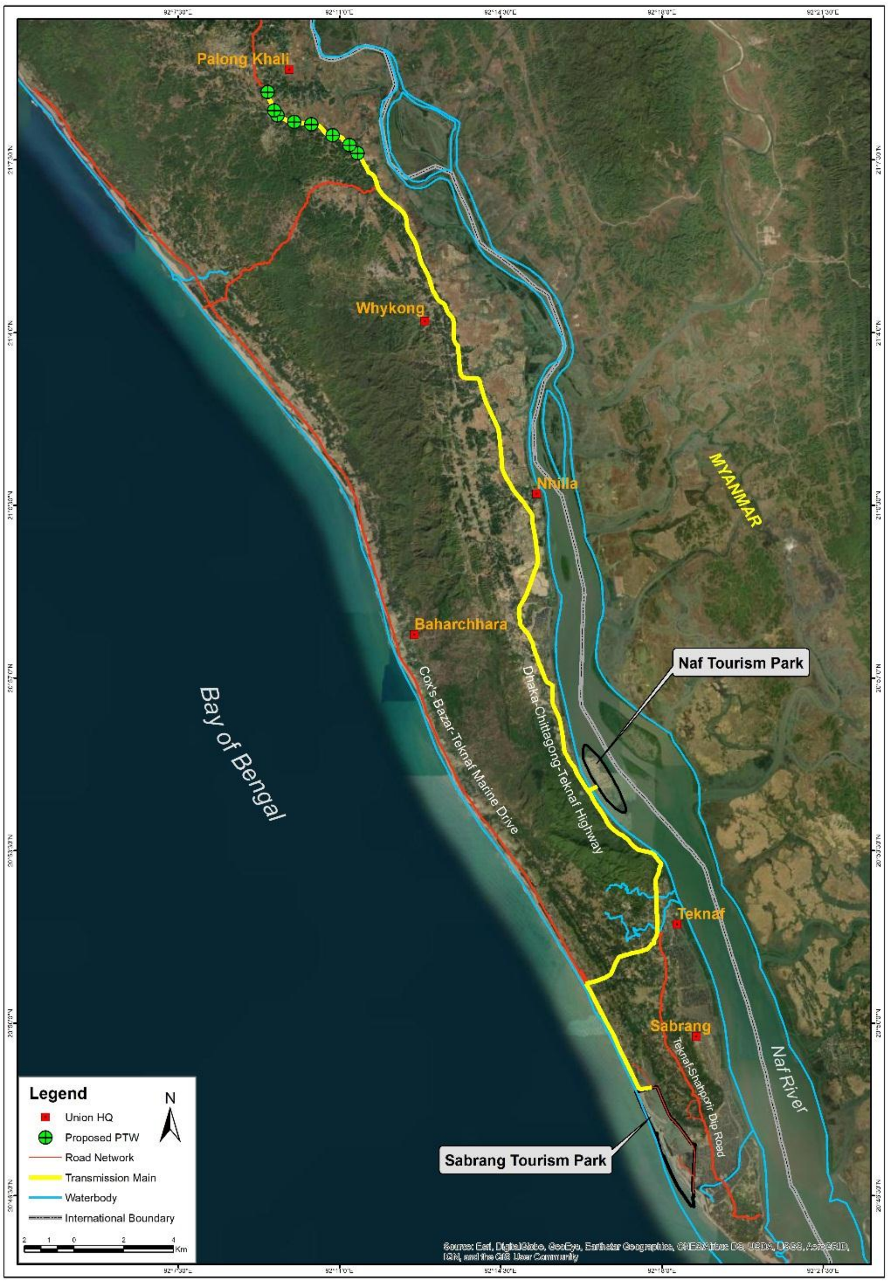


Figure E.1: Location map of the study area with proposed transmission main

The main objective of this study is to prepare a water supply master plan to fulfill water demand for Naf and Sabrang Tourism Park in the context with water availability and demand. The study work is divided in two phases. The objective of Phase-1 is to assess groundwater availability in and around the EZs particularly in Nhila, Teknaf. In Phase-2 water management plan including design of water supply related works will be completed.

The activities accomplished in Phase-1 is listed below:

- Water demand estimation for the two tourism parks;
- Secondary lithological data collection of the study area;
- Test tube wells construction and lithological analysis at 17 locations;
- Construction of two production tube wells and two long term aquifer tests;
- Water level and discharge measurement in Naf river and analysis;
- Surface water quality sampling, testing and analysis of Naf River;
- Assessment of roof top rainwater harvesting;
- Dam and reservoir analysis in Teknaf;
- Analysis of desalination plant;
- Assessment of bottling water plant;
- Preparation of water management plan in Sabrang and Naf tourism park;
- Tentative cost estimation

E.2 Demand Assessment

Following design criteria pertaining for estimating water demand is shown in **Table E.1**.

Table E.1: Design Criteria for computing water demand

Design Criteria	Considerations
No of Population	As per Master Plan projection
Coverage by Piped Water Supply	100%
Connections by Piped Water Supply	100%
Per Capita Water Demand for different usages (lpcd)	BNBC
Unaccounted For Water (UFW) %	20
Loss through WTP in %	5

Sabrang Tourism park area is divided into 5 major categories: public facilities including leisure & tourism, accommodation, utilities, administration and transportation in the Master Plan which will occupied 406.8 acres area. It is proposed that maximum about 35,785 nos. of tourist will visit and leave in the Tourism Park daily and about 4,700 nos. employee will be required to serve and facilitate them. Thus total population projection for the tourism park is about 40,485 nos. To fulfill their water requirement required production capacity would be about 10.0 MLD after full development in 2049.

Naf Tourism park area is divided into 5 basic zones in the Master Plan as accommodation, commercial space, open space, service and utility area and transportation area within area of about 269.8 acres. It is proposed that maximum about 3,665 nos. of tourist will visit and leave in the Tourism Park daily and about 1,225 nos. employee will be required to serve and facilitate them. Thus total population projection for the tourism park is about 4,890 nos. To fulfill their water requirement required production capacity would be about 1.15 MLD after full development in 2049.

E.3 Groundwater Investigation and Resource Assessment

Hydrogeological Investigation

For water resource potential assessment, hydrogeological data have been collected from different organizations/agencies.

Besides the above information, IWM has constructed 9 nos. test tube wells for delineation of potential aquifer. Two number of production wells and 08 nos. observation wells (04 nos. observation with each production well) have been installed in the project area at Puranpara, Shamlapur and Katakhali, Whykhong after finding potential aquifer.

Two long term aquifer tests (72 hour) were conducted in Shamlapur and Whykhong area with discharge capacity of 0.375 cusec and 0.625 cusec for determination of aquifer properties of the area followed by a recovery test. Transmissivity of dominantly fine sand aquifer of this area is calculated from aquifer pump test data at Puranpara, Shamlapur and Katakhali, Whykhong. Transmissivity depends on permeability. Permeability of these aquifers is also very low 0.8928 m/d and 2.031 m/d for Shamlapur and Whykhong area, respectively. Computed transmissivity at Shamlapur was 26 sqm/day and at Whykhong 65 sqm/day approximately.

Tipam and/or Upper Boka Bil Formation are highly heterogeneous and presence of calcareous band of variable length and thickness makes the studied aquifer discontinuous both laterally and vertically. The pump test results also reflect the complexity of the aquifer. Recorded responses during pump test and recovery time in observation wells as well as the main well clearly suggest lateral and vertical discontinuity of the aquifer.

Groundwater Resource Assessment

Based on the available data, groundwater resource volume has been calculated by using Depth-Storage (d-s) model. Prospective groundwater development area is divided into 2 zones, Zone-A (Whykhong area) and Zone-B (Shamlapur area). Based on the subsurface lithology and structural configuration, area of Zone-A is taken as 16.3 km^2 and Zone-B is taken as 3.0 km^2. Target drawdown can be taken as 5 m for estimating the available water resource. As per d-s model the available groundwater resource at maximum lower limit of 5m are as follows:

For Zone-A, groundwater resource is $16.3\ km^2 \times 0.10 \times 5\ m = 8.15\ Mm^3$

For Zone-B, groundwater resource is $3.0\ km^2 \times 0.07 \times 5\ m = 1.05\ Mm^3$

From aquifer test data analysis, it is observed that aquifer condition of Whykhong area is better than Shamlapur area. Pumping test conducted at Whykhong with higher rate (0.625 cusec) than Shamlapur (0.375 cusec) and drawdown is less than Shamlapur. More importantly recovery period is only 5 hours 30 minutes at Whykhong area and 14 hours at Shamlapur area. Considering the discharge rates of 0.5 cusec for 08 nos. PTW and a 17-hour operation window, there is a possibility to extract about ≈ 7.0 MLD or 2.54 million m^3 / year groundwater from the Whykhong area. Possible extraction volume of 2.54 million m^3 is only 31.16% of estimated resource of the whykhong area catchment.

Safe yield

Bangladesh Water Act 2013 requires the following for safer groundwater abstraction from any aquifers in the country:

a) Identify the safe limit for sustainable groundwater abstraction under present and future conditions;
b) Assess future water uses and identify possible conflicts with abstraction;
c) Depletion under different scenarios of groundwater use and potential recharge.

The estimated Potential Recharge is calculated on projected future water level fluctuation (with no rejection) and average specific yield values within the range of water level fluctuation. The net fluctuation under natural cycle of recharge and discharge (considering recharge rejection) would be approximately 2.0 m.

Considering the uncertainty of data, the potential recharge is also seen to be within a band of 25% to judge the sensitivity to abstraction under future demand scenarios.

	(0.75 * SY) (Mm^3)	Safe Yield (SY)(Mm^3)	(1.25 * SY) (Mm^3)
Potential Recharge	1.05	1.4	1.75

Increased demand has been tested under three scenerios (**Figure E.2**) of water resources availability considering the uncertainty attached to estimated Safe yield.

According to plan of demand to be implemented groundwater abstraction will increase in phases from 1.06 Mm^3/year to 2.54 Mm^3/year with different development stage of Naf and Sabrang Tourism Park. Scenario 1 is representing estimated recharge and planned abstraction and consequent drawdown in the aquifer against net abstraction. Negative portion of the graph represent net abstraction positive, I.e. abstraction is less than annual recharge volume (1.40 mm^3) and such condition will continue up to 2037 (Abstraction will be 1.84 mm^3/year). Same scenario will cross, planned 5-meter drawdown level in 2044 to 2045 and in end of 2049 drawdown in aquifer will be 11.73 m.

With 25% more recharge (Scenario 2) abstraction exceeds recharge in time beyond 2046, at least 11 year after the same thing happened with scenario 1. With 25% less recharge (Scenario 3), groundwater abstraction exceeds recharge in 2029 almost 8 year earlier than with Scenario 1 and drawdown in aquifer will cross planned 5 meter after 2036.

The actual situation in place need to be observed as soon as abstraction starts. It is expected that induced recharge will follow as soon as abstraction is imitated and under that case net drawdown in aquifer might be much less.

Aquifer conditions in the hilly areas are generally poor in terms of the recharge and aquifer properties. A good groundwater management under the condition requires monitoring of abstraction (local use, Tourism Park), review of recharge estimate, water quality and groundwater water level fluctuations as the development goes on. The area is in geologically complex (folding and faulting), having very low yield. Therefore, increase in abstraction under future development scenario needs close monitoring to understand aquifer response and bring the safe limit within a narrow range of confidence limit.

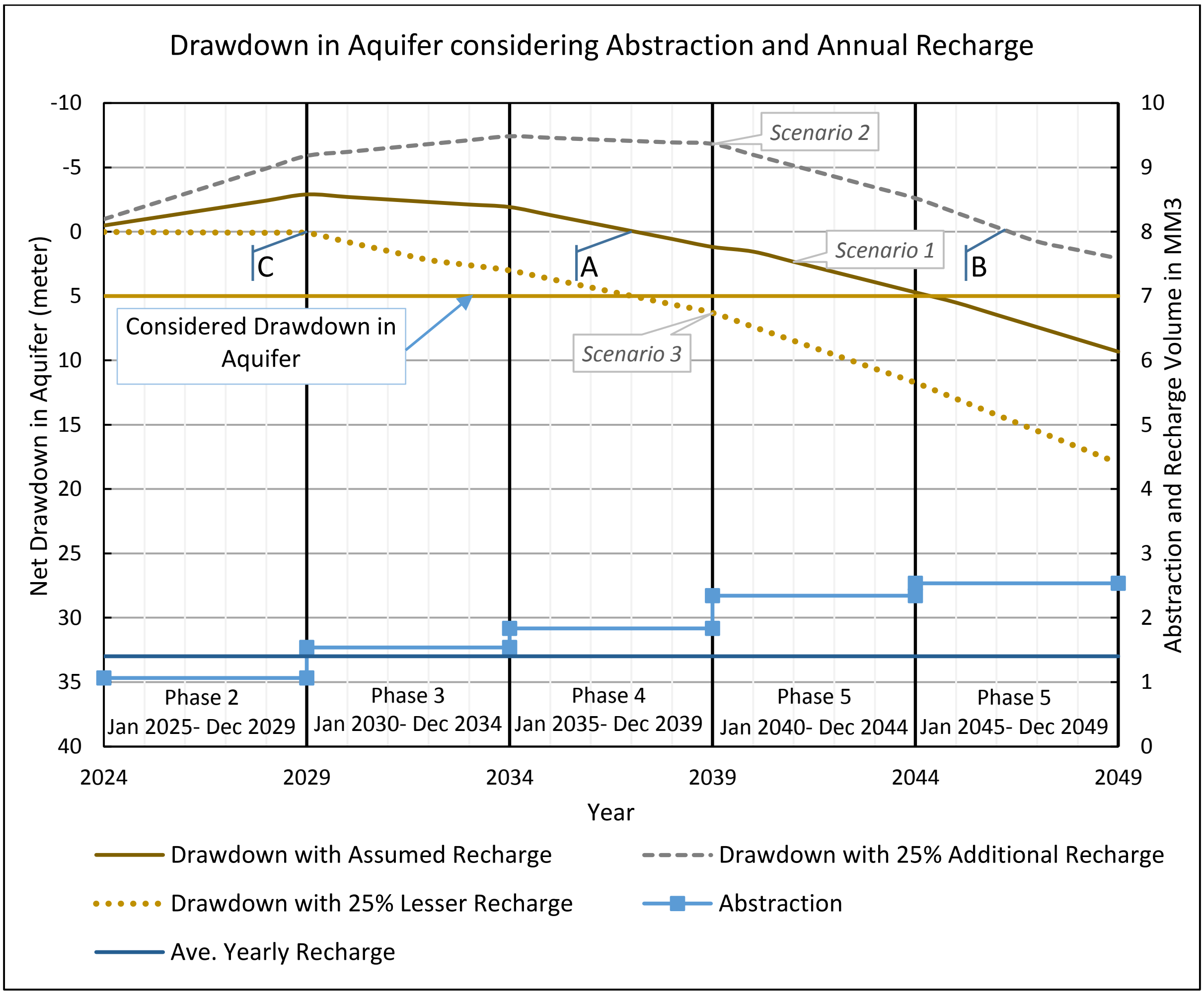


Figure E.2: Drawdown in aquifer due to planned abstaction considering assumed recharge with 25% additional and lesser recharge factor

E.4 Rainwater harvesting

The harvested rainwater can be used for non-potable water use like toilet flushing, floor cleaning, gardening, car washing etc. It has been observed that about more than 50% water of total requirement is used for non-potable usage. In Sabrang and Naf the non-potable water requirement is more than 3.85 MLD and 0.45 MLD respectively. So the harvested rainwater can fulfill partial demand of non-potable water usages.

The area proposed for accommodation, administration, welfare centre, old age home, shopping district and Heritage Museum, Convention Centre, Amphitheatre with an area of about 220.5 acre can be considered as potential for rainwater harvesting in Sabrang Tourism Park. In Master Plan it is suggested that the maximum permissible building height in Sabrang is G+10 and minimum plot area is about 0.3 acre which is suitable for rainwater harvesting. For using the water throughout the year about 0.73 MLD water can be available from roof top rainwater harvesting and maximum storage requirement is 140 Million lt. If the tank size is considered on average 860m^3 (including freeboard of 10%) then total 180 nos. of tank is required.

The total catchment area suitable for rainwater harvesting in Naf Tourism Park is about 17.92 acre which is reserved for hotels, apartments and central space, and maximum permissible building height is G+3 which is suitable for rain water harvesting. For using the water throughout the year about 0.22 MLD water can be available from roof top rainwater harvesting and maximum storage requirement is 47 Million lt. If storage tank is considered 63 nos. (total effective building is 62 nos.) then the average tank size is about 830m^3 (including freeboard of 10%).

E.5 Teknaf Reservoir-Dam Analysis

A dam on the foothills of north of Teknaf Pourashava is proposed to capture and store rainfall-runoff from the upstream hilly catchment. The feasibility study of this dam is now being carried out by IWM under *Emergency Multi-Sector Rohingya Crisis Response Project (EMCRP)* of DPHE.

The total catchment area of the proposed reservoir is about 102.1 ha (≈1km^2) and maximum storage elevation would be 27 m, MSL which corresponds to a storage volume 1.9 Mm^3. Deducting the dead storage, the proposed reservoir can supply 1.68 Mm^3 of water to meet the demand Teknaf Pourashava and Sabrang TP (Partially).

A treatment plant is planned to be constructed near Teknaf Pourashave to treat the water of the reservoir. The capacity of the treatment plant will be 400 m^3/hr and 1,412 m^3/d water will be available for Sabrang Tourism Park after fulfilling the water demand of Teknaf Pourashava.

The treated water transmission main from the treatment plant will be intersected with the groundwater transmission main from Whykhong well field and the network will carry combined water from the production wells in Whykhong and Teknaf surface water treatment plant water to Sabrang Tourism Park. The proposed treatment plant is situated beside the Cox's Bazar-Teknaf National Highway. From the injected point to Sabrang Tourism Park the length of the transmission main is about 11 km.

E.6 Water Desalination

With current technology trend a sea water reverse osmosis (SWRO) plant would be suitable for the economic zones as it is relatively less energy intensive technology. The performance of

SWRO depends heavily on the quality of the seawater at the intake location. The following treatment scheme can be considered for SWRO.

- Intake & Outfall System, Intake Basin & Intake Pumps
- Tube Settler, Dual Media Filtration
- Ultra Filtrations (UF), Nutrient Removal Filter
- Sea Water Reverse Osmosis (SWRO)
- Brackish Water Reverse Osmosis (BWRO)
- Product Water Collection and Transfer System
- Waste Water Collection and Transfer System

Based on similar project and assessment of current study approximate costs can be assumed for the 1MLD to 5 MLD desaliation plant as shown in **Table E.2**.

Table E.2: Approximate cost of desaliation plant

Item	1 MLD desaliation plant	3 MLD desaliation plant	5 MLD desaliation plant
Capital Cost	$1.5 million	$4.5 million	$7 million
Operating Cost	0.15 million/yr	0.4 million/yr	0.55 million/yr
Cost of Water	60-70 BDT/m^3	60-70 BDT/m^3	60-70 BDT/m^3

If traditional financing is not availabe for the project, a Concessions or BOOT financing can be considered as an alternative. Typically these contracts are 25 year long. This will require creation of Special Purpose Vehicle (SPV) to raise fund and to manage the development work. The client has to ensure 'Guarantee of sale' or 'Payment Security' for the service provider in this type of financing process.

E.7 Bottling Water Plant

In Sabrang Tourism Park total drinking water requirement is 81,000 liter/day and in Naf Tourism Park is 9,800 liter/day after full development in 2049. To meet the drinking water requirement of Sabrang and Naf Tourism Park, bottling water plant can be installed in Sabrang Tourism Park where the treated water from desalination plant can be used as feed water for bolting water plant. Total 3 nos. of bottling water plant is proposed to be installed in Phase 1, 3 & 5 with production capacity 3,200, 4,500 and 3,500 liter /hour respectively.

Approximately 2 acres of land may be required for the plant. Power is a major requirement to run a bottling water plant. The approximate power requirement may be 330volt/60Hz.

E.8 Phasing of Plan

Water supply system development plan is divided into six phases to make it consistent with the development Master Plan of Sabrang and Naf Tourism Park. All phases will comprise 5-year period as shown in **Table E.3**.

Table E.3: Phasing of water supply system development plan

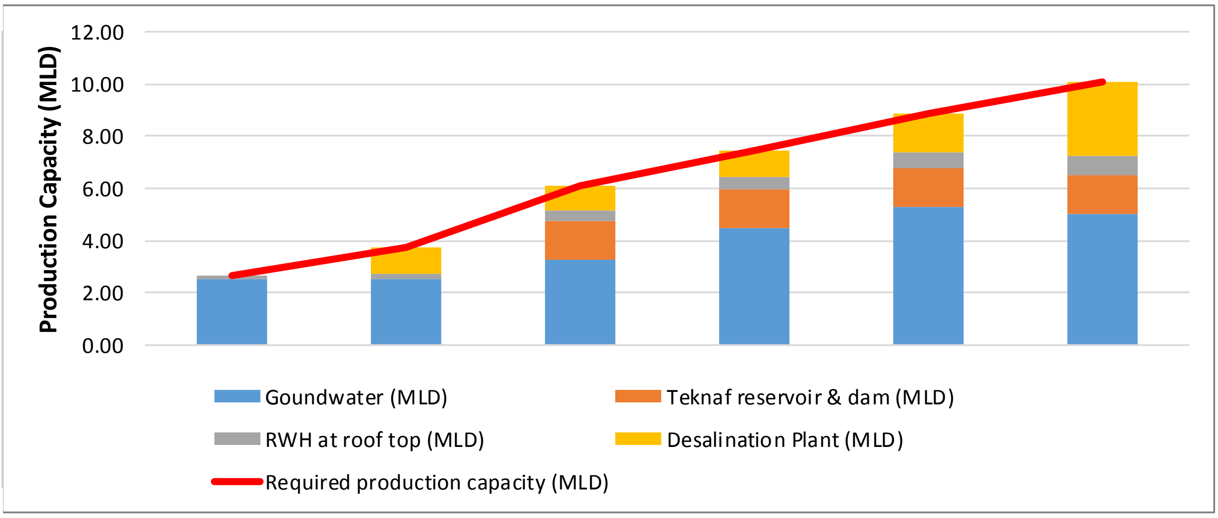
Phase	Period
Phase-1	2020-2024
Phase-2	2025-2029
Phase-3	2030-2034
Phase-4	2035-2039
Phase-5	2040-2044
Phase-6	2045-2049

E.9 Water management plan for Sabrang

Different sources has been considered for fulfilling the water demand in this economic zone as:

- Groundwater
- Water stored in dam in Teknaf
- Rainwater harvesting in the roof top of buildings
- Desalination plant

The phasing of water supply system has been planned as shown in **Figure E.3**.

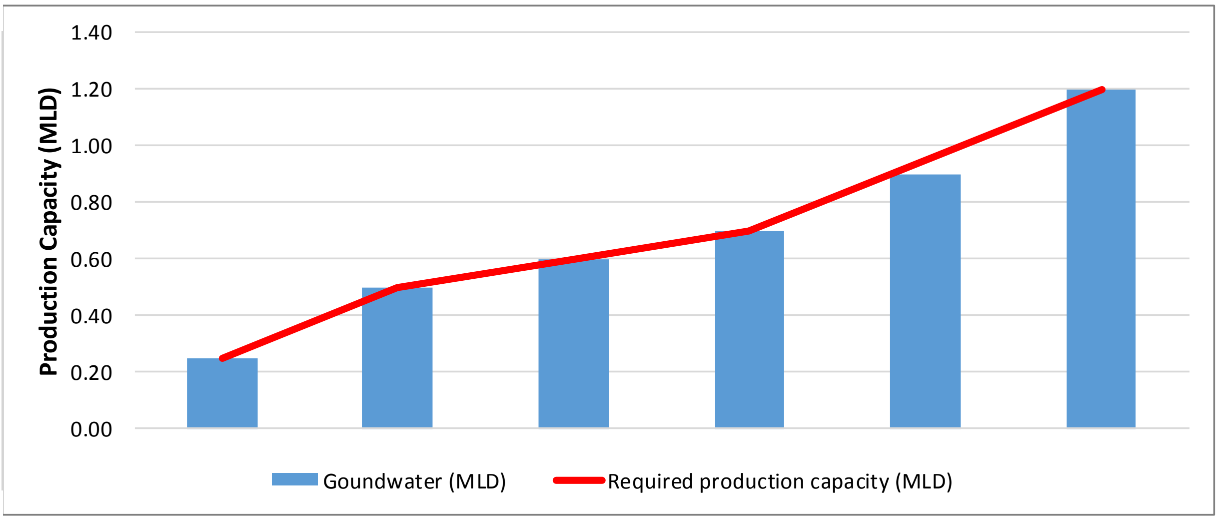


Planning hoizon	2024	2029	2034	2039	2044	2049
Water demand at user end (MLD)	2.01	2.85	4.67	5.69	6.77	7.69
Water lossess (MLD)	0.63	0.89	1.46	1.78	2.12	2.40
Required production capacity (MLD)	2.64	3.74	6.12	7.47	8.89	10.09
Goundwater (MLD)	2.51	2.49	3.28	4.50	5.29	5.03
Teknaf reservoir & dam (MLD)		0.00	1.48	1.48	1.48	1.48
RWH at roof top (MLD)	0.13	0.25	0.37	0.49	0.61	0.73
Gap (MLD)	0.00	1.00	0.99	1.00	1.51	2.85
Desalination Plant (MLD)		1.00	1.00	1.00	1.50	2.85
Production capacity (MLD)	2.64	3.74	6.13	7.47	8.88	10.09

Figure E.3: Future Sources of Supply for Sabrang Tourism Park

E.10 Water management plan for Naf

Different sources has been considered and finally only groundwater source is considered for fulfilling the water demand in Naf economic zone. The phasing of water supply system has been planned as shown in **Figure E.4**.



Planning hoizon	2024	2029	2034	2039	2044	2049
Water demand at user end (MLD)	**0.19**	**0.39**	**0.46**	**0.52**	**0.70**	**0.88**
Water lossess (MLD)	**0.06**	**0.11**	**0.14**	**0.18**	**0.25**	**0.32**
Required production capacity (MLD)	**0.25**	**0.50**	**0.60**	**0.70**	**0.95**	**1.20**
Goundwater (MLD)	0.25	0.50	0.60	0.70	0.90	1.20
Desalination plant/RWH (MLD)	0.00	0.00	0.00	0.00	0.00	0.00
Production capacity (MLD)	**0.25**	**0.50**	**0.60**	**0.70**	**0.90**	**1.20**

Figure E.4: Future Sources of Supply for Naf Tourism Park

E.11 Tentative Cost Estimation

The tentative project cost to meet the water requirement in Sabrang and Naf Tourism Park is about 3,308 Million BDT upto Phase-6 (2049) and about 1,572 Million BDT is required in Project-1 (Phase-1 & 2). The summary of tentative costs in different phases are shown in **Table E.4.** The tentative cost of reservoir cost (180 nos.) for roof top rain water harvesting including the plumbing system is 4,374 Million BDT which will be carried out by the land leaser/developer. The cost of earthen dam, raw water transmission pipeline, surface water treatment plant and water office in Teknaf will be financed by the GoB/Donor agencies and implemented by DPHE.

Table E.4: Tentative cost for full filled the total water demand

Item No.	Description	Project-1		Project-2				Total
		Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	
		Price in Million BDT (without price escalation)						
1	General Items	19.6	2.8	6.7	2.5	4.4	2.5	38.5
2	Production Tube well	67.1	0.0	16.8	33.6	16.8	0.0	134.3
3	Pipe material	377.1	5.1	5.2	5.2	2.8	2.8	398.2
4	Underground Water Reservoirs	256.6	0.0	239.4	0.0	134.9	0.0	630.9
5	Pump Station	179.6	0.0	71.2	0.0	30.1	0.0	280.9
7	Desalination plant	0.0	370.4	0.0	0.0	224.0	425.2	1019.6
8	Bottling water plant	187.5	0.0	238.8	0.0	174.9	0.0	601.2
9	Land Acquisition & development	17.8	0.0	0.0	0.0	0.0	0.0	17.8
10	Consultancy (6%)	65.2	22.7	34.7	2.5	35.3	25.8	186.2
	Total Project Cost	**1,171**	**401**	**613**	**44**	**623**	**456**	
		1,572		**1,736**				**3,308**

E.12 Summary Water Supply System Development Plan

Table E.5: Summary of water supply system development plan

Project	Phase	Period	Budget (Million BDT)	Water demand (MLD)	Source of water
Project-1	Phase-1	2020-2024	1,171	2.89	• GW • RWH
	Phase-2	2025-2029	401	1.35	• GW • RWH • Desalination Plant
Project-2	Phase-3	2030-2034	613	2.48	• GW • RWH • Desalination Plant • Reservoir
	Phase-4	2035-2039	44	1.45	• GW • RWH • Desalination Plant • Reservoir
	Phase-5	2040-2044	623	1.67	• GW • RWH

Project	Phase	Period	Budget (Million BDT)	Water demand (MLD)	Source of water
					• Reservoir • Desalination Plant
	Phase-6	2045-2049	456	1.45	• GW • RWH • Reservoir • Desalination Plant
	Total		**3,308**	**11.29**	

E.13 Summary Findings

Findings for Sabrang Tourism Park

- The total population including tourists that will visit and may stay at night and the service providers in Sabrang Tourism Park is about 40,485 daily.
- For total population in Sabrang Tourism Park the weighted average demand is 165 LPCD.
- Total water demand for Sabrang Tourism Park is 10.09 MLD and drinking water requirement is about 81,000 litre/day after full development in 2049.
- For Sabrang Tourism Park, groundwater, dam-reservoir water, roof top rainwater harvesting and desalination plant are considered for fulfilling water demand.
- From roof top rainwater harvesting about 0.73 MLD can be made available for Sabrang Tourism Park and recommended for water supply.
- From the dam and reservoir system in Teknaf Pourashava 1.48 MLD water will be available for Sabrang Tourism Park and the water will be required in Phase-3.
- Desalination RO plant is required in phase 2, 5 & 6 to fulfill the total water requirement in Sabrang Tourism Park. The capacity of the desalination plant would be 1, 0.5 and 1.35 MLD respectively.
- The tentative cost of roof top rain water harvesting system is 4,374 Million BDT which would be carried out by land leaser/developer.

Findings for Naf Tourism Park

- The total population including tourists that will visit and may stay at night and the service providers in Naf Tourism Park is about 4,890 daily.
- For total population in Naf Tourism Park the weighted average demand is 177 LPCD.
- Total water demand for Naf Tourism Park is 1.15 MLD and drinking water requirement is about 9,800 litre/day after full development in 2049.
- From roof top rainwater harvesting about 0.22 MLD can be made available for Naf Tourism Park. But for water supply roof top rainwater harvesting for Naf Tourism Park is not recommended.

- For Naf Tourism Park, only groundwater source is considered for fulfilling water demand.

Common findings

- The aquifer system is not dependable at Shamlapur, Teknaf so large scale groundwater development for long-term water supply is not advised and thus not considered as water supply source.
- Synthesis analysis of groundwater resource assessment shows that in Whykhong a well field can be developed with 8 nos. of production tube well of capacity 14.42 l/s. The PTWs will be installed in different phases depending on water demand of the tourism parks. About 134 Million BDT is required to construction these PTWs.
- About 6.2 MLD groundwater may be extracted from the Whykhong well field.
- To avoid conflict for local water demand, a new PTW should be constructed by BEZA to be retained for local use (domestic purpose).
- Uncertainty in safe yield assessment will need to be addressed by monitoring of groundwater level.
- The water quality of different exploratory wells in Whykhong area and during aquifer test, indicates that the iron concentration is within the allowable limit of Bangladesh standard and so no treatment plant is required.
- The tidal water level of Naf River varies from -1.8 to 2.5 mMSL in the month of May to September.
- The water quality of Naf River is saline and total dissolve solid concentration and hardness are very high.
- Total about 50.6 km transmission main is required to carry groundwater from Whykhong and hill reservoir near Teknaf Pourashava.
- Two booster pumps would be required along the transmission main to guarantee water pressure to the desired level for uninterrupted supply.
- Tentative total project cost upto Phase-6 (2049) is 3,308 Million BDT and for Project-1 (Phase 1 & 2) is 1,572 Million BDT.

E.14 Recommendations

Recommendations for Sabrang Tourism Park

- Sufficient apace shall be kept in the Master Plan for the operation and maintenance of underground water reservoir.
- The provision of roof top rainwater harvesting shall be kept in each building area of roof area >300m^2 from the very beginning. Otherwise extra costing will be needed for re-designing of the plumbing system.
- The water supplied from Teknaf reservoir shall be considered as supplementary water source, as due to rainfall variation in very dry year the storage volume could be lower than design storage volume.

- Metering system shall be installed with the water supply pipeline at every buildings. In that case, BEZA should establish and follow the rules & regulations prepared and approved by the Government of Bangladesh best on WASA Act 1996.
- To meet the drinking water requirement in Sabrang Tourism Park, bottle water industry can be developed.

Recommendations for Naf Tourism Park

- Sufficient apace shall be kept in the Master Plan for the operation and maintenance of underground water reservoir.
- Metering system shall be installed with the water supply pipeline at every buildings. In that case, BEZA should establish and follow the rules & regulations prepared and approved by the Government of Bangladesh best on WASA Act 1996.
- To meet the drinking water requirement in Naf Tourism Park, bottle water industry can be developed.

Recommendations for both Sabrang and Naf Tourism Park

- Monitoring of water level is required to ascertain its decline at different phase of development;
- Monitoring of water quality is required to ascertain any risk of salinity intrusion with development;
- Recharge and safe limit of abstraction is required to be updated reviewing the monitoring as mentioned above;
- Development of production tube wells in phases need to be reviewed based on the groundwater level and quality monitoring data.

1 INTRODUCTION

1.1 Background

With a view to encourage rapid economic development Bangladesh Economic Zones Authority (BEZA) is establishing Economic Zones (EZs) throughout Bangladesh under the Bangladesh Economic Zones Act, 2010. BEZA aims to establish economic zones in all potential areas in Bangladesh including backward and under developed regions through increase and diversification of industry, employment, production and export. BEZA aims to establish about 100 economic zones in the country over the next fifteen years. They have selected two economic zones, Naf and Sabrang in Teknaf upazila of Cox's Bazar district. The aim to develop Jaliar Dip and Sabrang area as economic zones are to enhance recreational facilities and tourism.

Field visits and assessment of present water supply situation shows that, so far water supply is mostly from groundwater sources. It has also become evident that the groundwater sources are being exploited but comprehensive assessment of groundwater resources to ensure safe, affordable and sustainable water supply is yet to be carried out.

Analysis of secondary information reveals that groundwater resource is being exploited in indiscrete manner, without considering the depth to groundwater level and piezometric height. It is not unlikely in near future, particularly in dry season there will be scarcity of groundwater and the constructed water wells might become inoperable. Already such situation is experienced in many of constructed water wells. It is also noticed that there are some artisan wells. These wells discharge water round the clock, but there should be some arrangement of regulating such discharge to avoid wastage of water.

Another important observation is that the existing surface water system (khal/chhara) are not being considered for water supply to its potential mainly due to the lack of data and assessment about sustainability of water availability of these sources.

1.2 Objective of the Study

The main objective of the study is to prepare a Water Supply Master Plan to fulfill water demand for Naf Tourism Park and Sabrang Tourism Park (TP) in the context with water availability and demand. The study work is divided in two phases. The objective of Phase-1 is to assess groundwater availability in and around the EZs particularly in Nhila, Teknaf. In Phase-2 water management plan including design of water supply related works will be completed.

1.3 Scope of the Study

The scope of work of the study includes, but not limited to the followings:

Phase-1

1) Examine the project site and existing situation analysis;
2) Hydrogeological investigation for groundwater resources assessment;
3) Hydraulic data collection and analysis;

4) Surface water quality assessment;
5) GIS mapping;
6) Identify possible groundwater source with relevant water quality and validate water availability in the context of development program for the project area;
7) Conduct a stakeholder workshop to share the groundwater condition for the project area and obtain feedback.

Phase-2

1) Topographic and Engineering survey;
2) Sub-soil investigation;
3) Prepare a water zoning and phasing plan for the project area;
4) Prepare a water management plan for the project on the point of environmental context;
5) Outline design of transmission and distribution line;
6) Cost estimation and documentation;
7) Conduct a training program to transfer the knowledge and capacity building of the client;
8) Conduct a stakeholder workshop to share the water supply related utility planning for the project area and obtain feedback.

1.4 Study Phasing

The study was planned to be implemented in two phases.

1.4.1 Progress Achieved in Phase-1

Under the Phase-1 study emphasis has been given for water supply to the tourism park areas by harnessing mainly groundwater resources. In this regards, test tube wells construction and lithological analysis, construction of two production tube wells and two long term aquifer tests, hydraulic data collection and analysis, surface water quality assessment were done.

For fulfilling the water demand, besides the hydrogeological investigation and groundwater resource assessment, rainwater harvesting analysis, dam and reservoir analysis in Teknaf, analysis of desalination plant has been done. Moreover, some advance work of Phase-2 has also been completed. The activities accomplished so far are given below:

- Water demand estimation for the two tourism parks;
- Secondary lithological data collection of the study area;
- Test tube wells construction and lithological analysis at 17 locations;
- Construction of two production tube wells and two long term aquifer tests;
- Water level and discharge measurement in Naf river and analysis;
- Surface water quality sampling, testing and analysis of Naf River;
- Assessment of roof top rainwater harvesting;
- Dam and reservoir analysis in Teknaf;
- Analysis of desalination plant;

- Preparation of water management plan in Sabrang and Naf tourism park;
- Tentative cost estimation.

Close coordination was maintained with BEZA office in the collection of all past studies, development works of BEZA in the proposed economic zones, and interaction with relevant stakeholders.

This is the Final Report of Phase-1 study. The report has been updated based on comments and suggestions on DFR of Phase-1 study (**Annex-15, 16 & 17**).

1.4.2 Works to be Done in Phase-2

Under the Phase-2 study, topographic and engineering survey, sub-soil investigation, outline design of water transmission and distribution system, zoning and phasing plan, finalization of cost estimate will be prepared.

1.5 Study Area

1.5.1 Sabrang Tourism Park

The proposed Sabrang Tourism Park (Sabrang TP), is located in Teknaf Upazila, Cox's Bazar district (**Figure 1.1**). The Sabrang Tourism Park has the potential to become a successful economic zone covering an area of 1048 acres (424 hectares). Sabrang TP area is approximately 96km away from Cox's Bazar town. Teknaf-Shahparirdwip highway (Z1099) runs parallel and adjacent to the site. The Cox's Bazar-Teknaf Maine Drive will be connected to this project site. Moreover, three access roads for connecting the project area to Teknaf –Shahparirdwip highway (Z1099) is under proposal. The nearest international airport from the project site is Shah Amanat International Airport in Chittagong which is about 250km away in the north and the nearest domestic airport is Cox's Bazar Airport about 90km in the north. The nearest seaport from the Sabrang TP is the Port of Chittagong which is located at 160 km away. There is no railway network in Cox's Bazar District, and the nearest existing railway station is Chittagong railway station, located at approximately 210 km away.

1.5.2 Naf Tourism Park

The proposed Naf Tourism Park is also located in Teknaf Upazila, Cox's Bazar district (**Figure 1.1**). The entire Jaliardiwp Island is designated as economic zone and has the potential to become a successful economic zone covering an area of 271.93 acres (110 hectares) with 21 acres (8.5 hectares) additional land opposite site of the park. The proposed economic zone is located in Teknaf Mouza and Dakshin Nhila Mouza under the Teknaf Upazila approximately 80 kms from the Cox's Bazar. Cox's Bazar-Teknaf National Highway (N1) runs parallel to the site at a distance of 3 km. The project area lies in the flood plain of Naf River and Bay of Bengal sea is about 10 Km in the south direction. The width of the river varies from 1.61 km to 3.22 km and average depth is 39m to 120 m and influenced by tidal activity. The Dakhin Nhila hill range lies between the Naf River on the east and the Bay of Bengal on the west.

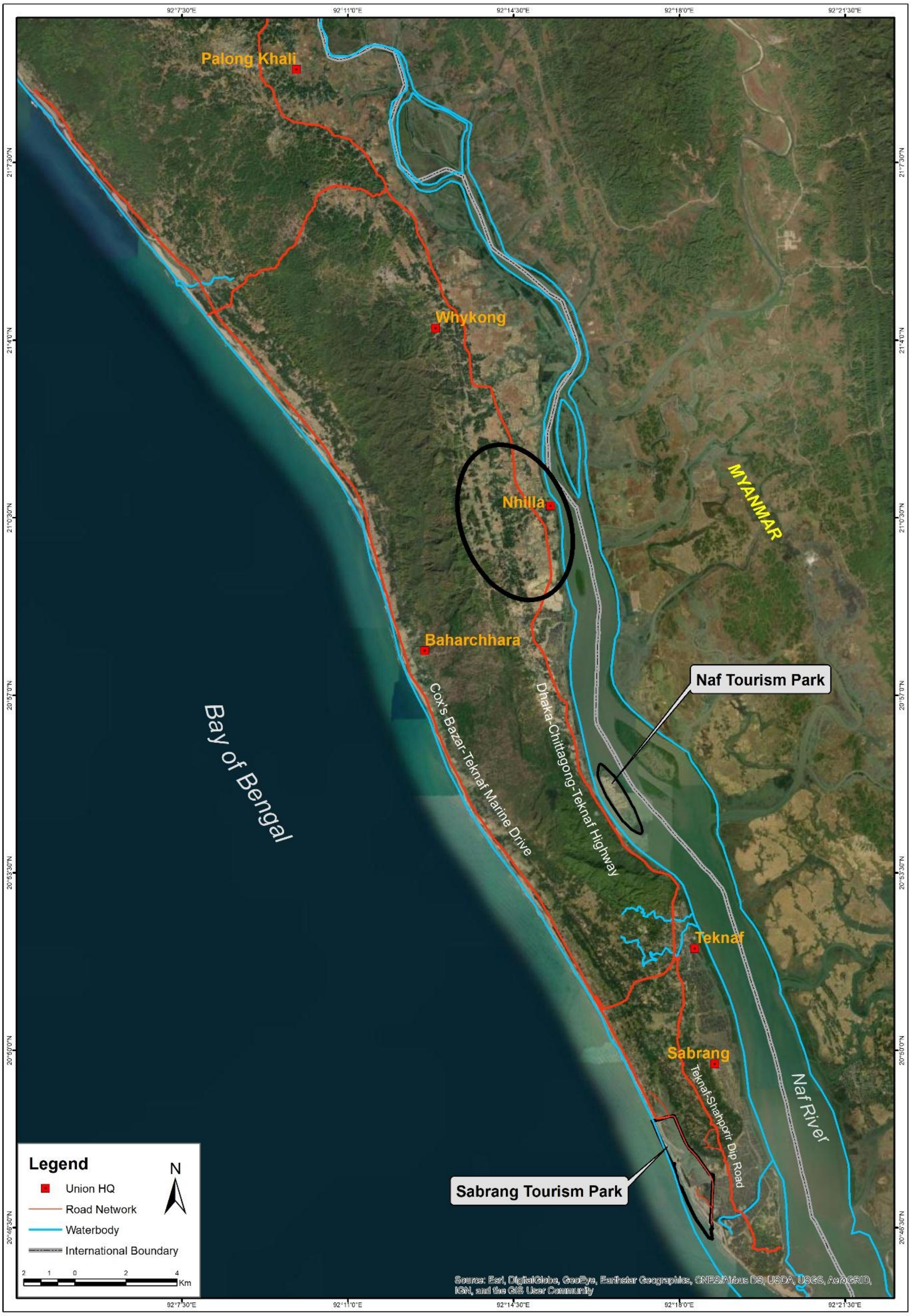


Figure 1.1: Location map of the study area

2 HYDROMETRIC & HYDRAULIC DATA COLLECTION

2.1 Secondary Data Collection and Analysis

2.1.1 Rainfall

Bangladesh Meteriological Department (BMD) maintains a regular rainfall monitoring station in Taknef since 1977 which is the closest rainfall station from proposed Naf and Sabrang Tourism Park. The station has historical record of daily rainfall data in Teknaf from 1977 to 2002. Since 2003, BMD started to record 3-hourly rainfall data. The rainfall data has been collected and analysed.

It is observed that annual average rainfall is about 4000mm in Teknaf and about 95% of the rainfall occur from May to October. The annual rainfall data from 1977 to 2018 and monthly average distribution is shown in **Figure 2.1** and **Figure 2.2**.

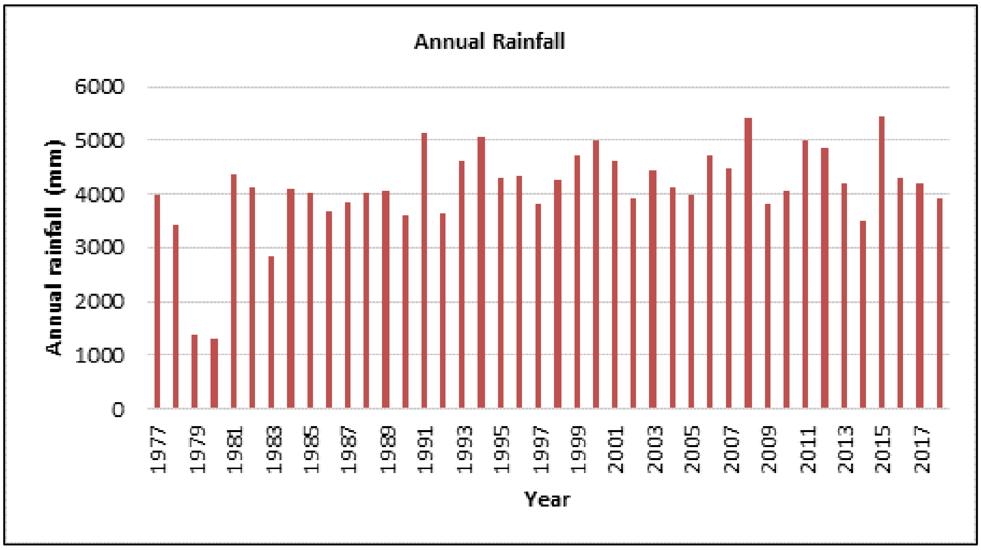


Figure 2.1: Annual rainfall in Teknaf

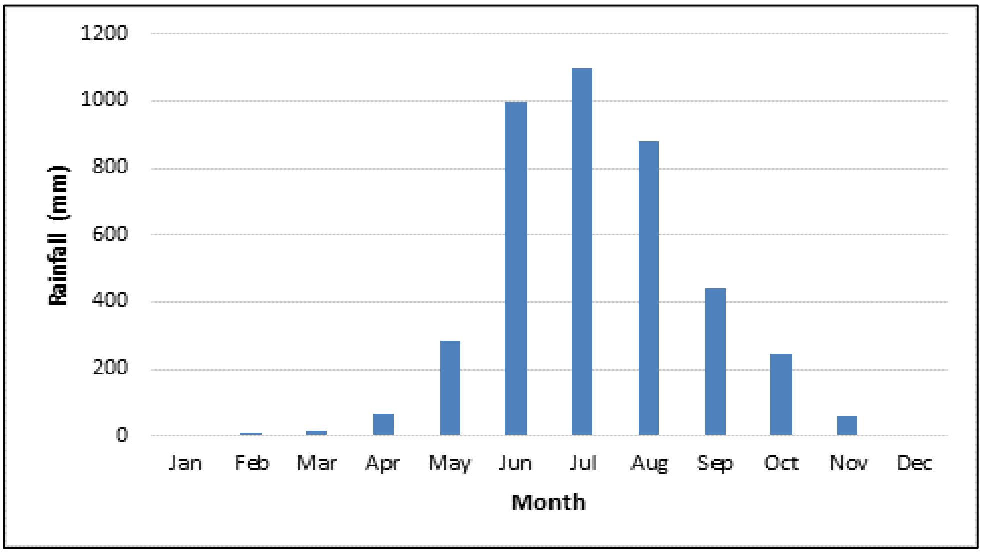


Figure 2.2: Monthly distribution of rainfall in Teknaf

A wide range of rainfall variation is observed in Teknaf. The average daily rainfall is about 230 mm but over the years' daily rainfall vary from 135 to 556 mm (**Figure 2.3**). The range of 2day cumulative and 5 day cumulative rainfall is about 190 to 600 mm and 310 to 960mm respectively. From the 3-hourly rainfall data (from 2003 to 2018) it is also observed that in 3 hour time duration, the maximum rainfall recorded in 2007 and the rainfall is 95 mm (**Figure 2.4**).

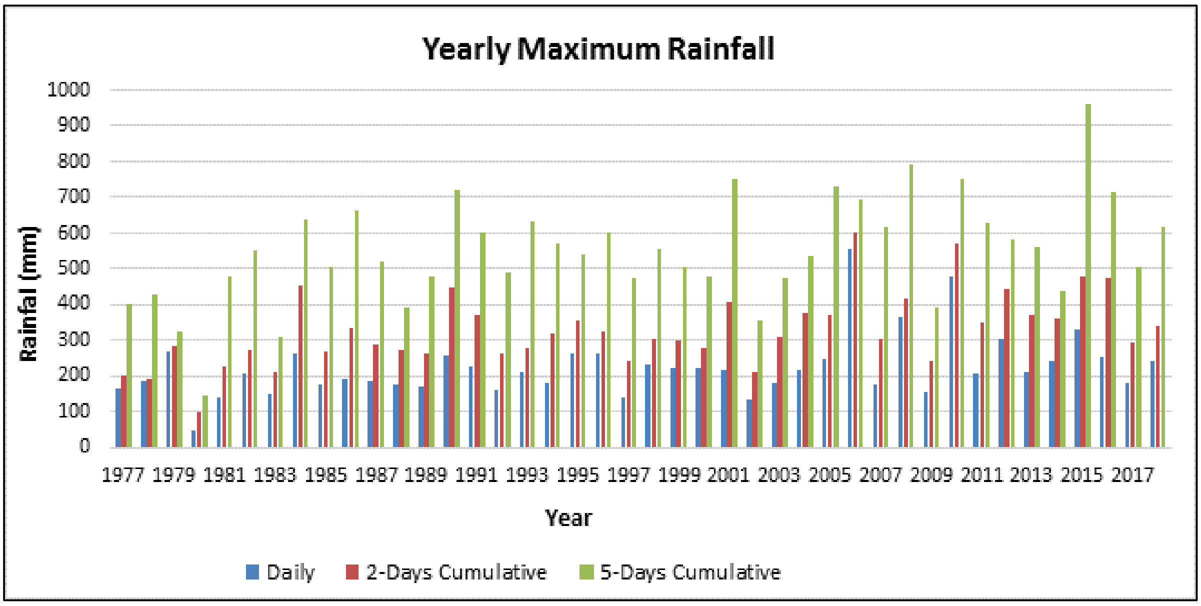


Figure 2.3: Yearly maximum rainfall in Teknaf

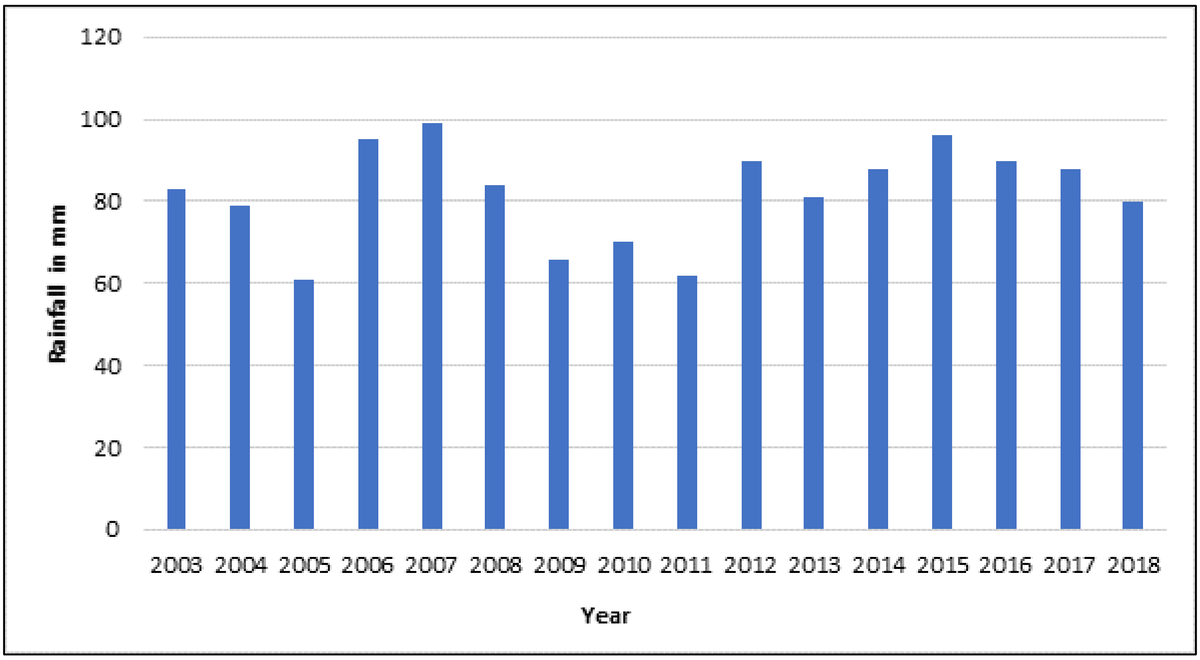


Figure 2.4: Yearly maximum rainfall occur within 3 hours in Teknaf

2.1.2 Image and Topography

The existing topographic data of proposed Naf and Sabrang Tourism Park has been collected from its Detailed Master Plan (Draft Final Report) as shown in **Figure 2.5** and **Figure 2.6**. It is observed that the elevation in Naf area varied from -1.99 to 7.4 mMSL and in Sabrang -2.1 to

6.98mMSL. The topography indicate that both Naf and Sabrang area is currently low laying where average height is 0.89 and 1.41mMSL respectively.

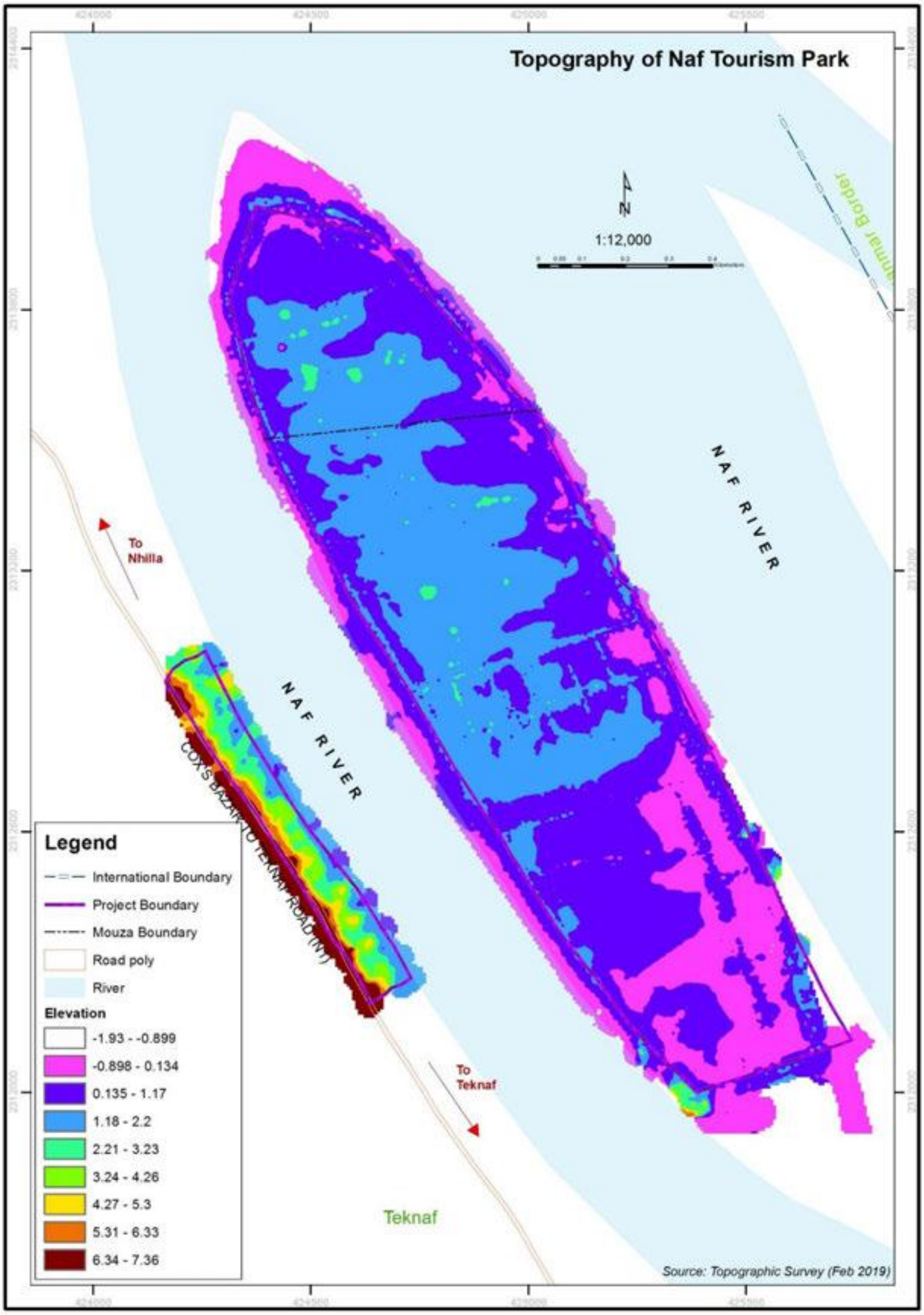


Figure 2.5: Topography map Naf Tourism Park

(Source: Detailed Master Plan (Draft Final Report))

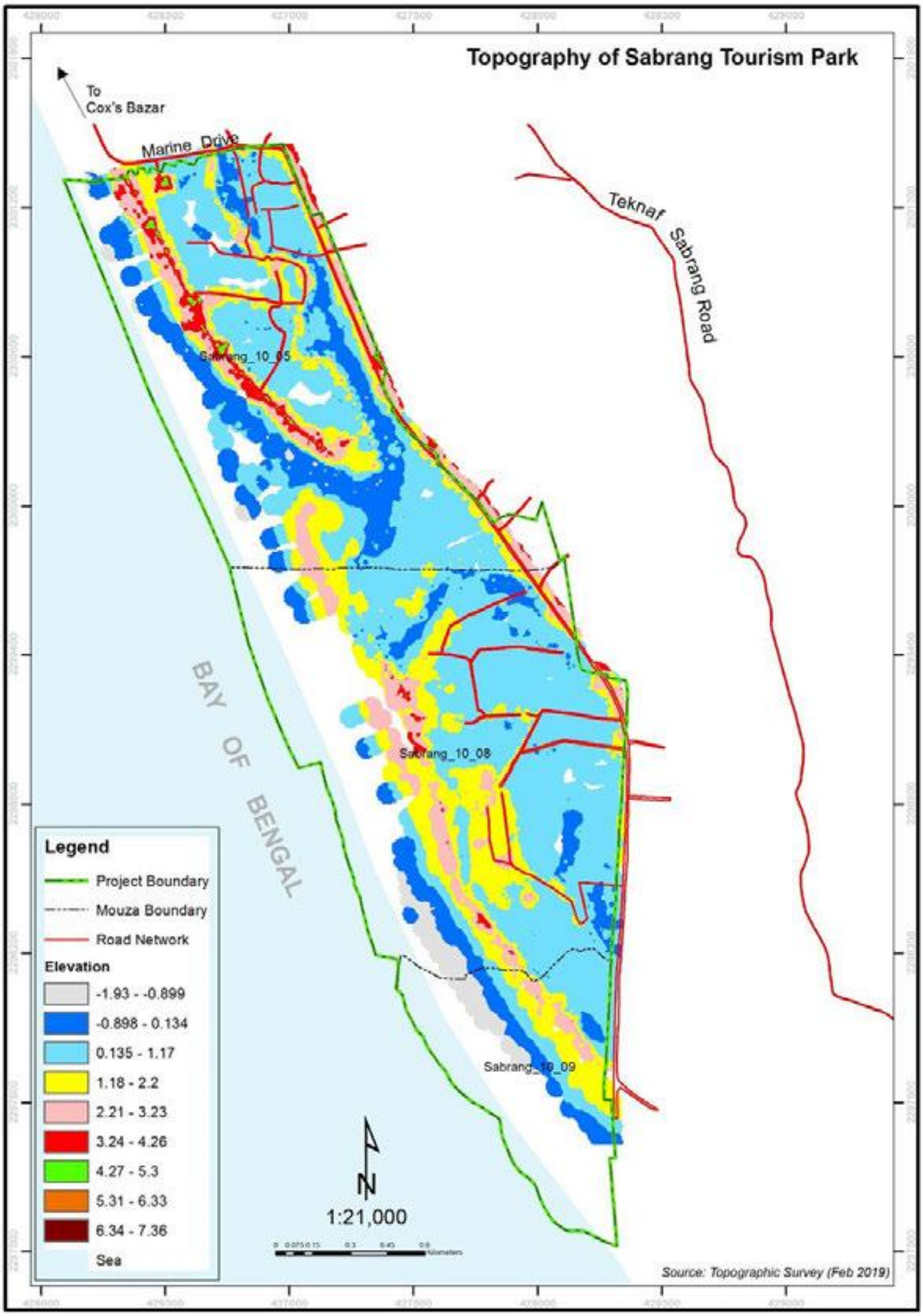


Figure 2.6: Topography map Sabrang Tourism Park

(Source: Detailed Master Plan (Draft Final Report))

For the surrounding area National Digital Elevation Model (DEM) of Bangladesh and FINNMAP data is available in IWM. National DEM of Bangladesh is available in rectilinear grid with 300 m pixel size and 0.1m elevation interval which is basically developed from a medium resolution

(500 m x 500 m) or semi-detailed DEM. The medium resolution DEM was developed in FAP 19 based on generalized BWDB spot elevation points. The BWDB data was derived from a grid of spot elevations obtained by ground survey and photogrammetric techniques (100 m – 300 m spacing, 0.1 ft, altitude resolution), and presented on a series of topographic maps. The FAP 19 team interpolated and digitized the spot elevation data from the BWDB topographic maps by manually superimposing a transparent 500 m grid template on the maps and recording the elevation point nearest to each grid intersection.

FINNMAP in 1990 compiled topographic map for the coastal area from aerial photographs under Bangladesh Inland Water Transport Authority (BIWTA) in corporation with FINNIDA (Finland) and the commission of the European Communities. Thus the land level DEM is further updated in the coastal area by 50m pixel. **Figure 2.7** shows the land elevation grid of the study area. The land level in the surrounding area varies from 0.11mPWD to 268.7mPWD.

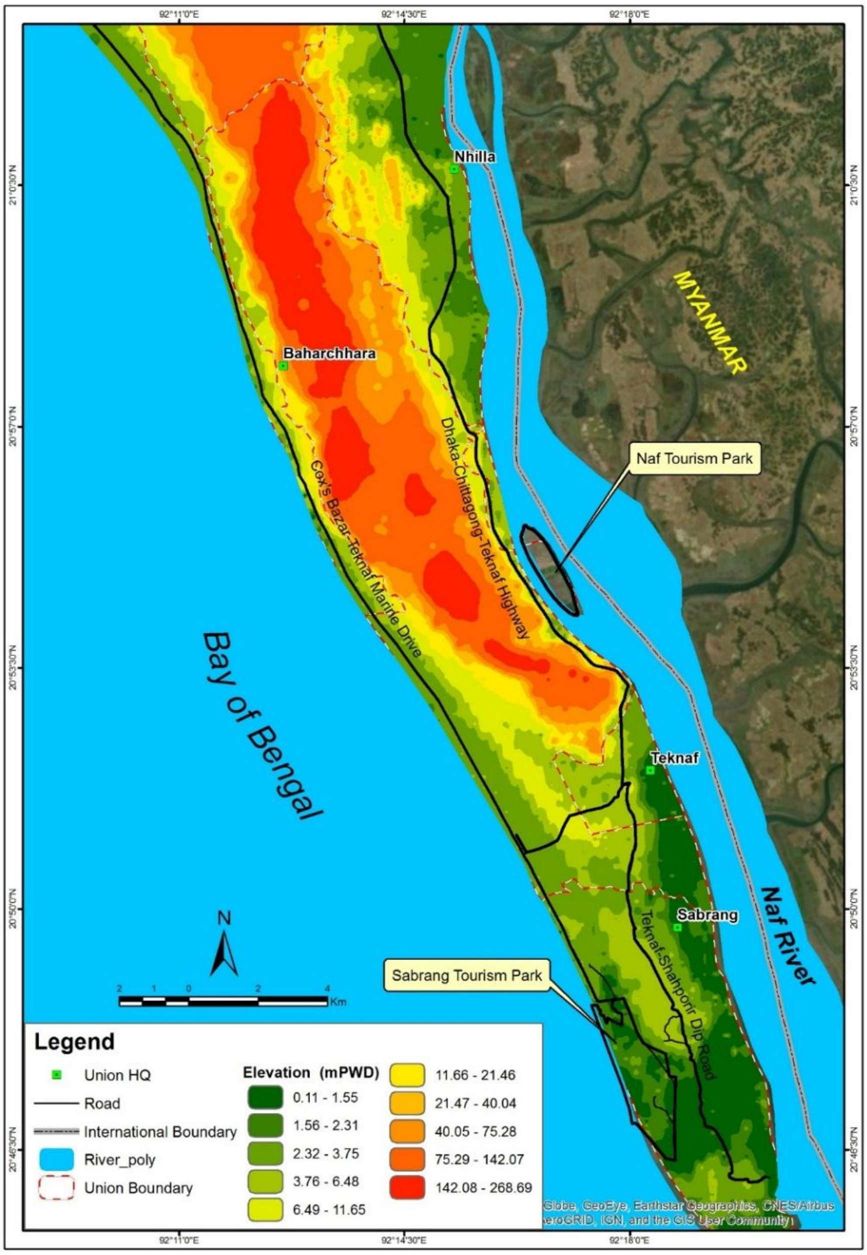


Figure 2.7: Digital Elevation Map (DEM) of surrounding area (Source: FINNMAP)

2.2 Primary Data Collection and Analysis

For the execution of the study, in addition to secondary data, primary water level and discharge of Naf River have been measured for hydraulic analysis. The water level and discharge of Naf River are influenced by tides of Bay of Bengal.

2.2.1 Water Level Observation

Tidal water level of Naf River have been collected from a location adjacent the proposed Naf Tourism Park as shown in **Figure 2.8**. Water level has been collected for 5 months from May to September 2019 using manual staff gauge. To observe the tidal range, the water level has been recorded for 1 hour interval as shown in **Figure 2.9**. The water level data indicate that the fluctuation of water level is between -1.8 to 2.5 mMSL in monsoon.

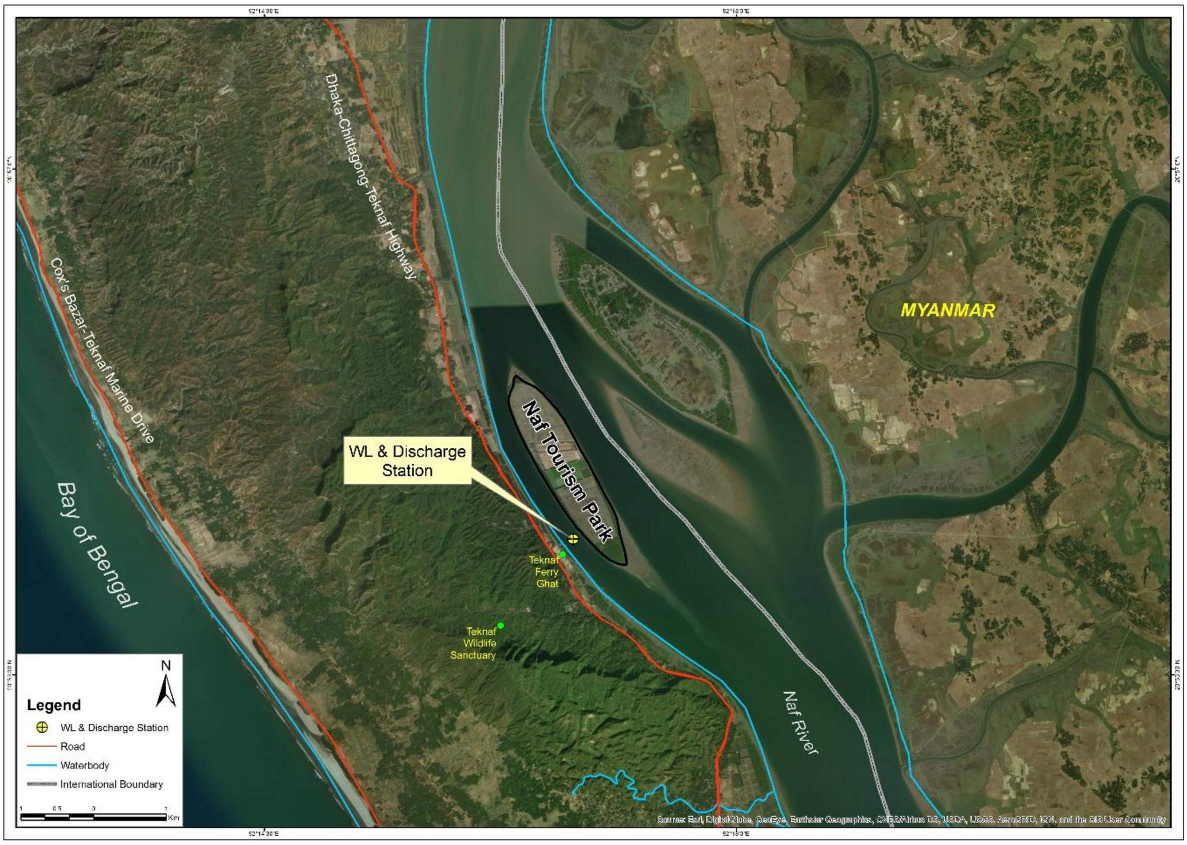


Figure 2.8: Map showing hydraulic data collection station

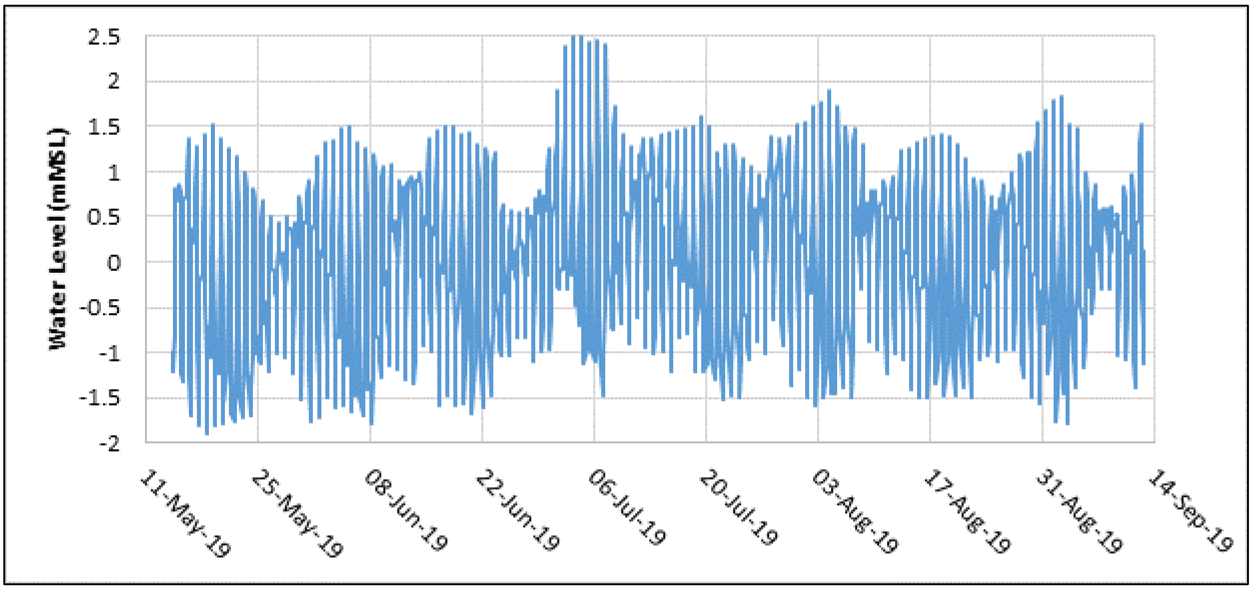


Figure 2.9: Water Level Hydrograph of Naf River

2.2.2 Discharge Measurement

Discharge has been measured at the same location of water level measuring station (**Figure 2.8**). As Naf is a border river, discharge measurement along the whole section was not possible due to international restriction. For this reason, discharge has been measured only for the right channel of Naf River near Naf Tourism Park. Teledyne RD Instruments (TRDI) River Ray 600 Khz ADCP has been used for the measurement. The velocity profiling range of the ADCP is from 0.40 meter depth up to 45 meter depth. The instrument is capable of measuring velocity without anchoring at measurement locations (moving boat condition). It measures flow velocity at each ensemble across the whole river. At each ensemble, velocity is measured at 10-50 cm interval along the water column depending on the total depth. Thus a series of velocity data is recorded along the transect line. The interval between ensembles varies from 1 to 3 seconds depending on the configuration and depth of the river. The software estimates the discharge of unmeasured areas (the top of instrument face, near bottom part and edges). The river flow is calculated by the WinRiver II Software by adding discharge of each ensemble as it moves along the transect line.

Tidal discharge data has been measured for the month of July to October forth nightly as shown in **Figure 2.10** to **Figure 2.13**.

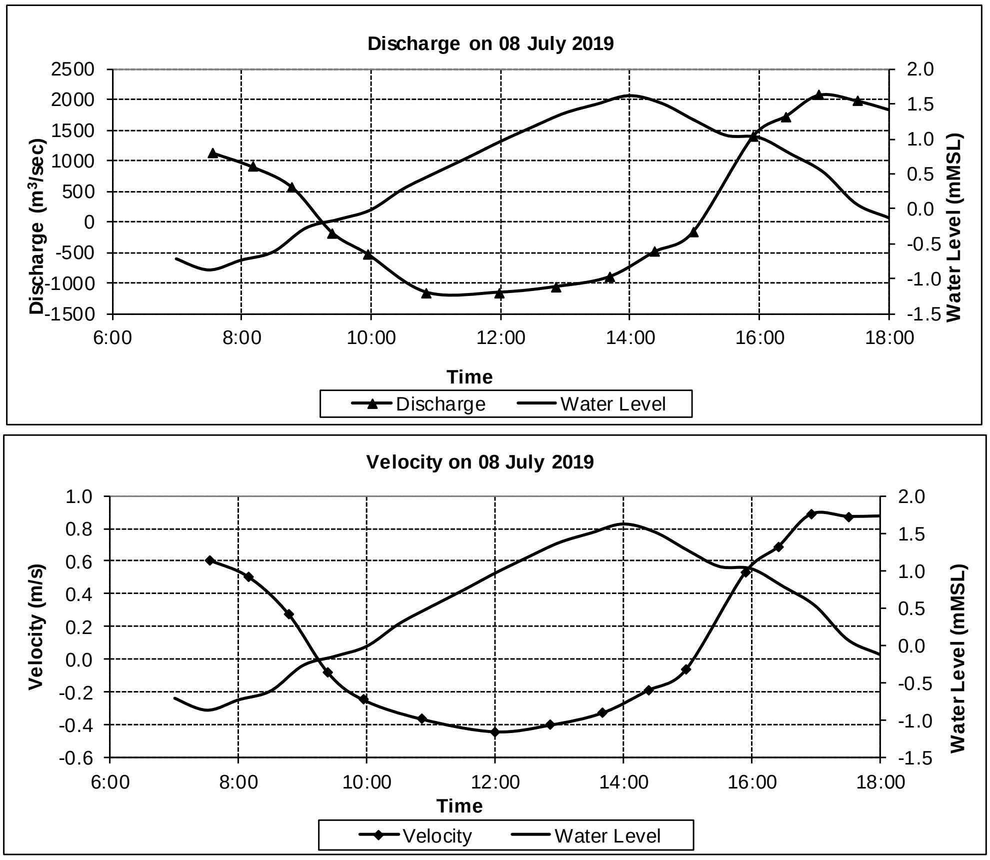


Figure 2.10: Tidal discharge, water level and velocity data for the month of July 2019

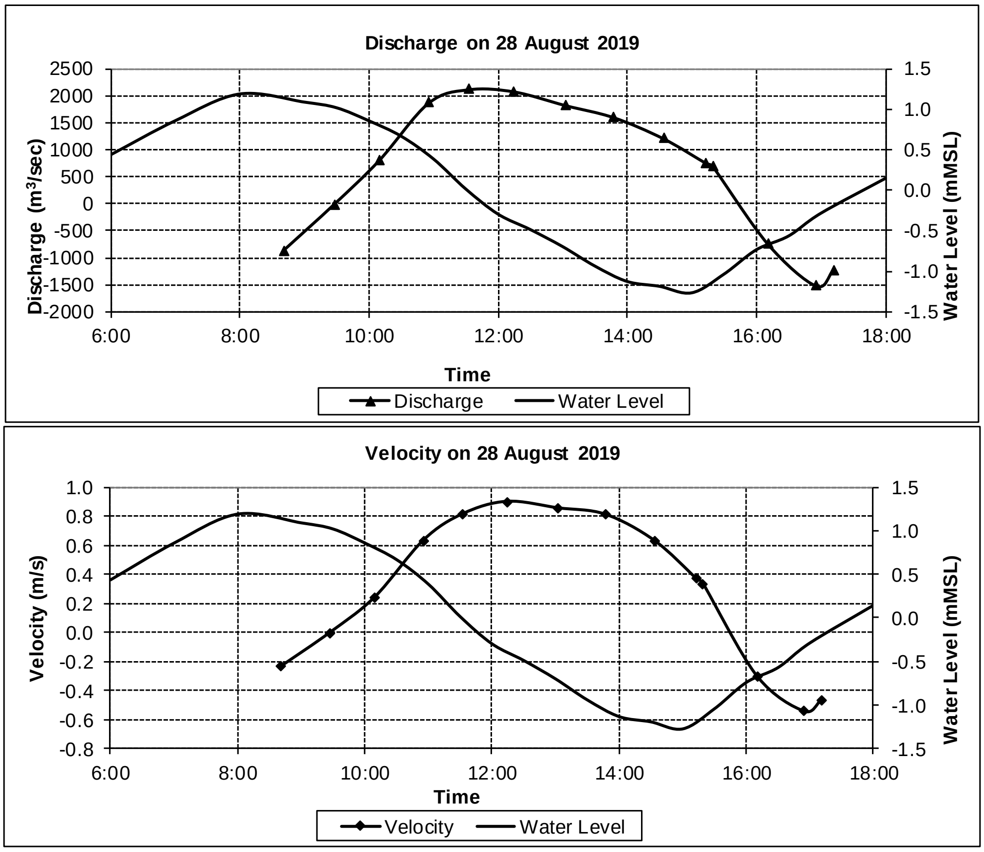


Figure 2.11: Tidal discharge, water level and velocity data for the month of August 2019

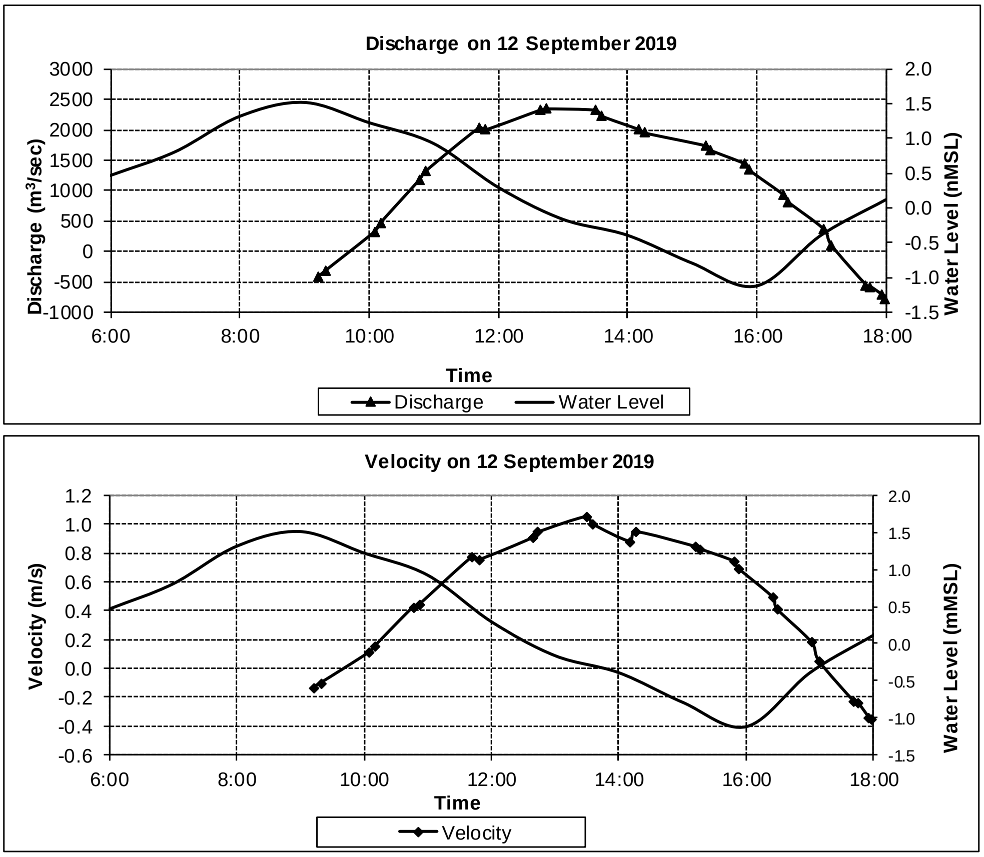


Figure 2.12: Tidal discharge, water level and velocity data for the month of September 2019

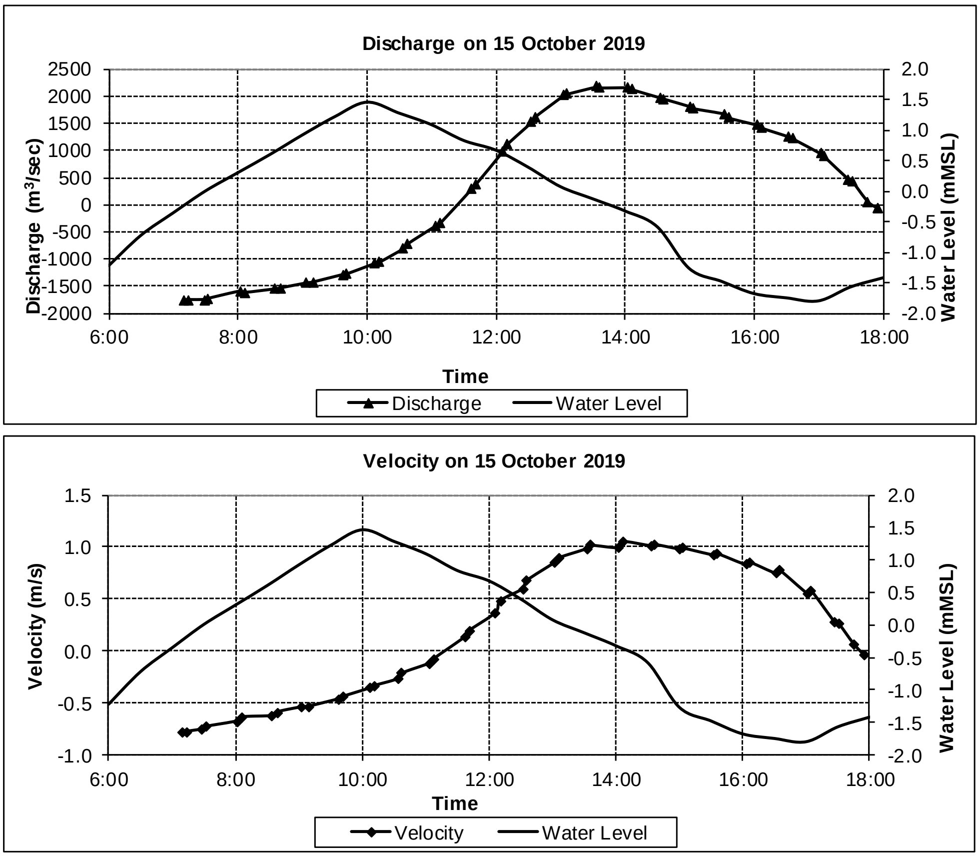


Figure 2.13: Tidal discharge, water level and velocity data for the month of October 2019

2.2.3 Bench Mark Flying Survey

Before mobilization of the survey team, a reconnaissance survey has been conducted. Based on the reconnaissance survey, a detailed survey plan has been prepared in consultation with the team. Survey of Bangladesh (SOB) has a number of Geodetic Bench Mark in and around the project area. These BM pillars are being used as reference for observing tidal water level and discharge in Mean Sea level (MSL) datum.

For establishing vertical datum in the project area in reference of SOB pillars, experienced surveyors were deployed for BM fly using optical level. One TBM has been kept near the water level and discharge station. To avoid reading error three cross hair staff readings are being taken during leveling survey (BM fly) and recorded in the field book. Equal distance from the instrument for back reading and fore reading has been maintained for minimizing error. Survey has been closed from BM to BM to ensure the elevation established for TBM is consistent. These BM and TBM pillars will be used as reference for conducting cross sections and land level survey in Phase-2 of the study. If needed, more TBM will be established while conducting survey in Phase-2. List of BMs and TBM pillars kept at different locations are given in **Table 2.1**.

Table 2.1: List of SoB BM Pillars and established TBM Pillar

ID	Description	UTM_X	UTM_Y	RL_MSL
GPS-295	The pillar is situated in north side of Whikhong Family Planning Centre, south-east corner of pond, east side of Chairman Office & Community entre, near to the Middle Nhila Primary School. Vill: Khanjarpara (Whailong), Upazilla: Teknaf.	418712.6	2330988	8.426
GPS-332	The pillar is situated in north side of Shaplapur Primary School playground at Shaplapur Bazar. It is about 8.75 km south - west of Whaikhyang Bazar and near sea beach. Vill: Shaplapur, Upazilla: Teknaf.	410743.6	2331098	6.127
BM 1420	The pillar is situated in the compound of Whaikong School & College. The pillar position is east side of pond, middle of Primary school building& college office. North side of Whaikong- Shaplapur road. Vill: Whaikong, Upazilla: Teknaf.	416448	2335155	5.577
BM1416	The pillar is situated in the compound of BWDB Office, about 12.5m east side of Teknaf- Cox's Bazar road and 1m north of south boundary wall. Vill: Barai Tali, Upazila: Teknaf.	426294.9	2310397	4.5219
TBM	Kept on the S/E corner of bridge wing wall, Boroitola, Teknaf.	426349	2310356	6.122

Projection System

Bangladesh Transverse Mercator (BTM) projection has been used during the survey. The parameters used in BTM projection system are shown below:

<u>Conversion parameter from WGS-84 Ellipsoid to Local Ellipsoid (Everest 1830)</u>

Everest-1830 ellipsoid

Semi-major axis a = 6,377,276.34518 m

Semi-minor axis b = 6,356,075.41511 m

Inverse flattening 1/f = 300.8017

<u>Datum Transformation Parameters</u>

Method	:Seven Parameters	
Rotation X	:	0
Rotation Y	:	0
Rotation Z	:	0
Translation X	:	-283.729 m
Translation Y	:	-735.942 m
Translation Z	:	-261.143 m
Scale	:	0 ppm

<u>Projection parameter</u>

Projection method	:	Transverse Mercator
Latitude of origin	:	0° N
Central meridian	:	90° E
False Northing	:	-2,000,000 m
False Easting	:	500,000 m
Scale factor	:	0.9996

2.2.4 Water Quality Measurement of Naf River

To capture the water quality in low tide and high tide, raw water samples have been collected from Naf River adjacent to the proposed Naf Tourism Park in March 2020. The samples have been tested in IWM water quality laboratory and are shown in **Table 2.2.**

Table 2.2: Water quality data of Naf River adjacent to the Naf Tourism Park

Parameters		Unit	Low Tide	High Tide	Bangladesh Standard*	WHO Guideline Values
pH			7.96	7.57	6.5-8.5	6.5-8.5
Conductivity		us/cm	46,900	49,400	-	-
COD		mg/L	179	175	-	-
BOD		mg/L	9.8	4.8	0	-
Turbidity		NTU	9.32	7.58	5	5
Hardness		mg/L	6110	6270	500	500
Nitrate	NO_3-N	mg/L	0.01	0.02		
	NO_3^-	mg/L	0.07	0.07	45	50
TDS		mg/L	29,300	31,200	1000	1000
TSS		mg/L	10	5	10	-
Ammonia	NH_4^+	mg/L	0.11	0.26	1.5	
	NH_3	mg/L	0.13	0.31	0.5	-
	NH_3 -N	mg/L	0.14	0.33	0.5	

Parameters	Unit	Low Tide	High Tide	Bangladesh Standard*	WHO Guideline Values
Iron (Fe)	mg/L	0.04	0.04	0.3-1.0	0.3
Chloride	mg/L	17500	19125	150-600	250

*Environmental Conservation Rule, 1997

It is observed that, the water quality of Naf River is saline and total dissolve solid concentration and hardness is very high. So desalination plant is required if needed to supply the river water for domestic or other usage.

3 ASSESSMENT OF WATER DEMAND

3.1 Design Criteria for Computing Water Demands

Following design criteria pertaining for estimating water demand is shown in **Table 3.1**.

Table 3.1: Design Criteria for computing water demand

Design Criteria	Considerations
No of Population	As mentioned in the Master Plan (Draft Final Report, August 2019)
Coverage by Piped Water Supply	100%
Connections by Piped Water Supply	100%
Per Capita Water Demand for different usages (lpcd)	BNBC (Table 3.2)
Unaccounted For Water in transmission and distribution system (UFW) %	20
Loss through WTP in %	5

According to BNBC code, water requirements for various usage are presented in **Table 3.2**.

Table 3.2: Domestic Water Requirements for Various Usages and Facility Groups as per BNBC

Class of Occupancy	Occupancy Groups	For Full Facilities* (lpcd)	For Restricted Facilities** (lpcd)
A: Residential	A4: Mess, Boarding Houses, Dormitories and Hostels	135	70
	A5: Hotels and Lodging Houses (per bed)	300	135
B: Educational Facilities	B1: Educational Facilities up to Higher Secondary Levels	70	45
	B2: Facilities for Training and above Higher Secondary Education	100	70
	B3: Pre-School Facilities	50	35
C: Institutional	C1: Institution for Care of Children	180	100
	C2: Custodian Institution for Physically Capable Adults	180	100
	C3: Custodian Institution for the Incapable Adults	120	70
	C4: Penal and Mental Institutions for Children	100	60
	C5: Penal and Mental Institutions for Adults	120	70
D: Healthcare Facilities	D1: Normal Medical Facilities (Small Hospitals)	340	225
	Big Hospitals (Over 100 beds)	450	250
	D2: Emergency Medical Facilities	300	135
	Nurses & Medical Quarters	250	135
E: Business	E1: Offices	45	30
	E2: Research and Testing Laboratories	70	45

Class of Occupancy	Occupancy Groups	For Full Facilities* (lpcd)	For Restricted Facilities** (lpcd)
	E3: Essential Services	70	45
F: Mercantile	F1: Small Shops and Market	45	30
	F2: Large Shops and Market	45	30
	F3: Refueling Station	70	45
I: Assembly	I1: Large Assembly with Fixed Seats (per seat)	90	45
	I2: Small Assembly with Fixed Seats (per seat)	90	45
	I3: Large Assembly without Fixed Seats	15	10
	I4: Small Assembly without Fixed Seats	15	10
	I5: Sports Facilities	15	10

* Full Facilities: The modern plumbing facilities allowed to the occupants of modern dwellings or, of VIP hotels and accommodations.

**Restricted Facilities: The minimum plumbing facilities acceptable for the occupants.

3.2 Water Demand Estimation for Sabrang Tourism Park

3.2.1 Proposed Land Use

Sabrang Tourism park area is divided into 5 major categories: public facilities including leisure & tourism, accommodation, utilities, administration and transportation. According to the Master Plan the total land distribution of proposed Sabrang Tourism Park is presented in **Table 3.3** and the land use zoning map is shown in **Figure 3.1**.

Table 3.3: Proposed Land use of Sabrang Tourism Park

Categories	Land Use	Area in Acres	Percentage (%)
Public facilities	Old age home	7.5	0.82%
	Welfare center	6	0.66%
	Golf course & Golf club	57	6.26%
	Amusement park	9	0.99%
	Heritage Museum, Convention Centre, Amphitheatre	3.5	0.38%
	Shopping district & Cable car station	7	0.77%
	Eco park & Jhaw Forest	60	6.59%
	Central Green & Park	22	2.42%
	Security	2	0.22%
Accommodation	Resorts & Hotels	161.5	17.75%
	Studio Apartment	29	3.19%
Utilities	Bio gas plant	27.3	3.00%
	Gas plant station		
	Power plant station		
	Electrical Substation		
	STP		
	Helipad		
	Garbage disposal station		
	Water Reservoir & Treatment Plant		
Administration	Administration	1.5	0.16%
	Fire station	1.5	0.16%

Categories	Land Use	Area in Acres	Percentage (%)
	Tourist police station	1.5	0.16%
	Hospital	1.5	0.16%
Transportation	Bus depot	3	0.33%
	Transportation hub	3	0.33%
	Jetty station	3	0.33%
Total		**406.8**	**44.68%**

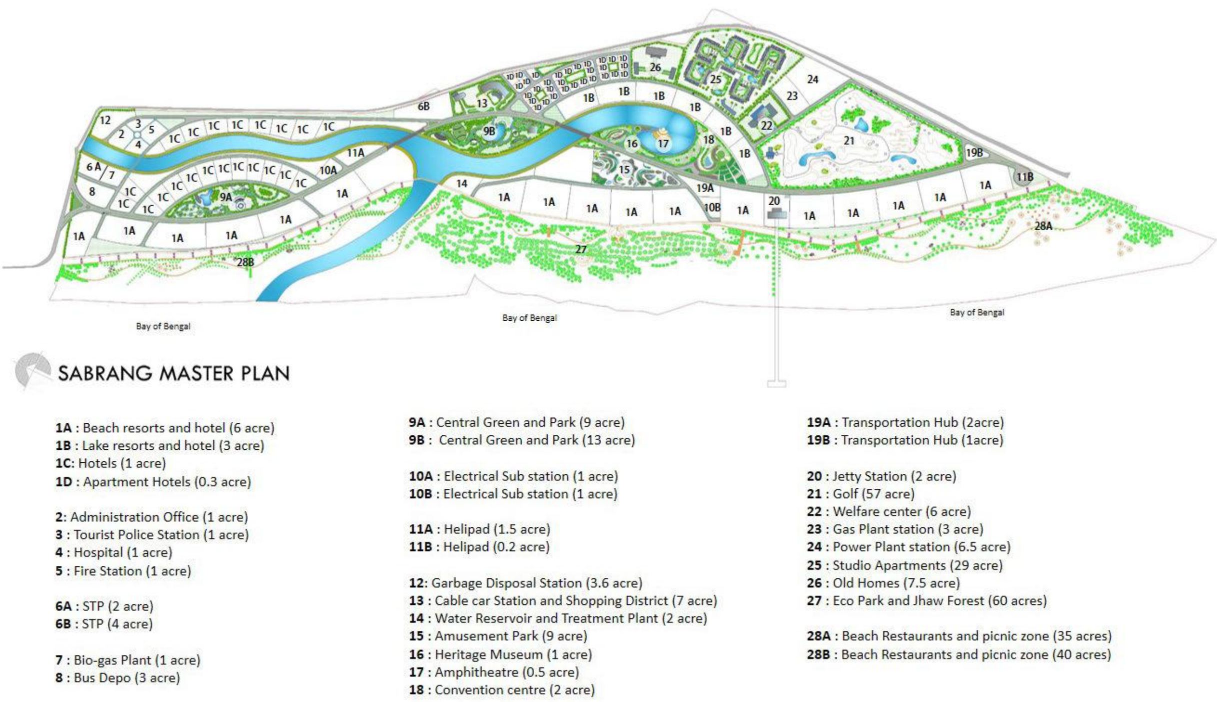


Figure 3.1: Proposed Land use Zoning of Sabrang Tourism Park

[Source: Draft Master Plan]

3.2.2 Population Projection

In the Master Plan, it is proposed that maximum about 35,785 nos. of tourist will visit and may stay at night in the Tourism Park daily. To serve and facilitate the tourists, about 4,700 nos. employee is required in different land usages. Thus total population projection for the tourism park is about 40,485 nos. The population projection for different land use pattern is given in **Table 3.4**.

Table 3.4: Population projection of Sabrang Tourism Park

Land Use	Tourist (Nos.)	Work Force (Nos.)	Total Population (Nos.)
Accommodation/Residential	24710	2510	27220
Studio Apartment	7740	860	8600
Old Age Home	500	50	550
Welfare center	90	10	100

Land Use	Tourist (Nos.)	Work Force (Nos.)	Total Population (Nos.)
Golf course & Golf club	90	10	100
Amusement park	450	50	500
Heritage Museum, Convention centre, Amphitheatre	1350	150	1500
Eco park & Jhaw Forest	180	20	200
Shopping district & Cable car station	315	35	350
Central Green & Park	182	20	200
Bus depot	0	10	10
Transportation Hub	0	50	50
Administration	0	50	50
Fire station	0	50	50
Tourist police station	0	50	50
Hospital	180	20	200
Jetty station	0	100	100
Security	0	50	50
Bio gas plant	0	50	50
Gas plant station	0	50	50
Power plant station	0	25	25
Electrical Substation	0	105	105
STP	0	50	50
Helipad	0	75	75
Garbage disposal station	0	200	200
Water Reservoir & Treatment Plant	0	50	50
Total	**35,785**	**4,700**	**40,485**

3.2.3 Water Demand

Water demand is calculated based on the per capita demand recommended in BNBC and population projection for Sabrang Tourism Park as shown in **Table 3.4**. Considering water availability, full facilities in considered only for the plots allocated for accommodations where the plot size in >= 3acre. For the other usage restricted facilities is considered. Thus the total water required is estimated as 10.09 MLD after full development in 2049. The water requirement at different phases as mentioned in the Master Plan is presented in **Table 3.5.** The detailed water demand estimation is stated in **Annex-2**.

Table 3.5: Estimated water demand for Sabrang Tourism Park

Usage	Water Requirement (Litre/day)						
	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	Total
Domestic usage	1,051,850	841000	1812300	985400	1083750	913,500	6,687,800
Amusement Park	0	0	0	40000	0	0	40,000
Sub Station Power plant	960,000	0	0	0	0	0	960,000
Total water demand	2,011,850 (2.01 MLD)	841,000 (0.84 MLD)	1,812,300 (1.81 MLD)	1,025,400 (1.03 MLD)	1,083,750 (1.08 MLD)	913,500 (0.91 MLD)	7,687,800 (7.69 MLD)
Maximum Day Water Requirement for Distribution System	2,514,813 (2.51 MLD)	1,051,250 (1.05 MLD)	2,265,375 (2.27 MLD)	1,281,750 (1.28 MLD)	1,354,688 (1.35 MLD)	1,141,875 (1.14 MLD)	9,609,750 (9.61 MLD)
Water Treatment Capacity to be Installed	2,640,554 (2.64 MLD)	1,103,813 (1.10 MLD)	2,378,644 (2.38 MLD)	1,345,838 (1.35 MLD)	1,422,423 (1.42 MLD)	1,198,969 (1.20 MLD)	10,090,241 (10.09 MLD)

The weighted average demand for tourist, workforce and total population in Sabrang Tourism Park is as follows:

- For tourist weighted average demand-183 LPCD
- For workforce weighted average demand-28 LPCD
- For total population weighted average demand-165 LPCD

3.2.4 Water Requirement for Drinking Purpose Only

The amount of fluid intake required per day depends on physical activity, age, health, and environmental conditions. In a temperate climate under normal conditions, adequate fluid intake is about 2.7 litres for adult women and 3.7 litres for adult men. These amount cover fluids from water, other beverages and food. About 20% of daily fluid intake usually comes from food and the rest from drinks. Usually health advisors recommend to drink at least 2 lire of water daily.

In Sabrang Tourism Park daily 40,485 population will visit, serve the tourist and may stay at night. If we considered water requirement of 2 litre daily, then about 81,000 litre of water is required only for drinking purpose in Sabrang Tourism Park. The phase wise drinking water requirement is presented in **Table 3.6**.

Table 3.6: Water Requirement for Drinking Purpose in Sabrang Tourism Park

Phase	Drinking Water Requirement (Litre/day)
Phase-1	12,520
Phase-2	10,300
Phase-3	21,040
Phase-4	12,360
Phase-5	17,650
Phase-6	7,100
Total	**80,970**

3.3 Water Demand Estimation for Naf Tourism Park

3.3.1 Proposed Land Use

Naf Tourism park area is divided into 5 basic zones: accommodation, commercial space, open space, service and utility area and transportation area.

The master plan has planned eco-friendly accommodation and divided into 3 categories which will be separated by roads to maintain security and tranquility of the more privileged zones. Park & Garden, Reserved Forest, Water Body and Open Green Area & Pavement are considered as open space zone. BGB, Power House, Service Staff, Security Staff, Pump & Gas, STP and Garbage Sorting Station etc. are considered as service and utility zone. Tunnel, Cable Car Station and Helipad are considered as transportation zone. According to the Master Plan the total land distribution of proposed Naf Tourism Park is presented in **Table 3.7** and the land use zoning map is shown in **Figure 3.2**.

Table 3.7: Proposed Land use of Naf Tourism Park

Land Use	Facilities	Area in Acres	Percentage (%)
Accommodation	Hotel & Cottages Zone	40	15%
	Cottages	4.93	2%
	Apartment Zone	18	7%
	Sub-Total	**62.93**	**24%**
Commercial	Central Plaza & Public Facility (Shopping, Restaurant)	50	19%
	Sub-Total	**50**	**0.19**
Open Space	Park & Garden	27.5	10%
	Reserved Forest	73.48	27%
	Water body	8.9	3%
	Open Green Area & Pavement	39.98	15%
	Sub-Total	**149.86**	**55%**
Service and Utilities	Power House	1	0%
	Service Staff	2	1%
	Security Staff	1	0%
	Gas Station	1	0%

Land Use	Facilities	Area in Acres	Percentage (%)
	STP	0.06	0%
	Garbage Sorting	0.5	0%
	Sub-Total	**5.56**	**1%**
Transportation	Tunnel	0.2	0%
	Cable Car Station	1.2	1%
	Helipad	0.05	0%
	Sub-Total	**1.45**	**1%**
	Total	**269.8**	**100%**

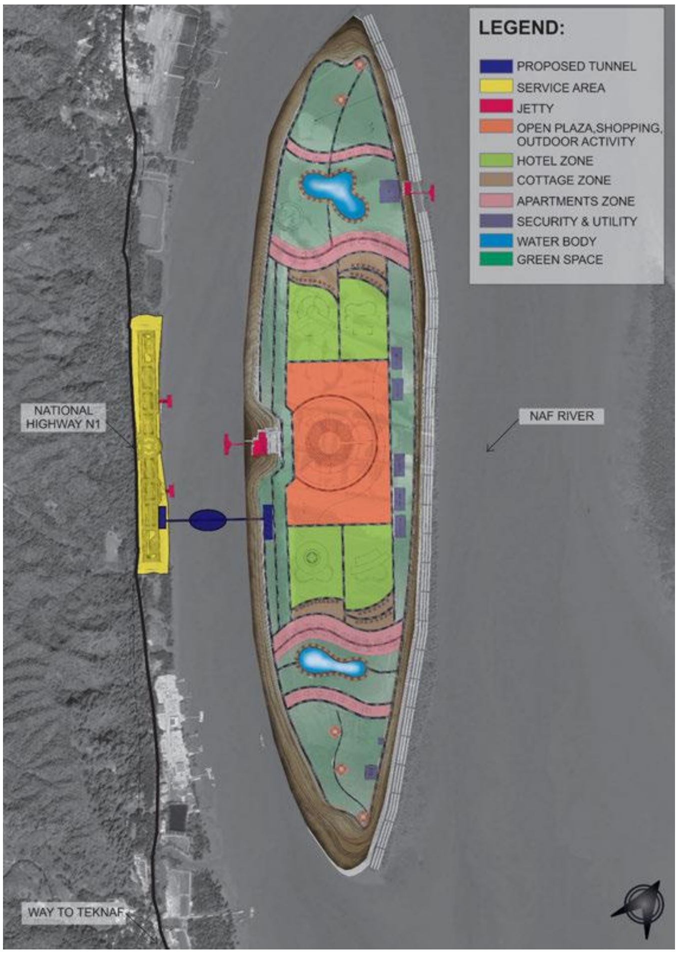


Figure 3.2: Proposed Land use Zoning of Naf Tourism Park

[Source: Draft Master Plan]

3.3.2 Population Projection

In the Master Plan, it is proposed that maximum about 3,665 nos. of tourist will visit and may stay at night in the Tourism Park daily. To serve and facilitate the tourists, about 1,225 nos. employee is required in different land usages. Thus total population projected for the tourism park is about 4,890 nos. The population projection for different facilities is presented in **Table 3.8**.

Table 3.8: Population projection of Naf Tourism Park

Facilities	Tourist (Nos.)	Work Force (Nos.)	Total population (Nos.)
Hotels	2000	200	2200
Cottages	525	200	725
Apartments	1140	220	1360
BGB	-	70	70
Central Plaza & Shopping District	-	15	15
STP	-	15	15
Fire Station	-	30	30
Power House	-	20	20
Service Staff	-	170	170
Security Staff	-	95	95
Gas & Pump House	-	15	15
Garbage Sorting Station & STS	-	15	15
Cable Car Station	-	25	25
Parking & Tunnel Access Station	-	50	50
Helipad	-	5	5
Restaurants	-	60	60
Water Reservoir & Treatment Plant	-	20	20
Total	**3665**	**1225**	**4890**

3.3.3 Water Demand

Water demand is calculated based on the per capita demand recommended in BNBC and population projection for Naf Tourism Park as shown in **Table 3.8**. Considering water availability, full facilities is considered only for the Hotels and restricted facilities for other usages. Thus the total water required is estimated as 1.15 MLD after full development in 2049. The water requirement at different phases as mentioned in the Master Plan is presented in **Table 3.9**. The detailed water demand estimation is given in **Annex-3**.

Table 3.9: Estimated water demand for Naf Tourism Park

Usage	Water Requirement (Litre/day)			
	Phase-1	Phase-2	Phase-3	Total
Domestic usage	375,447	135042.6	354021	864,511
Water for CCPP	14,000	0	0	14,000
Total demand	389,447 (0.39 MLD)	135,043 (0.14 MLD)	354,021 (0.35 MLD)	878,511 (0.88 MLD)
Maximum Day Water Requirement for Distribution System	486,809 (0.49 MLD)	168,804 (0.17 MLD)	442,527 (0.44 MLD)	1,098,139 (1.10 MLD)
Water Treatment Capacity to be Installed	511,150 (0.51 MLD)	177,244 (0.18 MLD)	464,654 (0.46 MLD)	1,153,048 (1.15 MLD)

The weighted average demand for tourist, workforce and total population in Naf Tourism Park is as follows:

- For tourist weighted average demand-225 LPCD
- For workforce weighted average demand-32 LPCD
- For total population weighted average demand-177 LPCD

3.3.4 Water Requirement for Drinking Purpose Only

In Naf Tourism Park daily 4,890 population will visit, serve the tourist and may stay at night. If we considered water requirement of 2 litre daily, then about 9,800 litre of water is required only for drinking purpose in Naf Tourism Park. The phase wise drinking water requirement is presented in **Table 3.10**.

Table 3.10: Water Requirement for Drinking Purpose in Naf Tourism Park

Phase	Drinking Water Requirement (Litre/day)
Phase-1	3,710
Phase-2	2,423
Phase-3	3,646
Total	**9,779**

4 GROUNDWATER INVESTIGATION AND RESOURCE ASSESSMENT

4.1 Introduction

Tectonic structures, topography, and stratigraphy are the three key geological attributes that can greatly influence the groundwater movement and accumulation in the surface and subsurface of a hilly terrain. The current study area is situated in a complex geological terrain where hills and coastal plain play significant role in defining the hydrogeology of the area. The trends of geological structures (e.g., anticline), stratigraphy, topography, and drainage pattern are interlinked with the spatial variation of hydraulic head, aquifer thickness and continuity, and groundwater salinity in the region.

The geology of the Teknaf Peninsula region, consisting of many types of rocks that have been subjected to a variety of tectonic deformation, is stratigraphically and structurally complex. These rocks form a complex, three-dimensional framework that can be subdivided into aquifers and confining units on the basis of their ability to store and transmit water. Lithostratigraphic units in the region are disrupted by variable-magnitude offset thrust, strike-slip, and normal faults. Combinations of reverse, normal and strike slip faulting, and folding episodes have been resulted in a complex distribution of rocks. Consequently, diverse rock types with associated diagenetic effects, ages, and deformational structures are juxtaposed, creating variable and complex subsurface hydrogeological conditions. Faults juxtapose units with different hydraulic properties may disrupt regional groundwater flow and recharge capacity. Therefore, deciphering the groundwater flow system in the Teknaf Peninsula region will depend on understanding the geologic framework of the area, especially stratigraphy, structure, and topography.

4.2 Geology

The current study area is geologically situated in the Chittagong Tripura Fold Belt (CTFB), the eastern folded flank of the Bengal Basin formed due to the still-ongoing collision between the Indian Plate and the Burmese Plate and exposing the Miocene to Recent deposits (Steckler et al., 2008; Khan et al., 2015; Hossain et al., 2019).

4.2.1 Regional Geology

The Bengal Basin is one of the largest peripheral collisional foreland basins in the South Asia (Hossain et al., 2019), which consists a section of Mesozoic and Tertiary deposits covered by Recent alluvium. This is also the thickest sedimentary basin in the world consists of Early Cretaceous–Holocene sedimentary succession with a maximum thickness of ~21 km (Curray, 1991; Curray and Munasinghe, 1991). Geographically, the Bengal Basin lies approximately between 20° 34′ to 26° 40′ N and 87° 00′ to 92° 45′ E with its major portion belongs to Bangladesh and also covers a part of the Indian states of West Bengal, Tripura, and Assam (**Figure 4.1**). The basin is bordered on the west by the Indian Shield and the Shillong Plateau to the north, the Indo-Burman Ranges to the east and the Bay of Bengal to the south (Uddin and Lundberg, 2004; Hossain et al., 2020).

The tectonic evolution of the Bengal Basin is directly related to the development of the Himalayan Orogeny in the north and the Indo-Burman Ranges (IBR) to the east due to the north and north-eastern collision of the Indian Plate with the Eurasian Plate and the Burmese Plate, respectively (Steckler et al., 2016; Hossain et al., 2019).

The pericratonic part on the eastern margin of the Bengal Basin has continuously subsided and received an immense volume of sediments from the Late Mesozoic through the Tertiary to Recent times (Johnson and Alam, 1991; Khan et al., 2018). Sediment contributions to the basin began to arrive primarily from the Himalaya around the Early Oligocene epoch (~35 Ma) and later from the IBR, and have been prograding southward to the present day (Curiale et al., 2002). To maintain the isostatic equilibrium, the massive mass of the arriving sediments loaded and depressed the underlying lithosphere further, leading to the creation of additional accommodation space for deltaic sediments. This additional lithospheric depression and accommodation space have resulted from the southward thrusting of the Shillong Plateau over the basin through the past 3.5 million years in the north, and from the westward overthrusting of the IBR toward the basin in the east (Johnson and Alam, 1991; Khan et al., 2018; Hossain et al., 2019). Although the initiation time of the IBR in the east, is widely argued, the estimates range from the Late Eocene–Early Oligocene to the Late Miocene. The progressive westward fold-thrust overprinting within the IBR was due to rapid propagation of the accretionary wedge westward since Pliocene (Maurin and Rangin, 2009; Najman et al., 2016). This westward propagating fold-thrust belt component of the IBR is known as the CTFB. According to Maurin and Rangin (2009), a very rapid development and westward propagation of the CTFB started occurring since 2 Million years.

Based on overall regional tectonic setting, geophysical investigations, field geological mappings and on well data, the Bengal Basin has been divided into three major geotectonic provinces (**Figure 4.1**): i) the Stable Shelf to the northwest or the Geotectonic Province 1, ii) the Foredeep Basin to the center or the Geotectonic Province 2, and iii) Folded Flank to the east or the Geotectonic Province 3 (Bakhtine, 1966; Alam et al., 2003; Hossain et al., 2019; Hossain et al., 2020). The N–S trending eastern folded flank consists of Neogene molasse sediments is widely known as the CTFB, forming less intensely deformed low hill tracts to the west of the IBR.

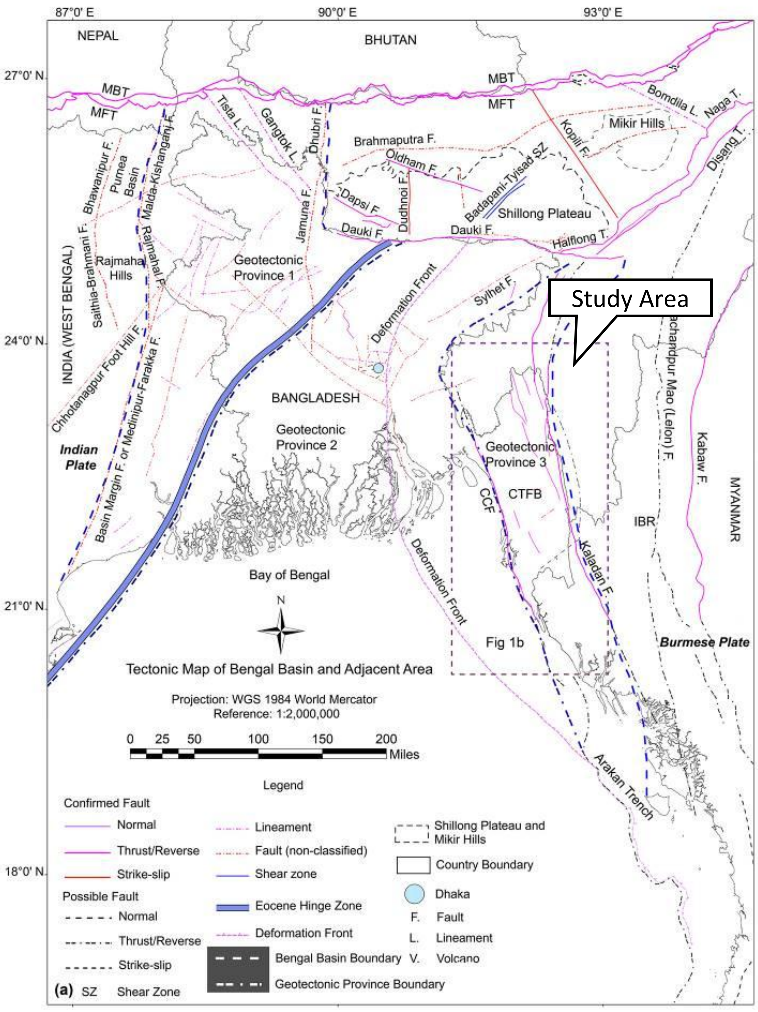


Figure 4.1: Simplified tectonic map of the Bengal Basin and its surroundings

4.2.2 Tectonics and Structure

The folds of the CTFB comprise the youngest structural subdivision of the western flank of the Indo-Burman Ranges (Hossain et al., 2014). The geological studies carried out in this western folded flank region indicate that the CTFB has not been developed synchronously; rather, this fold-thrust belt has grown progressively westward (Steckler et al., 2008; Maurin and Rangin, 2009; Steckler et al., 2016; Khan et al., 2018; Hossain et al., 2019). The deformation intensity of the fold belt varies from west to east. Based on the geometric shape and folding intensity, Bakhtine (1966) divided the CTFB into three subdivisions. From west to east, these are eastern highly compressed disturbed zone, middle asymmetric thrust faulted zone, and western quiet zone.

The current study area falls within the western quiet zone. This zone is situated west of the middle asymmetric thrust faulted zone, and the overall trend of the anticline is ~NNW-SSE (**Figure 4.2**). In general, axial plane is steeply inclined to the west and structures plunge very gently towards N here. The widths of the synclines are commonly broad in the north than those to the south, and steep limbs of anticlines are generally faulted. Overall, the axial plane of the anticlines strikes 335-350º, dips 55-65º towards NE, and have interlimb angle of 70-90º. Plunge varies 3° to 10º, either to the north or to the south (Hossain et al., 2019). Some of the prominent anticlines in this zone are St Martin‘s Island, Dakhin Nhila, Inani, Olathang/Waylataung, Maheskhali, Jaldi, Patia, Sarta/Lambaghona, Sitakund, and Semutaung. A major fault is present in this zone running NNW-SSE along the western edge of the Dakhin Nhila-Inani-Maheskhali-Sitakund structures (**Figure 4.2**). Due to this fault, western flank of the Inani structure is under-thrusted and subsided along the Cox's Bazar-Inani Marine Drive. Moreover, Dakhin Nhila structure is extensively faulted, and six major faults have been identified, which are mainly situated in the west, east and southern part of the structure (Khan et al., 2015; geological field work during this study). Among these, two major longitudinal thrust faults define the eastern and western edge of the structure, and another transverse fault result abrupt termination of the southern part of the structure (**Figure 4.3**). Geologically, the Teknaf Penonsula is basically comprises the Dakhin Nhila structure.

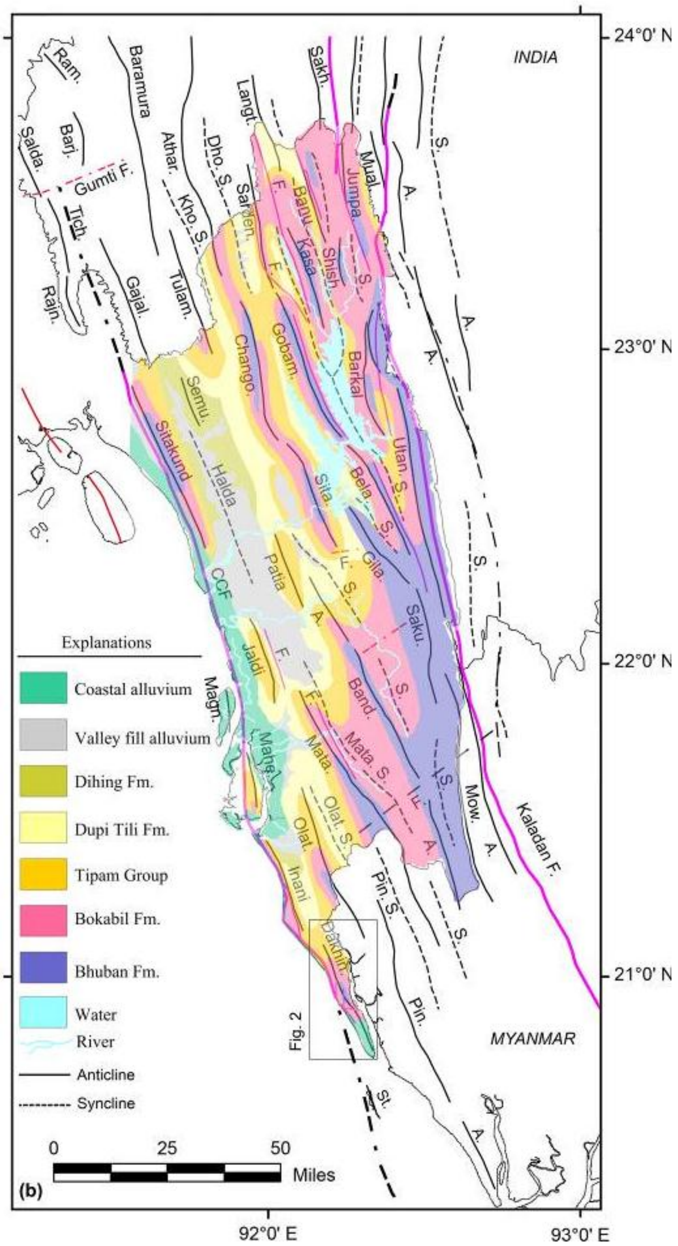


Figure 4.2: Simplified geological and tectonic map of the CTFB area of the Bengal Basin and its surroundings

(Modified after Rahman et al., 2020)

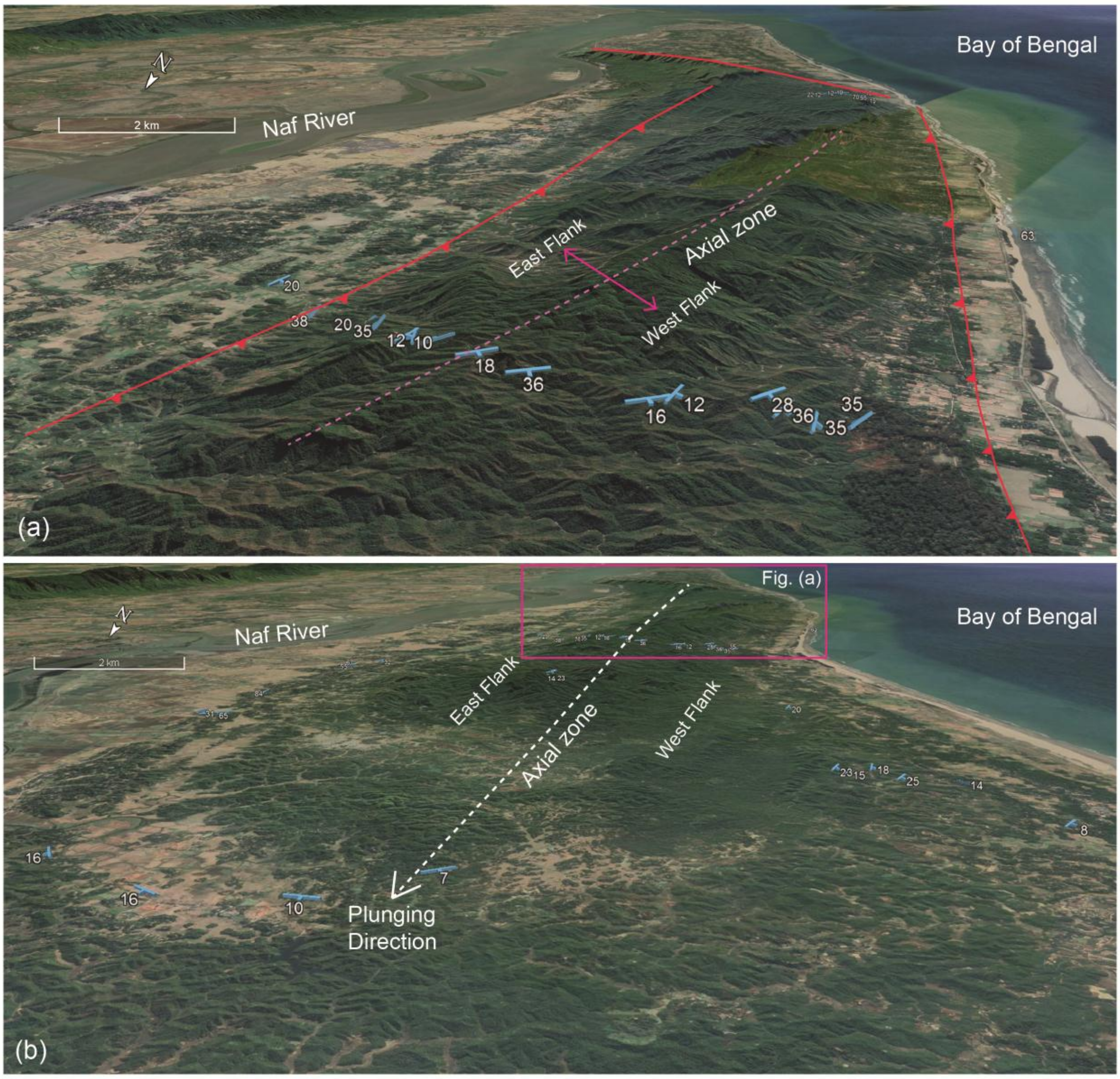


Figure 4.3: Visualization of the structural elements of the Dakhin Nhila Anticline using Satellite Image

(a) 3D visualization of the bedding attitude data of the Dakhin Nhila structure along the Jahagpara-Hnila Bazar section. Orientation of the blue bar indicates strike direction, short edge at the middle of the blue bar suggests dip direction, and white font numerical value indicates dip amount (b) Determination of the northern plunging direction of the structure based on the attitude data

4.2.3 Structural Analysis Using Bedding Attitude Data

A total of 60 attitude measurements' were taken for the bedding plane, from which 49 data has been used for geometric analysis of the Dakhin Nhila Structure. Approximately, 62% measurements were taken from the western flank and remaining 38% from the eastern flank. The poles to the bedding planes have been plotted on the Schmidt's equal area lower hemisphere projection and then create pole density contoured diagram (**Figure 4.4**). In addition, within the pole point diagram mean vector of the pole point have been interpreted. These two mean vector pole points of the two flanks are represented as larger dots within circle. Fold axial plane orientation trend is 339.5°, dip of axial plane is 87° W, and the interlimb angle is 125º, which, indicate that the structure is a gentle fold, and slightly asymmetrical.

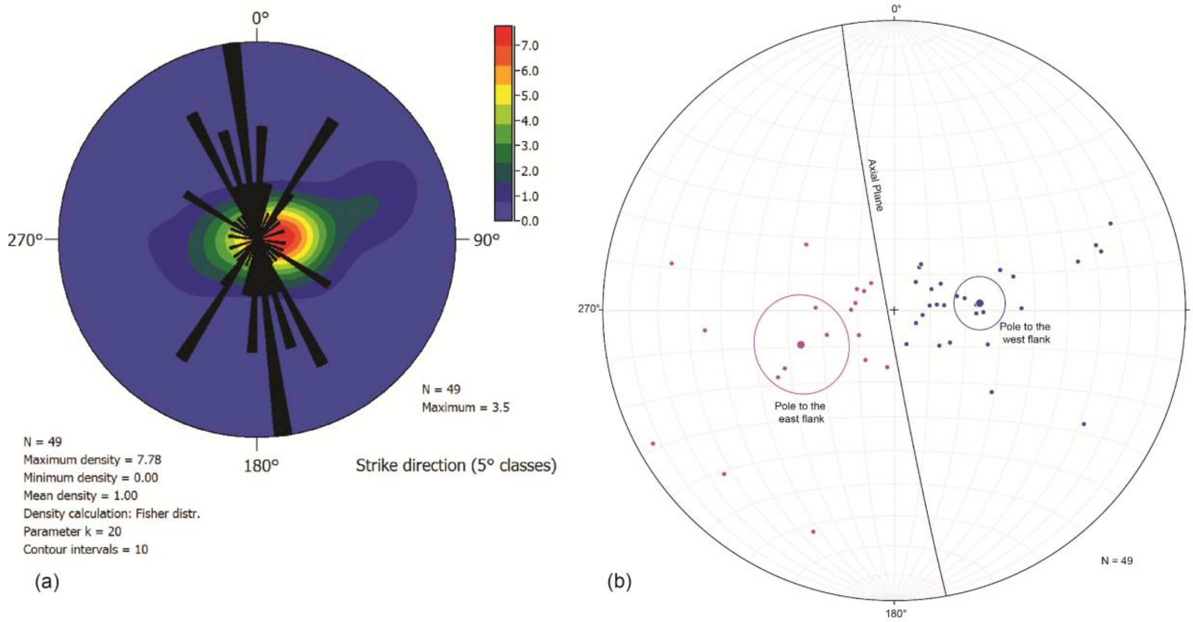


Figure 4.4: Structural interpretation using stereographic projection of the bedding attitude data

(a) Color fill contour diagram of the poles to the bedding planes in lower hemisphere equal area projection with superimposed Rose diagram based on strike of the bedding attitude data of the Dakhin Nhila Structure plotted with 5̊ class interval (petals parallel strike direction) (b) Poles of the bedding attitude data measured from the west (dark blue color) and east (pink color) flank of the Dakhin Nhila Structure. Mean vectors of the flanks and axial plane of the structure are marked by circles, and line respectively

4.3 Stratigraphy

Geological formations of different groups are exposed in different places of the study area. The Coastal Holocene deposit predominately consists of Dihing Formation and Dupi Tila Formation of Plio-Pleistocene age. The formations are characterized by fine to coarse grained sandstone of variable color sand clay. To the south of Dihing and Dupi Tila formations, the Girujan Clay of Pleistocene and Neogene age is present followed by Tipam Formation of Pliocene age (Alam et al., 1990). The formation covers Ukhia Upazila on the south, part of Ramu Upazila in the north and north east and a thin zone to the east of Cox's Bazar. Brief description of the stratigraphic formations is given in **Table 4.1**.

Table 4.1: Stratigraphic formations in the study area (modified after Hossain et al., 2019)

Age (approx)	Group	Formation	Lithology	Thickness Max (m)	Depositional Environment	Tectonic Events
Holocene		Alluvium			Fluvial	

Age (approx)		Group	Formation	Lithology	Thickness Max (m)	Depositional Environment	Tectonic Events
Plio-Pleistocene			Dupi Tila	Coarse ferruginous sandstone with layers of quartz pebbles and siltstone with lignitic fragments and petrified wood.	1,600	Fluvial	Folding in the eastern Bengal Basin
		Tipam	Girujan Clay	Clay and siltstone.		Alluvial	Dauki Fault
			Tipam Sandstone	Coarse-grained, pebbly, cross-bedded sandstone.			
Miocene	Late Miocene	Surma	Boka Bil	Dark grey pyrite-bearing shale, sandy shale and sandstone.	1,600	Fluvial tidal-deltaic estuarine	Miocene upliftment of the Himalaya
	Middle Miocene		Bhuban	Sandstone and pebbly sandstone at the top and sandy shale at the bottom	1,500	Shallow marine	

4.3.1 Surface and Subsurface Geology

Beach and sand dunes, Dupi Tila Formation, Tipam Sandstone formation and Bokabil Formation are exposed on surface in the study area and consequently unexposed portion lies beneath the exposed formation as per stratigraphic chronology of the study area. **Figure 4.5** showing exposed geological formation of the study area.

4.3.1.1 Beach and Dune sand:

Usually pale-gray to light-yellowish gray, fine to coarse, poorly sorted to well-sorted contains angular to rounded fragments, comprises deposits of coastal barrier islands and narrow beach dune ridges bordering the brackish-water of the Bay in the study area.

4.3.1.2 Dihing Formation:

This formation is Pleistocene mappable rock body. It has scattered occurrence in the Bengal Basin and has merely of local importance. The formation consists of yellow and grey, medium-grained, occasionally pebbly sandstone and clayey sandstone with interbeds of mottled clay. It is hard to define in target deposit separately in the study area.

4.3.1.3 Dupi Tila Formation:

It is a Plio-Pleistocene mappable rock body of the area. The unit uncomfortably overlies of Tipam sandstone. In the study area, the Dupi Tila Formation consists of variegated colour, fine to medium grained sandstone and occasionally cross-bedded with subordinate claystone and siltstone. Sometimes pebble, cobbles are also observed within this formation.

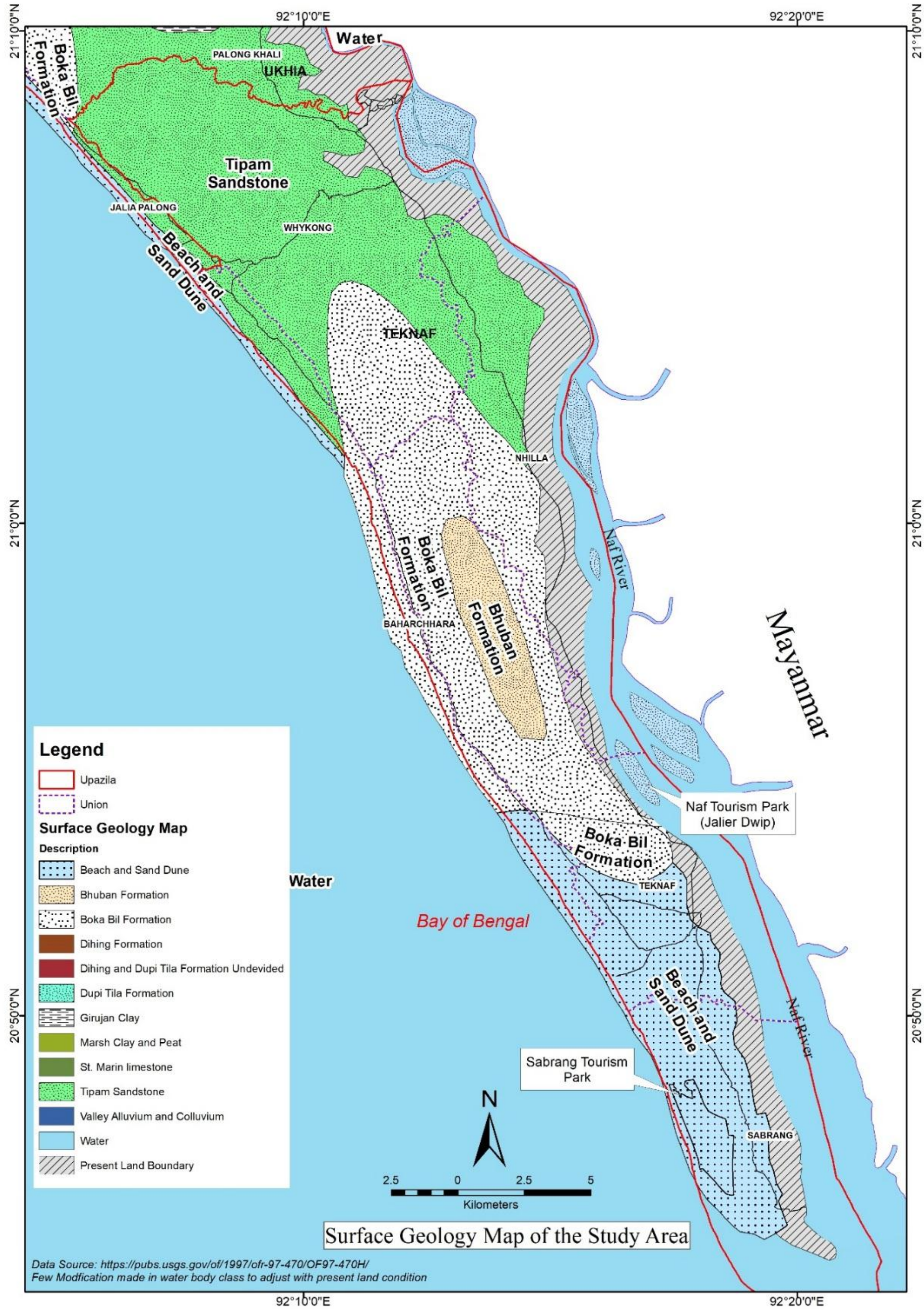


Figure 4.5: Surface Geology Map of the Study Area.

4.3.1.4 Tipam Formation:

This formation is fine to medium grained sandstone, siltstone and shale, massive to thinly bedded, locally cross-bedded and current-bedded. In the south Tipam Formation merges to the Late Miocene Boka Bil Formation. The area included Teknaf Upazila in the south and eastern part of Cox's Bazar city. The formations are characterized by massive to thinly bedded shale, siltstone and sandstone.

4.3.1.5 Upper Boka Bil Formation:

This formation is Bluish grey shale with alternation of massive or bedded sandstone. Commonly sandstone is interbedded with thin shale layer of siltstone. Fossiliferous bed occasionally found within this formation. During the field work, a 15 cm thick fossiliferous sandstone bed within shale has been found at study area. Fossils are also found in more than 1m thick shale layer. On field fossil identification guideline reveals that these fossils are mainly of Pelecypod and Brachiopod types.

4.4 Structure of the Aquifer System

Analysis of the satellite images and subsequent ground truthing through detailed geological field investigation suggests that lithology of the possible aquifer system is highly heterogeneous both laterally and vertically. Surface geology data indicates that the possible aquifer system exists only in the northern plunging part, and within the narrow strips along the northwestern and northeastern edge of the Dakhin Nhila structure. As the area is folded and highest topography exists along the axial zone, the approximately north-south water divide line (axial line) divides the aquifer virtually into two parts: eastern and western parts. Therefore, lateral recharge connectivity between these two aquifers is also very limited excepting in the northern most part. Moreover, presence of two major faults along the eastern and western edge of the structure further restricted lateral flow of water, hence also limiting the recharge capacity of the aquifer. Therefore, heterogeneous lithology, dipping stratum due to folding, and presence of two major faults in this area not only make the aquifer system structurally complex but also limit their recharge capacity.

4.5 Hydrogeology of the Study Area

Hydrology of the south-eastern coastal plains of Bangladesh presents a complex interaction between fresh water flowing from the upstream to the east and the tides flowing from the Bay of Bengal to west and south. The study area is representative of typical hill slope hydrology where numerous charas (hilly streams) flow downslope from the higher hills and flows into the Naf estuary. On the coastal side (i.e., western part) hundreds of small and large khals (canals) run from the Peninsula's hilly hinterland to the bay including the Reju, Inani, Mankhali, Rajarchar and Mathabhanga by discharging freshwater runoff to the Bay of Bengal. Overall dendritic stream pattern is evident along with locally developed trellis pattern.

Coastal Holocene deposits overlying the Tertiary rocks at the western coastal part, and create different surface forms than the eastern hilly terrain. At present, morphology of this area is influenced by the active tectonics, Holocene sea level rise, tidal and fluvial discharges. Holocene alluvium composed of unconsolidated heterogeneous mixture of sand, silt and clay, which is unconformably overlies the Miocene Boka Bil shale. Tipam sandstone occurs in the low hills region, mainly in the northwestern and northeastern parts of the Dakhin Nhila structure (Khan et al., 2015).

The groundwater occurrence is different at Teknaf Peninsula compared to other part of the country. UNDP (1982) has divided the country into 15 zones (A-Q) of varying potentiality for development of groundwater resources based on lithology, thickness and structure of rock formations along with recharge potentiality and aquifer characteristics. The Teknaf Peninsula is a part of the Zone N where complex groundwater condition exists and is not suitable for shallow wells. A recent simplified classification proposes six hydrogeological provinces for the country where the Teknaf Penonsula falls into the Zone V, characterized by a complex geology of folded tertiary sediments with very low potential for large scale groundwater development (Ahmed, 2003).

Some artesian wells are found in Teknaf area, which are mostly seasonal. In dry season most of the artesian condition disappears.

4.6 Hydrogeological Investigation

4.6.1 Lithology of the Study Area

For water resource potential assessment identification, hydrogeological data have been collected from different organization/agencies. Numbers of borehole have been drilled for tube wells installation for water supplying purpose in the Teknaf area for tourists and local settlers by different government and non-government agencies. Besides the above information, IWM has done nine boreholes and installed test tube wells. Two production tube wells are also installed in the project area.

4.6.2 Test Tube Well Construction

For studying hydrogeological parameter of both shallow and deep aquifer, exploratory boreholes have been installed in 9 selected locations of the study area, which are later used as groundwater test wells. These 9 boreholes are of 38 mm diameter. Drilling depths of exploratory wells were limited up to 250 meters because of secondary data suggest there is little possibility of getting aquifer in Teknaf area below 200 meter. Even more south, new shallow aquifer is present. Towards Ukhiya, aquifer thickness and possibility of occurrence of aquifer below 200-meter increases. The evident is collected from mainly two different studies carried out by DPHE-INGO Forum Bangladesh -IWM titled “Water Resource Potential Assessment of Ukhia and Teknaf Upazila Area, Cox’s Bazar, Bangladesh” and DPHE-JICA titled “Project for Improvement of Comprehensive Management Capacity of Department of Public Health Engineering on Water Supply (PICMaC)”. Occurrence and distribution of aquifer system in Teknaf and Ukhiya (Adjacent to Teknaf) is furnished in **Annex-4**.

4.6.3 Lithologic Description of the Exploratory Boreholes

Aquifer characteristics of the study area have been determined from the lithologs prepared from the borehole information and subsequent hydrostratigraphic classification and their hydraulic properties. Grain size analyses data of the collected sediment samples and the lithological information has been analyzed using customized computer software for constructing single section of borelog (**Figure 4.6 to Figure 4.17**) and spatial distribution (**Figure 4.18**). Lithological characterization and aquifer storage volume has been estimated from such analyses. Formation permeability (K) and transmissibility (T) is determined from 9 no. exploratory wells data.

Test well 1 shows 4 thin aquifer layers in upper portion existing in 6.10 m to18.29 m, 36.59 m to 42.68 m, 54.88 m to57.93 m and 64.02 m to67.07 m. All these layers are medium to fine sand. Below these layers, a comparatively thick fine to medium sand layer of about 12 m is present from 70.12 m to 82.32 m depth. Again, comparatively thick layers of fine to medium sand exists from 100.61 m to140.24 m, 149.39 m to 182.93 m, and 189.02 m to 195.12 m depth.

Test well 2 shows very fine to fine sand layer exists from 18.29 m to 30.49 m depth. Fine sand to medium sand exists from 64.02 m to 79.27 m depth. Medium to fine sand exist from 94.51 m to 131.10 m and 134.15 m to 146.34 m depth. Again, fine to medium sand exists from 195.12 m to 210.37 m depth.

Test well 3 shows fine to medium sand exists from 48.78 m to 54.88 m. Medium sand to coarse sand exist from 60.98 m to 73.17 m depth. This borelog also shows coarse sand to medium sand from 82.32 m to 88.41 m, fine sand to medium sand from 88.41 m to 97.56 m, 134.15 m to 140.24 m depth. Very fine sand to fine sand exists from 146.34 m to 152.44 m. Fine to medium sand exists from 182.93 m to 198.17 m depth.

Test well 4 shows fine to medium sand exists from 6.10 m to 12.20 m, 18.29 m to 24.39 m, 30.49 m to 36.59 m, 60.98 m to 67.07 m 91.46 m to 97.56 m and 140.20 m to 158.54 m depth. Medium to fine sand exist from 36.59 m to 60.98 m 67.07 m to 85.37 m and 118.90 m to 128.05 m.

Test well 5 shows fine to medium sand exists from 3.05 m to 12.20 m, 67.07 m to 88.41 m and 140.24 m to 146.34 m. Medium sand to fine sand are present from medium sand to fine sand from 18.29 m to 24.39 m, 97.56 m to 106.71 m and 112.80 m to 134.15 m.

Test well 6. Depth of this well is 100.61 m. It shows Medium sand to fine sand up to 6.10 m depth. From 6.10 m to 100.61 m this borehole shows clay, silt and fine sand.

Test well 7 shows medium sand to fine sand exists from 12.20 m to 18.29 m and 60.98 m to 67.07 m depth. Fine sand to medium sand is encountered from 91.46 m to 115.85 m.

Test well 8 shows fine sand to medium sand exists from 63.98 m to 70.12 m, 73.17 m to 79.27 m, 85.37 m to 91.46 m, 118.90 m to 121.95 m and 149.39 m to 152.44 m depth. Medium to fine sand is present from 121.95 m to134.15 m depth.

Test well 9 shows that fine sand to medium sand is present from 24.39 m to 36.59 m, 51.83 m to 54.88 m, 67.07 m to 79.27 m (Coarse sand also present) and 79.27 m to 85.37 m depth. Coarse sand is present from 103 m to 106 m. Medium sand to coarse sand is present from 109.76 m to 118.90 m depth. Medium sand to fine sand is present from 106.71 m to 109.76 m and 152.44 m to 158.54 m depth.

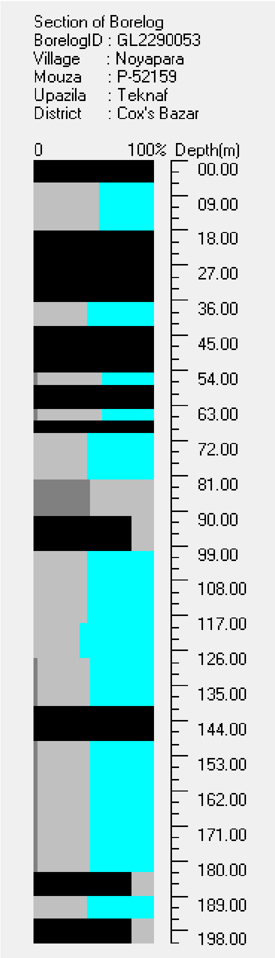


Figure 4.6: Single section of TTW-1

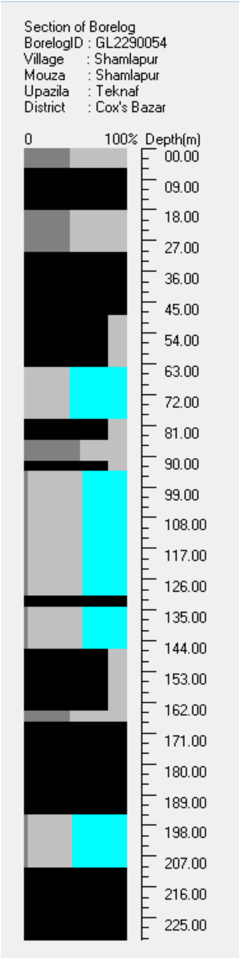


Figure 4.7: Single section of TTW-2

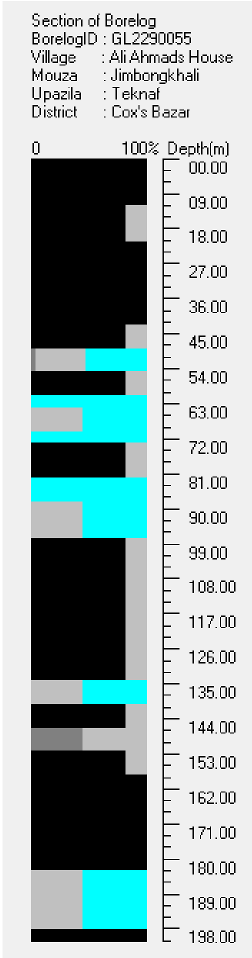


Figure 4.8: Single section of TTW-3

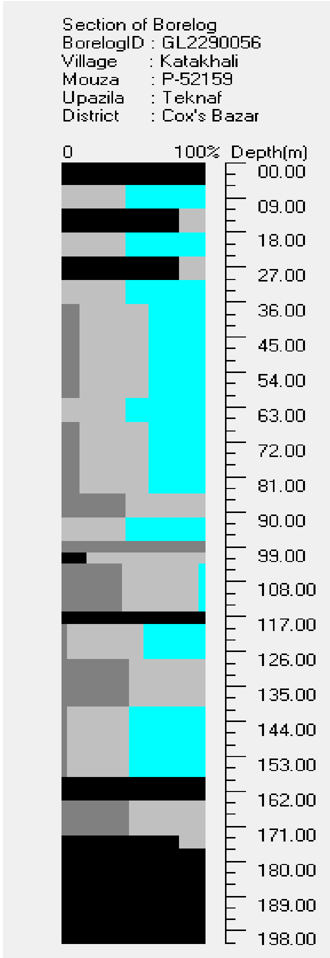


Figure 4.9: Single section of TTW-4

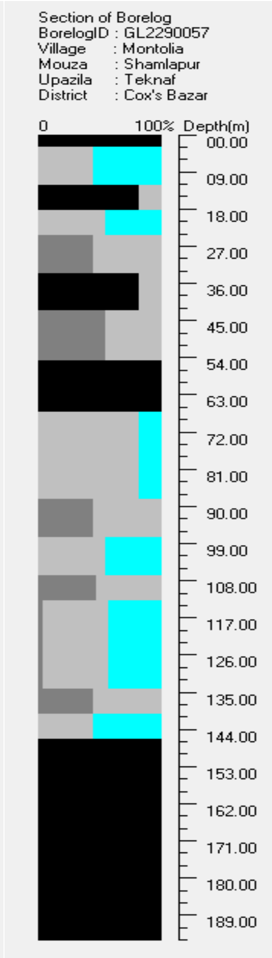


Figure 4.10: Single section of TTW-5

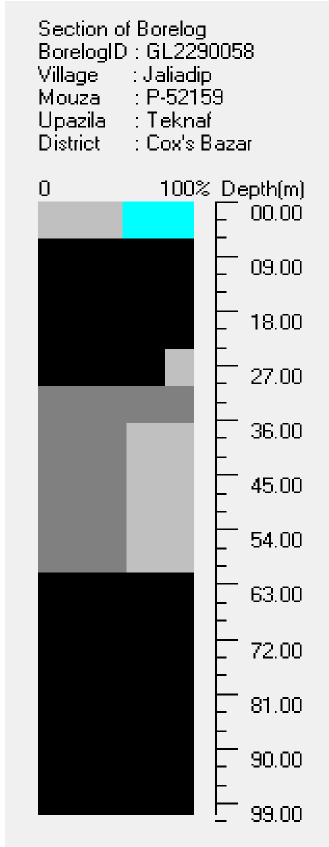


Figure 4.11: Single section of TTW-6

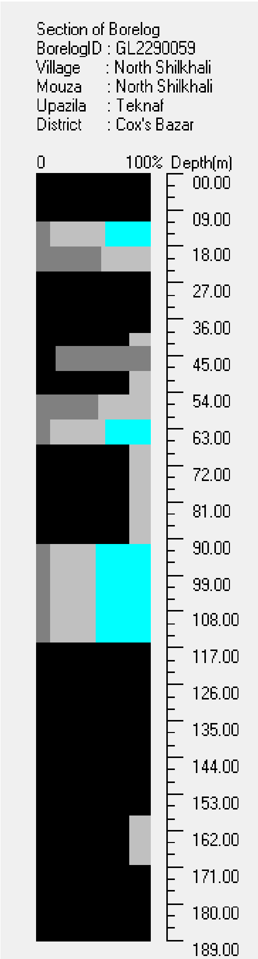


Figure 4.12: Single section of TTW-7

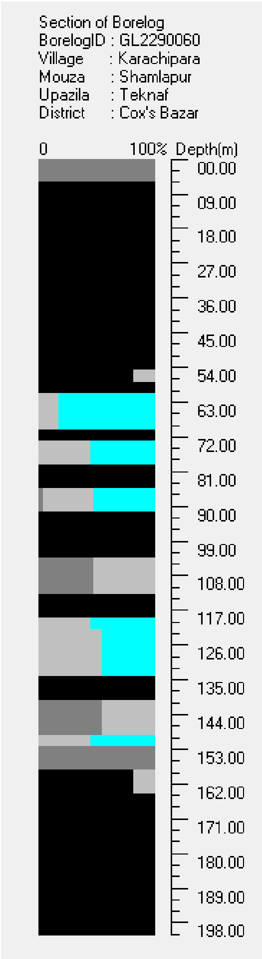


Figure 4.13: Single section of TTW-8

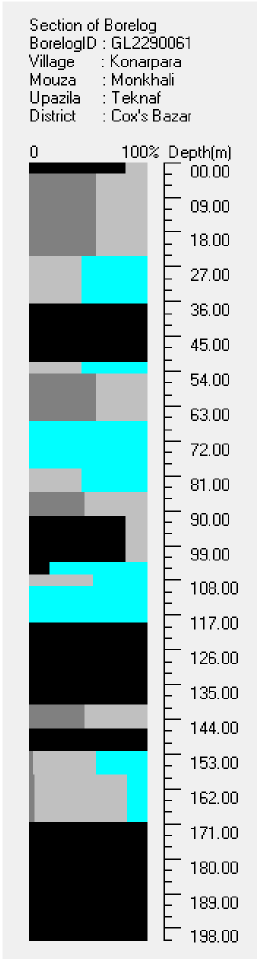


Figure 4.14: Single section of TTW-9

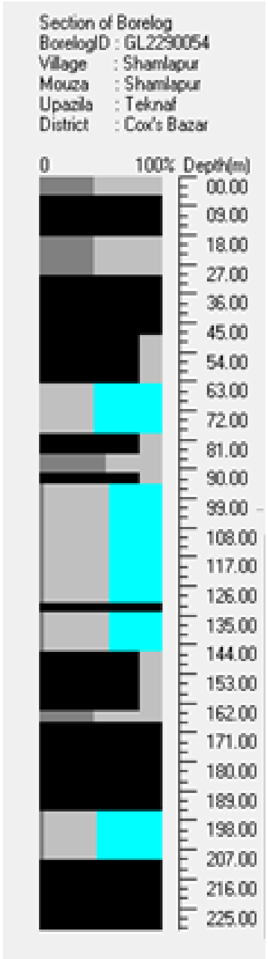


Figure 4.15: Single section of PTW 2

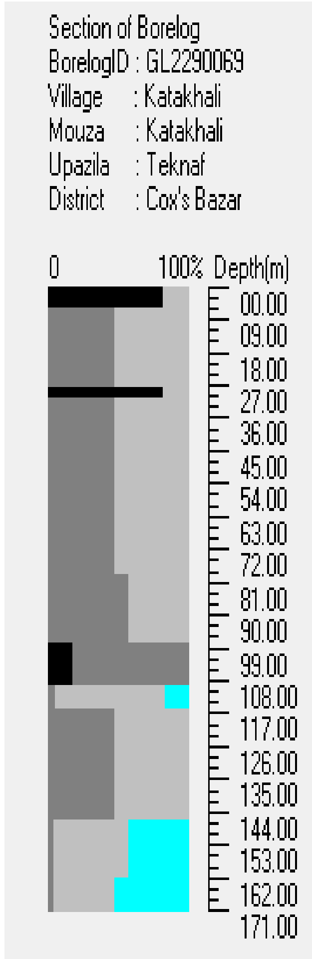


Figure 4.16: Single section obs 1, PTW 1

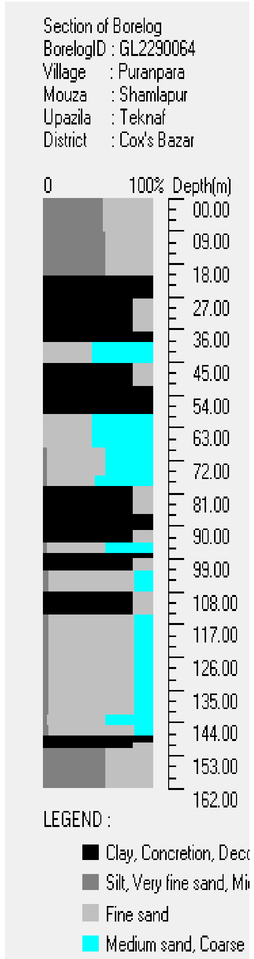


Figure 4.17: Single section of PTW 1

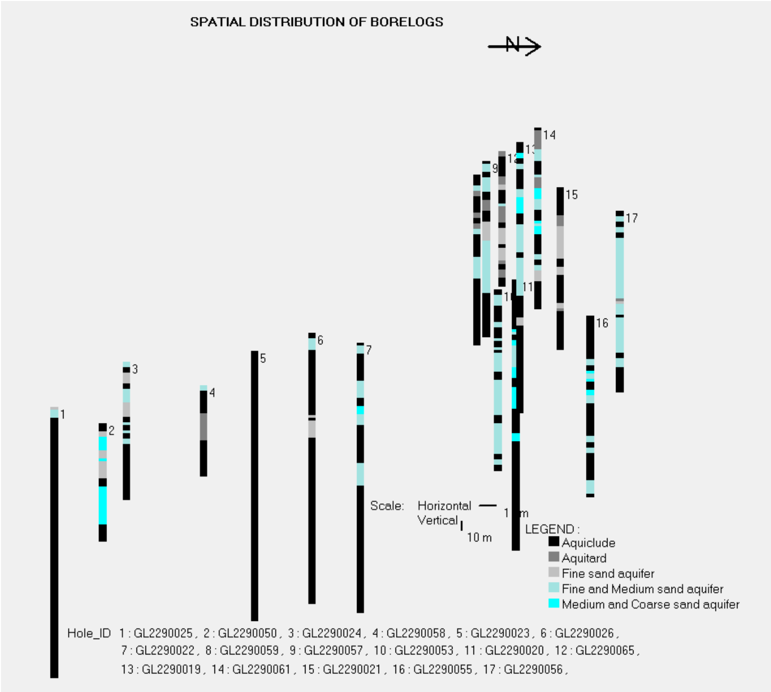


Figure 4.18: Spatial distribution of bore logs of the tube wells at Teknaf

4.6.3.1 Hydrostratigraphic Columnar Section

Lithological information of 09 drilled exploratory well of the study area is analyzed and interpreted to Hydrostratigraphic unit such as Aquiclude, Aquitard, Fine Sand Aquifer and Productive Aquifer. based on interpreted Hydrostratigraphic units, Hydrostratigraphic columnar section of the of the exploratory wells has been prepared for understanding aquifer system, vertical occurrence of aquifer types and dominant aquifer type of the study area shown in **Figure 4.19**.

4.6.4 Installation of Production Wells

Two number of production wells have been installed in the project area at Shamlapur and Katakhali after finding potential aquifer. Dimension of the test production wells is 350 mm X 150 mm. Selection of the places and design of the tube wells have been done by the professional hydrogeologist in the field after completion of test borings. Well screens have been placed from 117.92 m to 146.39 m at Shamlapur area and 138.83 m to 177.68 m at Katakhali, Whykhong area. Detailed design of the pumping wells are given in **Figure 4.20** and **Figure 4.21.**

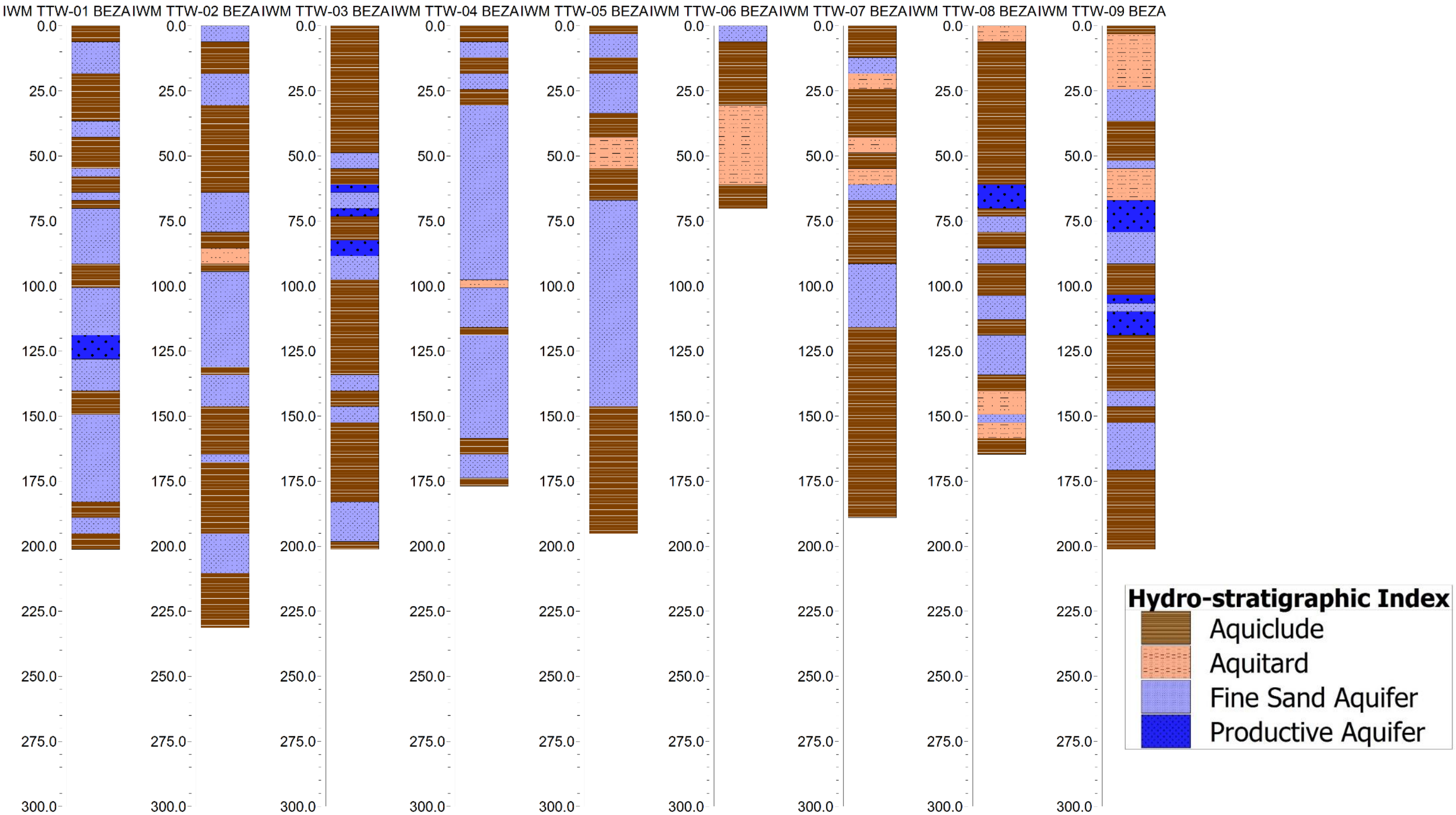
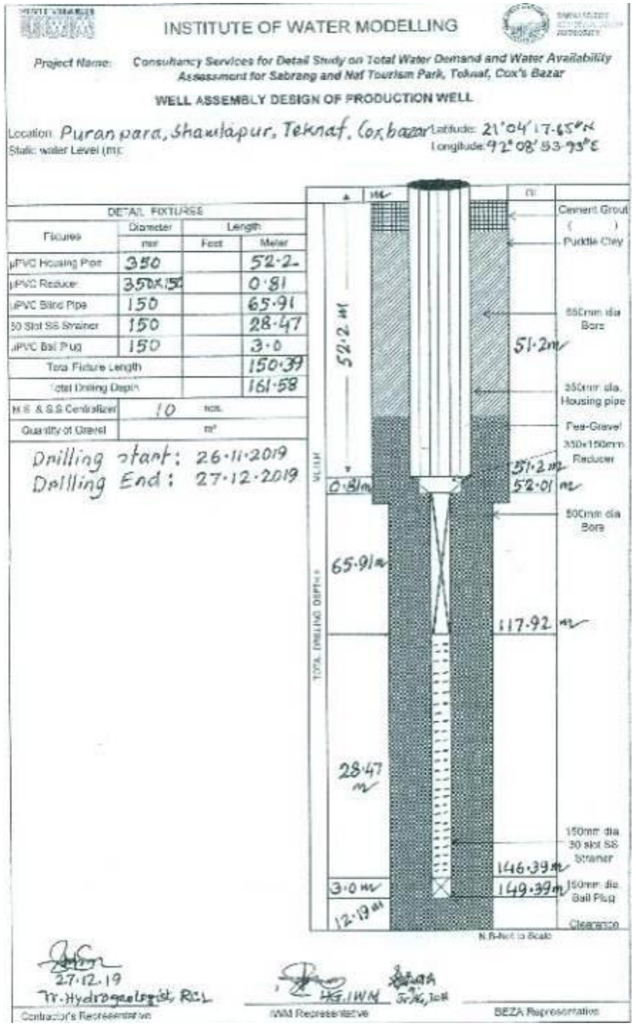


Figure 4.19: Hydrostratigraphic Columnar section of TTW driller in Tehnaf area (Nayapara, Jaliardwip, Shamlapur and Whykhong)



INSTITUTE OF WATER MODELLING

Project Name: Consultancy Services for Detail Study on Total Water Demand and Water Availability Assessment for Sabrang and Naf Tourism Park, Teknaf, Cox's Bazar

WELL ASSEMBLY DESIGN OF PRODUCTION WELL

Location: Puran para, Shamlapur, Teknaf, Cox bazar Latitude: 21°04'17.65"N

Static water Level (m): Longitude: 92°08'53.93"E

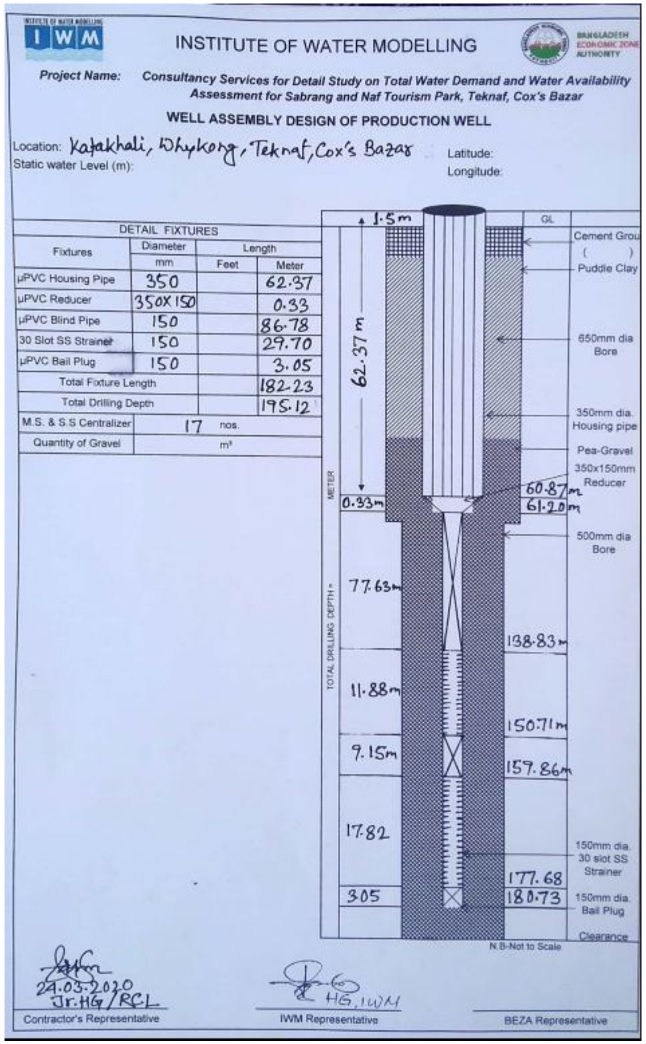
DETAIL FIXTURES

Fixtures	Diameter mm	Length Feet	Length Meter
uPVC Housing Pipe	350		52.2
uPVC Reducer	350X150		0.81
uPVC Blind Pipe	150		65.91
30 Slot SS Strainer	150		28.47
uPVC Bail Plug	150		3.0
Total Fixture Length			150.39
Total Drilling Depth			161.58
M.S & S.S Centralizer	10	nos.	
Quantity of Gravel		m³	

Drilling start: 26.11.2019
Drilling End: 27.12.2019

27.12.19
Tr. Hydrogeologist, RCL
Contractor's Representative
HG, IWM
IWM Representative
BEZA Representative

Figure 4.20: Design of production well at Shamlapur, Teknaf



INSTITUTE OF WATER MODELLING

BANGLADESH ECONOMIC ZONES AUTHORITY

Project Name: Consultancy Services for Detail Study on Total Water Demand and Water Availability Assessment for Sabrang and Naf Tourism Park, Teknaf, Cox's Bazar

WELL ASSEMBLY DESIGN OF PRODUCTION WELL

Location: Katakhali, Whykong, Teknaf, Cox's Bazar Latitude:

Static water Level (m): Longitude:

DETAIL FIXTURES

Fixtures	Diameter mm	Length Feet	Length Meter
uPVC Housing Pipe	350		62.37
uPVC Reducer	350X150		0.33
uPVC Blind Pipe	150		86.78
30 Slot SS Strainer	150		29.70
uPVC Bail Plug	150		3.05
Total Fixture Length			182.23
Total Drilling Depth			195.12
M.S. & S.S Centralizer	17	nos.	
Quantity of Gravel		m³	

24.03.2020
Jr. HG/RCL
Contractor's Representative
HG, IWM
IWM Representative
BEZA Representative

Figure 4.21: Design of production well at Katakhali, Whykhong, Teknaf

4.6.5 Determination of Aquifer Characteristics

One long term aquifer test has been performed at Shamlapur in the project area using the installed production well and another at Katakhali, Whykhong area. Test has been done to determine aquifer characteristics of the project area. Total 8 no 38 mm diameter observation wells have been installed at different depths and distances from the main well (04 nos. of observation with each production well). Aquifer test has been run for 72 hours. After completion of aquifer test, acquired data have been used to compute aquifer characteristics by using customized software. By using this software, formation transmissibility (T), storage co-efficient (S), and permeability (K) has been determined.

4.6.5.1 Aquifer test of production well 1 at Shamlapur, Teknaf

A long-term aquifer test has been done at Shamlapur in Teknaf upazila. This continuous pumping test has been continued up to 72 hours at a discharge rate of 0.37 cusec (166 gpm). Hydraulic properties of the aquifers and then successive design and development of the production wells are the most important part of groundwater study. To determine the hydraulic properties, long term aquifer test is essential. Aquifer test includes continuous test, recovery test and step drawdown test. Continuous and recovery tests are the most essential tests to determine the hydraulic properties of aquifer namely transmissivity (T), storage co-efficient (S), permeability (K) and hydraulic resistance. The storage co-efficient (S) is an essential parameter to determine the aquifer type, and transmissivity (T) and permeability (K) are used to determine the flow system of that particular aquifer.

4.6.5.1.1 Step drawdown test

Step drawdown is generally conducted to measure the drawdown at steady condition of the pumping well due to design, development and nature of aquifer materials. The drawdown due to design and development is called well loss and drawdown due to the properties of formation is called formation loss. The parameters Cw and Cf derived from step drawdown test is called well loss constant and formation loss constant, respectively. The well loss is a measure of design and development of pumping well whereas the formation loss depends on the flow system of the aquifer.

This test has been performed in three steps. The pump has been operated at 3 different stages: 0.25 cusec, o.37 cusec, and 0.40 cusec for 2 (two) hours each and corresponding draw down have been recorded (**Table 4.2**).

Table 4.2: Step drawdown test data of Shamlapur, Teknaf

Discharge (Cusec)	Static water level (m)	Pumping water level (m)	Drawdown (m)	Specific Capacity (m/L/s)
0.25	4.85	25.13	20.28	0.36
0.37	4.85	42.15	37.30	0.28
0.40	4.85	50.29	45.44	0.25

4.6.5.1.2 Continuous aquifer test

An aquifer performance test with the setup of a pumping well of 149.39 m deep with the constant discharge of 0.37 liter/sec (166 gpm) and 5 (five) observation wells installed at different depth levels from 121.80 - 140.24 m (**Figure 4.22** and **Table 4.4**) have been performed to obtain the values of the general hydraulic properties of the aquifer and also to predict the effect of withdrawals on aquifer system. The drawdown, discharges, and the radius of the zone of influence for individual well have been observed and recorded. All piezometric observation wells have been installed in the pumped aquifer level. Important water quality parameters have also been monitored and samples were collected at different time interval during the test. The prime information about the aquifer test at Shamlapur is stated in **Table 4.3**.

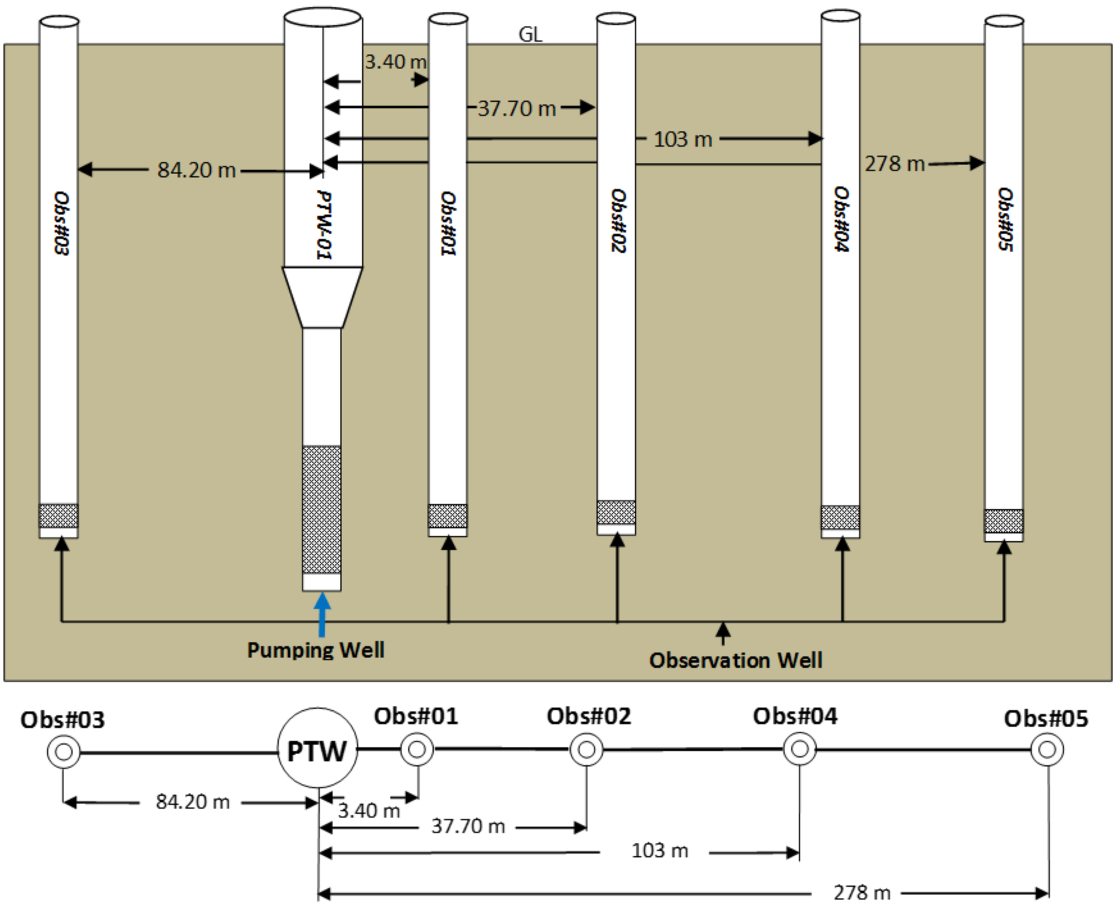


Figure 4.22: Layout Plan of Pumping and Observation Well at Shamlapur Area

Table 4.3: Aquifer test information of Shamlapur area.

Name	Specific Information
Aquifer thickness	31 m (116-147 m)
Aquifer materials	Dominantly fine sand
Screen position of main well	117.92-146.39 m
Screen length	30 m
Percentage of aquifer thickness screened	100 %
Screen diameter	150 mm
Screen slot size	0.50 mm

Name	Specific Information
Open area of screen	17%
Depth of observation well no.1	126.99 m
Depth of observation well no.2	121.80 m
Depth of observation well no.3	127.06 m
Depth of observation well no.4	136.16 m
Depth of observation well no.5	134.24 m
Distance of observation wells 1, 2, 3, 4 and 5 from pumping well.	3.40 m, 37.70 m, 84.20 m, 103 m & 278 m, respectively.

Table 4.4: Depth and distance of observation wells related to Shamlapur pump test

Obs Well no.	Depth (M)	Distance (m)	SWL (m)	Max PWL (m)
1	126.99	3.40	4.14	25.54
2	121.80	37.70	2.50	19.76
3	127.06	84.20	1.08	3.00
4	136.16	103.0	Artesian well	5.18
5	134.24	278.0		No response

The static water level just before the test started, time since the pump started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of water levels after the pump stopped (recovery data) are extremely valuable for recovery test. So, after the continuous pumping, the recovery data have been collected at fixed time interval.

The long duration aquifer test was completed for the deep aquifer at Shamlapur to determine the lateral and vertical extent of the aquifer, the chemical characteristics and potability of the aquifer water and the response of the deep aquifer to development stresses. The specific conductivity of water pumped from the production well was monitored during the 72-hour test to determine if higher conductive water was being captured by the well during the test.

4.6.5.1.3 Response in groundwater level

Response in main well

The water level in the pumping well declined abruptly during first minute of pumping from 5.35 to 22.26 m (**Figure 4.23**). After the first minute, the water level declined gently and it stabilized at 46.15 m at 1320 minutes. The same water level continued up to the end of the aquifer test at 4320 minutes (72 hours). The pumping phase of the aquifer test was completed after 4320 minutes (72 hours).

Response in observation wells

Out of 5 observation wells, observation well no. 1 has responded gently and pumping water level reaches to 25.54 m in72 hours. The observation well 2, 3, and 4 have responded more gently and pumping level of these wells reached to 19.76 m, 3.00 m and 5.18 m, respectively. Observation well 5 has not responded during the aquifer test.

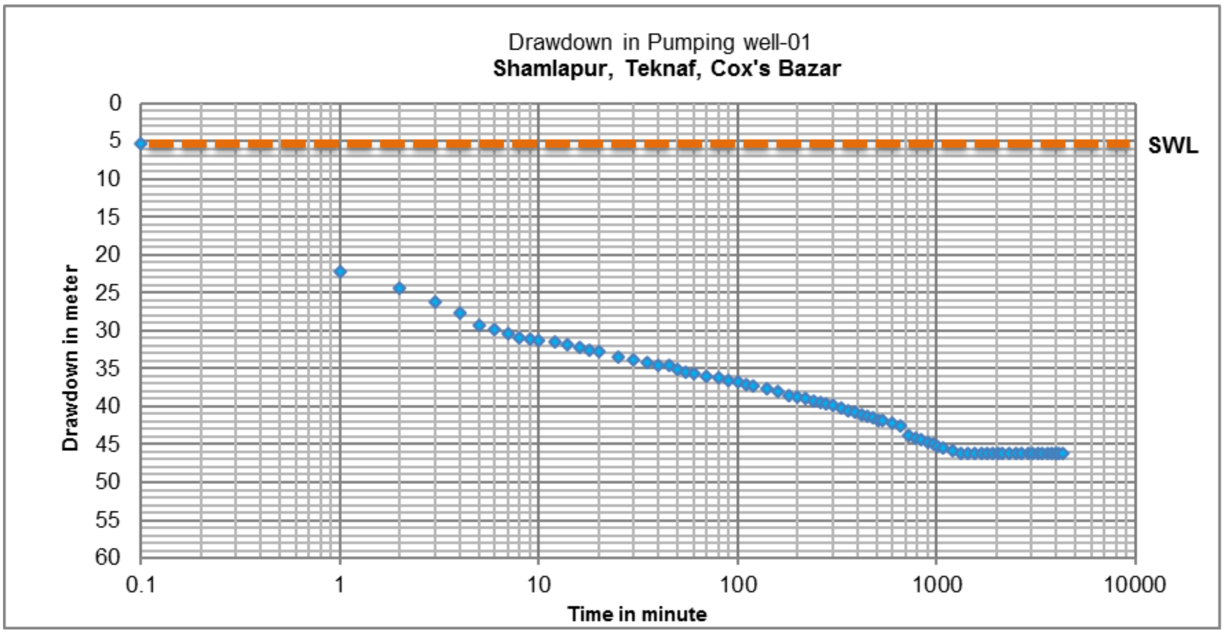


Figure 4.23: Time VS Drawdown curve in PTW at Shamlapur during Long Term Aquifer Test

4.6.5.1.4 Recovery test

Recovery is the most essential part of aquifer test to determine the aquifer properties. Then the pump was stopped and recovery data has been collected during the recovery phase of the test until 5400 minutes (90 hours) after the test had begun.

4.6.5.1.5 Analysis of the aquifer test data

The aquifer test data of Shamlapur has been analyzed by IWM customized software in three different methods, namely Theis, Jacobs, and Walton methods. The outputs of these analyses are given in **Figure 4.24** to **Figure 4.31**. Storage co-efficient (S), transmissivity (T), leakage factor (L) and permeability (K) has been analyzed from these analyses. Average transmissivity 26 m^2/d indicates that the flow system of that particular aquifer is not good. The average storage coefficient (0.0005545) has been determined from the analysis. Comparison of the average storage coefficient and hydrogeologic section indicates that the aquifer is confined in nature. All the analysis results are summarized in **Table 4.5**.

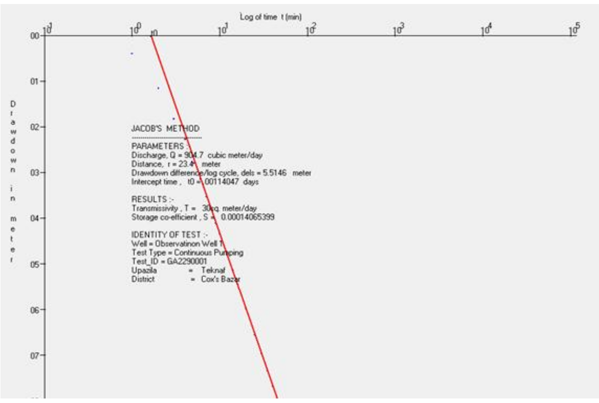


Figure 4.24: Jacobs method of analysis for Obs well 1

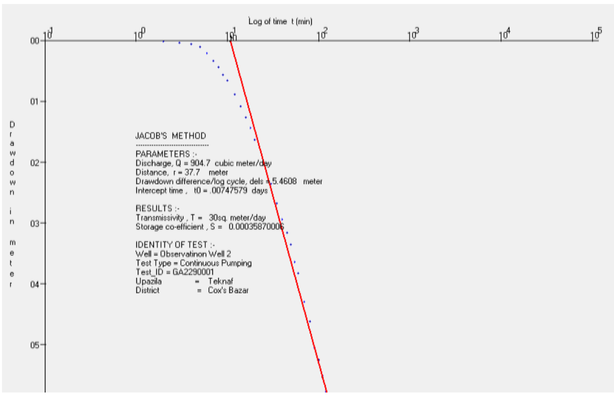


Figure 4.25: Jacobs method of analysis for Obs well 2

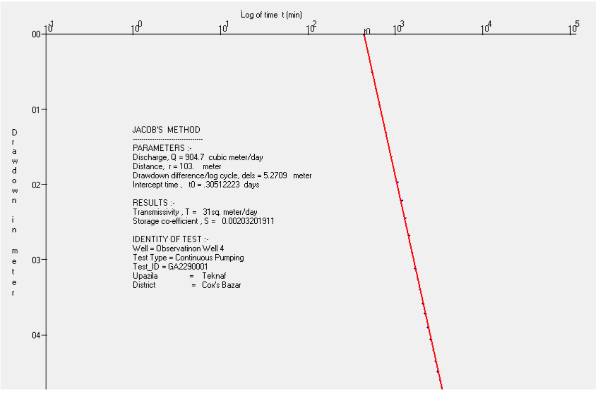


Figure 4.26: Jacobs method of analysis for Obs well 4

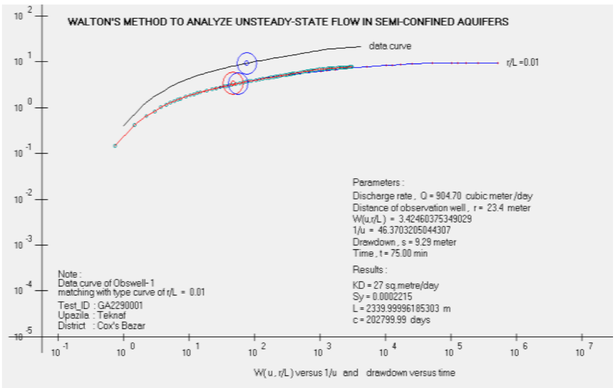


Figure 4.27: Waltons method of analysis for Unsteady state of flow, Obs well 1

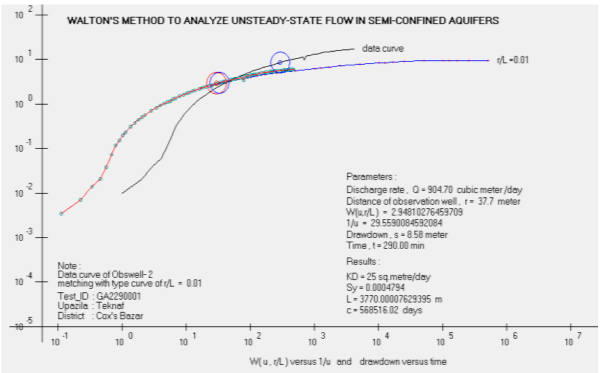


Figure 4.28: Waltons method of analysis for Unsteady state flow of Obs 2

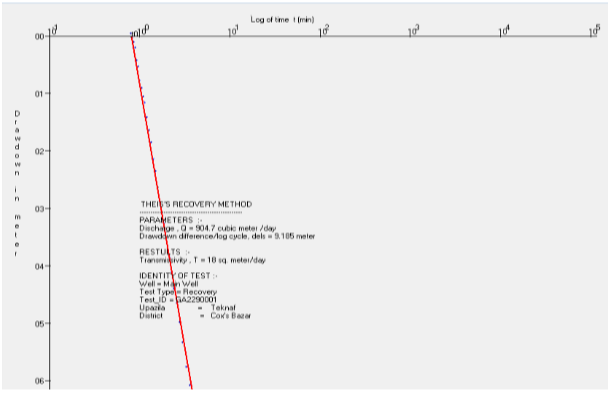


Figure 4.29: Theis's Recovery method for analysis of main well

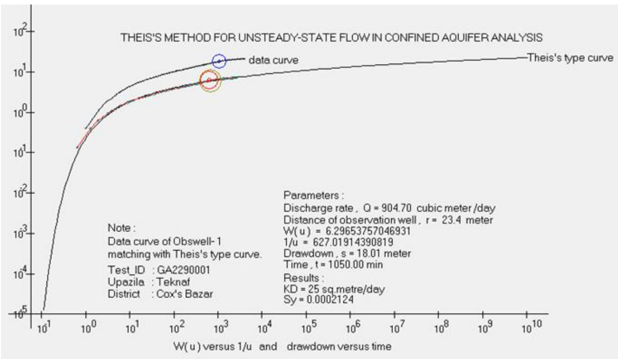


Figure 4.30: Theis's method for unsteady state flow for analysis of Obs 1

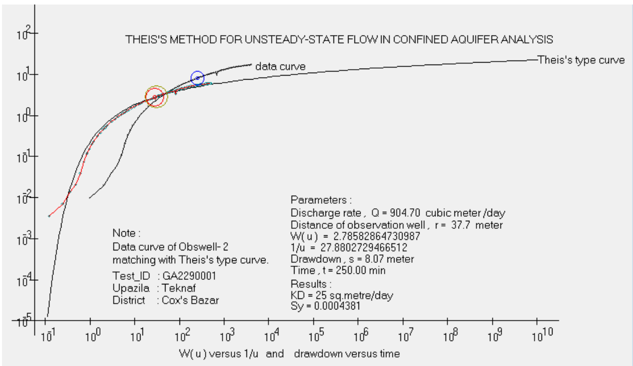


Figure 4.31: Theis's method for unsteady state flow for analysis of Obs 2

Table 4.5: Summaries of all results determined using different methods.

Method	Well Type	Transmissivity, T (m^2/day)	Storage coefficient, S	Hydraulic Resistance, C (days)	Leakage Factor L (m)	Average Storage coefficient, S	Average Transmissivity, T (m2/day)	Permeability, K (m/day) approximately
Jacob's method	Obs#1	30	0.000140	--	--	0.0005545	26	0.89

Method	Well Type	Transmissivity, T (m^2/day)	Storage coefficient, S	Hydraulic Resistance, C (days)	Leakage Factor L (m)	Average Storage coefficient, S	Average Transmissivity, T (m^2/day)	Permeability, K (m/day) approximately
Jacob's method	Obs#2	30	0.000358	--	--			
Jacob's method	Obs#4	31	0.002032	--	--			
Walton's method	Obs#1	27	0.000222	202799.99	2339.99			
Walton's method	Obs#2	25	0.0004794	568516.02	3770.00			
Thiess Recovery method	Main well	18	---	--	--			
Theis's Method	Obs#1	25	0.0002124	--	--			
Theis's Method	Obs#2	25	0.0004381	--	--			

4.6.5.2 Aquifer test of production well 2 at Katakhali, Teknaf

Determination of the hydraulic properties of the aquifers and then successive design and development of the production wells are the most important part of groundwater study. To determine the hydraulic properties, different kinds of aquifer tests are essential. Aquifer test includes continuous test, recovery test, and step drawdown test. Continuous and recovery tests are the most essential test to determine the hydraulic properties of aquifer namely transmissivity (T), storage co-efficient (S), permeability (K), and hydraulic resistance. The storage co-efficient (S) is an essential parameter to determine the aquifer type, and transmissivity (T) and permeability (K) are used to determine the flow system of that particular aquifer.

4.6.5.2.1 Step drawdown test

Step drawdown is generally conducted to measure the drawdown at steady condition of the pumping well due to design, development and nature of aquifer materials. The drawdown due to design and development is called well loss and drawdown due to the properties of formation is called formation loss. The parameters Cw and Cf derived from step drawdown test is called well loss constant and formation loss constant, respectively. The well loss is a measure of design and development of pumping well whereas the formation loss depends on the flow system of the aquifer.

This test was performed in three steps. The pump was driven at 3 different stages: 0.50 cusec, 0.625 cusec, and 0.75 cusec for 2 (two) hours each and corresponding draw down were recorded (**Table 4.6**).

Table 4.6: Step drawdown test data of Katakhali, Teknaf.

Discharge in Cusec	Static water level in meter	Pumping water level in meter	Drawdown in meter	Sp. Cap in L/s
0.50	0	25.75	25.75	0.55
0.625	0	36.18	36.18	0.49
0.75	0	47.86	47.86	0.44

4.6.5.2.2 Continuous aquifer test at Katakhali

A long-term aquifer test was done at Katakhali in Teknaf upazila. This test was continued up to 72 hours at a discharge rate of 0.625 cusec (280.5 gpm). Detailed design of the pumping well is given in **Figure 4.32**. An aquifer performance test with the setup of a pumping well of 180.73 m deep with the constant discharge of 17.70 liter/sec and 4 (four) observation wells installed at different depth levels from 152.61 – 180.63 m (**Figure 4.32**) were used to obtain the values of the general hydraulic properties of the aquifer and also to predict the effect of withdrawals on aquifer system. The drawdown, discharges, and the radius of the zone of influence have been observed and recorded. All piezometric observation wells have been installed in the pumped aquifer level but at different distance (**Figure 4.32**). Important water quality parameters were also monitored and samples were collected at different time interval during the test. The prime information about the aquifer test at katakhali is given in **Table 4.7**.

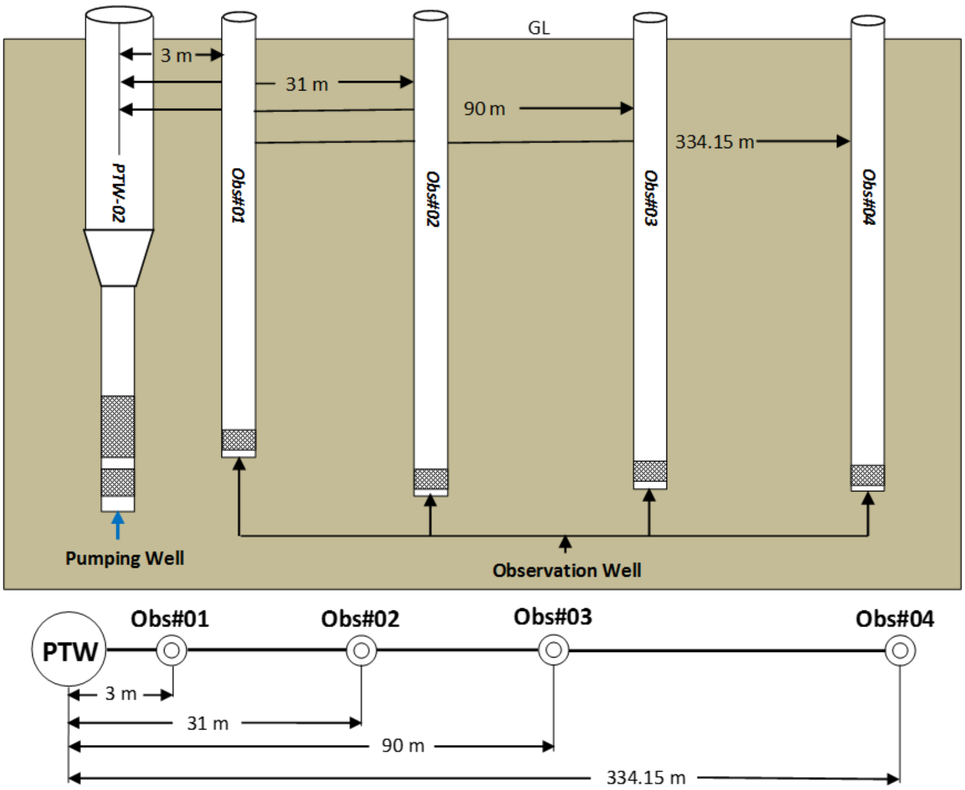


Figure 4.32: Layout plan of the Pumping test at Katakhali.

Table 4.7: Aquifer test information of the Pumping well at Katakhali.

Name	Specific Information
Aquifer thickness	32 m
Aquifer materials	Dominantly fine sand
Screen position of main well	(138.83-150.71 &159.86-177.68) m
Screen length	29.70 m
Percentage of aquifer thickness screened	94 %
Screen diameter	150 mm
Screen slot size	0.50 mm
Open area of screen	17%
Depth of observation well no.1	156.12 m
Depth of observation well no.2	180.63 m
Depth of observation well no.3	177.77 m
Depth of observation well no.4	152.61 m
Distance of observation wells 1, 2, 3 & 4 from pumping well.	3 m, 37.70 m, 31 m, 90 m & 334.15 m, respectively.

The static water level just before the test, time since the pumping started, pumping rate, dynamic groundwater levels at various interval during the pumping period were recorded to complete the aquifer test. Measurement of the aquifer water levels after the pump stopped (recovery data) are extremely valuable for recovery test. Hence, after the continuous pumping, the recovery data have been collected at fixed time interval.

The long duration aquifer test has completed for the deep aquifer at Katakhali to determine the lateral and vertical connectivity and extent of the aquifer, the chemical characteristics and potability of the aquifer water, and the response of the deep aquifer to long-term production stresses. The specific conductivity of water pumped from the aquifer was monitored during the 72-hours test to determine if higher conductive water was being captured by the well during the test.

4.6.5.2.3 Response in groundwater level

Response in main well

The water level in the pumping well declined rapidly during first 2 minutes of pumping from 0 to 24.53 m (**Figure 3.33**). After first 2 minutes, the water level declined slowly and stabilized at 35.32 m at 2040 minutes. Water level remains static at 35.32 m up to the end of the aquifer test at 4320 minutes (72 hours). The pumping phase of the aquifer test was completed after 4320 minutes.

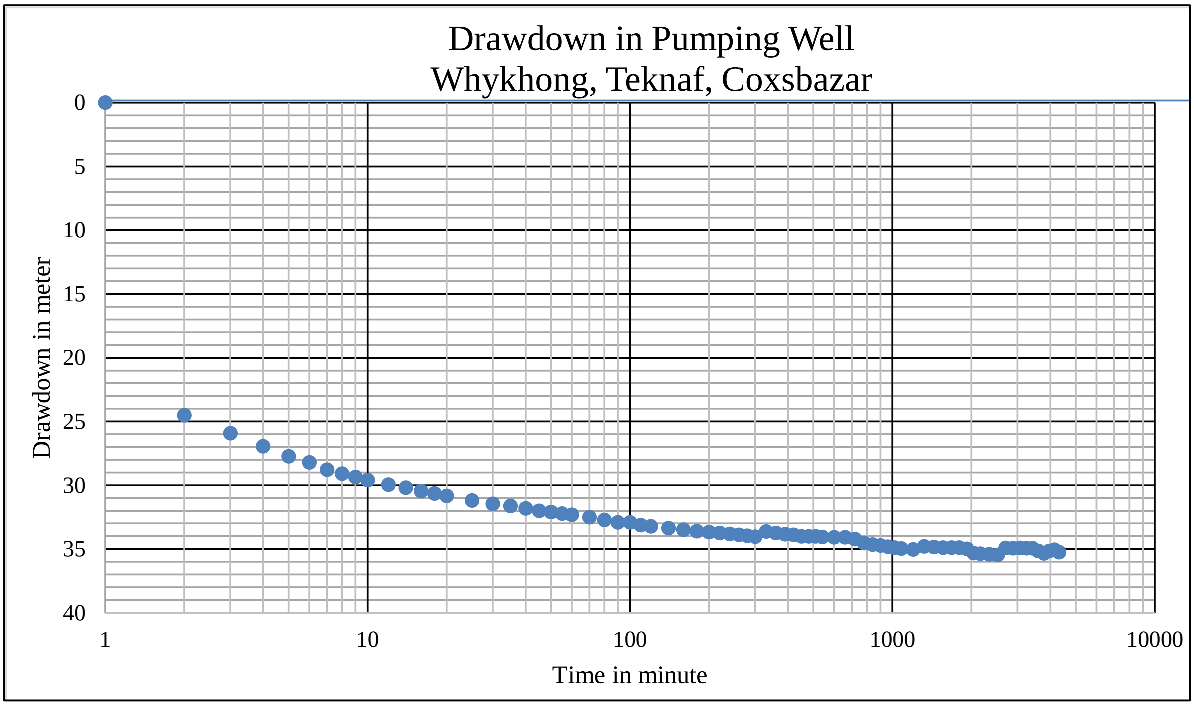


Figure 4.33: Water level response in pumping well during 72 hours long pumping test.

Response in observation wells

Out of 4 observation wells, water level in observation well no. 1 initially responded rapidly and then slowly reaches to 10.43 m in72 hours. Groundwater level in the observation well 2, and 3 responded less rapidly and pumping level of these wells reached to 10.52 m and 5.82 m, respectively (**Table 4.8**). However, the observation well 4 is not responded during the aquifer test.

Table 4.8: Depth and distances of the observation wells related to Katakhali pump test.

Observation Well no.	Depth (m)	Distance (m)	SWL (m)	Max PWL (m)
1	156.12	3.00	0	10.43
2	180.63	31.00	0	10.52
3	177.77	90.00	0	5.82
4	152.61	334.15	0.97	0.97

4.6.5.2.4 Recovery test

Recovery is the most essential part of aquifer test to determine the aquifer properties. In Katakhali, the pumping phase of the aquifer test was completed after 4320 minutes (72 hours). Then immediately after the pump was stopped, the recovery data was started to collect during the recovery phase of the test until 4650 minutes (5 hours 30 minutes) after the test had stopped.

4.6.5.2.5 Analysis of the aquifer test data

The aquifer test data of Katakhali was analyzed by using IWM customized software in three different methods, namely Theis, Jacob, Chow, and Walton methods. The outputs of these analyses are given in the **Figure 4.34** to **Figure 4.42**. Storage co-efficient (S), transmissivity (T), leakage factor (L) and permeability (K) was analyzed by using the above methods. Average transmissivity 65 m^2/d indicates that the flow system of that particular aquifer is not good. The average storage coefficient (0.0051976) has been determined from the analysis. Comparison of the average storage coefficient and hydrogeologic section indicates that the aquifer is confined in nature. All the analysis results are summarized below in **Table 4.9**.

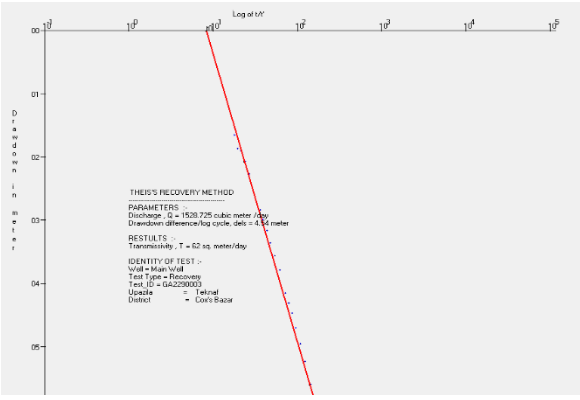


Figure 4.34: Thies's Recovery method for analysis of the Main well.

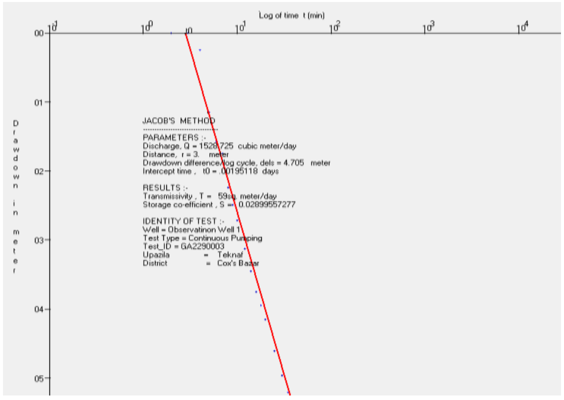


Figure 4.35: Jacob's method for analysis of the observation well-1.

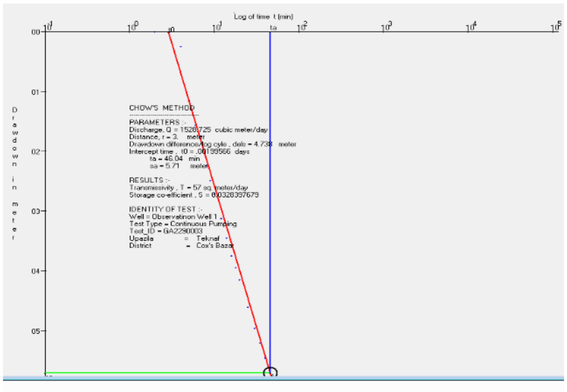


Figure 4.36: Chow's method for analysis of the observation well-1.

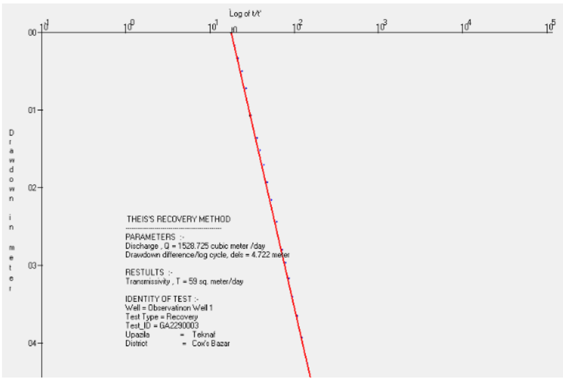


Figure 4.37: Theis's Recovery method for the observation well-1.

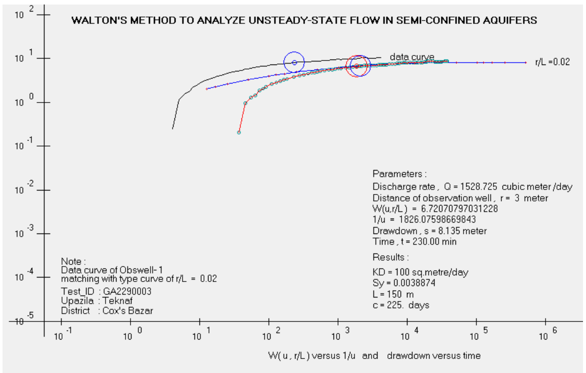


Figure 4.38: Walton's method for analysis of the observation well-1.

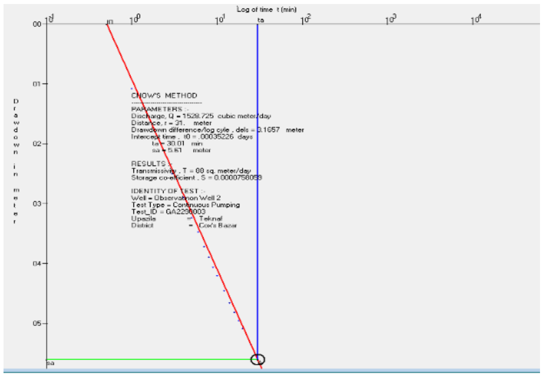


Figure 4.39: Chow's method for analysis of the observation well-2.

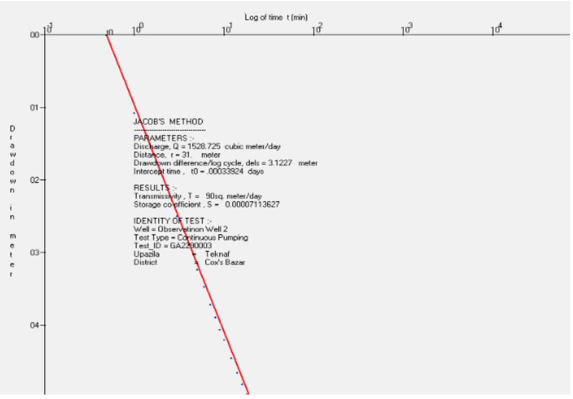


Figure 4.40: Jacob's method for analysis of the observation well-2.

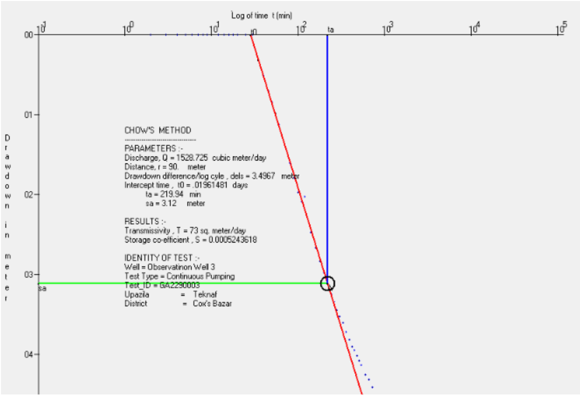


Figure 4.41: Chow's method for analysis of the observation well-3.

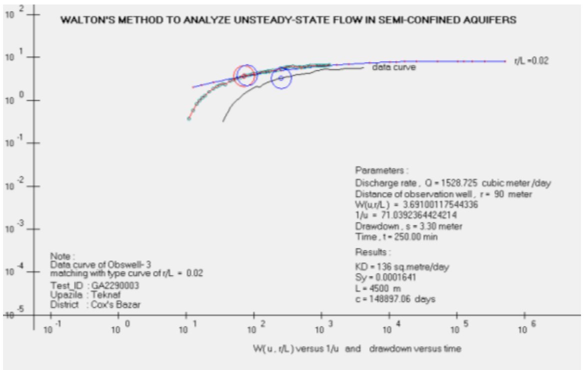


Figure 4.42: Walton's method for analysis of the observation well-3.

Table 4.9: Summaries of aquifer test results determined using different methods.

<table>
<tr><th>Method</th><th>Well Type</th><th>Transmissivity, T (m²/day)</th><th>Storage coefficient, S</th><th>Hydraulic Resistance, C (days)</th><th>Leakage Factor L (m)</th><th>Average Storage coefficient, S</th><th>Average Transmissivity, T (m²/day)</th><th>Permeability, K (m/day) approximately</th></tr>
<tr><td rowspan="2">Thiess Recovery</td><td>Main well</td><td>62</td><td>--</td><td>--</td><td>--</td><td rowspan="8">0.0051976</td><td rowspan="8">65</td><td rowspan="8">2.03</td></tr>
<tr><td>Obs#1</td><td>59</td><td>0.000358</td><td>--</td><td>--</td></tr>
<tr><td>Jacob's method</td><td>Obs#1</td><td>59</td><td>0.002032</td><td>--</td><td>--</td></tr>
<tr><td>Chow method</td><td>Obs#1</td><td>57</td><td>.032839</td><td>--</td><td>--</td></tr>
<tr><td>Walton's method</td><td>Obs#1</td><td>100</td><td>0.0004794</td><td>225</td><td>150</td></tr>
<tr><td>Jacob's method</td><td>Obs-2</td><td>90</td><td>.0000711</td><td>--</td><td>--</td></tr>
<tr><td rowspan="2">Chow Method</td><td>Obs#2</td><td>88</td><td>0.000075</td><td>--</td><td>--</td></tr>
<tr><td>Obs#3</td><td>73</td><td>0.000529</td><td>--</td><td>--</td></tr>
</table>

4.6.6 Causes of Low Transmissivity of Shamlapur and Whykhong Area

Teknaf area has a complex and relatively recent tectonic history and lies within the outer western margin of the Chittagong-Tripura Fold Belt (CTFB) region. Unique geographic location and complex geology makes Teknaf not suitable for shallow groundwater development. Layers are characterized by low resistivity (ranging from 10 to 150 Ω), indicating poor water bearing character (Sultana et al., 2012).

The project area is situated in the active fold thrust belt. As this zone is under high east-west compressive stress, the sediments in this area are subjected to compression, therefore, structurally distributed, and lithologically heterogeneous. Due to diagenetic effects, transmissibility of sediments of this area has been decreased. Due to it geological setting, the groundwater occurrence is different at Teknaf Peninsula compared to other part of the country. As mentioned before, UNDP (1982) has divided the country into 15 zones (A-Q) of varying potentiality for development of groundwater resources based on lithology, thickness and structure of the rock formations along with recharge potentiality and aquifer characteristics. The Teknaf peninsula is part of the zone N where complex groundwater condition exists and is not suitable for large-scale groundwater development. The findings of this study also support UNDP (1982) observations.

Sabrang and Naf project area for which the hydrogeological study carried out lies on the south-western zone of the CTFB along the eastern coast of the Bay of Bengal and includes Dakhin Nhila and Inani anticlines. This part of the Bengal Basin is exposing the Miocene to Recent deposits (Steckler et al., 2008; Hossain et al., 2019). The geological studies carried out in this western folded flank region indicate that the deformation intensity of the CTFB varies from west to east. At the western edge of the CTFB, a major fault running NNW-SSE under-thrusted west flank of Inani and Dakhin Nhila structures along the Cox's Bazar-Inani Marine Drive (Hossain et al., 2020b). The Dakhin Nhila anticline is the significant geological feature of this area. It is surrounded by the Teknaf shear zone and fault-related subsided buried anticline to the south, the Inani anticline to the north, the Naf River to the east and the Bay of Bengal to the west.

From the recent study (Yang et al., 2020), it is found that the project area is related with young and active orogenic development. As this area is in active tectonic zone and directly related to tectonic compressive stress which results faulting and folding. These in turn causes not only lateral and vertical discontinuity of the lithology, but also decreased porosity and permeability of the sediments. Transmissivity of dominantly fine sand aquifer of this area is calculated from aquifer pump test data at Puranpara, Shamlapur is found ≅ 26 sq. m/day and at Katakhali, Whykhong is ≅ 65 sq. m/day. Transmissivity depends on permeability. Permeability of these aquifers is also very low 0.8928 m/d and 2.031 m/d for Shamlapur and Whykhong area, respectively. In general, permeability of clean fine sand is 8.5 m/day. Permeability depends on grain size distribution, porosity, shape and arrangement of pores (Ref: GroundWater, HM Raghunath, third edition, P-78, 2006). Due to orogenic compressive stress and subsequent diagenetic effects, sediments permeability decreased.

Tipam and/or Upper Boka Bil Formation are highly heterogeneous and presence of calcareous band of variable length and thickness makes the studied aquifer discontinuous both laterally and vertically. The pump test results also reflect the complexity of the aquifer. Recorded responses during pump test and recovery time in observation wells as well as the main well clearly suggest lateral and vertical discontinuity of the aquifer. Observation wells within distance of 38 m show more or less similar pattern during pump test and in recovery time. The data analysed using different methods also shows similar results (**Table 4.5** and **Table 4.9**). The time versus recovery and drawdown of main wells and observation wells at two locations are given in **Figure 4.43** and **Figure 4.44**.

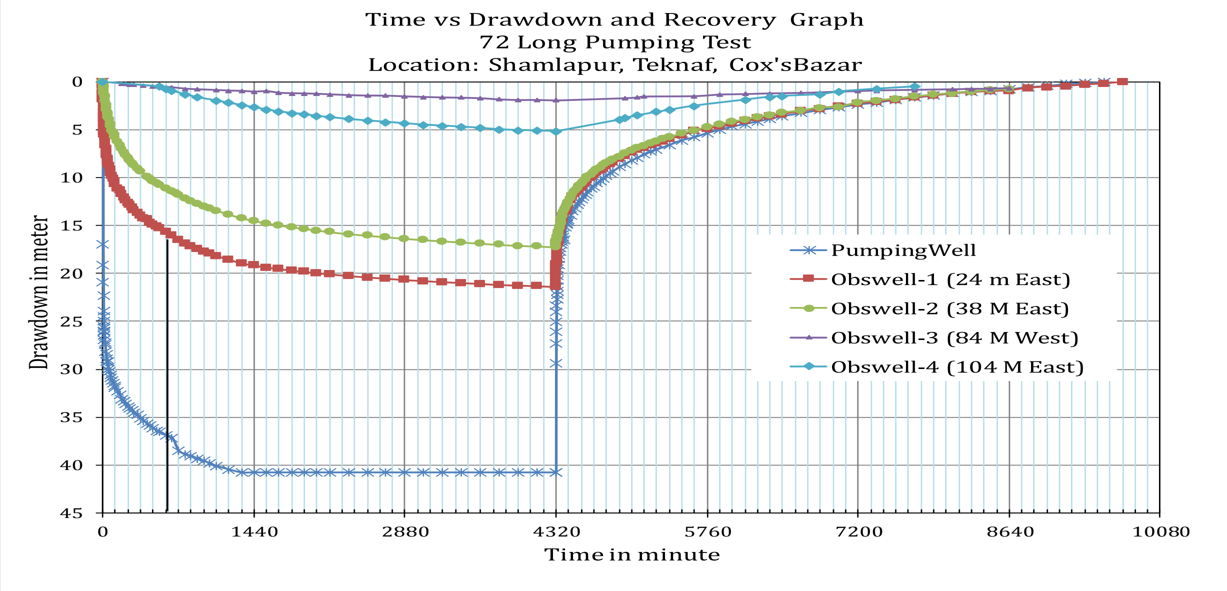


Figure 4.43: Time versus drawdown and recovery graph of the Shamlapur, Teknaf

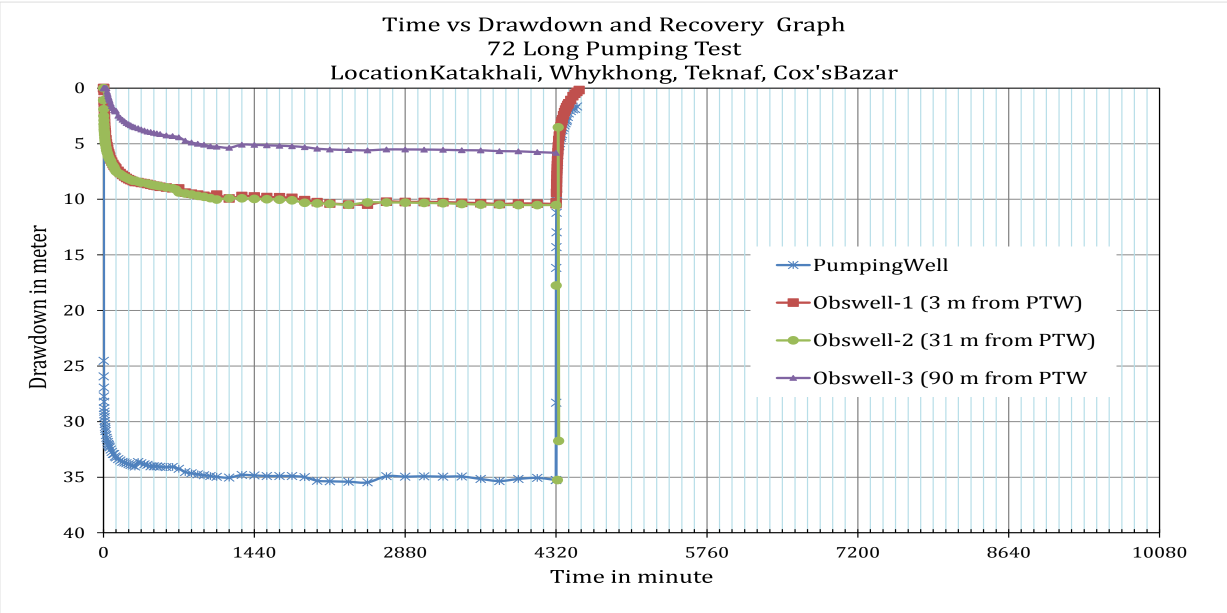


Figure 4.44: Time versus drawdown and recovery graph of the Katakhali, Whykhong

4.7 Resource Assessment of Shamlapur and Katakhali

4.7.1 Assessment Using Depth-storage Model

Based on the available data, groundwater resource volume has been calculated by using Depth-Storage model. Prospective groundwater development area is divided into 2 zones (**Figure 4.45**), Zone-A (Whykhong area) and Zone-B (Shamlapur area). Based on the subsurface lithology and structural configuration, area of Zone-A is taken as 16.3 km^2 and Zone-B is taken as 3.0 km^2.

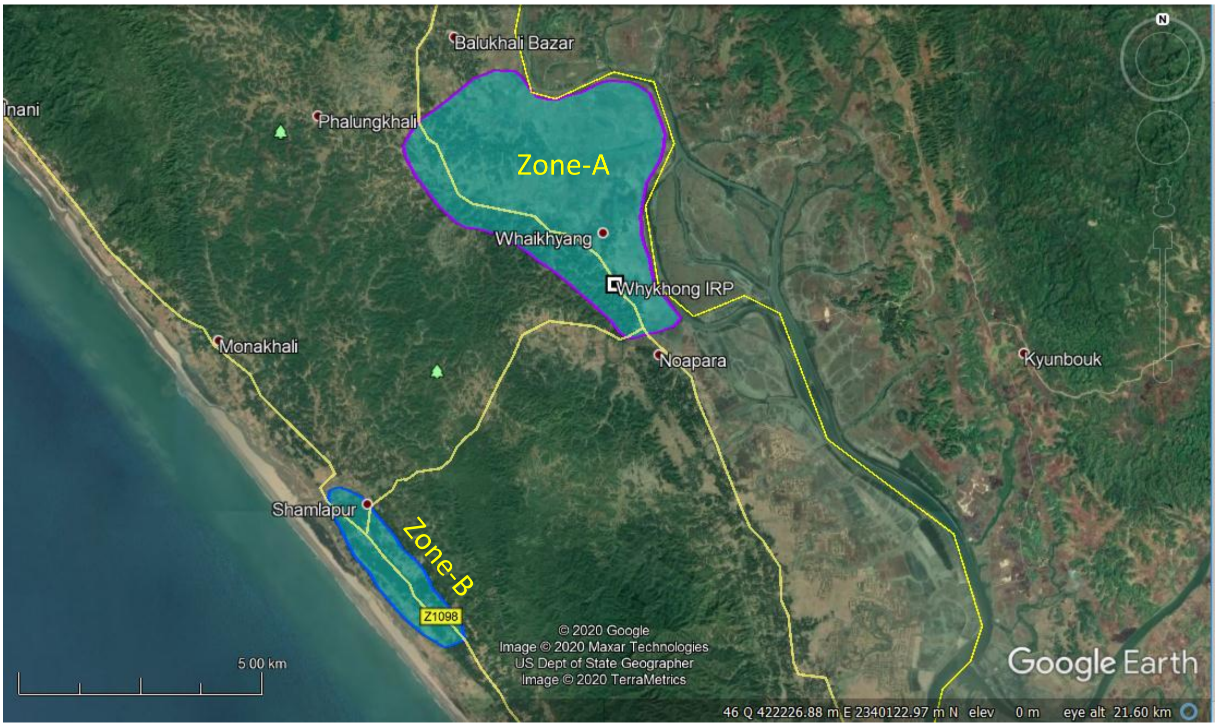


Figure 4.45: Prospective Groundwater Development Area

For Shamlapur area (Zone-B), target rated drawdown can be taken as 5 m for estimating available water resource. Using maximum lower limit (5 m) of groundwater level, Depth-Storage model is determined. **Figure 4.46** shows the depth-storage relationship of the study area Zone-A.

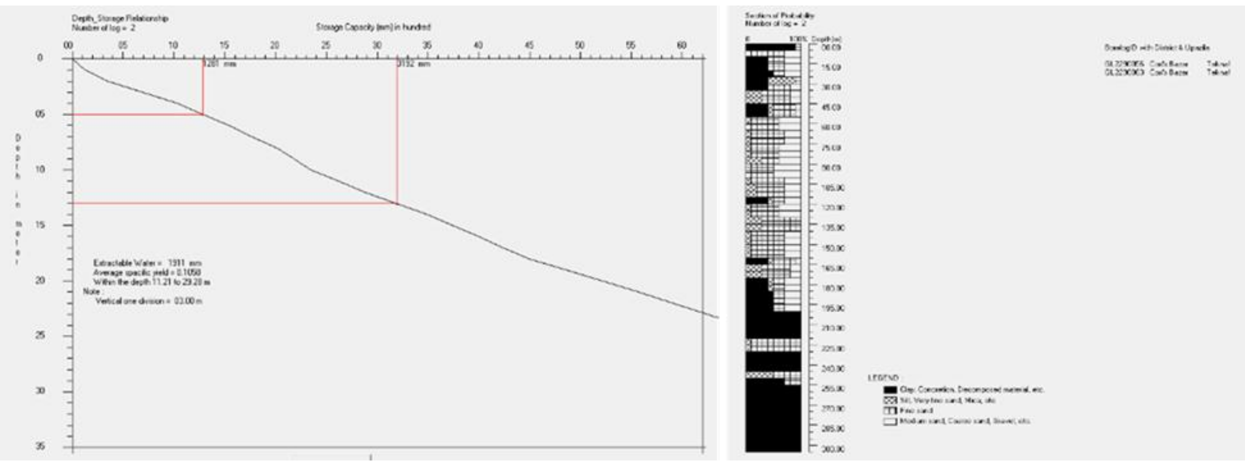


Figure 4.46: Depth-storage model

For Zone-A, groundwater volume is 16.3 km^2×0.10×5 m = 8.15 Mm^3

For Zone-B, groundwater volume is 3.0 km^2×0.07×8 m = 1.05 Mm^3

Storage of the aquifer system is the combined effect of available groundwater column and specific yield values of the aquifer material. Depth-storage relationship of the study area has been determined by using a customized computer program. Similar program has also been used by WARPO for groundwater resource assessment and the National Water Management Plan (NWMP). Instead of groundwater table fluctuation data of this area, rated drawdown value has been used. From the depth-storage curve, available groundwater volume from the storage of the aquifer has been computed in conservative way and furnished in **Table 4.10.**

Table 4.10: Resource estimation is based on 5 drawdown in aquifer

Zone	Average Sp. Yield	Area of Zone (km^2)	Considered drawdown in aquifer (m)	Total storage Mm^3
A	0.10	16.3	5	8.15
B	0.07	3.0	5	1.05
Total		**19.3**		**9.2**

4.7.2 Production Well Spacing

Distance vs drawdown curve has been generated for determination of radius of influence of Production tube well 01 during long term aquifer test (**Figure 4.47**). It is observed that radius of influence is about 280 meters toward east and 150 meters towards west from trend analysis of field data and during long term aquifer test. Zero drawdown is recorded in Observation well 5 which is 278 meters away from PTW. Westward zone of influence is only 150 meters. During long term aquifer test physical parameter of discharge water measured time to time and Electrical conductivity remain almost same till the end of test.

Similarly, Distance vs Drawdown curve for PTW-02 has been generated (**Figure 4.48**) and it is observed69 that radius of influence is about 240 meters from trend analysis after 72 hours. Zero drawdown is recorded in Observation well 4 which is 334.15 meters away from PTW-2. During long term aquifer test physical parameter of discharge water measured time to time and Electrical conductivity remain almost same till the end of test.

Well spacing for Shamlapur and Whykhong area are not less than 560 meters and 480 meters respectively. Considering the situation well spacing fixed for Shamlapur is 600 meter and for Whykhong is 500 meters. Due to land unavailability, if the well spacing is less than the recommended distance then the abstraction should be managed by well operation hour.

Considering well spacing criteria 03 nos. of production well in Shamlapur area and 08 nos. of production well in Whykhong area may be constructed (**Figure 4.49**).

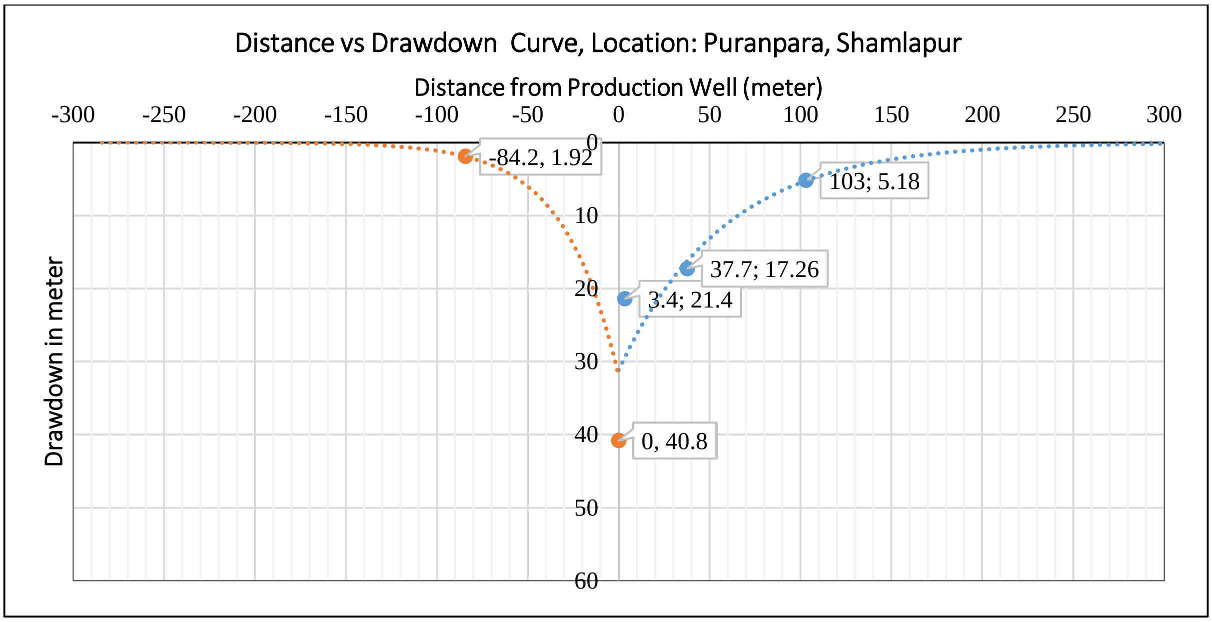


Figure 4.47: Distance vs Drawdown curve of PTW-01, Shamlapur

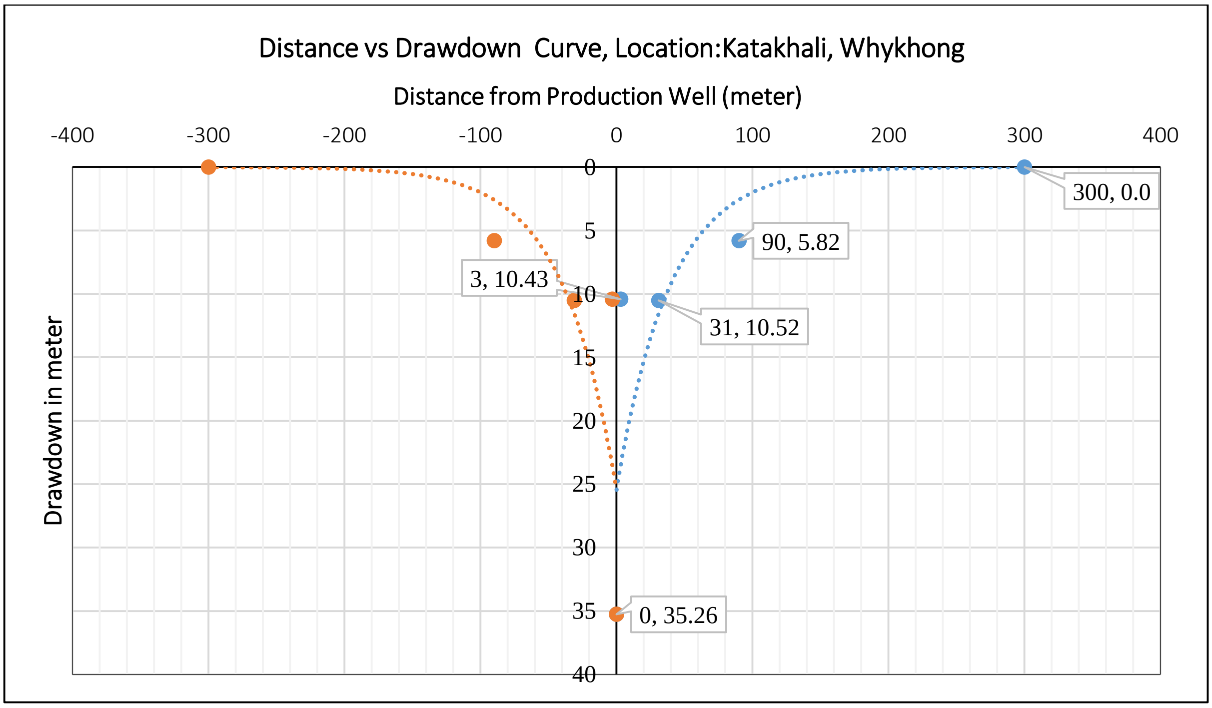


Figure 4.48: Distance vs Drawdown curve of PTW-2, Whykhong

Figure 4.49: Production well spacing considering Zone of influence (Red Circle)

4.7.3 Synthesis of the Resource Assessment

4.7.3.1 Shamlapur area

From the long-term aquifer test result, it is assumed that pumping more than 10 hours with a capacity of 0.5 cusec or 0.5 MLD from a single well will not be sustainable. If PTW operates for 10 hours, the aquifer will get 14 hours for recovery. Considering the narrow foot hill area with complex geological setting to the east and the sea to the west side of the Zone-B, the aquifer has very limited scope to recharge and to provide a good quantity of water. Considering the total area, only 03 no of PTW can be installed in zone B. With a discharge rate of 0.5 cusec for 03 no PTW, and a 10-hour operation window, there is a possibility to extract about 1.5 MLD groundwater form the Shamlapur aquifer.

4.7.3.2 Whykhong area

From aquifer test data analysis, it is observed that aquifer condition of Whykhong area is better than Shamlapur area. Pumping test conducted at Whykhong with higher rate (0.625 cusec) than Shamlapur (0.375 cusec) and drawdown is less than Shamlapur. More importantly recovery period is only 5 hours 30 minutes at Whykhong area. Considering the discharge rates of 0.5 cusec for 08 nos. PTW and a 17-hour operation window, there is a possibility to extract about ≈ 7.0 MLD groundwater from the Whykhong area.

4.8 Sustainable Limit of Groundwater Abstraction (Safe Yield) Quantification for Whykhong area

Bangladesh Water Act 2013 requires the following for safer groundwater abstraction from any aquifers in the country:

d) Identify the safe limit for sustainable groundwater abstraction under present and future conditions;

e) Assess future water uses and identify possible conflicts with abstraction;

f) Depletion under different scenarios of groundwater use and potential recharge.

4.8.1 Safe Limit of Groundwater Abstraction

Potential Recharge is the upper limit of recharge, replenished annually from rainfall and flood, constraint by only upper soil profile in an infinite aquifer. For the present purpose Potential Recharge is considered as the upper limit of recharge that can be sustainably developed without significant impact with the surrounding environment. In absence of site-specific detail information about soil, lithology and land, indirect approach of groundwater level fluctuation in the nearest observation well and an estimated specific yield averaged over the area has been adopted to assess the potential recharge.

The hydrograph (**Figure 4.50**) signifies the natural recharge and discharge conditions (without abstraction), with highest annual levels attainment from rainfall recharge and the lowest levels during the end of the dry season due to natural discharges, assuming presently there is no large abstraction excepting some abstraction for portable water usages. Annual fluctuation of groundwater levels fluctuations as depicted by the hydrograph in Whykhong area of Ukhiya ranges between 1.5-2m. There is a clear sign of natural recharge rejection in the hydrograph during monsoon when upper aquifer is full.

The net fluctuation under natural cycle of recharge and discharge (considering recharge rejection) would be approximately 2.0 m.

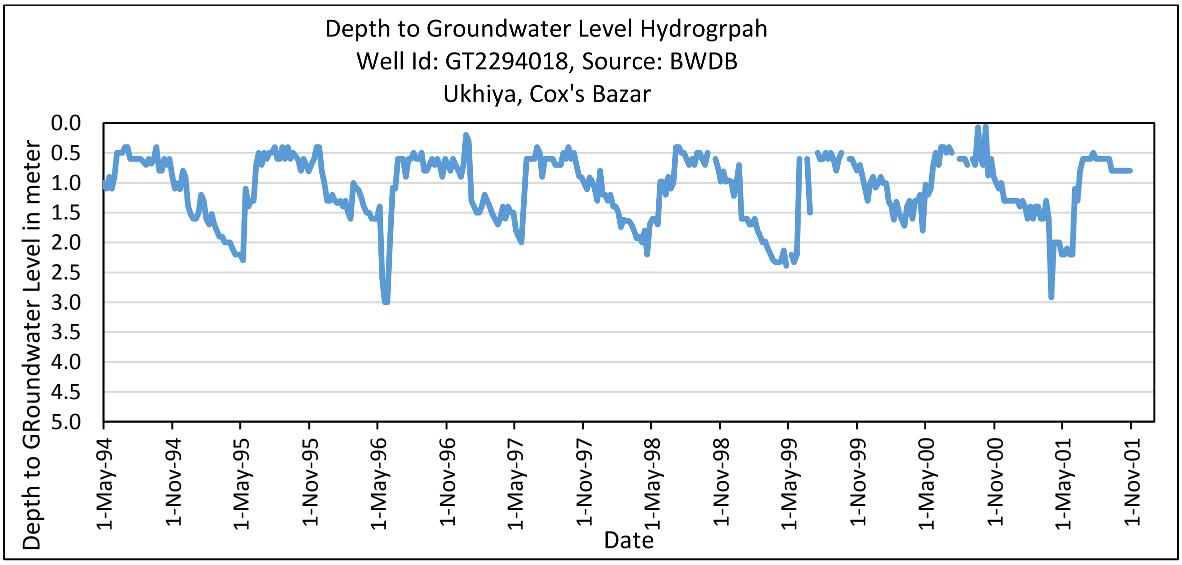


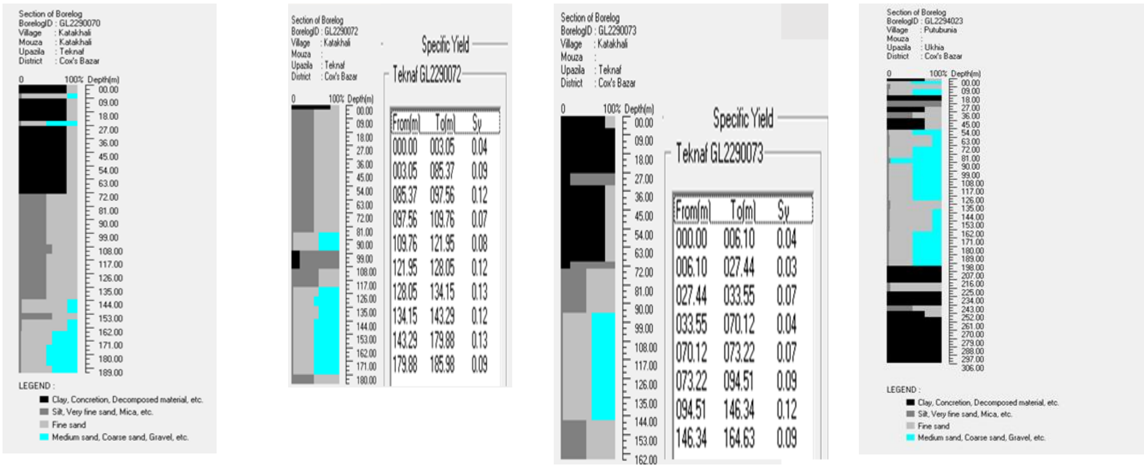
Figure 4.50: Long term depth to groundwater level graph of GT2294018, monitoring station at Ukhiya

The drawdown in the well ranges from 25.75 m to 47.68 m with discharge ranging from 50 m^3/h and 75 m^3/h. The step test was followed by a 3-day constant rate test at 63.4 m^3/h, followed by a full recovery within 5-hour 30 minute. Based on the test the aquifer may be classified as confined with the following characteristics.

- Average transmissivity varies between 26 m^2/day;
- Storativity varies between 0.0000711 to 0.032839 and average is 0.0051976

- Permeability indicates 2.03 m/day;
- Radius of Influence is 280 m.

The depth varied sediments deposits are mainly clay and silt as revealed from the four lithologs for the upper 20 meter depth (**Figure 4.51**). Specific yield values for depth is shown in the **Table 4.11.**



PTW-2, Katakhali — Obs-3, PTW-02 — Obs-4, PTW-2 — IWM_TTU_14

Figure 4.51: Borelog within Catchment area considered for Specific yield calculation

Table 4.11: Specific Yield for selected well

Depth (m)		GL2290072, OBS-03, PTW-2, Katakhali	GL2290073, OBS-04, PTW-2, Kahltakhali	GL2294023 (TTU_14)	GL2290070 (PTW02), Katakhali	Average Specific Yield
From	To	Sy	Sy	Sy	Sy	
0	3.05	0.04	0.04	0.05	0.04	0.043
3.05	6.1	0.09	0.03	0.13	0.04	0.073
6.1	9.15	0.09	0.03	0.1	0.11	0.083
9.15	12.2	0.09	0.03	0.1	0.04	0.065
12.2	15.25	0.09	0.03	0.13	0.04	0.073
15.25	18.3	0.09	0.03	0.13	0.04	0.073
18.3	21.35	0.09	0.03	0.03	0.04	0.048

The estimated Potential Recharge is calculated on projected future water level fluctuation (with no rejection) and average specific yield values within the range of water level fluctuation. Considering the uncertainty of data, the potential recharge is also seen to be within a band of 25% to judge the sensitivity to abstraction under future demand scenarios.

	(0.75 * SY) (Mm^3)	Safe Yield (SY)(Mm^3)	(1.25 * SY) (Mm^3)
Potential Recharge	1.05	1.4	1.75

4.8.2 Future Water Use and Demand Plan

At present use of groundwater for agriculture or industry is almost nonexistent with small potable water uses. Three different demand scenarios have been synthesized and analyzed to check the impact of year wise groundwater abstraction plan (**Table 4.12**) on abstraction and recharge as describe in Sec 9.4.

Table 4.12: Groundwater abstraction Plan

Year	Abstraction (Million m^3)
2025-2029	1.06
2030-2034	1.54
2035-2039	1.84
2040-2044	2.34
2045-2049	2.54
2050 - onward	2.54

4.8.3 Groundwater Depletion vs Abstraction

Depth storage relationship based on medium values of specific yield is shown in **Figure 4.52** to assess the depletion of groundwater lever that may affect future potable use of resources.

Increased demand has been tested under three scenerios (**Figure 4.53**) of water resources availability considering the uncertainty attached to estimated Safe yield.

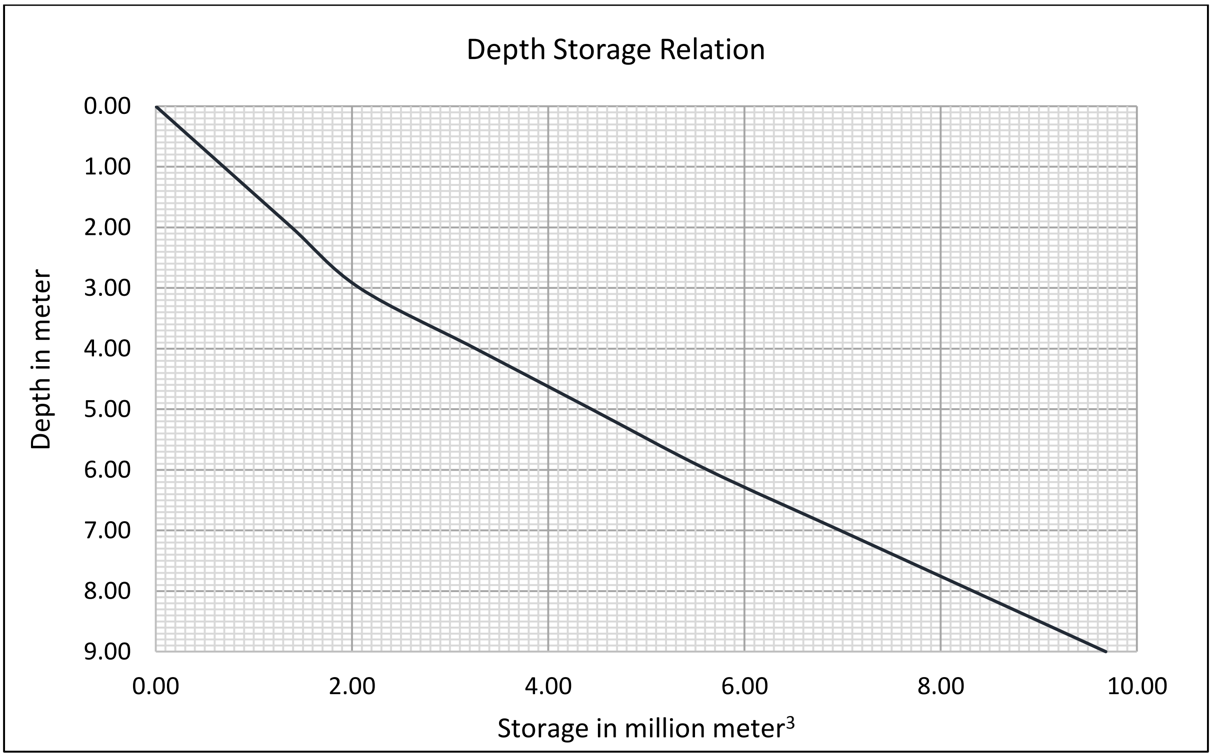


Figure 4.52: Dpeth storage relation curve

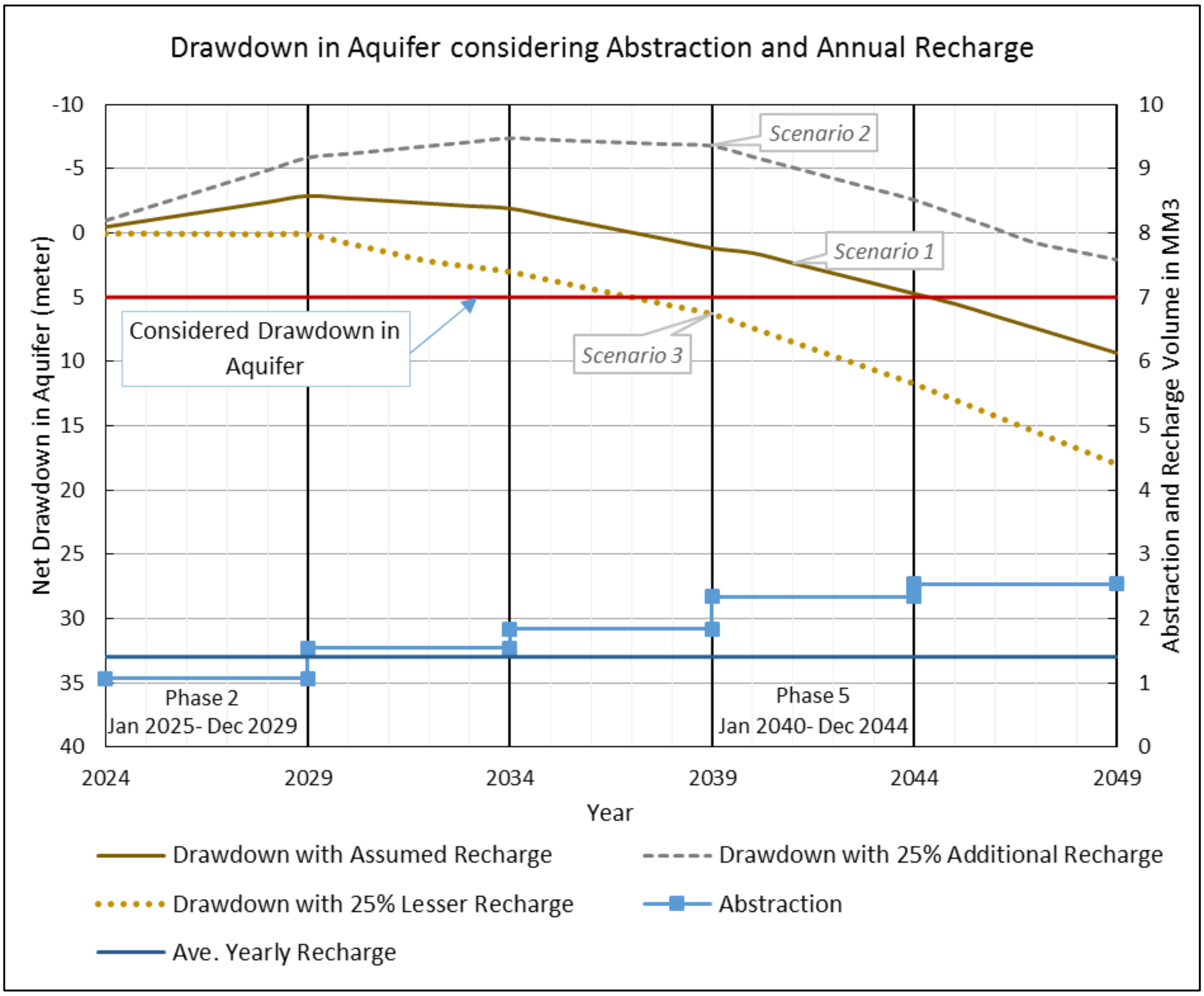


Figure 4.53: Drawdown in aquifer due to planned abstaction considering assumed recharge with 25% additional and lesser recharge factor

According to plan of demand to be implemented groundwater abstraction will increase in phases from 1.06 Mm^3/year to 2.54 Mm^3/year with different development stage of Naf and Sabrang Tourism Park. Scenario 1 is representing estimated recharge and planned abstraction and consequent drawdown in the aquifer against net abstraction. Negative portion of the graph represent net abstraction positive, I.e. abstraction is less than annual recharge volume (1.40 mm^3) and such condition will continue up to 2037 (Abstraction will be 1.84 mm^3/year). Same scenario will cross, planned 5-meter drawdown level in 2044 to 2045 and in end of 2049 drawdown in aquifer will be 11.73 m.

With 25% more recharge (Scenario 2) abstraction exceeds recharge in time beyond 2046, at least 11 year after the same thing happened with scenario 1. With 25% less recharge (Scenario 3), groundwater abstraction exceeds recharge in 2029 almost 8 year earlier than with Scenario 1 and drawdown in aquifer will cross planned 5 meter after 2036.

The actual situation in place need to be observed as soon as abstraction starts. It is expected that induced recharge will follow as soon as abstraction is imitated and under that case net drawdown in aquifer might be much less.

4.8.4 Observations on Safe Yield Quantification.

Aquifer conditions in the hilly areas are generally poor in terms of the recharge and aquifer properties. A good groundwater management under the condition requires monitoring of abstraction (by local use and/or Tourism Park), review of recharge estimate, water quality and groundwater water level fluctuations as the development goes on. The area is in geologically complex (folding and faulting), having very low yield. Therefore, increase in abstraction under future development scenario needs close monitoring to understand aquifer response and bring the safe limit within a narrow range of confidence limit.

4.9 Groundwater quality analysis

4.9.1 Test by Field Kit

By analyzing the groundwater quality tested by field kit (**Table 4.13**), it is found that temperature of all the test tube wells are within the allowable limit of Bangladesh standard (within 20° to 30° centigrade). EC and TDS of well nos. TTW-1, TTW-3 and TTW-6 are very high. TDS of TTW-1, TTW-3 and TTW-6 are 4510 mg/l, 16470 mg/l and 11100 mg/l respectively, these 3 wells water is not potable. pH of all the wells are within allowable limit of Bangladesh.

Table 4.13: Field parameter of groundwater quality in test wells

Well ID	Location	Date	Groundwater Quality (Field Parameters)			
			pH	Temp. (°C)	EC (µS/cm)	TDS (mg/L)
TTW-01	Nayapara	11.01.2020	6.67	25.10	8120.00	4510.00
TTW-02	Puranpara	19.12.2109	7.04	26.40	341.00	163.70
TTW-03	Jimongkhali	09.01.2020	7.12	25.90	28200.00	16470.00
TTW-04	Katakhali	20.12.2109	7.92	28.60	1012.00	497.00
TTW-05	Montolia	28.12.2019	7.74	25.10	479.00	233.00
TTW-06	Jaliar Dwip	11.01.2020	6.72	25.50	18450.00	11100.00
TTW-07	North Shilkhali	19.12.2109	7.61	26.10	318.00	151.00
TTW-08	Dhaler Mukh	01.01.2020	7.38	25.60	367.00	173.50
TTW-09	Konarpara	01.01.2020	8.50	25.80	568.00	261.00

4.9.2 Laboratory Test

Concentrations of Iron, arsenic, manganese, Bi carbonate, chloride and sodium are tested in Environmental Engineering Laboratory, BUET. By analyzing the test result of groundwater (**Table 4.14**), it can be inferred that 3 wells (TTW-1, TTW-3 and TTW-6) contain much higher concentrations of chloride (3150mg/l, 167500mg/l and 9400 mg/l respectively) than Bangladesh standard. Sodium concentrations of these wells are also much higher. Iron concentration of TTW-1 and TTW-6 are 25mg/l and 7 mg/l respectively. These waters cannot be used for drinking or house hold purposes.

Arsenic concentrations in all these nine wells are within Bangladesh standard (0.05mg/l). Iron concentrations of well no. 1, 2, 4, 5, 7, 8 and 9 are within the allowable limit of Bangladesh standard. Manganese concentrations of the well nos.1, 2, 3, 5, 6 and 7 are higher than Bangladesh standard (max concentration is 9.96 mg/l in well no. TTW-1. Concentrations of manganese in well nos. 4, 8 and 9 are within Bangladesh limit. Water of well nos. 2, 4, 5, 7, 8 and 9 can be used for drinking and household purposes, as these wells contain slightly higher concentrations of manganese.

Table 4.14: Laboratory analysis of groundwater samples of test wells

Parameter	Sodium	Chloride	Iron	Arsenic	Manganese	Bi-carbonate
Unit	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Allowable limit of Bangladesh	200	150-600	0.3-1.0	0.05	0.1	-
WHO guideline value*	No guideline	No guideline	No guideline	0.01	No guideline	-
TTW-1	1195	3150	25	0.005	9.96	28.13
TTW-2	28.6	6	0.02	<MDL	0.334	202
TTW-3	7622	167500	0.5	0.025	3.36	208.3
TTW-4	321	106	0.05	0.002	0.113	356.7
TTW-5	48.3	15	0.15	<MDL	0.32	268
TTW-6	3718	9400	7	0.021	2.22	176.5
TTW-7	49.1	14	1	0.005	0.38	169.4
TTW-8	40.5	13	0.04	<MDL	0.076	205
TTW-9	145.7	12	0.06	<MDL	0.082	340

MDL: Minimum detection level
*4th WHO guideline value, 2011 incorporating 1st addendum, 2017

4.9.3 Water Quality of Production Wells

During 72 hours aquifer tests in both the production wells, groundwater samples were taken after 1hour, 24 hours, 48 hours and 72 hours period in running condition for laboratory analysis to identify whether the explored aquifer is connected with other water source or not. It is observed from analysis (**Annex-4**) of the 4 samples taken from each aquifer that none of the two aquifers is connected with other water source, as, all the 4 samples (1 hour, 24 hours, 48 hours and 72 hours) of each aquifer shows similar results, that is, no variation of chemical quality of 1, 24, 48 and 72 hours samples. The laboratory test results after 72 hours period is shown in **Table 4.15**.

Both the wells water has concentrations of Iron, Arsenic, Chloride, and sodium within Bangladesh drinking water standard. Manganese concentration of PTW-1 is slightly higher than Bangladesh standard which may be acceptable, because WHO is in an opinion that more consumption of manganese shows no bad effect on human health in many countries. As well as WHO imposed no guideline value for manganese in 4th guideline value, 2011 incorporating 1st addendum, 2017.

From the above observation it is clear that water of these wells can be used for drinking and household purposes.

Table 4.15: Laboratory analysis of groundwater samples of production wells after 72 hours

Sl. No.	Parameter	Unit	Allowable limit of Bangladesh	WHO guideline value*	PTW-1 Depth: 150.39m	PTW-2 Depth: 180.73m
1	Sodium	mg/l	200	No guideline	23.7	136.7
2	Chloride	mg/l	150-600	No guideline	12	13
3	Iron	mg/l	0.3-1.0	No guideline	0.02	0.05
4	Arsenic	mg/l	0.05	0.01	<MDL	<MDL
5	Manganese	mg/l	0.1	No guideline	0.22	0.029
6	Bi-carbonate	mg/l	-	-	180.9	351.4

MDL: Minimum detection level

*4th WHO guideline value, 2011 incorporating 1st addendum, 2017

4.10 Observation and Recommendation

The 72 hours long pump test at Shamlapur yields low quality aquifer system, which shows poor performance. During pumping test, constant flow rate of water was 0.37 cusec for the total test period. The drawdown water level took 18 hours to recover after shutting the pump. Very low transmissivity (26 m^2/day) indicates that the quality of the aquifer system is not good. Permeability of this aquifer system is less than 1m/second. Based on geological field investigation, topography, structural analysis of the aquifer system, hydrostratigraphy, and long term pump test data, it is possible to conclude that the discharge rate of any production well in this area need to be restricted within the 0.5 cusec only. Finally, all available facts suggest that the Shamlapur aquifer system is not suitable for large scale groundwater development for long-term water supply. Moreover, the distance from Shamlapur to Sabrang Tourism Park is about 30km along the Shamlapur-Teknaf bus-stand road (possible route for transmission main) parallel to Cox's Bazar-Teknaf Marine drive. And after deducting loss along the transmission system, the amount of remaining water would not be cost effective. Thus Shamlapur is not considered as groundwater source for water supply in Sabrang or Naf Tourism Park.

From the synthesis of the result, a total of 7.0 MLD groundwater may be extracted from the Tekna Whykhong area. From the field investigation, desktop analysis of the filed data, and long-term pump test result suggest that vertical and horizontal recharge is very limited due to lateral discontinuity of the lithological unit, and vertical heterogeneity of the aquifer materials, respectively. These recharge limitations of the aquifer are further aggravated by the presence of sea water in close proximity to the west. Therefore, it is logical to recommend not only limited groundwater abstraction but also good monitoring and management system should be in place for regular assessment of the groundwater depletion and possibility of sea water intrusion. Therefore, increase in abstraction under future development scenario needs close monitoring to understand aquifer response and bring the safe limit within a narrow range of confidence limit. Considering recommended well spacing and available open land in Whykhong area 08 nos. of production well is recommended as shown in **Figure 4.54**. The coordinates of these proposed locations are given in **Table 4.16**. A good groundwater management under the condition requires monitoring the abstraction (by local user and/or Tourism Park), recharge, water quality and groundwater water level fluctuations as the development goes on.

The water quality in Whykhong area show no abrupt change during 72 hours aquifer tests. So no treatment plant is required for Whykhong well field.

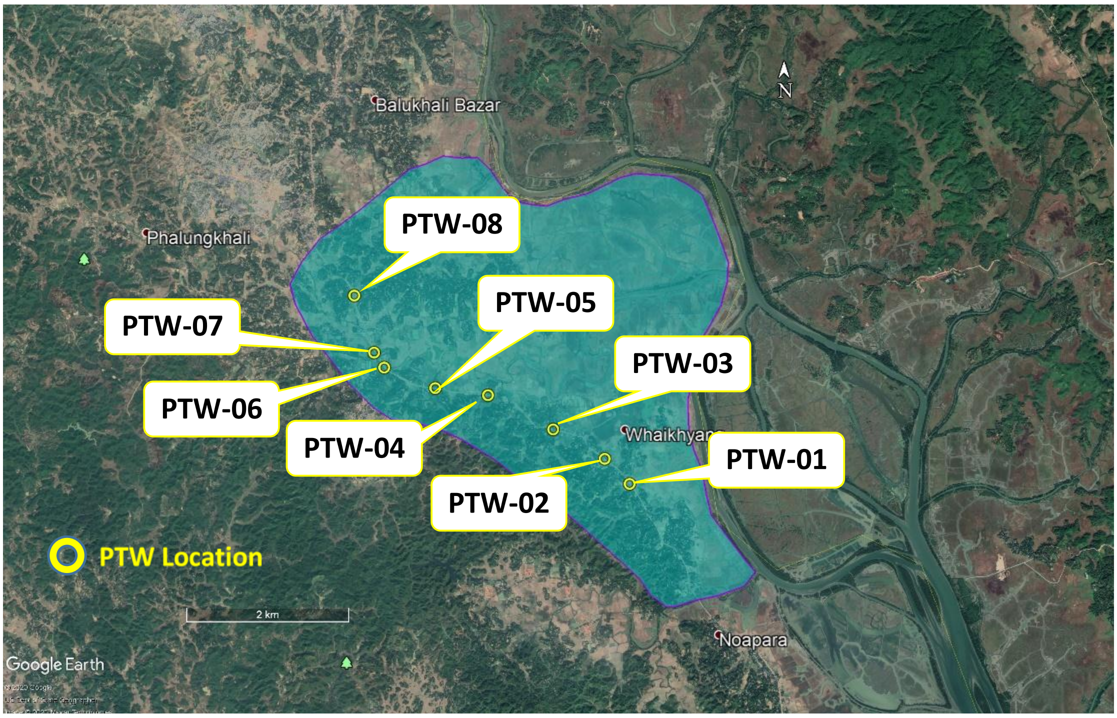


Figure 4.54: Proposed production tube well locations in Whykhong

Table 4.16: Locations of proposed production wells in Whykhong

Sl. no.	Well ID	Latitude	Longitude
1	PTW-01	21° 7'38.40"N	92°11'23.30"E
2	PTW-02	21° 7'48.30"N	92°11'12.70"E
3	PTW-03	21° 7'59.90"N	92°10'50.80"E
4	PTW-04	21° 8'13.40"N	92°10'23.10"E
5	PTW-05	21° 8'16.20"N	92°10'0.70"E
6	PTW-06	21° 8'24.30"N	92° 9'39.00"E
7	PTW-07	21° 8'30.20"N	92° 9'34.70"E
8	PTW-08	21° 8'52.70"N	92° 9'26.30"E

4.11 Transmission Main for Groundwater Distribution

The proposed transmission main to carry water from Whykhong well field to the tourism parks will follow Cox's Bazar-Teknaf National Highway (N1) and then Cox's Bazar-Teknaf Marine drive road upto Sabrang Tourism Park (**Figure 4.55**). In the meanwhile it will supply water to Naf Tourism Park. The total length of the transmission line is about 49.8 km including the length of transmission main from PTW-08 to PTW-01. After travelling about 29km from PTW-01 this transmission main will supply water in Naf Tourism Park after crossing the Naf River through the proposed tunnel.

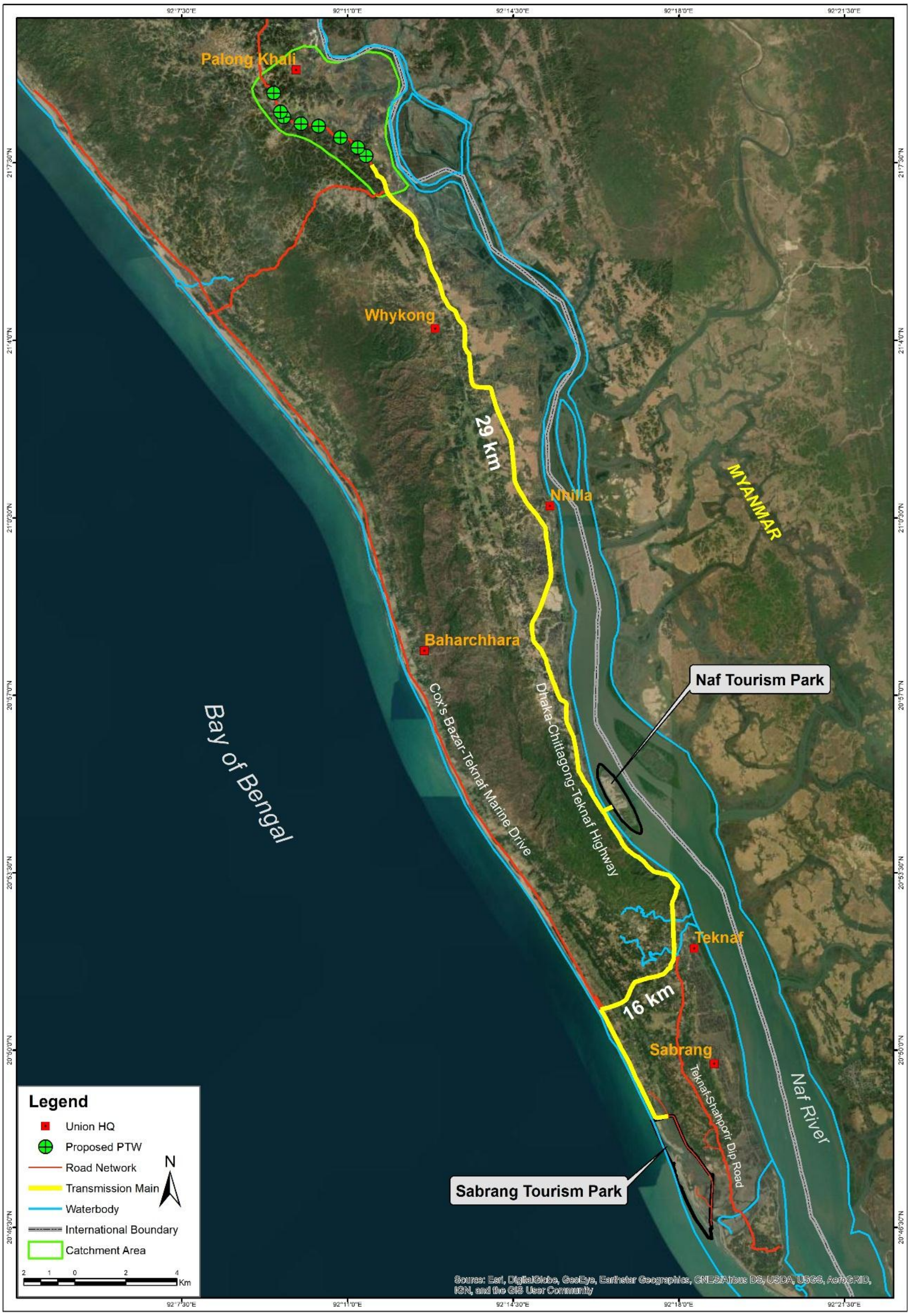


Figure 4.55: Proposed alignment of transmission main for GW distribution

5 RAINWATER HARVESTING

5.1 Introduction

Rainwater harvesting is a technology used to collect, convey and store rain for later use from relatively clean surfaces such as a roof or other surfaces, rather than allowing it to run off. Rainwater harvesting (RWH) has been practiced for over 4,000 years throughout the world, traditionally in arid and semi-arid areas. Now-a-days, rainwater harvesting has gained as a modern, water-saving and simple technology. There are many different uses for harvested rainwater no matter what type of rainwater harvesting system is used:

- Drinking and cooking
- Bathing and laundry
- Flushing toilets
- Watering lawns, gardens and houseplants
- Washing vehicles and equipment
- Fire protection
- Groundwater recharge

5.2 Criteria for Selection of Rainwater Harvesting Technologies

Several factors should be considered when selecting roof top rainwater harvesting systems for domestic use:

- Type and size of catchment area
- Local rainfall data and weather patterns
- Length of the drought period
- Alternative water sources
- Cost of the rainwater harvesting system.

5.3 Global Practice of Rainwater Harvesting

Canada: substantial reform of Canadian law increased its use since the 2000s.

Australia (the driest inhabited continent with huge rainfall variability): 1.5 million households had fitted rainwater tanks to their households as a source of water for domestic purposes (Eroksuzand Rahman, 2010)

Germany (leads the RWHS application in Europe): one third of new buildings are equipped with this system (Schuetze, 2013).

China: More than 5.5 million tanks have been built to supply supplemental drinking and irrigation water throughout China since 2001 (Gould et al., 2014).

Thailand: has the largest fraction of the population in the rural area (~40%) relying on rainwater harvesting.

India: RWH compulsory in buildings in Tamil Nadu and Pune, buildings over a certain size in Bangalore, Mumbai is planning similarly

Britain: Code For Sustainable Homes encouraged fitting large underground tanks to newly built homes.

United States: More than 100,000 residents use RWH (Lye, 2002). Hugely promoted in Texas in particular.

Japan: Use of RWH increased since the 1980s especially in earthquake-prone areas

Taiwan: New water law in 2009, requires new buildings with a total floor area larger than 10,000 m^2 must install domestic RWH equipment.

5.4 Rainwater Harvesting in BNBC

In Bangladesh National Building Code (Volume I, Final Draft (2015)), it is mentioned that every building proposed for constructing on plots measuring 300sqm or above shall have facilities for conserving and harvesting rainwater. A prior permit is required by Building Authority for rainwater harvesting installation.

5.4.1 Precautions in Rainwater Harvesting

Following precautions need to be cared for roof top Rainwater Harvesting according to BNBC:

a) No sewage or wastewater should be admitted into the system.
b) Wastewater likely to have oil, grease or other pollutants shall not be connected to the system.
c) Each rainwater seepage well shall have an inlet chamber with a silt trap to prevent any silt from finding its way into the sub-soil water.
d) The wells should be terminated at least 5m above the natural static sub-soil water at its highest level so that the incoming flow passes through the natural ground condition and prevents contamination hazards.
e) No recharge structure or a well shall be used for drawing water for any purpose.

5.4.2 Qualifying Rainwater for Harvesting

Rainwater shall be treated adopting following methods mentioned according to the purpose of use:

a) For using rainwater in drinking, cooking, washing utensils, bathing and ablution water shall be disinfected along with filtration
b) For cloth washing, floor washing, fountain, water fall cascade etc. rainwater shall be filtered
c) For using in sprinkler, firefighting, air conditioning etc. sedimentation of suspended particles will be required
d) For toilet flushing, gardening, cleaning artificial ground, parking lots etc. screening floating materials are needed

5.5 Process of Rainwater Harvesting System

Rainwater from the house roof is collected through rainwater gutters and stored in a storage tank for further use. For using the water for drinking or industrial use some treatment is required. Schematic diagram of such arrangement system is presented in **Figure 5.1**.

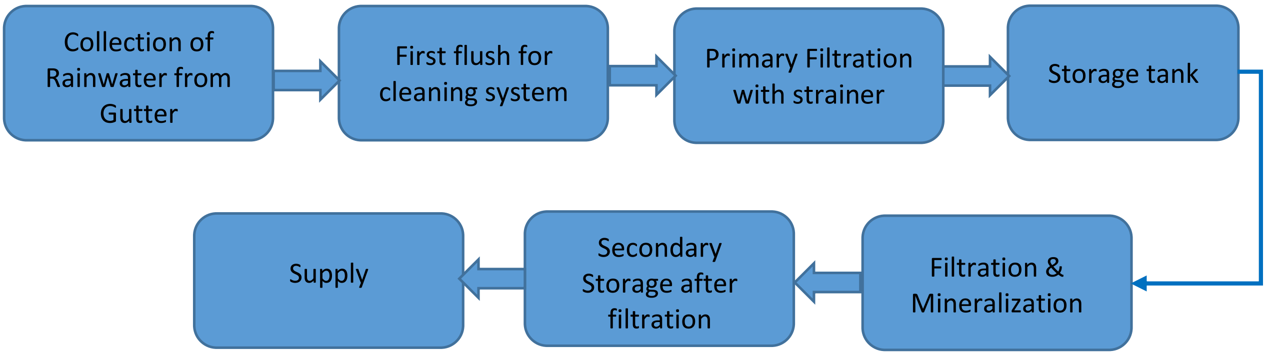


Figure 5.1: Schematic diagram of rainwater harvesting system

For using the rainwater for non-potable usage filtration & mineralization and secondary storage is not required.

5.6 Advantages and Disadvantages of Rainwater Harvesting

Rainwater Harvesting is an effective and ecofriendly method of utilizing the resources we have all around us. However, there is always at least a little bit of cloud to every silver lining and the balance of the positives and negatives should be considered carefully before settling on investing in any such system. A summarized advantages and disadvantages of rainwater harvesting system is stated in **Table 5.1**.

Table 5.1: Advantages and Disadvantages of rainwater harvesting system

Advantages	Disadvantages
• Rainwater is a relatively clean and free source of water. • Delivers water direct to the building without need for carrying. • Rainwater harvesting provides a source of water at the point where it is needed. • It is socially acceptable and environmentally responsible. • It promotes self-sufficiency and conserves water resources. • It reduces storm water runoff and non-point source pollution. • It uses simple, flexible technologies that are easy to maintain. • Offers potential cost savings especially with rising water costs. • Provides safe water for human consumption after proper treatment.	• Rainfall is hard to predict and sometimes little or no rainfall can limit the supply of rainwater. • Installing a rainwater harvesting system can be costly, depending on the system's size and technology level. • Rainwater harvesting systems require regular maintenance as they may get prone to rodents, mosquitoes, algae growth, insects and lizards. Self-cleaning rainwater filters help to minimize maintenance and keep the water clean. • Certain types of roofs may seep chemicals, insects, dirt or animals droppings that can be harmful.

Advantages	Disadvantages
• Running costs are low, construction, operation and maintenance are not labor-intensive.	• The collection and storage facilities may be restrictions due to the tank size.

5.7 Components of Roof Top Harvesting System

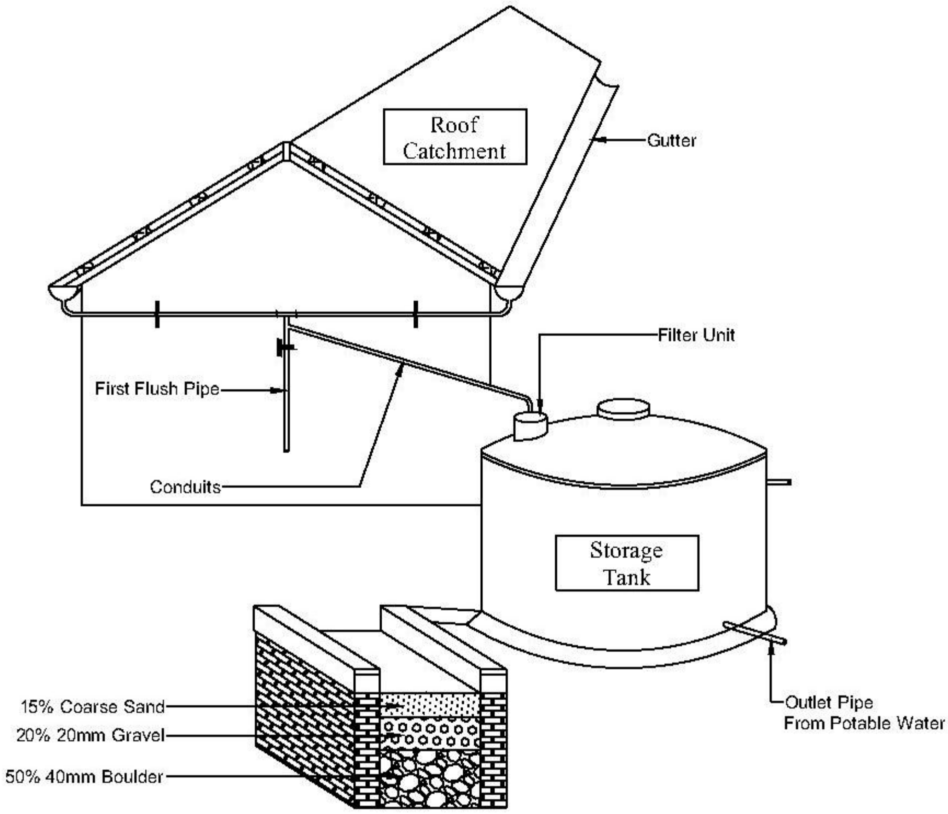


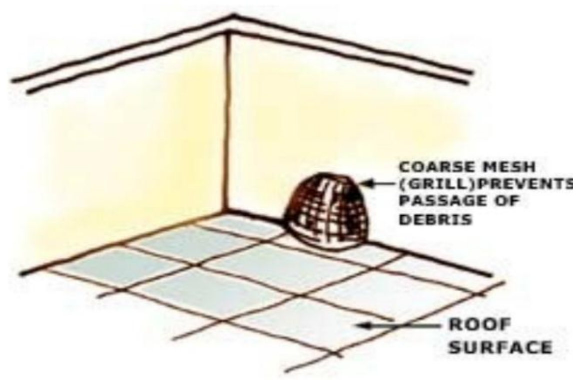
Figure 5.2: Different components of rainwater harvesting system

5.7.1 Catchment

The surface that receives rainfall directly is the catchment of rainwater harvesting system. It may be terrace, courtyard, or paved or unpaved open ground. The terrace may be flat RCC/stone roof or sloping roof. Therefore the catchment is the area, which actually contributes rainwater to the harvesting system. Usually surface area >300m^2 is potential to be considered as catchment area.

5.7.2 Coarse Mesh

It prevents the passage of debris, provided in the roof.



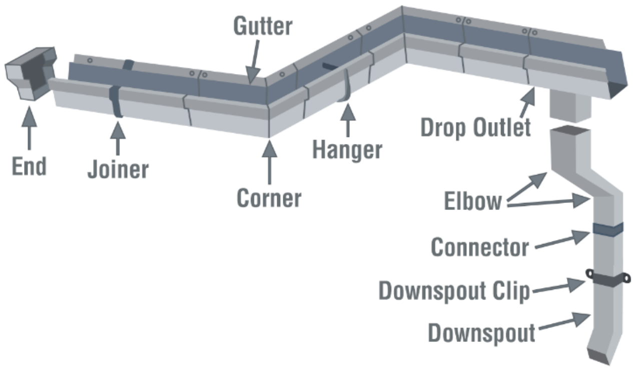


Figure 5.3: Different Coarse mesh

Figure 5.4: Different Gutters and conduits

5.7.3 Gutters

Channels which surrounds edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi – circular or rectangular and mostly made locally from plain galvanized iron sheet. The size of the gutter should be according to the flow during the highest intensity rain. It is advisable to make them 10 to 15 per cent oversize. Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed mainly depends on the construction of the house, mostly iron or timber brackets are fixed into the walls.

5.7.4 Conduits

Conduits are pipelines or drains that carry rainwater from the catchment or roof top area to the harvesting system. Commonly available conduits are made up of material like polyvinyl chloride (PVC) or galvanized iron (GI).

5.7.5 First-flushing

A first flush device is a valve which ensures flushing out of first spell of rain away from the storage tank that carries a relatively larger amount of pollutants from the air and catchment surface.

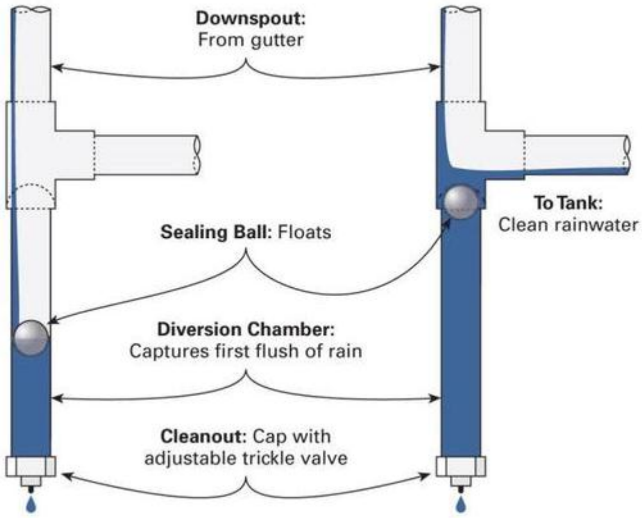


Figure 5.5: Different Gutters and conduits

5.7.6 Filters

The filter is used to remove suspended pollutants from rainwater collected from roof top water. The Various types of filters generally used for commercial purpose are Charcoal water filter, Sand filters, Horizontal roughing filter and slow sand filter.

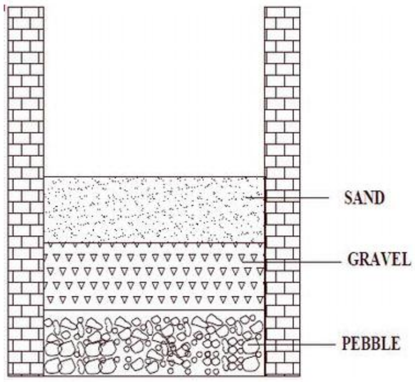


Figure 5.6: Sand filter

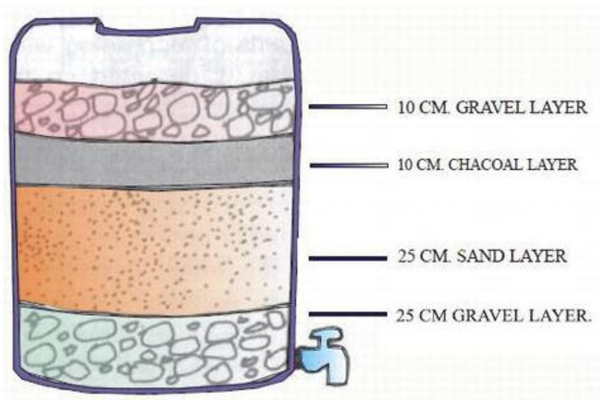


Figure 5.7: Charcoal filter

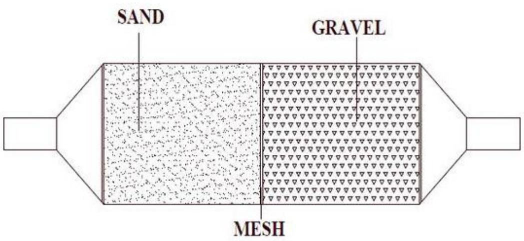


Figure 5.8: PVC pipe filter

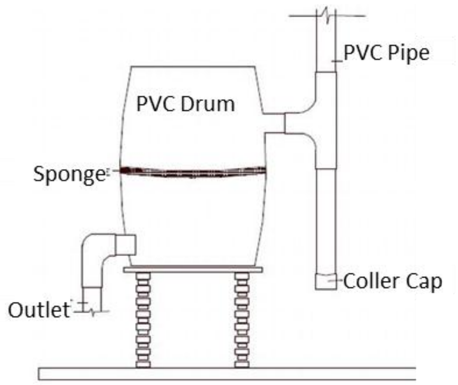


Figure 5.9: Sponge filter

5.7.7 Storage Facility

There are various options available for the construction of these tanks with respect to the shape, size, material of construction and the position of tank and they are: -

Shape: Cylindrical, square and rectangular.

Material of construction: Reinforced cement concrete (RCC), masonry, Ferrocement, plastic (polyethylene) or metal (galvanized iron) sheets are commonly use.

Position of tank: Depending on land space availability these tanks could be constructed above ground, partly underground or fully underground. Some maintenance measures like disinfection and cleaning are required to ensure the quality of water stored in the container.

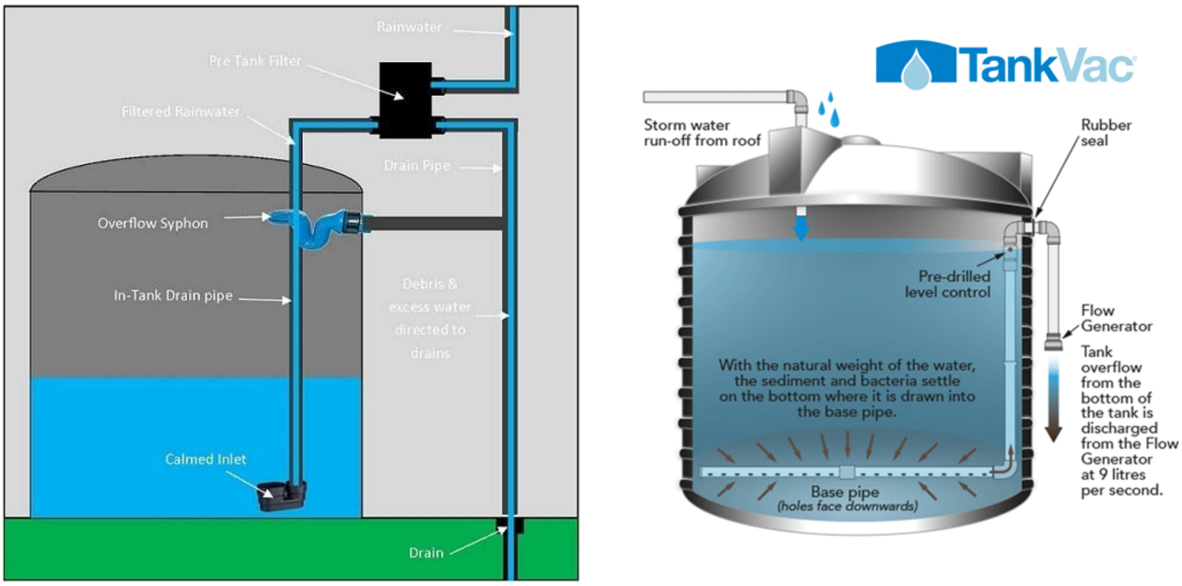


Figure 5.10: Different types of storage tank

5.7.8 Recharge Structures

Rainwater Harvested can also be used for charging the groundwater aquifers through suitable structures like dugwells, borewells, recharge trenches and recharge pits. Various recharge structures are possible – some of which promote the percolation of water through soil strata at shallower depth (e.g., recharge trenches, permeable pavements) whereas others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells).At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any fresh structures.

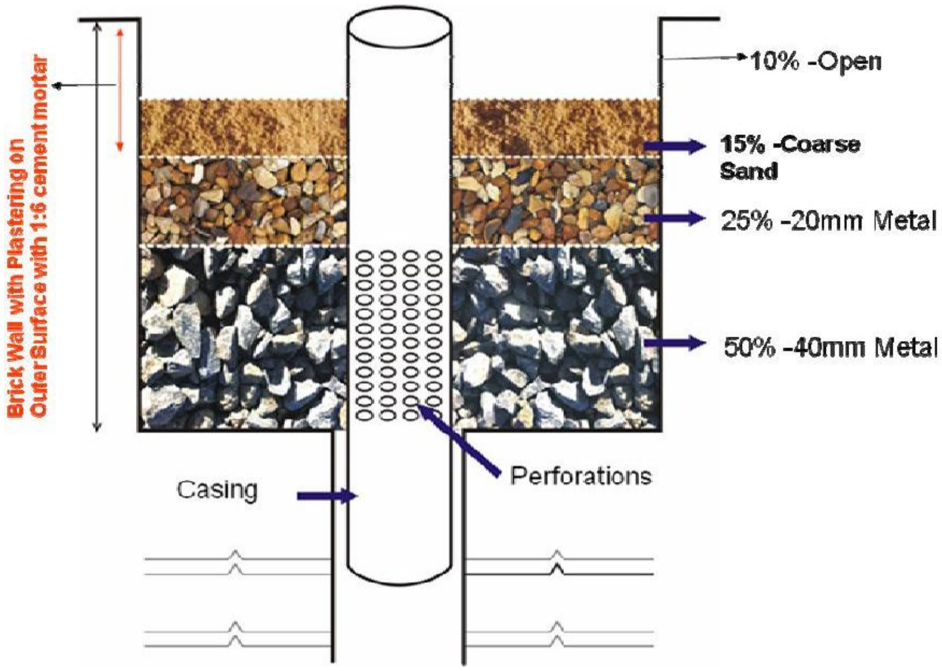


Figure 5.11: Recharge through injection well

5.8 Scope of Rainwater Harvesting in Sabrang Tourism Park Area

The annual rainfall at Teknaf is about 4000mm (sec. 2.1.1) and 95% of the rainfall occur between May and October. For rainwater harvesting on the roof top requires an area greater than 300m^2.

5.8.1 Non-potable Water demand in Sabrang Tourism Park

In Sabrang Tourism Park the total water demand is about 7.7 MLD at the user end. The harvested rainwater can be utilized for non-potable water use like toilet flushing, floor cleaning, gardening, car washing etc. It has been observed that about more than 50% of total water requirement is for non-potable usage (**Figure 5.12**). In Sabrang the non-potable water requirement is more than 3.85 MLD. So the harvested rainwater can fulfill partial demand of non-potable water usages.

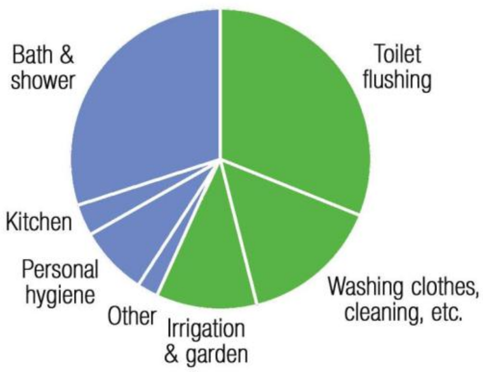


Figure 5.12: Household water usages

(Source: www.purewater2000.com)

5.8.2 Rainwater Harvesting Potential in Sabrang Tourism Park

In the Master plan, the land use plan has been prepared for about 406.8 acres (sec. 4.2.1) in land use plan for Sabrang Tourism Park In the Master plan covers an area about 406.8 acres (sec. 4.2.1). The building roof top area to be used may be accommodated in the buildings for, administration, welfare centre, old age home, shopping district and Heritage Museum, Convention Centre, Amphitheatre etc. with an area of about 220.5 acre can be considered as potential for rainwater harvesting. Master Plan suggests that the maximum permissible building height of each building in this economic zone is G+10 which is suitable for rain water harvesting. It is also mentioned in the Master Plan that, the minimum plot area should be around 0.3 acre and it if the building foot print area is considered 25% then the minimum roof area is >300m^2. So all the buildings associated in this 220.5 acre can be used for rainwater harvesting. If the building foot print area is considered 25% on average, and 80% building can be used as catchment area, then total catchment area potential for RWH is about 44 acres. Rainfall available during May to October is considered for estimating the amount of rainfall that can be harvested. Annual potential rainfall and harvested water in Sabrang Tourism Park is presented in **Table 5.2**. The annual rainfall varies between 1800 to 4100 mm and average potential rainfall is about 3100mm. The potential storage volume varies from 320 to 740 million liters which is equivalent to 0.88 to 2.03 MLD with an average of 1.45 MLD.

Table 5.2: Potential storage volume through RWH in Sabrang Tourism Park

Year	Effective RF	Potential storage volume through RWH		Year	Effective RF	Potential storage volume through RWH	
	mm	Million lt	MLD		mm	Million lt	MLD
1977	1950	487	1.33	1999	2341	613	1.68
1978	1707	470	1.29	2000	2471	659	1.81
1981	2108	587	1.61	2001	2255	605	1.66
1982	1988	579	1.59	2002	1937	485	1.33
1983	1256	321	0.88	2003	2210	608	1.66
1984	2049	570	1.56	2004	2066	523	1.43
1985	1976	511	1.40	2005	1916	545	1.49
1986	1783	468	1.28	2006	2329	636	1.74
1987	1823	509	1.39	2007	2194	518	1.42
1988	1943	523	1.43	2008	2670	722	1.98
1989	2010	508	1.39	2009	1902	543	1.49
1990	1752	481	1.32	2010	2008	488	1.34
1991	2546	660	1.81	2011	2458	641	1.76
1992	1749	441	1.21	2012	2412	643	1.76
1993	2188	616	1.69	2013	2076	559	1.53
1994	2435	678	1.86	2014	1655	484	1.33
1995	2081	552	1.51	2015	2689	739	2.03
1996	2108	504	1.38	2016	2102	574	1.57
1997	1800	521	1.43	2017	2007	550	1.51
1998	2085	573	1.57	2018	1905	461	1.26

5.8.3 Estimation of Number and Tank Size

Mass curve method is used to determine the number and size of the tank. It is estimated that maximum of 0.73 MLD water would be available from roof top rainwater harvesting from the rainfall over the year. Cumulative rainfall analysis and available water supply through RWH (**Table 5.3** & **Figure 5.13**) shows that the maximum deficit occurs in September with a water storage of 140 Million litre. With an average tank size of 860m^3 (including freeboard of 10%) the total number of tank required is around 180 nos. The dimension of each tank should be 16mX16mX4m (including 0.5m freeboard).

Table 5.3: Estimation of tank size in Sabrang Tourism Park

Month	RF (mm)	Rainfall harvested (Million lt)	Cumulative Rainfall harvested (Million lt)	Supply through RWH (Million lt)	Cumulative Supply through RWH (Million lt)	Difference between availability and demand (Million lt)
Jun	997.17	66.7	66.7	22.00	22.0	44.7
Jul	1095.88	73.3	140.1	22.00	44.0	96.1
Aug	879.45	58.9	198.9	22.00	66.0	132.9
Sep	439.88	29.4	228.4	22.00	88.0	140.4
Oct	245.50	16.4	244.8	22.00	110.0	134.8
Nov	58.83	0.0	244.8	22.00	132.0	112.8
Dec	6.83	0.0	244.8	22.00	154.0	90.8
Jan	5.24	0.0	244.8	22.00	176.0	68.8
Feb	10.57	0.0	244.8	22.00	198.0	46.8
Mar	16.24	0.0	244.8	22.00	220.0	24.8
Apr	65.14	0.0	244.8	22.00	242.0	2.8
May	287.45	19.2	264.0	22.00	264.0	0.00
Total	**4108**	**264.0**		**264.0**		

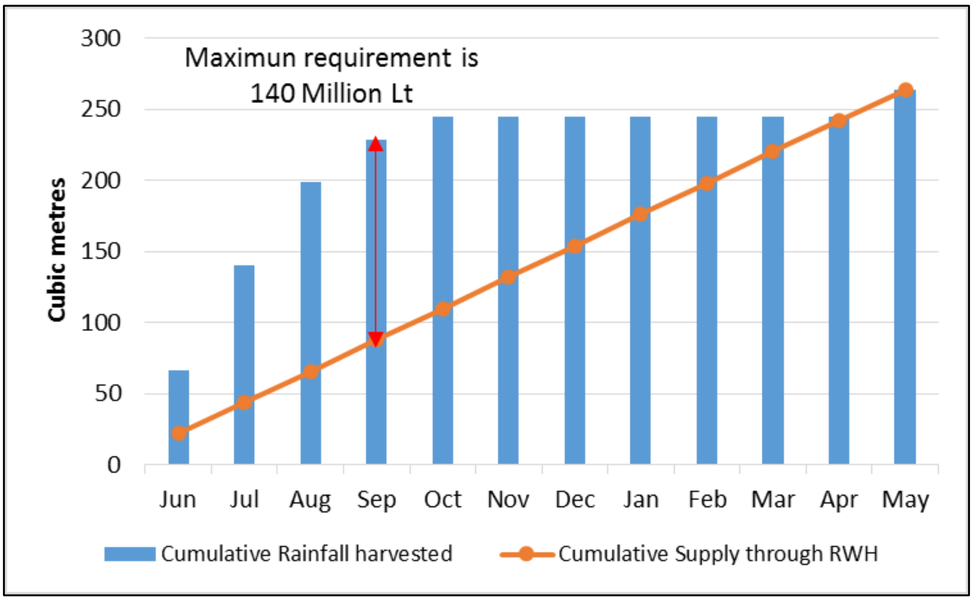


Figure 5.13: Mass curve to arrive the size of the tank in Sabrang Tourism Park

5.8.4 Phasing of Roof Top RWH in Sabrang Tourism Park

The amount of water that can be available from roof top rain water harvesting at different development phase has been estimated based on the development plan and total harvested water as shown in **Table 5.4**.

Table 5.4: Potential storage volume in different phases in Sabrang Tourism Park

Different Phase	Potential RWH volume (MLD)
Phase-1	0.13
Phase-2	0.12
Phase-3	0.12
Phase-4	0.12
Phase-5	0.12
Phase-6	0.12
Total	**0.73**

5.9 Scope of Rainwater Harvesting in Naf Tourism Park Area

5.9.1 Non-potable Water demand in Naf Tourism Park

In Naf Tourism Park the total water demand is about 0.9 MLD at the user end. In Naf the non-potable water requirement is more than 0.45 MLD. So the harvested rainwater can fulfill partial demand of non-potable water usages.

5.9.2 Rainwater Harvesting Potential in Naf Tourism Park

In the Master plan, the land use plan has been prepared for about 270 acres (sec. 4.3.1). The area reserved for accommodation and commercial purposes are potential for rainwater harvesting. The building foot print area is about 22.121 acre according to Master plan as shown in **Table 5.5**.

Table 5.5: Building Foot Print area of Naf Tourism Park

Program	Foot print area (acre)	No of plot	Foot print area per plot (m^2)
Hotels	6.67	4	6758
Cottages	4.2	105	162
Apartment	4.65	57	330
Central Space	6.6	1	26710
Total	**22.12**		

Foot print area for the cottages are <300m^2, thus these areas are not suitable for rainwater harvesting. So the total catchment area for this economic zone is about 17.92 acre. In Master Plan it is suggested that the maximum permissible building height of each building in this economic zone is G+3 which is suitable for rain water harvesting. The yearly potential rainfall and harvested water for Naf Tourism Park is presented in **Table 5.6**. Due to rainfall variation the potential harvesting varies from 104 to 240 million liters. If we can use this harvested water throughout the year the storage volume is equivalent to about 0.18 to 0.41 MLD which is in average 0.29 MLD.

Table 5.6: Potential storage volume through RWH in Naf Tourism Park

Year	Effective RF	Potential storage volume through RWH		Year	Effective RF	Potential storage volume through RWH	
	mm	Million lt	MLD		mm	Million lt	MLD
1977	98,990	99	0.27	1999	124,444	124	0.34
1978	95,465	95	0.26	2000	133,872	134	0.37
1981	119,339	119	0.33	2001	122,965	123	0.34
1982	117,686	118	0.32	2002	98,598	99	0.27
1983	65,152	65	0.18	2003	123,458	123	0.34
1984	115,713	116	0.32	2004	106,169	106	0.29
1985	103,849	104	0.28	2005	110,753	111	0.30
1986	95,001	95	0.26	2006	129,144	129	0.35
1987	103,356	103	0.28	2007	105,299	105	0.29
1988	106,314	106	0.29	2008	636	147	0.40
1989	103,211	103	0.28	2009	110,347	110	0.30
1990	97,699	98	0.27	2010	99,091	99	0.27
1991	134,046	134	0.37	2011	130,304	130	0.36
1992	89,664	90	0.25	2012	130,681	131	0.36
1993	125,170	125	0.34	2013	113,566	114	0.31
1994	137,846	138	0.38	2014	98,308	98	0.27
1995	112,232	112	0.31	2015	150,175	150	0.41
1996	102,369	102	0.28	2016	116,554	117	0.32
1997	105,821	106	0.29	2017	111,652	112	0.31
1998	116,322	116	0.32	2018	93,638	94	0.26

5.9.3 Estimation of Number and Tank Size

Mass curve method is used to determine the number and size of the tank. It is estimated that maximum of 0.22 MLD water would be made available from roof top rainwater harvesting from rainfall over the year. Cumulative rainfall analysis and available water supply through RWH (**Table 5.7** & **Figure 5.14**) shows that the maximum deficit occurs in September with a water storage of 47 Million lt. With an average tank size of 830 m^3 (including freeboard of 10%) the total number of tank required is around 63 nos. (total effective building is 62 nos.). The dimension of each tank should be 16mX16mX4m (including 0.5m freeboard).

Table 5.7: Estimation of tank size in Naf Tourism Park

Month	RF (mm)	Rainfall harvested (Million lt)	Cumulative Rainfall harvested (Million lt)	Supply through RWH (Million lt)	Cumulative Supply through RWH (Million lt)	Difference between availability and demand (Million lt)
Jun	997.17	21.7	21.7	6.71	6.7	14.99
Jul	1095.88	23.8	45.5	6.71	13.4	32.12
Aug	879.45	19.1	64.7	6.71	20.1	44.55
Sep	439.88	9.6	74.2	6.71	26.8	47.41
Oct	245.50	0.0	74.2	6.71	33.5	40.70
Nov	58.83	0.0	74.2	6.71	40.2	33.99

Month	RF (mm)	Rainfall harvested (Million lt)	Cumulative Rainfall harvested (Million lt)	Supply through RWH (Million lt)	Cumulative Supply through RWH (Million lt)	Difference between availability and demand (Million lt)
Dec	6.83	0.0	74.2	6.71	47.0	27.29
Jan	5.24	0.0	74.2	6.71	53.7	20.58
Feb	10.57	0.0	74.2	6.71	60.4	13.87
Mar	16.24	0.0	74.2	6.71	67.1	7.16
Apr	65.14	0.0	74.2	6.71	73.8	0.45
May	287.45	6.3	80.5	6.71	80.5	0.00
Total	**4108**	**80.5**		**80.5**		

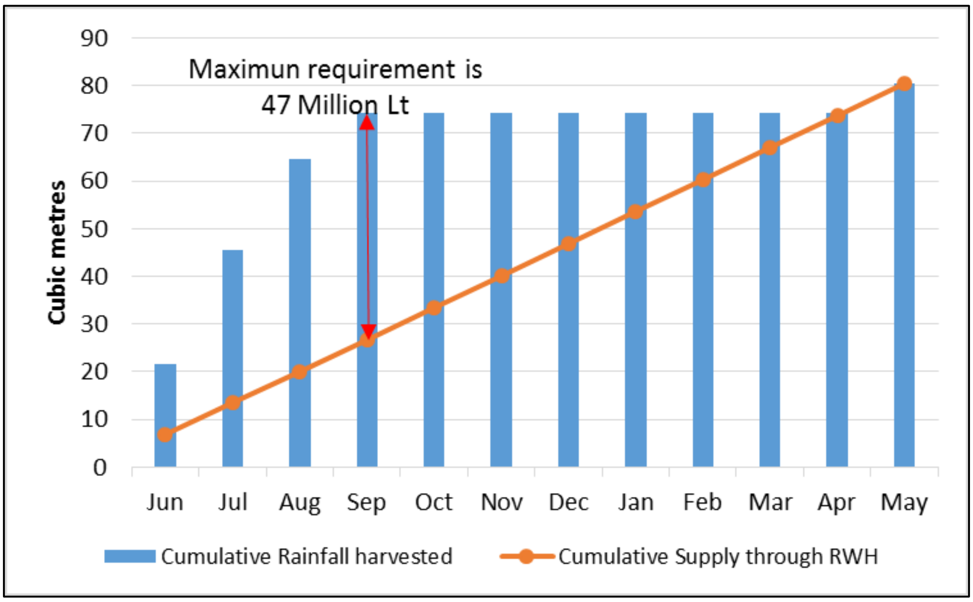


Figure 5.14: Mass curve to arrive the size of the tank in Sabrang Tourism Park

5.9.4 Phasing of Roof Top RWH in Naf Tourism Park

The amount of water that can be available from roof top rain water harvesting at different development phase has been estimated based on the development plan and total harvested water as shown in **Table 5.8**.

Table 5.8: Potential storage volume in different phases in Naf Tourism Park

Different Phase	Potential RWH volume (MLD)
Phase-1	0.09
Phase-2	0.05
Phase-3	0.08
Total	**0.22**

6 REVERVOIR ANALYSIS

6.1 Resource Assessment of the Reservoir

A dam on the foothills of north of Teknaf Pourashava is proposed to capture and store rainfall-runoff from the upstream hilly catchment. The feasibility study of this dam is now being carried out by IWM under *Emergency Multi-Sector Rohingya Crisis Response Project (EMCRP)* of DPHE.

This distribution reservoir of the dam could be filled up by rain water during monsoon and be fed into the pipe network water supply system within the Teknaf Pourashava as well as in Sabrang Tourism Park area. The projected population and water demands of Teknaf Pourshava and Sabrang TP have been computed as shown in **Table 6.1**. It is observed that for Sabrang TP 1,412 m^3/d water is considered to be required in the distribution system which can be served for 10,000 population. So at the treatment plant about 1,483 m^3/d raw water is required from the proposed reservoir.

Table 6.1: Design Population and Domestic Water Demand stated in EMCRP, Feasibility Report

Sl. No.	Item		2025	2035	2045
1	Population (nos.)	Projected for Teknaf Pourashava	39,780	50,182	59,959
		Considered for Sabrang TP (nos.)	10,000	10,000	10,000
2	Maximum day water requirement for distribution system (m^3/d)	In Teknaf	2,681	4,450	6,638
		In Sabrang	1,412	1,412	1,412
		Total	**3,355**	**5,336**	**7,724**
3	Water Treatment Capacity to be Installed (m^3/d)	In Teknaf	2,816	4,673	6,970
		In Sabrang	1,483	1,483	1,483
		Total	**4,299**	**6,156**	**8,453**

6.1.1 Catchment Area of the Reservoir

Based on the detailed topographic survey carried out by 3D Terrestrial Laser Scanner (Teledyne Optic Polaris TLS-1500) and FINMAP surveyed data, 4 sub-catchments have been delineated which contribute runoff to the proposed reservoir water at main dam site with a contour of interval 25 cm; having a total catchment area is 102.1 ha (≈1km^2). In **Figure 6.1**, the drainage network and the delineation of the catchment area upstream of the reservoir dam have been shown.

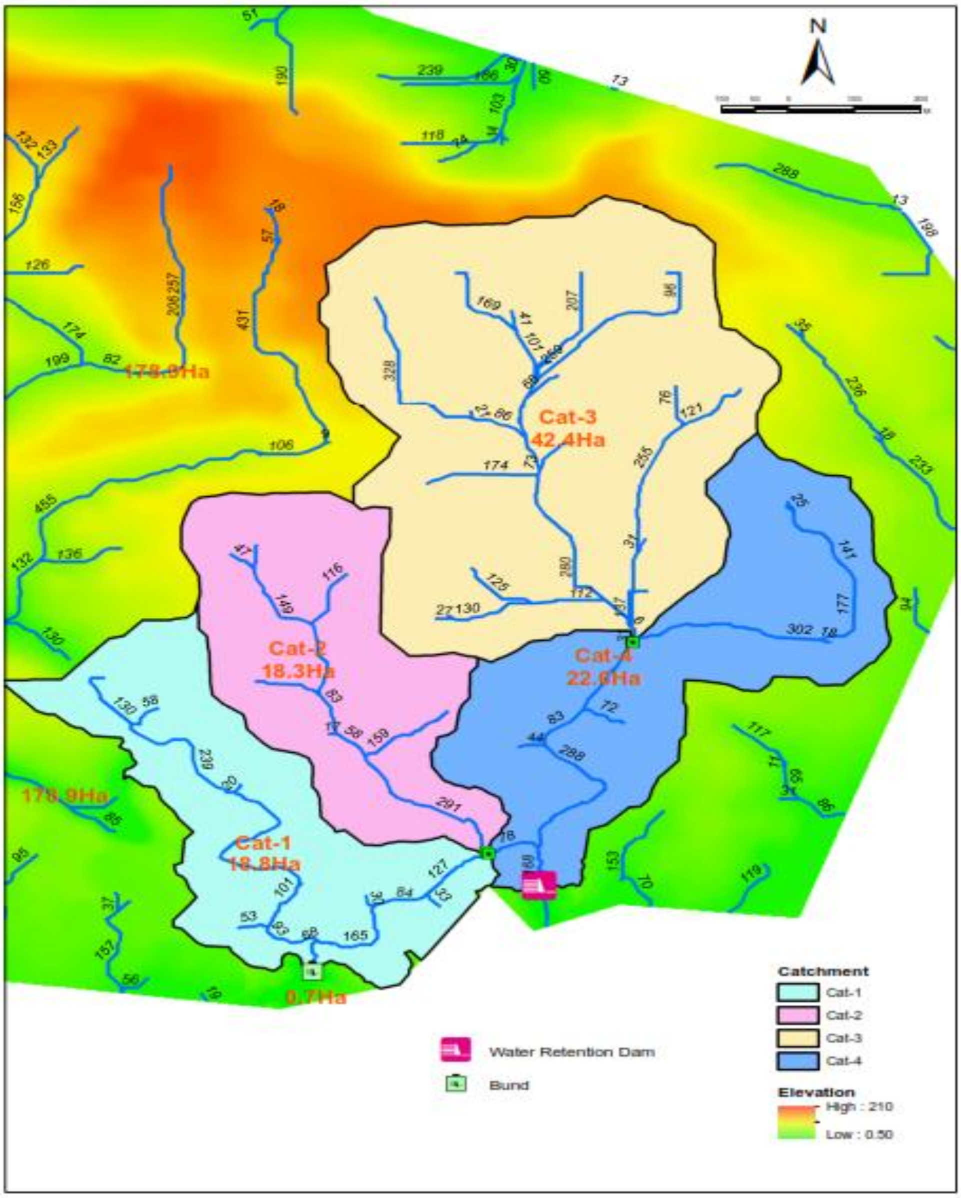


Figure 6.1: Catchment area and Drainage Network of the Proposed Distribution Reservoir at Teknaf

The area and storage at different elevations (contours) have been estimated using GIS technology as shown in **Figure 6.2.** It shows that maximum storage elevation would be 27 m, MSL which corresponds to a storage volume of 1898269 m^3 or 1.9 Mm^3. Assuming dead storage 0.22 Mm^3 for the reservoir upto elevation 12 m, MSL, the proposed reservoir will be able to supply 1.68 Mm^3 of water, if filled to level 27m, to meet the demand Teknaf Pourashava and Sabrang TP (Partially).

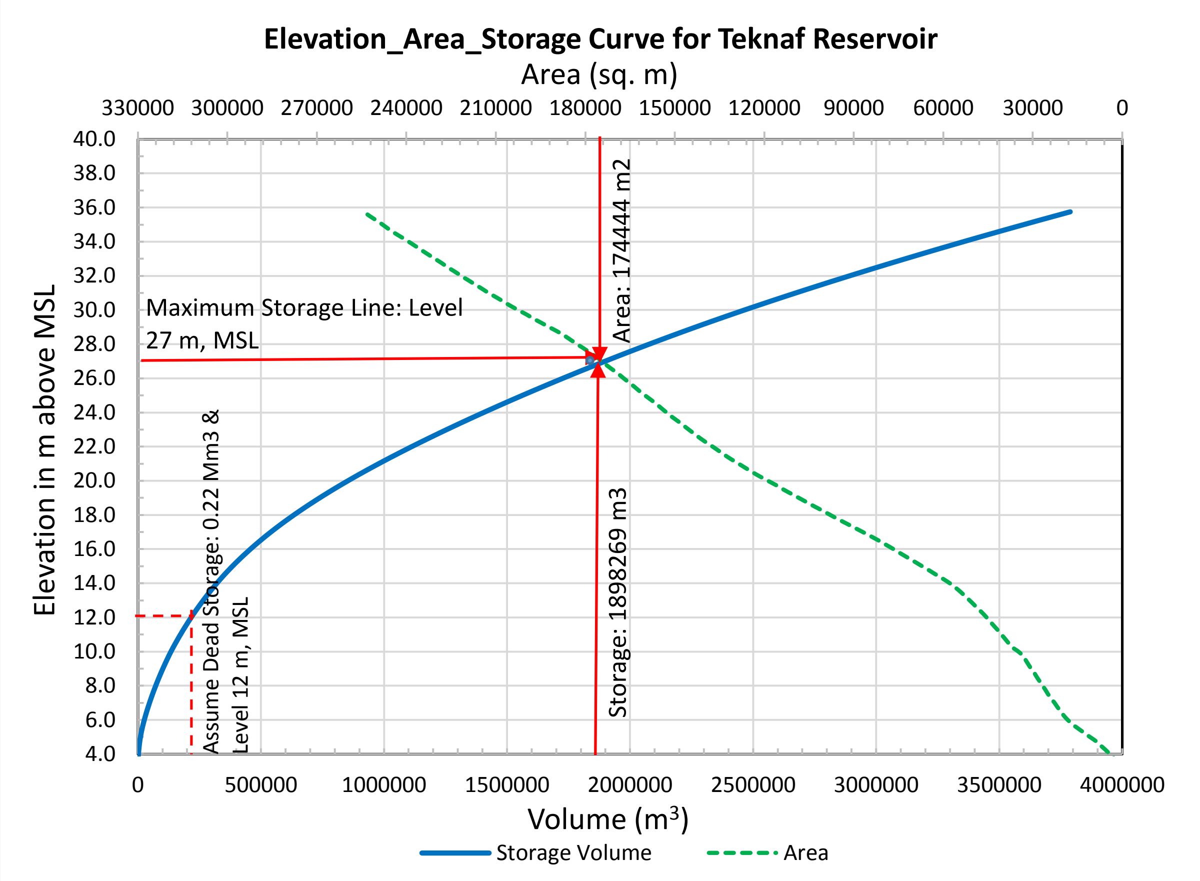


Figure 6.2: Area-elevation curve and Capacity-elevation curve

6.1.2 Catchment Runoff Analysis

The runoff volumes at DAM site have been evaluated by computing runoff depth using runoff coefficient:

$$Q = K.P$$

Where, Q = runoff

P = Precipitation

K = a constant which reflects rainfall losses, having a value of 0.60 for forested area with hilly land (gravel-sand and silt loam) 10% to 30% slope (similar to reservoir area at Teknaf)

The maximum inflow rate for the reservoir has been analyzed using daily rainfall data (2003-2011) of Teknaf BMD station, and 3-hourly rainfall data of Coxsbazar BMD station (2012-2018). The storage capacity and the spillway discharge capacity of the dam or reservoir have been estimated based on the generated inflow or runoff volumes from the above 16-years rainfall data of Teknaf, meeting the water demand of Teknaf Pourashava and Sabrang TP and considering evaporation and percolation losses.

The analysis results for reservoir water level and inflow volumes for these two periods of data have been shown in **Figure 6.3** and **Figure 6.4** respectively. The generated rainfall-runoff volumes could not be calibrated in the absence of measured flow data. However, the results have been verified to some extent with the inflow runoff and outflow results computed using the RORB rainfall-runoff model of Australia. **Figure 6.3** and **Figure 6.4** shows that storage capacity reaches maximum 27m level between 2008 and 2018, when spillway discharge occurs as a result of the increased rainfall compared to the earlier period. The maximum spillway discharge during 2008-2018 varies from 2.9 to 3.7 m^3/s.

Initially, the reservoir has been planned to fill up by gravity flow during the first couple of months in monsoon to attain the full reservoir level.

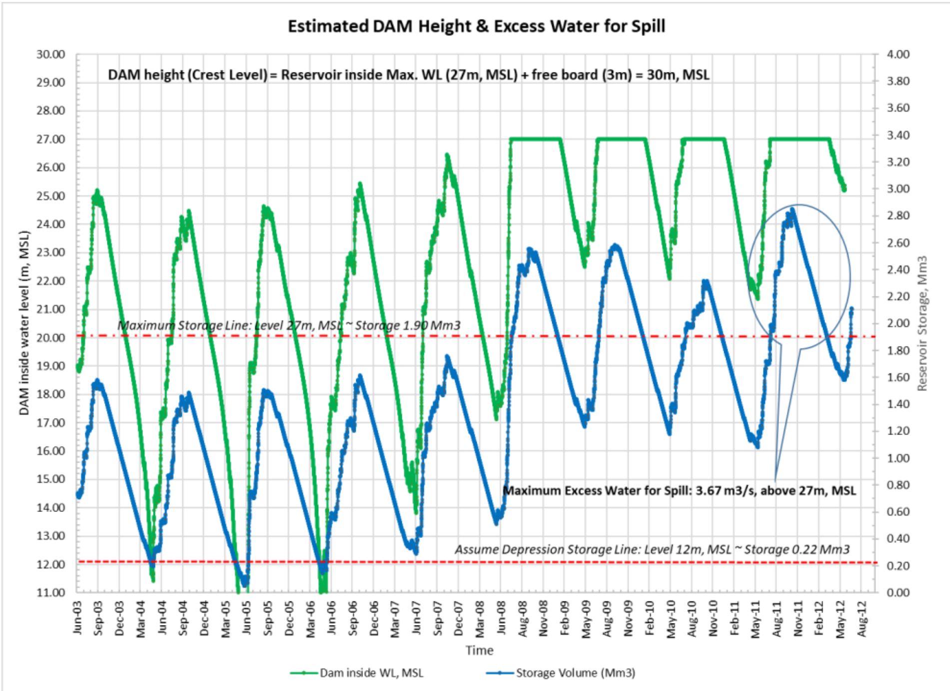


Figure 6.3: Estimated DAM height and excess water for Spill based on actual rainfall at Teknaf from 2003 to 2011

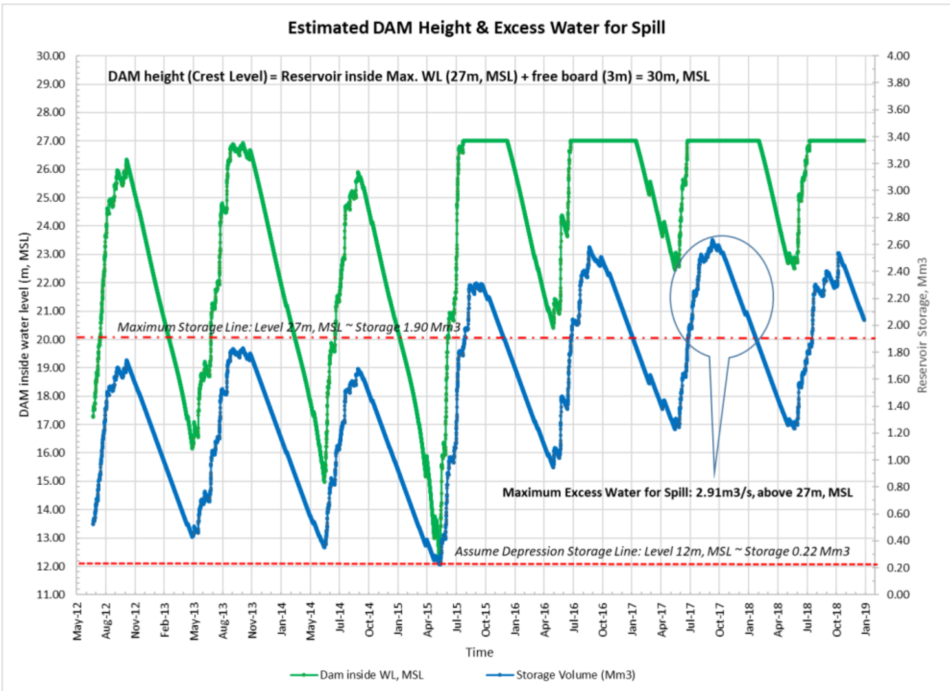


Figure 6.4: Estimated DAM height and excess water for Spill based on actual rainfall at Teknaf from 2012 to 2018

The inundation surfaces of the storage reservoir for storage level at 12m and 27m levels have been shown in **Figure 6.5** and **Figure 6.6** respectively.

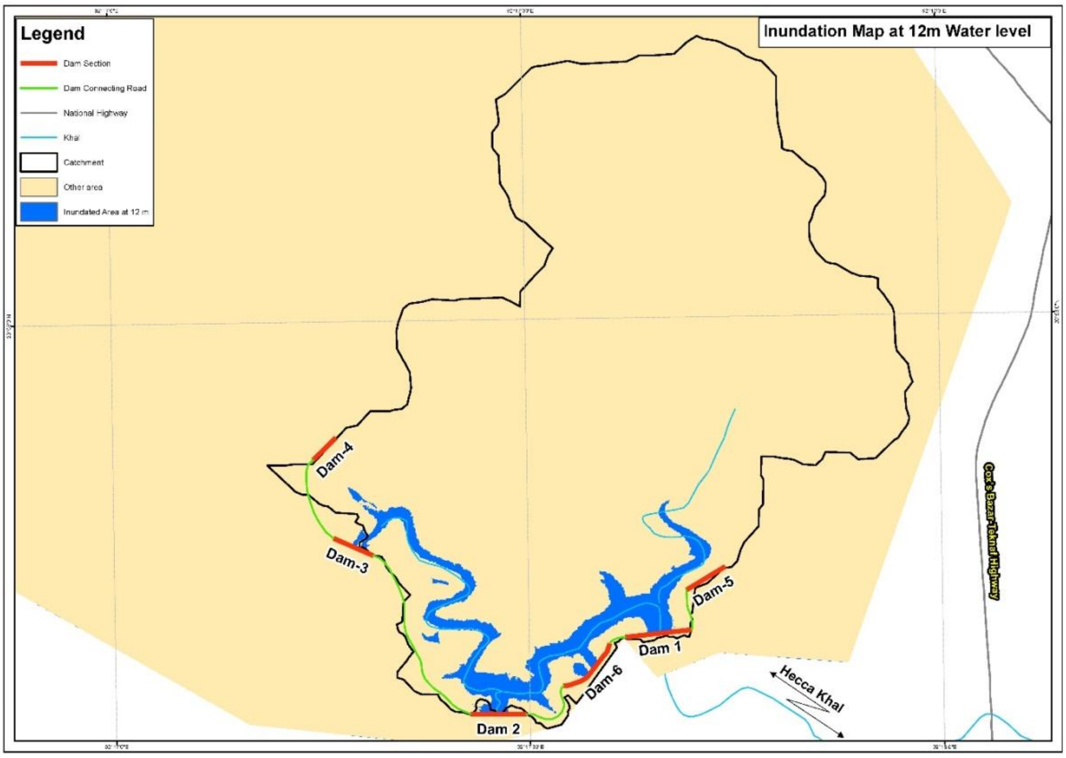


Figure 6.5: Reservoir inundation surface area at 12m, MSL

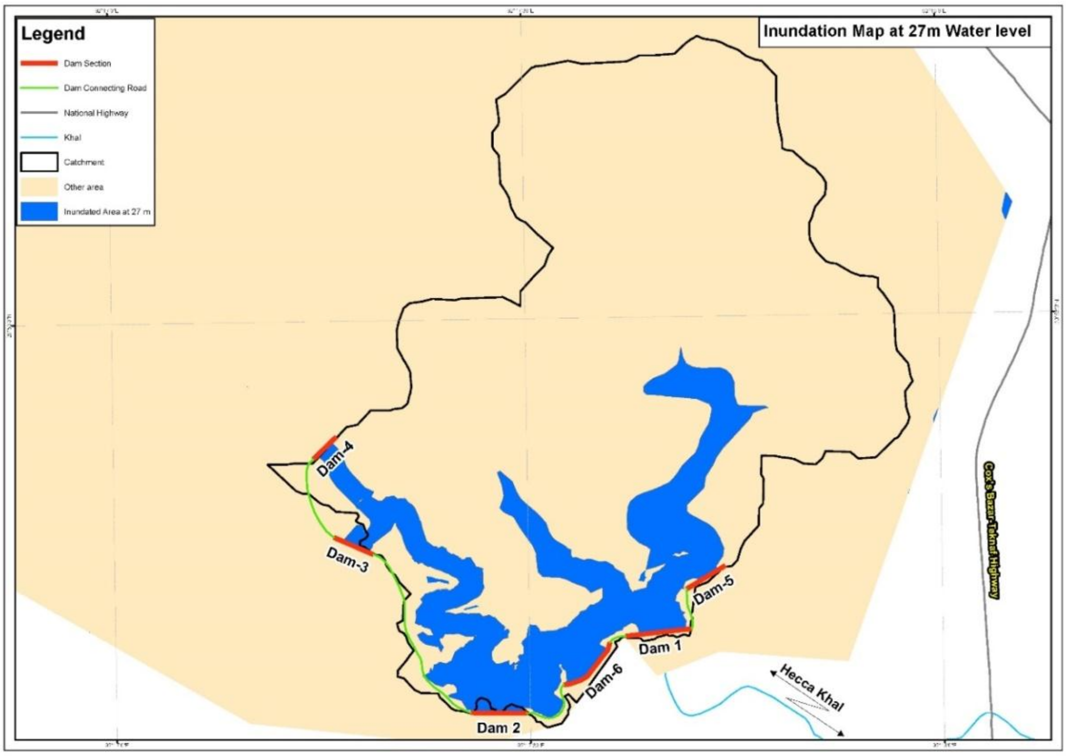


Figure 6.6: Reservoir inundation surface area at 27m, MSL

6.1.3 Hydraulic Design Parameters of Proposed Reservoir

The hydraulic design parameters adopted for the feasibility study are as follows:

Catchment area: 1021000 sq. m

Surface area:	174444 sq. m.
Storage capacity of reservoir:	1.68 Mm^3
Dam height:	30 m, MSL
Maximum pool level:	27 m, MSL
Minimum pool level:	12 m, MSL
Dead storage:	0.22 Mm^3
Dam free board:	3 m
Invert level of spillway:	27 m, MSL
Capacity of spillway:	3.67 m^3/s
Size of spillway:	2 m wide

6.1.4 Selected Dams for Proposed Reservoir

The inundation surface shown in **Figure 6.7** indicates that to conserve the water in the storage at 27m, MSL, dams at six locations including the main dam with spillway are to be provided.

The locations of the dams with interconnecting roads are shown in **Figure 6.7**. The topography with cross-section at main dam site is shown in **Figure 6.8**. The topographic details of the six dams are provided in **Table 6.2**.

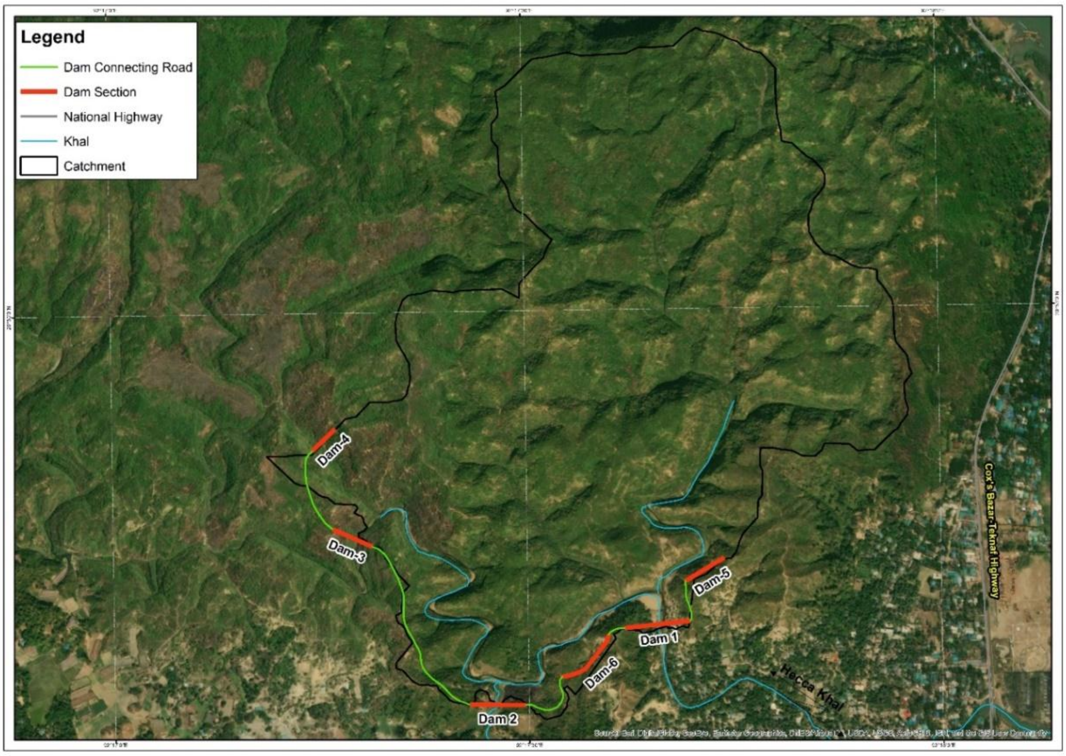


Figure 6.7: The identified locations of the dams with interconnecting roads

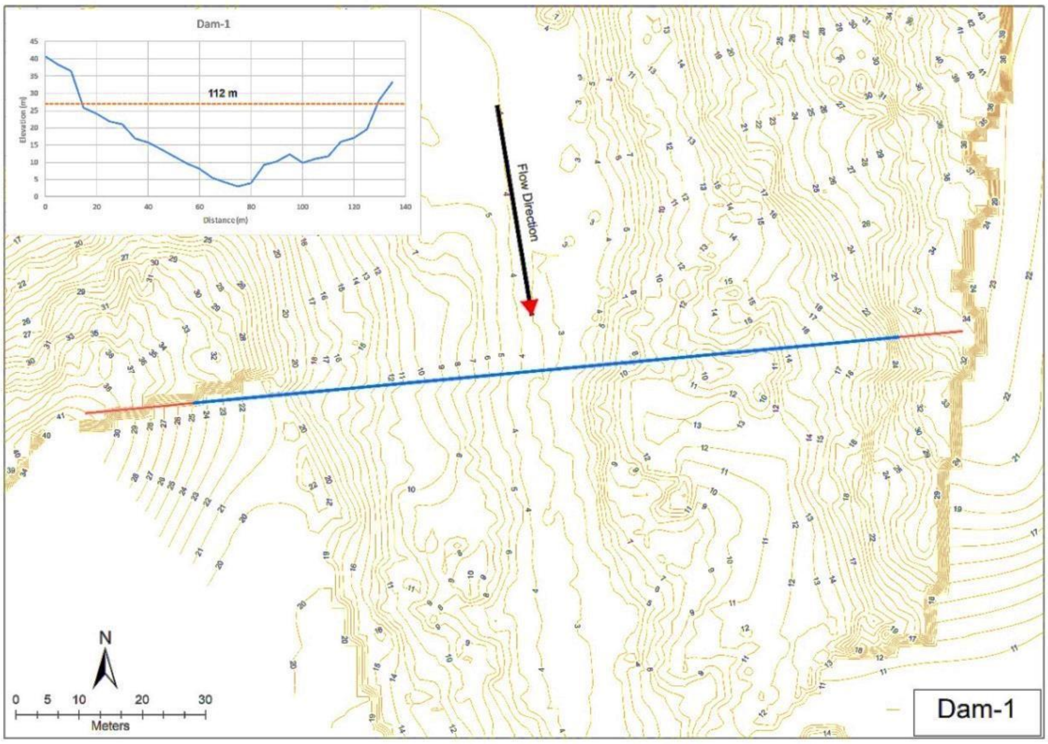


Figure 6.8: The topography with cross-section at main dam site

Table 6.2: Selected DAM features

DAM No.	DAM Type	Horizontal Length (m)	Maximum Depth (m)	Remarks
DAM-1	Main DAM with Spillway	112	23	
DAM-2	Subsidiary	104	22	
DAM-3	Subsidiary	57	17	
DAM-4	Subsidiary	41	8	
DAM-5	Subsidiary	45	2.5	
DAM-6	Subsidiary	120	14	

6.2 Assessment of Surface Water Quality of the Reservoir

The present surface water quality (January 2020) inside the reservoir area has been tested in the DPHE Laboratory. The following key parameters of the laboratory test have been summarized in **Table 6.3**.

Table 6.3: Surface Water Quality for collected sample in January 2020

Sl. No.	Water Quality Parameters	Unit	Allowable Limit (Bangladesh Standard)	Present Concentration
1	Alkalinity	mg/l	-	74
2	Ammonia	mg/l	0.5	0.3
3	Biochemical Oxygen Demand (BOD)	mg/l	0.2	4
4	Coliform (Feacal)	N/100ml	0	8
5	Coliform (Total)	N/100ml	0	20
6	EC	μS/cm	-	224
7	Phosphate	mg/l	6.0	0.27
8	Sulfate	mg/l	400	3
9	Total Dissolved Solid (TDS)	mg/l	1000	110

6.3 Design of Proposed Earthen Dam

This proposed earthen dam has been planned to be constructed with natural materials with a minimum of processing and primitive equipment. The plan-view and cross-section of main dam is shown in **Figure 6.9** and **Figure 6.10**.

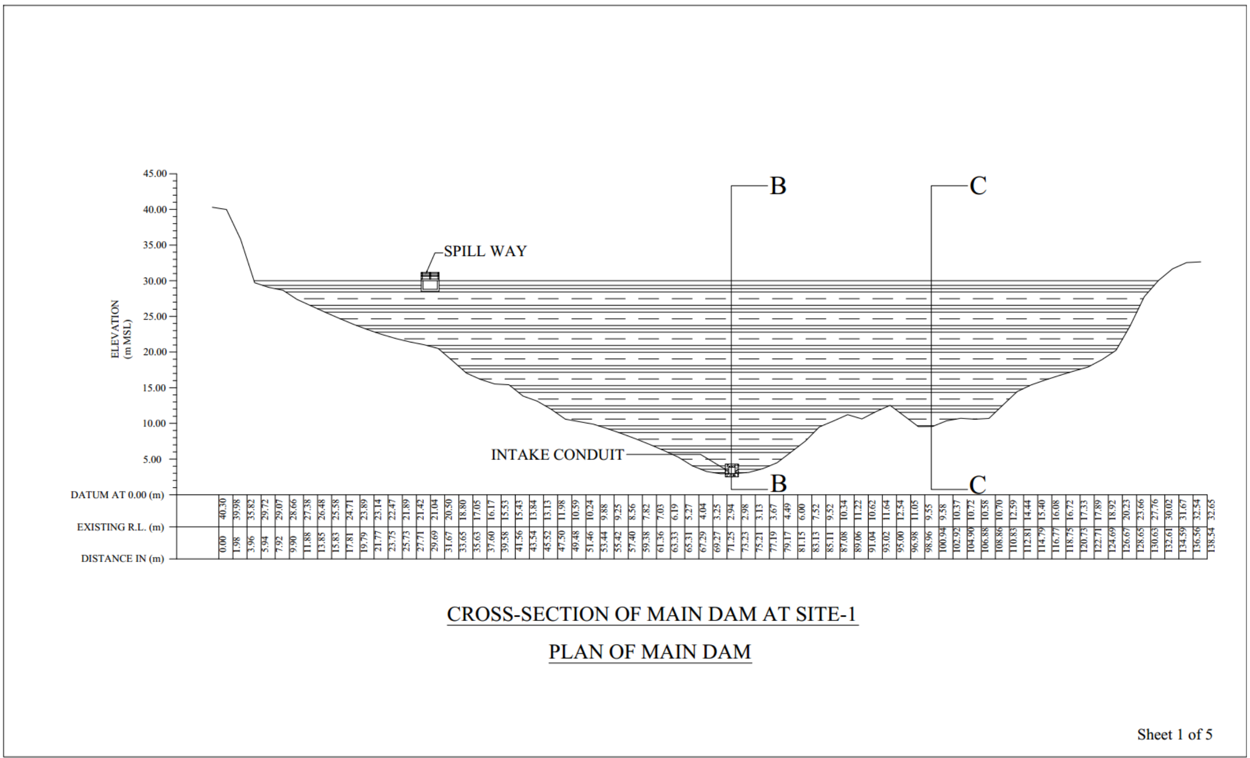


Figure 6.9: The plan-view of main dam (DAM-1)

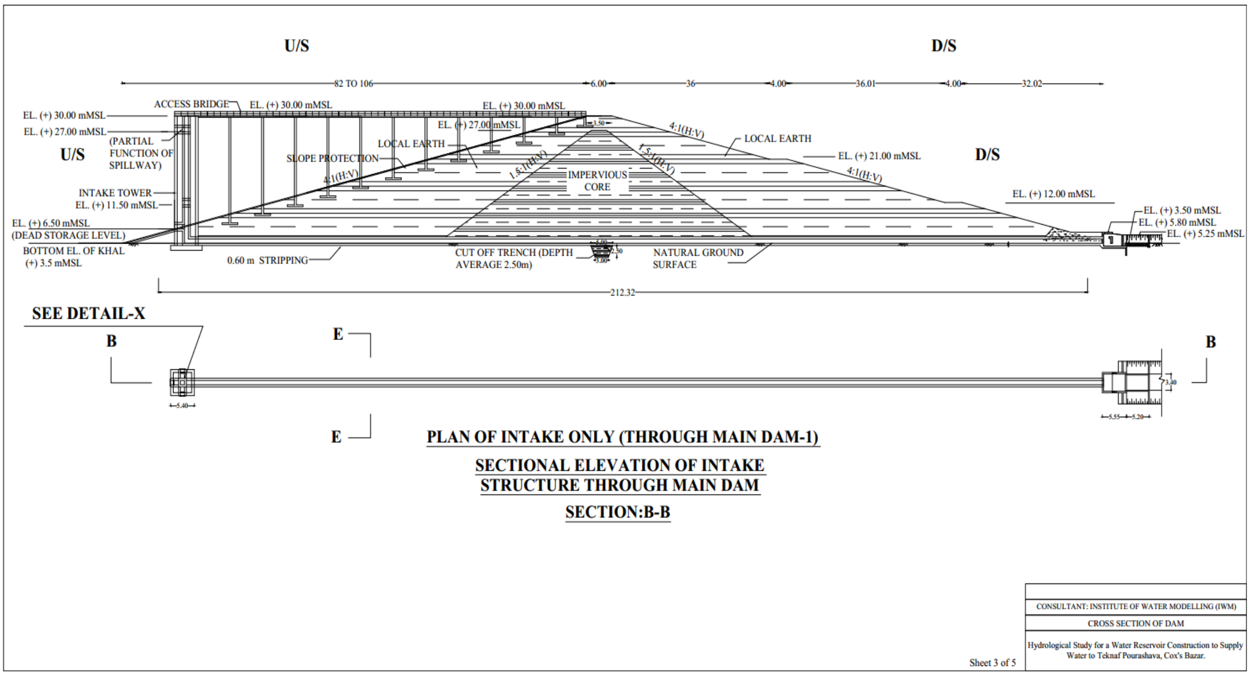


Figure 6.10: The cross-section of main dam (DAM-1)

6.4 Water Supply Plan

The proposed water supply system, considering the dam at the foot hills of north of Teknaf Pourashava is planned to be implemented in three Phases:

- Phase-I to be implemented by the year 2025 to cover 70% of the Teknaf Pourashava population and 10,000 population of Sabrang TP,
- Phase-II to be implemented by the year 2035 to cover 80% of the Pourashava population and 10,000 population of Sabrang TP, and
- Phase-III to be implemented by the year 2045 to cover 85% of the Pourashava population and 10,000 population of Sabrang TP.

According to the planned Sabrang TP would be served by the rain water stored in the reservoir by the year 2025.

6.5 Surface Water Treatment Plant (SWTP)

A treatment plant is required to treat the reservoir water. The location of the SWTP is shown in **Figure 6.11**. The process design of surface water treatment plant (SWTP) has been carried out under *EMCRP*, DPHE project. The number of required treatment plant units including capacity and its run-time for Phase-I, II & III is shown in **Table 6.4**.

Figure 6.11: Location of Surface Water Treatment Plant for Teknaf Pourashava

Table 6.4: The Treatment Plant Facilities in Phase-I, II and III

Item/Year	2025	2035	2045
	Phase-I	Phase-II	Phase-III
Water Treatment Capacity to be Installed (m^3/d)	3523	5603	8111
Treatment Plant Capacity (m^3/hr)	200	200+200 = 400	400
No. of unit in Treatment Plant	1	1+1 = 2	2
Run time (hr)	18	14	21

In the recommended treatment plant, 200 m^3/hr capacity of individual unit has been suggested for implementation in Phase-I, which will be supplemented by another unit of same capacity (200 m^3/hr) in Phase-II to fulfill the water demand of Teknaf Pourashava and Sabrang TP. These two units together having a capacity of 400 m^3/hr will be capable to meet the demand in Phase-III.

6.5.1 Treatment Process

Considering the country context, particularly the level of operations and maintenance skill requirement by the local operator, the conventional unit processes have been selected for the surface water treatment plant at Teknaf Pourashava. The process flow diagram of the proposed treatment plant is shown in **Figure 6.12**.

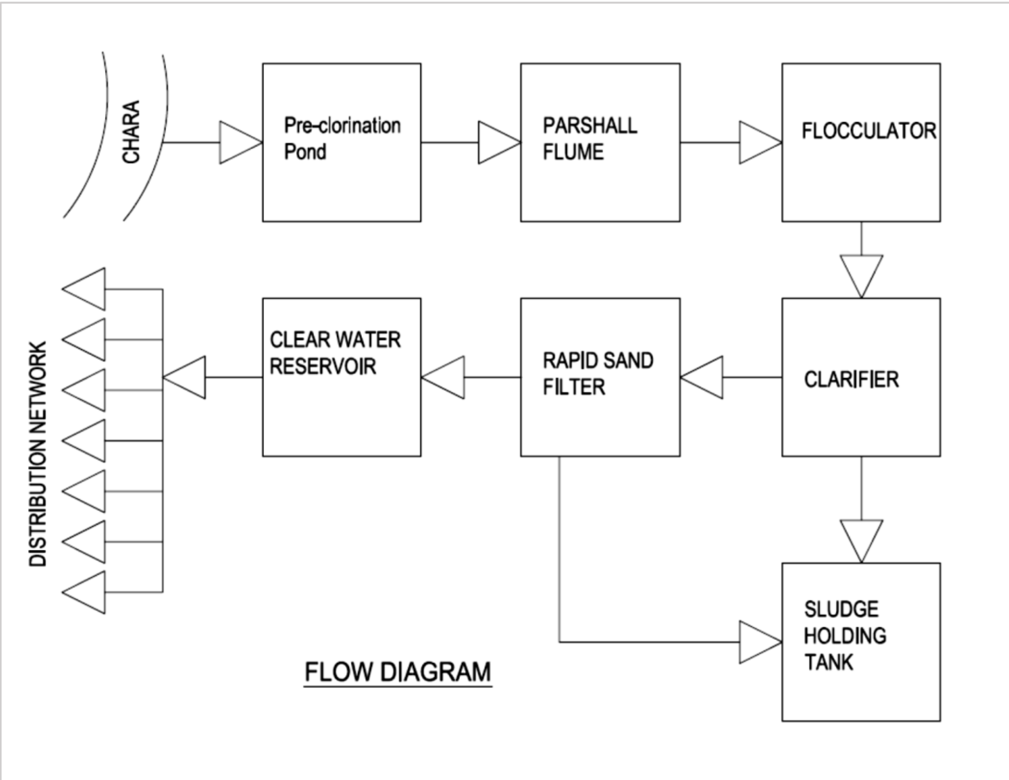


Figure 6.12: Process Flow Diagram of proposed Surface Water Treatment Plant

6.6 Water Transmission Main for Reservoir water distribution

The treated water transmission main from the treatment plant will be intersected with the groundwater transmission main from Whykhong well field and the network will carry combined water from the production wells in Whykhong and Teknaf surface water treatment plant water to Sabrang Tourism Park. The proposed treatment plant is situated beside the Cox's Bazar-Teknaf National Highway (N1) and the length is only about 50m. From the injected point to Sabrang Tourism Park the length of the transmission main is about 11 km (**Figure 6.13**).

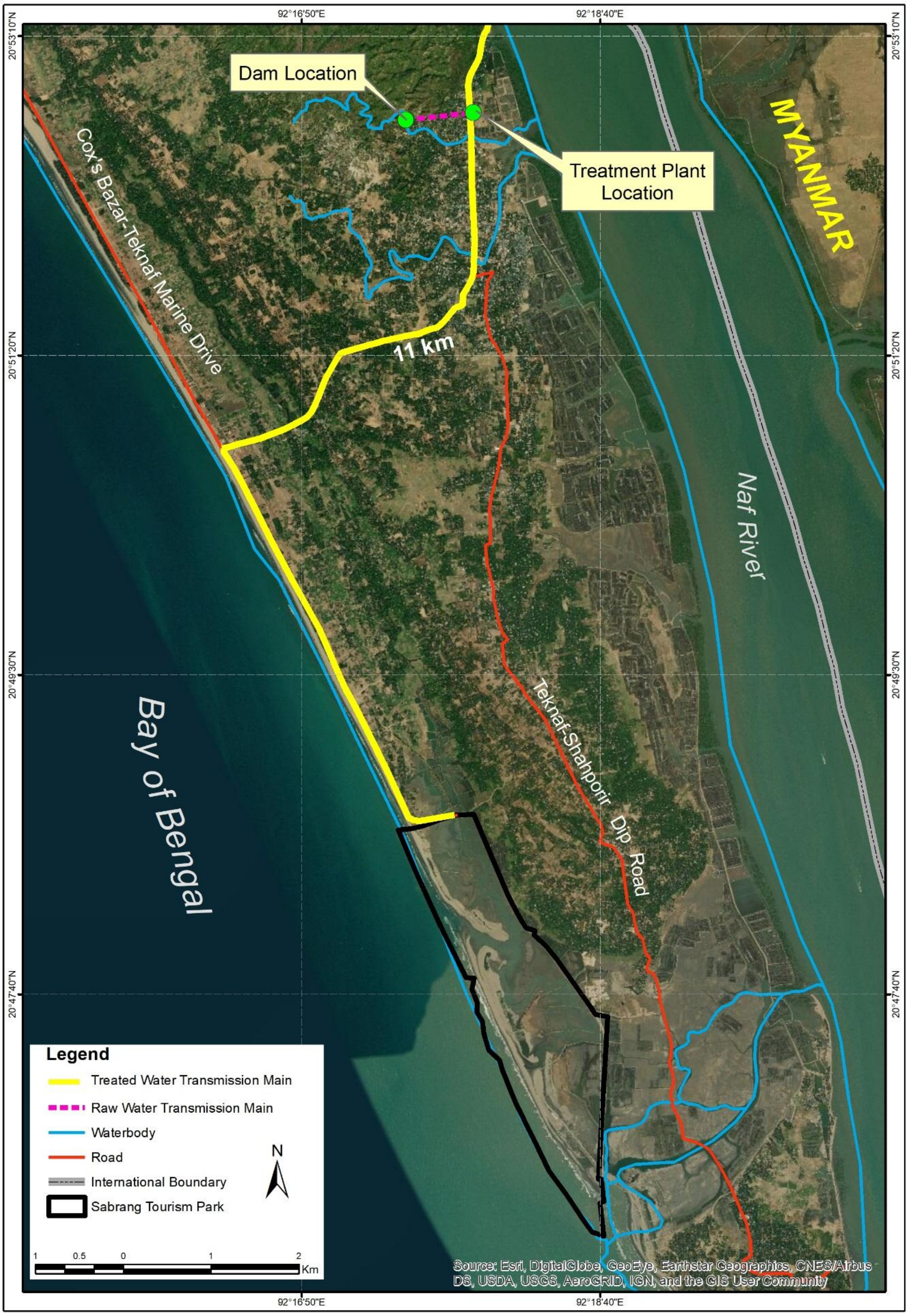


Figure 6.13: Proposed alignment of transmission main for Teknaf reservoir water distribution

7 WATER DESALINATION

7.1 Introduction

Desalination is a process of removing dissolved salts from saline water to produce freshwater for consumption. There are two major types of desalination technologies around the world, namely membrane desalination and thermal desalination. The former technology features the use of a special filter (membrane) to produce desalinated water, whereas the latter technology involves the boiling/evaporation of seawater to give off water vapor which, on condensation, yields salt-free liquid water.

Reverse osmosis ("RO") is a predominant form of membrane desalination. For thermal desalination, the most commonly adopted technologies are multi-stage flash evaporation ("MSF") and multi-effect distillation ("MED"). RO is currently the most widely used method for desalination. In 2012, it accounted for 63% of the desalination production capacity worldwide, followed by MSF (23%) and MED (8%).

7.2 Three Major Seawater Desalination Technologies

7.2.1 Reverse Osmosis

RO is a desalination process with the use of semi-permeable membranes which allow the passage of water molecules but not the dissolved salts. In RO process, seawater is firstly pre-treated to remove suspended solids. Sufficient pressure is then applied with the use of high pressure pumps to force water passing through the semi-permeable membranes, leaving the dissolved salts behind. Desalinated water then undergoes post-treatment, such as pH adjustment and disinfection, to make it suitable for drinking. The above process is depicted in **Figure 7.1**.

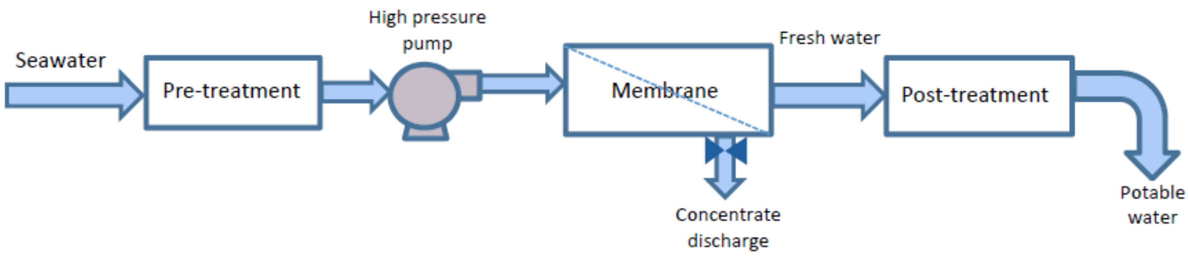


Figure 7.1: Basic process of reverse osmosis

7.2.2 Multi-stage Flash Evaporation

MSF is a type of thermal desalination which has already been in use since around 1960s. The first desalination plant in Hong Kong, which was built in the 1970s, adopted the MSF technology. MSF facilities consist of a number of chambers connected to one another, with each successive chamber operating at a progressively lower pressure. Source water/pre-treated water (i.e. feed water) first passes from back to front through a tubing system to the brine heater, where water is heated under a high pressure. The heated water then enters the first chamber at reduced pressure, causing it to boil rapidly with a portion evaporating into vapor (**Figure 7.2**). In each successive chamber which operates at a reducing pressure, the same process repeats. The vapor generated by evaporation is converted into freshwater by condensation.

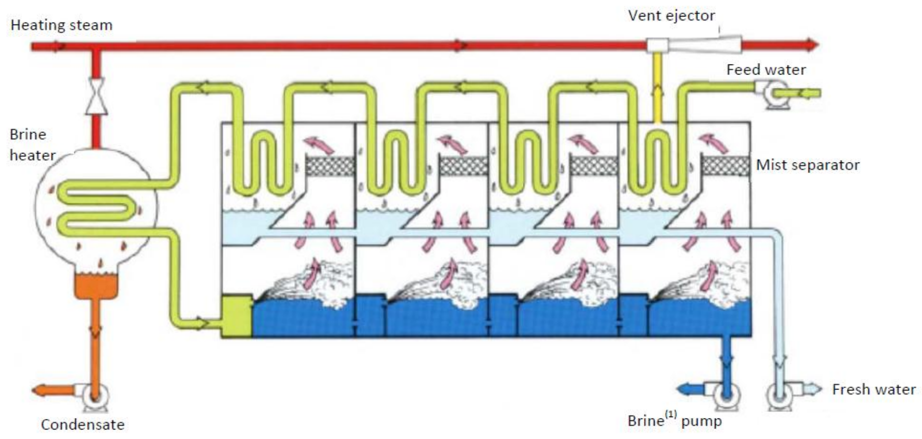


Figure 7.2: Basic Process of multi-stage flash evaporation

7.2.3 Multi-effect Distillation

Similar to MSF, MED is an evaporation process going through a series of chambers (also known as "effects"), with each successive chamber operating at a progressively lower pressure. Yet MED differs from MSF in that the vapor formed in one chamber condenses in the next chamber with the heat released acting as a heating source. In addition, feed water is sprayed over the tube bundle on top of each chamber in a typical MED process. As shown in **Figure 7.3**, external steam is introduced in the first chamber and feed water evaporates as it absorbs heat from the steam. The resulting vapor enters through the tube to the second chamber at a reduced pressure. The heat released by condensation causes the feed water in the second chamber to evaporate partly. The process repeats in the third chamber and so on. In each chamber, the vapor condensing into freshwater inside the tube is then pumped out

The efficiency of MED can be raised with the addition of a vapor thermo-compressor. As indicated in **Figure 7.3**, the thermo-compressor extracts part of the steam generated in the final chamber for recycling use. The extracted steam will be mixed with the external steam for compression under a high pressure, which then acts as a heating source in the first chamber.

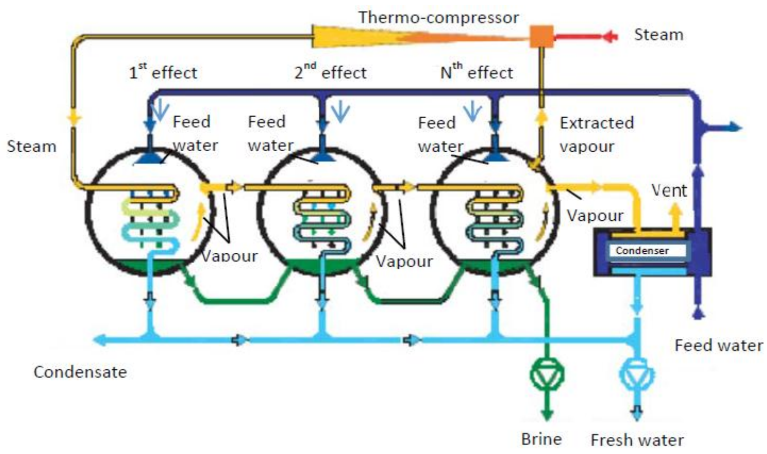


Figure 7.3: Basic Process of multi-effect distillation

7.3 Comparison of the Three Major Desalination Technologies

7.3.1 Reverse Osmosis

The RO technology has been increasingly adopted for seawater desalination during the past decade or so, attributable to its improved performance in terms of energy consumption and reliability. RO desalination generally consumes less energy than thermal desalination. In addition, its water recovery rate is relatively higher, as one tonne of desalinated water can be produced with an input of 2.5-3.2 tonnes of seawater.

However, RO membranes are typically made of cellulose acetate or other composite polymers, which are susceptible to fouling that may lead to shorter membrane lifetime and lower quality of desalinated water. Replacement of membrane is considered costly. In order to minimize fouling, thorough pre-treatment of seawater to remove particles and organic matter is required, which adds to the cost of freshwater production. Moreover, a higher level of skills is required for the operation of an RO facility.

7.3.2 Multi-stage Flash Evaporation

MSF is relatively simple to operate as it requires much less seawater pre-treatment and the level of skills required for plant operation is also lower. It has an added advantage of being capable of treating a large volume of water and producing high-purity water.

Nevertheless, MSF is very energy intensive and energy cost indeed accounts for the bulk of the plant operation cost. Since a considerable amount of thermal energy is needed, some desalination facilities are integrated with power plants to make use of their excess heat energy produced. Besides, water recovery rate of MSF is lower than the RO technology. Production of one tonne of desalinated water requires an input of about 8-10 tonnes of seawater.

7.3.3 Multi-effect Distillation

MED is the oldest water desalination technique. Like to MSF, MED requires minimum pre-treatment of seawater and can produce high-purity water. Yet it has a higher water recovery rate than MSF. About 5-8 tonnes of seawater are required to produce one tonne of desalinated water. However, MED compares unfavorably with the RO technology in terms of higher energy consumption and lower water recovery rate.

The strengths and weaknesses of the RO, MSF and MED technologies are summarized in **Table 7.1.**

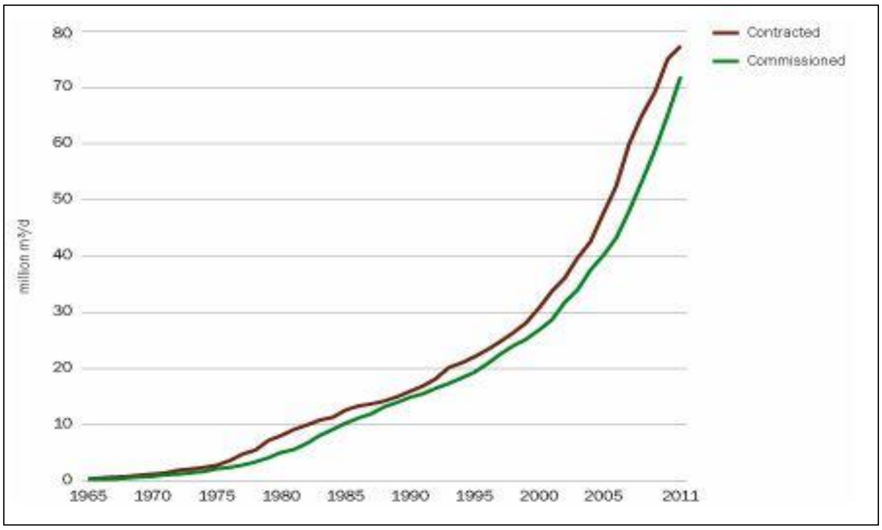
Table 7.1: Comparison of the three major desalination technologies

	RO (membrane-based-technology)	**MSF and MED (thermal-based- technology)**
Strengths	• Lower energy requirement • Higher water recovery	• Relatively simple to operate • Capable of producing high-purity water
Weakness	• Membrane susceptible to fouling	• Higher energy requirement • Lower water recovery

	RO (membrane-based-technology)	MSF and MED (thermal-based- technology)
	• Requirement for thorough seawater pre-treatment	

7.4 Global Desalination Industry

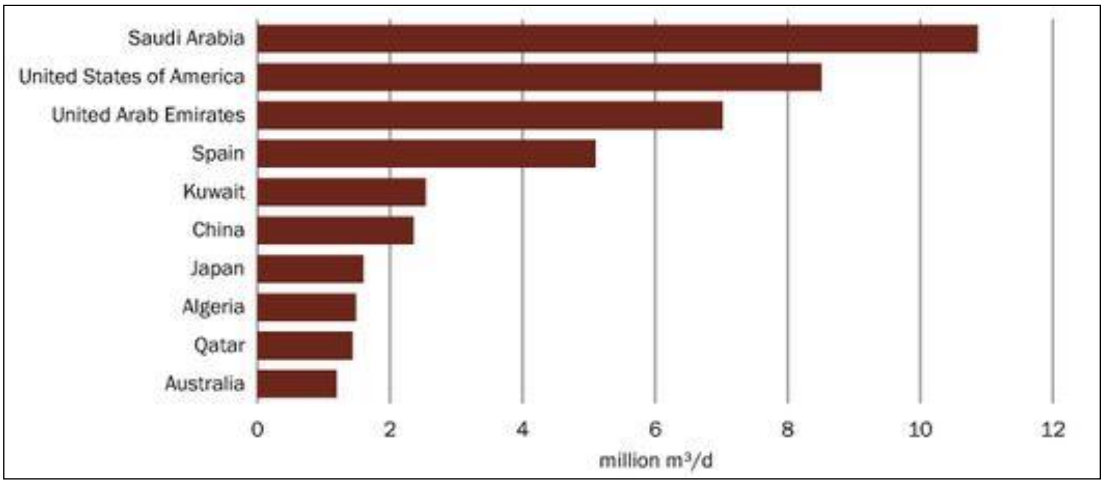
Freshwater is often talked about as being "the next gold", and for good reason. 97.5% of all water on Earth is saltwater, leaving only 2.5% as freshwater. 70% of that freshwater is frozen in the icecaps of Antarctica and Greenland and < 1% of the world's freshwater is accessible for direct human use. With agriculture being responsible for 87 % of the total water used globally, about one-third of the world's population lives in countries that are experiencing water stress. This begs the question, how can we turn saltwater into freshwater. The process of turning saltwater into freshwater is called "desalination" and over 18,500 desalination plants have now been built worldwide as shown in **Figure 7.4**.



Source: www.desalination.com

Figure 7.4: Cumulative contracted and commissioned desalination capacity from 1965-2011

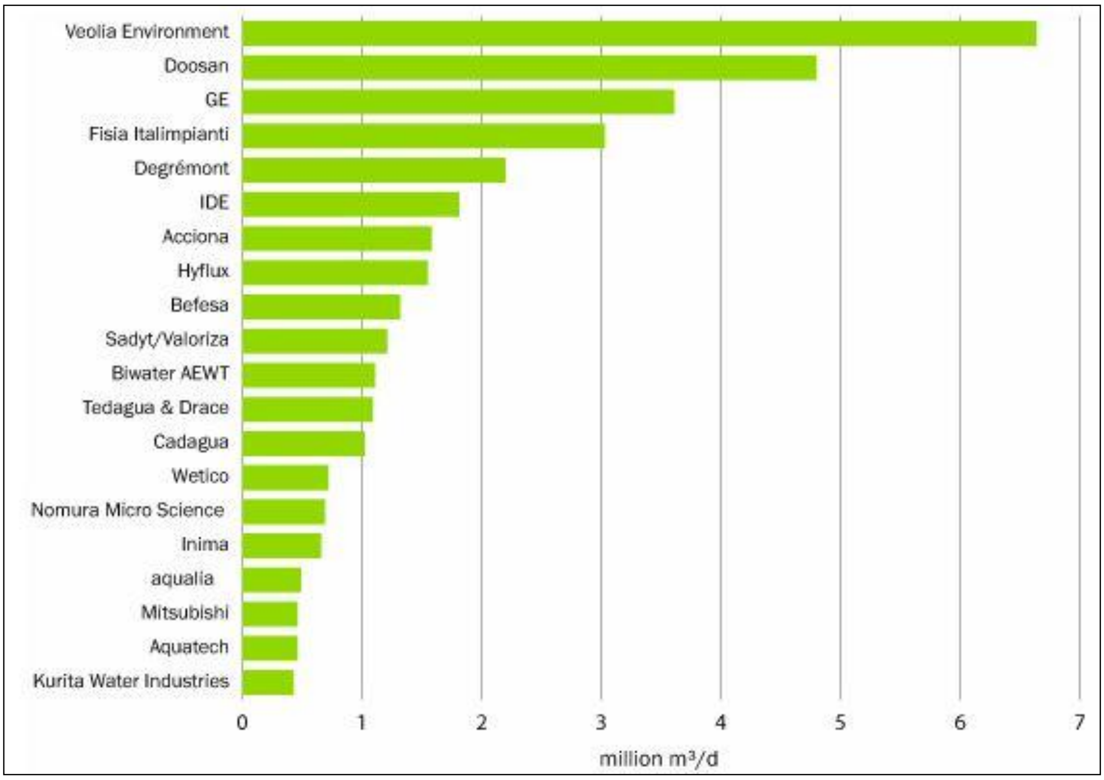
With such a huge number of desalination plants being built, the question is where `they are located. The below chart in **Figure 7.5** shows the distribution of desalination plants by country.



Source: www.desalination.com

Figure 7.5: Desalination plants in different countries

The chart in **Figure 7.6** shows the top engineering, procurement and construction contractors for desalination plants constructed from 2000-2011.



Source: www.desalination.com

Figure 7.6: Contractors to build desalination plants

7.4.1 Technology Trends

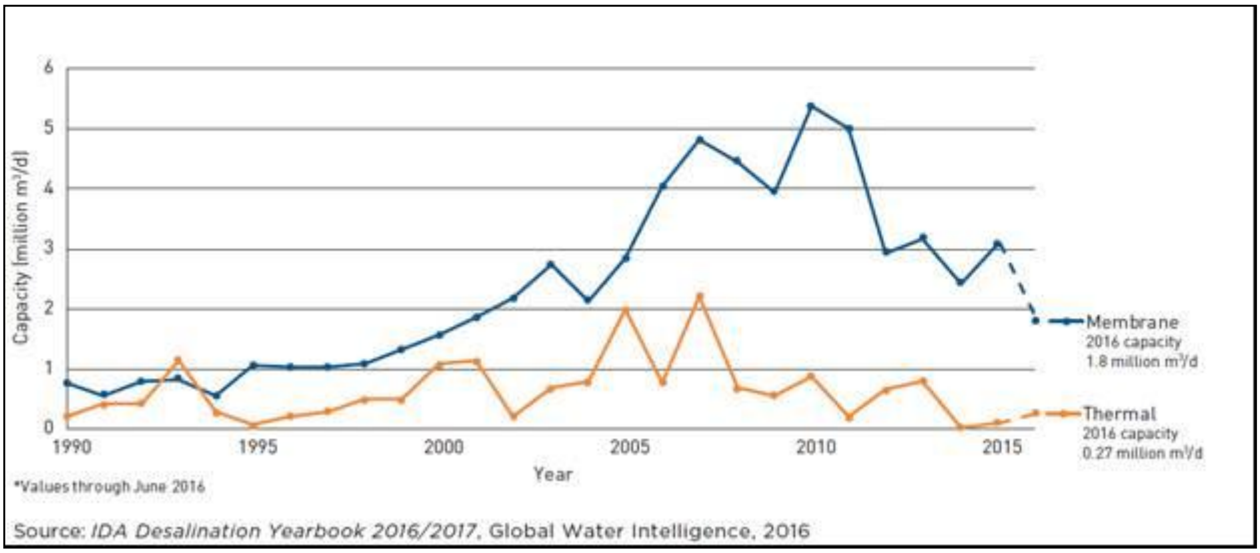


Figure 7.7: Technology trend of desalination plant

Energy costs account for the highest proportion in the overall desalination costs, mounting up to nearly 50%. On the plus side, technological innovation continues to bring down the overall desalination cost. The relatively less energy intensive technology at present is Reverse Osmosis

(RO) which is 30% lower than Multi-stage-flash (MSF) and 15% lower than Multi-effect Distillation (MED) technologies.

RO is more economically suitable for end-user applications such as high-temperature gas cooled nuclear plants, thermal power plants, chemical and petrochemical plants, and domestic municipal desalination plants when energy can be guaranteed but has potential problems of membrane blockages and needs periodic cleaning. MED is often applied in low-temperature nuclear plant, thermal power plant, steel and metal plants when heat is sufficient to support the distillation. A mixed combination of RO and MED desalination in power plants is another option when cooling, processing or even drinking water supply is needed for the specific project. This hybrid desalination technology is often adopted in centralized industrial parks.

7.4.2 Global Practice of Desalination Plant

Desalination Plant in India

The Minjur Desalination Plant is the largest desalination plant in India completed in 2010. It is in Chennai, India, on the coast of the Bay of Bengal and supplies water to the city of Chennai. Water from the plant is utilized mainly for industrial purposes. It also supplies water for public usage for an estimated population of 1,000,000. This RO plant produces 100 MLD of desalinated water from 273 MLD of sea water. The cost of this plant is 48.66 Indian Rupee (US$0.7) per m^3 of water.

Second largest RO plant, the Nemmeli water Desalination Plant is located at Nemmeli, Chennai, on the coast of the Bay of Bengal that supplies water to the city of Chennai and commissioned on February 2010. The capital cost of the plant is 5,333.8 million Indian rupee (US$ 78 million) with production capacity of 100 MLD. The production cost of treated water at the plant has been calculated as 30 Indian rupee (US$ 0.44) per m^3.

Another desalination plant with a capacity of 150 MLD at a cost of 10,000 million Indian rupee has been planned, which will come up on the 10.50 acre plot of vacant land near the existing plant.

Desalination Plant in Singapore

Singapore's National Water Agency PUB has construct two desalination plants with a combined capacity of 100 million gallons (455 MLD) that can meet up to 25% of Singapore's current water demand. Three more desalination plants would be completed by 2020. They have planned to meet up to 25% of Singapore's future water demand by 2060 through sea water desalination. The 1st Plant, SingSpring Desalination Plant was commissioned on September 2005 with capacity of 30 million gallons (137 MLD). The capital cost of this plant was US$ 300-400 million. The price of desalinated water in the first year of delivery was set at S$0.78 (US$ 0.57) per m^3. The 2nd Plant, Tuaspring Desalination Plant was constructed in 2011 having capacity of 70 million gallons (318 MLD). The price of this plant was set of S$0.45 (US$ 0.33) per m^3 in the first year of delivery.

In Singapore, seawater is processed into desalinated water which is then blended with treated water from the reservoir for distribution to homes and industries.

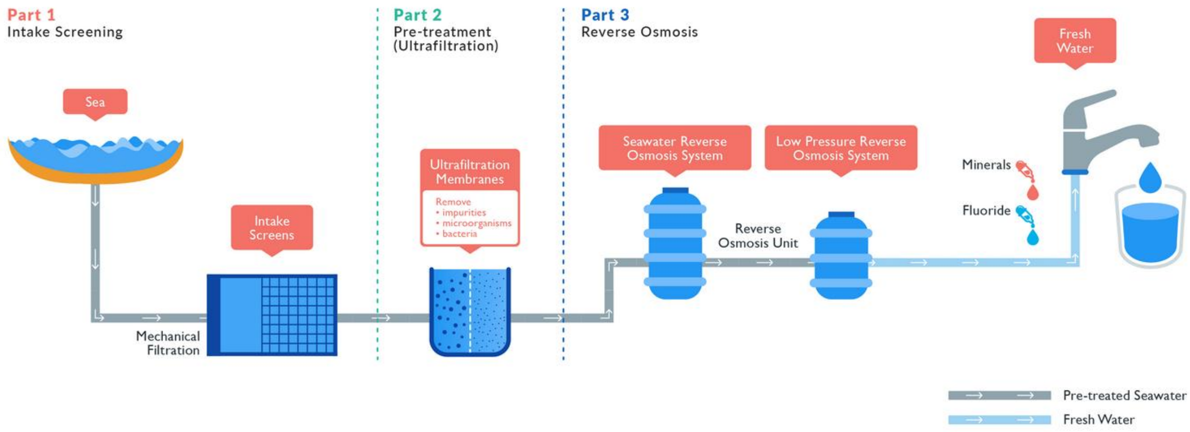


Figure 7.8: Flow diagram of Tuaspring Desalination Plant in Singapore

Desalination Plant in Israel

Currently, about 60% of Israel's domestic water demand is met through desalination – the process by which salt and other impurities are removed from seawater to produce potable water. By reverse osmosis technique seawater is forced through ultra-fine membranes that filter out larger salt molecules – was pioneered by Israeli scientist Sidney Loeb in the 1960s at Ben-Gurion University (BGU), which is located in the Negev, Israel's largest desert. There are three desalination plants in Sorek, Ashkelon and Hadera, along Israel's coastline. These plant produce 600 million cubic meters of potable water daily. The production cost of Sorek plant is only US$ 0.16 per m^3 and Israeli households pay about US$30 a month for their water supply.

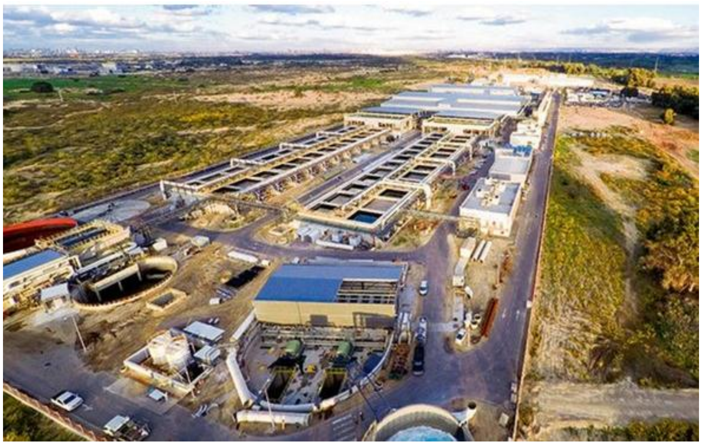


Figure 7.9: Sorek desalination plant in Israel

7.4.3 Factors Driving Desalination Industry

Medium to large scale desalination plants normally need large investment to support the technologies, engineering and construction involved. So far, privatization in the desalination plant market is in its developing stage with 70-80% of the projects financed by the industry end users or the government.

Build-operate-transfer (BOT) or Design-build-operate (DBO) modes of business are expected to become prevalent for desalination projects. Direct incentives or funds from the Govt. is needed to facilitate implementation of desalination projects. Financing is the biggest issue preventing many technology suppliers to tap into the desalination market opportunities.

It is estimated that for a 50,000 m^3/day desalination plant, the overall investment can be up to U$30 million or more, which is almost three to four times the cost of a water treatment plant with the same treatment capacity. Medium to small engineering or investment companies find it difficult to develop such projects due to a lack of financial muscle. This leaves only companies with strong financial support and experience in the desalination water business to step up and become significant contenders in this market.

Befesa and Aqualyng projects are good examples of innovative financing practice, taking advantage of the 'non-recourse' financing mode that relies 70-100% on local bank loan (Tsingtao Befesa Desalination Plant, 100,000 m^3/day, 2009; Caofeidian Desalination Plant, 50,000 m^3/day, 2010).

7.5 Major Impacts on Desalination Cost

Factors that have a direct and major impact on desalination cost include, but are not limited to, desalination technology, raw and product water quality, type of intake and outfall, the location of the plant or project, the type of energy recovery used, the price of electricity, post-treatment needs, storage, distribution, local infrastructure costs, and environmental regulations.

7.5.1 Desalination Technology

Almost 95% of the installed desalination capacity today is either thermal (35%) or membrane based (60%) technology (Ghaffour, et al., 2012). Each type of system varies considerably in footprint, materials of construction, equipment, pre-treatment requirements, power and steam requirements, amongst other differences. The technology selection will also determine the type of chemicals that will be used for pretreatment and post-treatment which impact operational costs.

7.5.2 Location

The site where a desalination facility is constructed can have a major impact on the overall costs of the project. The plant should be located as close as possible to the intake source to avoid higher costs for intake pipelines and complex intake structures. Optimal project siting will also reduce the concentrated brine discharge line back to the sea. Land acquisition cost is also a significant factor required for water transmission main. Careful considerations are recommended for items such as local soil conditions (may require new soil fill or structural concrete piles) and close proximity to a reliable power source to reduce the power transmission costs.

7.5.3 Raw Water Quality

The site-specific raw water quality can have a major impact on the number and type of pretreatment steps and the overall sizing of the desalination plant. The total dissolved solids (TDS) level and temperature of the source water directly impacts the operational costs, as higher operating pressures (RO) and temperatures (thermal) must typically increase as raw water salinity increases. Higher raw water salinity may also reduce the feasible product water recovery per gallon of raw water for both RO and thermal systems. Areas near small bays, gulfs or channels can have higher local salinity levels, higher total suspended solids, higher temperature variations, and higher organic loadings and biological activity compared to water in the open ocean. All these factors add design and construction complexity and, therefore, can significantly increase both CAPEX and OPEX costs.

7.5.4 Intake and Outfall

Important factors that need to be evaluated are intake type (submerged vs. open intake), the distance of the intake relative to the plant, type of intake screens, type of intake structure, the type of intake pipeline (buried vs. above ground), and environmental considerations with regards to impingement and entrainment of marine life. Each of these items has a significant cost impact. The cost of the intake system can vary from a low of \$0.13 million per thousand m^3/day (\$0.5 M million M per MGD) of capacity for an open intake to \$0.79 million per thousand m^3/day (\$3.00 million per MGD) for complex tunnel and offshore intakes (WRA, 2012).

7.5.5 Pretreatment

Pretreatment costs are impacted by the type and complexity of the pretreatment system. The type of pretreatment required depends on the raw water quality at the project site. Some raw seawater or brackish surface water sources have a high level of organics and biological activity and require more robust pretreatment technologies, such as DAF (Dissolved Air Flotation) and UF (Ultrafiltration). Other raw water sources that use submerged intakes or well-based intakes may require less pretreatment, such as a single-step media filtration or MF (Microfiltration).

According to an article by the Water Reuse Association entitled “Seawater Desalination Costs,” pretreatment costs will typically range from \$0.13MM to \$0.40MM per thousand m^3/day (\$0.5 million to \$1.5 million per MGD). At the lower end of this range, conventional single-stage media filtration systems are adequate. Pretreatment costs increase as additional pretreatment steps are added, such as two-stages of media filters or media filtration followed by MF or UF systems.

7.5.6 Energy Recovery

RO systems use high-pressure pumps to overcome the osmotic pressure of the raw feed water. For example, some sea water reverse osmosis (SWRO) plants can require up to 70 bar (1000 psig) feed pressures. The RO concentrate brine stream from this process contains pressure energy that can be recovered in order to reduce the overall RO system energy requirements. Energy recovery technologies reduce the overall energy input, thereby reducing operating expenditures.

7.5.7 Electric Power

Local energy prices, transmission distance, connection fees, and possibly tariffs at the proposed location of the desalination facility play an important role in determining the supply price for connected power. For very large thermal desalination plants, consideration of co-locating the facility with a power plant may be promising due to the inherent advantages of such a combination.

7.5.8 Post-treatment

Final product water quality will determine the specific type of post-treatment that is required. A second RO pass may be required to achieve very low TDS levels or reduce the concentrations of specific ions, such as boron or chloride, to acceptable levels can be an expensive option. A two-pass RO system will typically be 15 % to 30 % more costly than a single pass RO system (WRA, 2012).

Also, stabilization of the product water typically requires a pH adjustment and the addition of bicarbonate alkalinity, which can be done using a combination of carbon dioxide, lime and/or sodium hydroxide and, again, this adds additional cost.

For desalination plants located on a coast in close proximity to the communities using the water, land is usually priced at a premium. The cost of locating a facility closer to the point of use and a suitable power source should be weighed against the costs associated with additional intake and discharge pipeline right of ways, pipeline costs, materials transport, permits, labor and maintenance associated with moving a plant farther away from the coast or distribution service area (WRA, 2012).

7.5.9 Local Infrastructure Costs

Infrastructure costs include items such as earthworks, concrete, steel, structures, drainage, and building materials. Depending on the location of the plant, the costs for each of these items can vary significantly. Remote plant locations that are located far from industrial cities will typically have to incur higher construction costs vs. plants that are constructed near concrete-producing facilities and industrial zones that have an ample supply of building materials.

7.5.10 Environmental Regulations

Each geographic region will have its own set of environmental rules and regulations, and these can also vary from state to state within a single country. For example, permitting costs for projects in California are almost four times the typical permitting costs in Florida (WRA, 2012). California has more stringent regulations and/or guidelines for potable water production compared to those in Texas or Florida, which adds regulatory cost to a desalination project. Longer environmental review periods can also lengthen the project schedule, which typically results in higher project costs as well.

7.6 Cost Components of a Desalination Plant

7.6.1 CAPEX

CAPEX is subdivided into the two major categories of direct and indirect costs. Direct costs include equipment, buildings and other structures, pipelines, and site development, and are typically in the range of 50% to 85% of the total CAPEX. The remaining indirect costs include financing interest and fees, engineering, legal and administrative costs, and contingencies (Ghaffour, et al., 2012). The typical CAPEX cost and components for most desalination plants can be further divided into nine parts, as follows: intake and raw water conveyance; pretreatment; desal treatment; post-treatment; product water pumping and storage; electrical and instrumentation system; plant buildings, site and civil works and balance of plant; brine discharge and solids handling; and miscellaneous engineering and development costs. Other costs, such as financing fees and other commercial related fees, also have to be considered. **Figure 7.10** shows one example of a CAPEX cost breakdown for an SWRO plant.

CAPEX, to a significant extent, depends on scale with larger desalination plants costing less per million gallons of installed capacity. Based on **Figure 7.11**, a medium size 10 MGD SWRO plant would cost about $80 million to build and a large plant, such as the 35 MGD Carlsbad SWRO plant near San Diego, would be expected to cost $250 million. Note: Due to environmental, permitting and construction issues, that plant ended up costing much more.

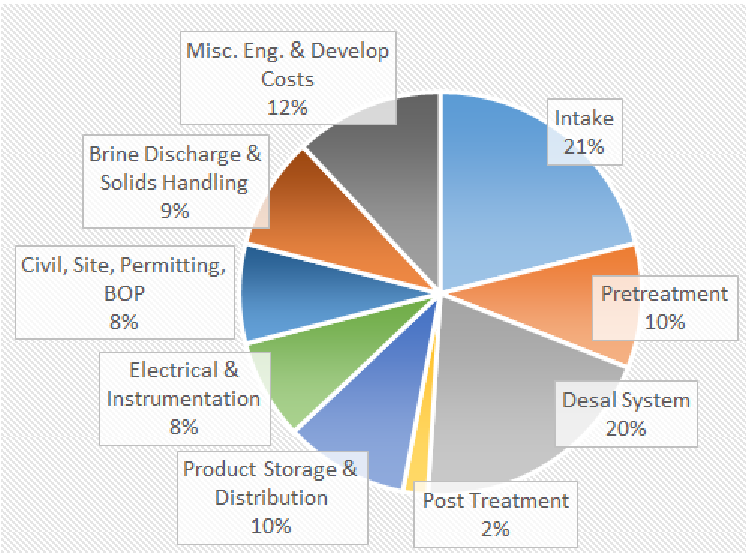


Figure 7.10: Typical SWRO desalination plant CAPEX breakdown

Figure 7.11: Unit construction cost vs. capacity for SWRO plants

7.6.2 OPEX

Operating costs (OPEX) generally fall into two broad categories: fixed costs (such as labor, administrative, equipment and membrane replacement costs, and property fees/taxes [as applicable to the locality], etc.) and variable costs (such as power, chemicals, and other consumables. (Arroyo, et al., 2012). The typical OPEX cost and components for most desalination plants can be further subdivided into nine parts comprising of the followings: power consumption, consumables, solid waste, chemicals, labor, maintenance, equipment warranty, balance of plant & utilities, and other fixed costs (administration, spares, contingency, etc.), as shown in **Figure 7.12**.

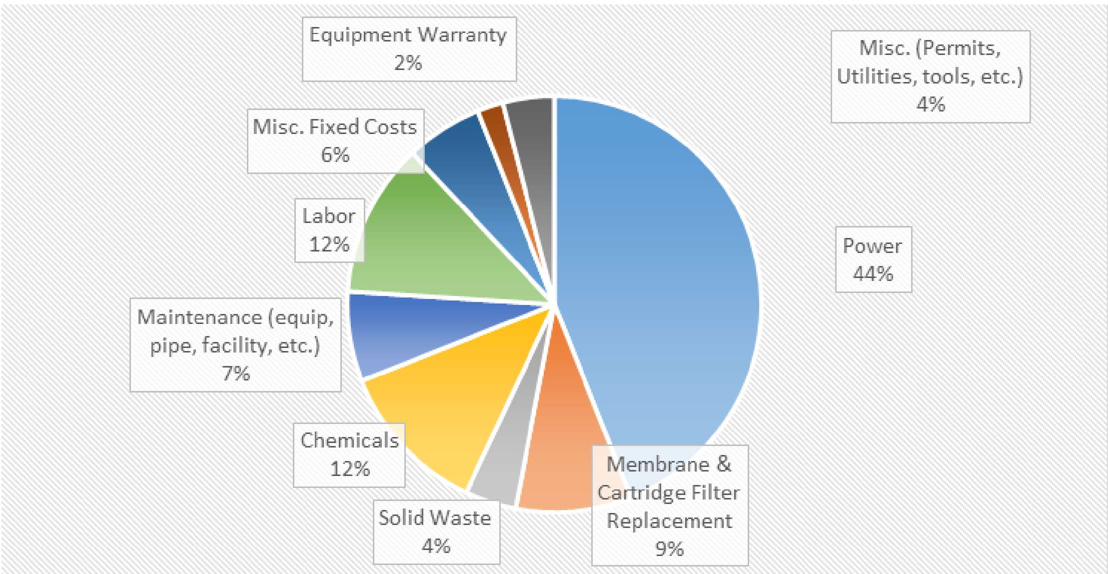


Figure 7.12: Typical SWRO desalination plant OPEX breakdown

[Source: Advisian]

7.6.3 Total Cost to Desalinate Water

Life cycle cost, also called unit production cost or annualized cost, is the cost of producing a thousand gallons or cubic meter of water by desalination and considers all CAPEX (including debt servicing) and OPEX and may be adjusted by a predicted or actual plant operating factor. Because of all the variables involved, these annualized costs can be very complex, and unit production cost differences among projects may not be directly comparable. At best, predicting future costs using past plant cost information will typically only result in ballpark estimates.

Figure 7.13 shows that annualized costs for various types of completed RO projects have varied widely. The average costs, represented by the best fit line in the data shown, are about $0.70/m^3 ($2.65 per thousand gallons) for very large plants (325,000 m^3/day) and rise to $1.25/m^3 ($4.75 per thousand gallons) for small plants (10,000 m^3/day).

However, costs can range as high as $3.20/m^3 for very small capacity plants (less than 4,000 m^3/day or 1 MGD) that have costly site-specific intake, discharge, and conveyance peculiarities. Removing the effects of intake, discharge, and conveyance reduces and narrows the annualized cost range to $0.53/m^3 to $1.58/m^3 ($2.00 to $6.00 per thousand gallons) for SWRO plants and $0.11 to $1.10/m^3 ($0.40 to $4.00 per thousand gallons) for brackish water RO plants (WRA, 2012).

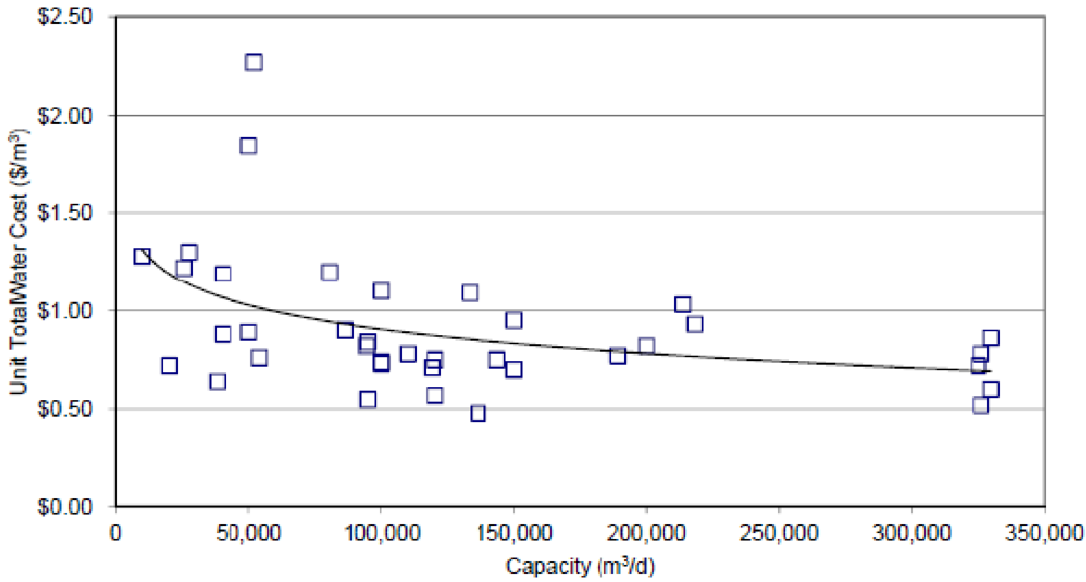


Figure 7.13: RO plant unit production cost vs. project capacity

[Source: Ludwig, H., 2010]

Figure 17.14 shows a typical life cycle cost comparison of MSF, MED, and SWRO to produce one cubic meter (264 gallons) of water per day. As shown, MSF and MED, which are thermal desalination technologies, require steam (thermal energy) in addition to electrical energy, which is the main reason why they have higher total water life cycle costs compared to SWRO.

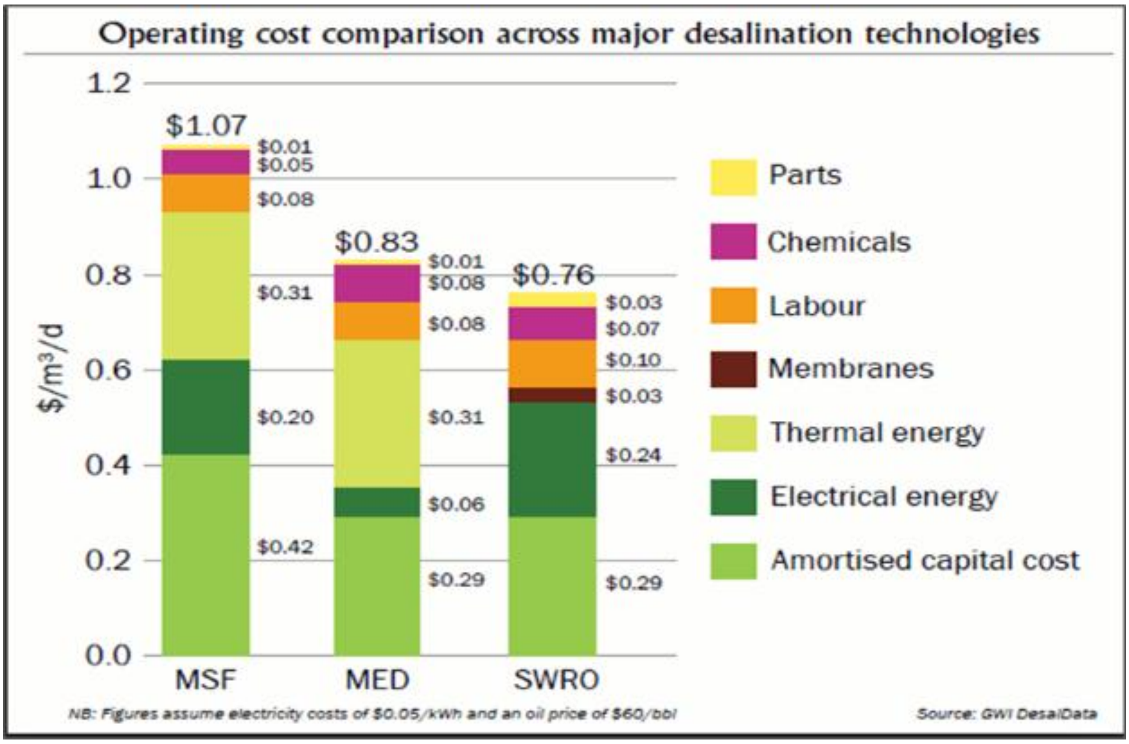


Figure 7.14: Unit production cost of water for desalination technologies

[Source: Instituto Murciano (2012)]

7.7 Financing Consideration

With the increase of the water demand and the need for more desalination plants, the public sector has been seeking the help of the private sector in order to develop large infrastructure projects in order to relieve the financing burden of the government. Private finance initiatives foresee the financing of infrastructure projects with an upfront spend element in a way that removes recourse by the lenders to the Sponsors (non-recourse financing) or limits such recourse (limited recourse financing). In such projects the sole security of the lenders is the revenue stream and assets of the project. Project financing initiative are generally deals with structured to move liabilities from the Sponsor's balance sheet and contain the risk in the project vehicle company.

Private finance initiative is an alternative method of raising finance for capital projects such as power and desalination without adding to the national debt. The public sector acquires services cost-effectively through a competitive process rather than directly owning and operating assets. The private sector is invited to put together consortia that bid to provide a specified power and water outcome through a process of negotiation.

The public sector then pays for the delivery of the water by the private sector partner, rather than procuring power and desalination assets that are used to provide that service. In financial terms, shifting from a publicly funded capital scheme to a publicly funded revenue scheme.

The introduction of privatization in the desalination business has greatly contributed to generate lower desalination costs and introduce new technology innovation in the sector. The project finance model tends to generate lower CAPEX and OPEX costs due to a more market service oriented basis and despite (as it can be seen from the **Figure 7.15**) the financing costs tend to be marginally higher, the general effect is a reduction of OPEX and CPEX that is capable of generating a lower final water/power tariff.

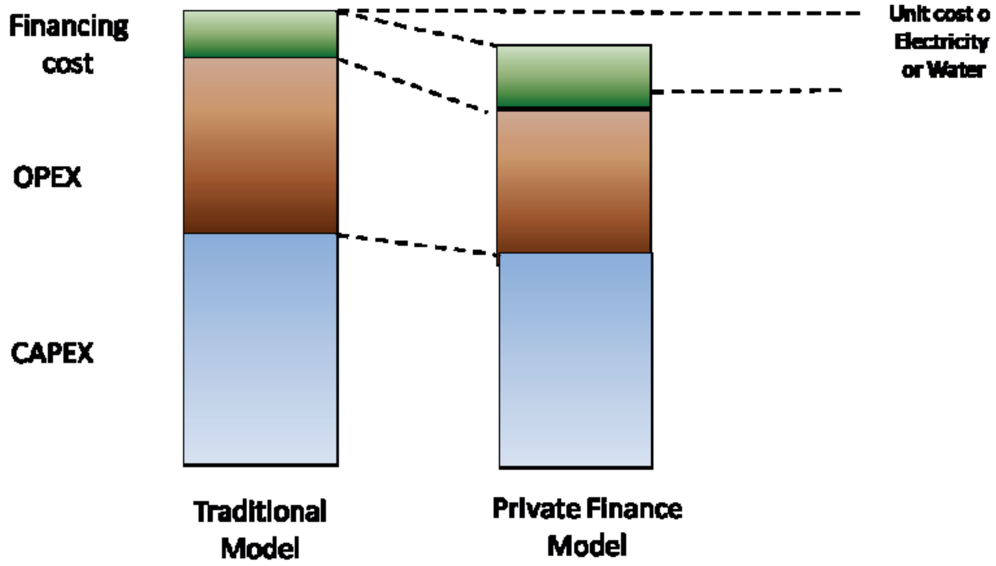


Figure 7.15: Comparison of CAPEX and OPEX between traditional and private finance project

Private finance initiative is an alternate method of raising finance for capital projects without adding to the national debt. In a Private Finance Initiative project, private sector consortium establishes a company, a Special Purpose Vehicle (SPV) which then raises the finance necessary via the means available to all private sector companies such as the issue of risk capital (shares), borrowing, etc. The public service body then pays for the delivery of service via an agreed payment mechanism relating to volume, quality and performance.

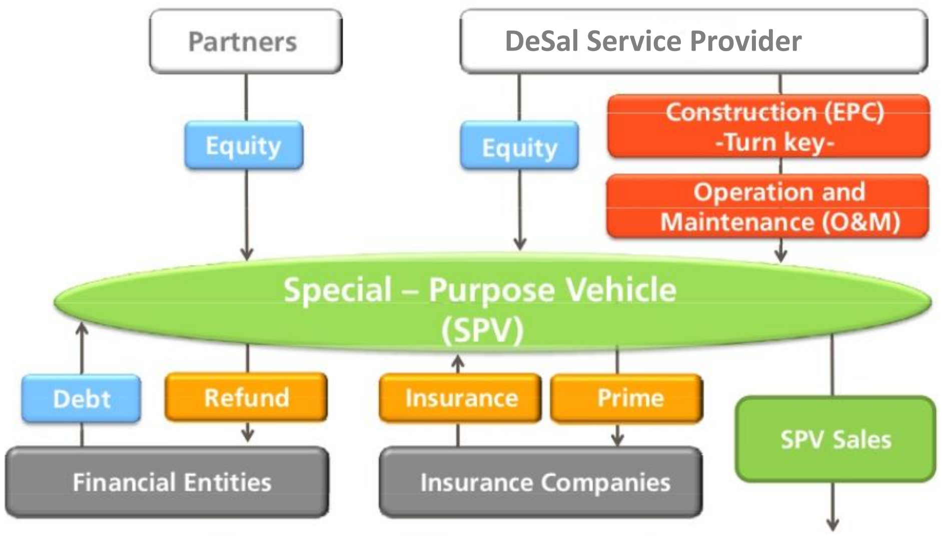


Figure 7.16: Financing of a BOOT project

7.8 Consideration for Naf & Sabrang Tourism Park

With current technology trend a sea water reverse osmosis (SWRO) plant would be suitable among the three types of desalination technologies. This is because relatively less energy intensive technology at present is Reverse Osmosis (RO) which is 30% lower than Multi-stage-flash (MSF) and 15% lower than Multi-effect Distillation (MED) technologies.

The performance of SWRO depends heavily on the quality of the seawater at the intake location. It is recommended to remove the pollutants present in feed water. Hence, before entering the SWRO unit, raw sea water is required to be pretreated suitably. The following treatment scheme can be considered.

- Intake & Outfall System, Intake Basin & Intake Pumps
- Tube Settler, Dual Media Filtration
- Ultra-Filtrations (UF), Nutrient Removal Filter
- Sea Water Reverse Osmosis (SWRO)
- Brackish Water Reverse Osmosis (BWRO)
- Product Water Collection and Transfer System
- Wastewater Collection and Transfer System

Several buildings will be required to house the treatment plant. These can be UF building, SWRO/BWRO building, Electrical & Control building and Chemical building. Approximately 15 acres of land may be required for the plant. Power is a major requirement to run a desalination treatment plant. The approximate power requirement for a 50 MLD plant can be 200 MWh/day. The cost associated with power supply, civil works, land purchase and all necessary permits/approvals/clearance certificates are typically considered separate from the actual costs for plant installation and commissioning.

Based on similar project and assessment of current study approximate treatment unit costs can be assumed for the 1 MLD to 5 MLD desaliation plant as shown in **Table 7.2**.

Table 7.2: Approximate cost of desaliation plant

Item	1 MLD desaliation plant	3 MLD desaliation plant	5 MLD desaliation plant
Capital Cost	$1.5 million	$4.5 million	$7 million
Operating Cost	0.15 million/yr	0.4 million/yr	0.55 million/yr
Cost of Water	60-70 BDT/m^3	60-70 BDT/m^3	60-70 BDT/m^3

If traditional financing is not availabe for the project, a Concessions or BOOT financing can be considered as an alternative. Typically these contracts are 25 year long. In Bangladesh RAJUK has taken up a BOOT project for the water supply of Purbachol City. This will require creation of Special Purpose Vehicle (SPV) to raise fund and to manage the development work. The client has to ensure 'Guarantee of sale' or 'Payment Security' for the service provider in this type of financing process.

7.9 Challenge of Desalination Plant in Naf & Sabrang Tourism Park

Cost of desalination cost: CAPEX and OPEX of desalination plant is higher than surface water and groundwater treatment technologies. Moreover, CAPEX mainly depends on the technology used for desalination plant and financial & administrational factors. OPEX mainly depends on work force, membrane and chemical and power cost. The detailed cost factors are describe in Sec. 7.5 and 7.6.

High energy: Sea water reverse osmosis (SWRO) plant requires continuous and high energy for its operation. In most systems, electrical energy is about 35% to 40% of total operating costs. Energy recovery devices (ERDs) can reduce energy consumption by as much as 60%. Use of renewable enengy also is an alternative for continuous supply of energy.

Changing Seawater Conditions: Some natural phenomenon is difficult to predict, such as the occurrence of harmful algal bloom in the coasts can cause irreversible damages to the reverse osmosis membranes surface affecting the operation of desalination plants. Moreover, algal bloom events can cause health problems to the population since they could change the physical, chemical and biological characteristics of water organisms. Several technologies can be used as pretreatment systems in desalination plants to reduce the organic load present in seawater during an algal bloom event, such as sedimentation, dissolved air flotation, granular media filtration, and ultrafiltration membranes. Another alternative to face the algal bloom problem is to install subsurface intake systems that improve the quality of feed water. To face the natural harmful phenomenon adequate strategies should be put in place at an operational level, but it may require a large capital expense for the installation of the alternatives.

Brine Disposal: Discharging RO brine (the concentrate left after desalinating water) into ocean environments can have negative ecosystem impacts due to its high density. The contaminants can be carried to the ocean floor where benthic organisms may be harmed because there is minimal wave propagation for mixing and dilution. Brine disposal cannot be discharged into municipal sewers or surface water bodies and may require dilution and/or diffusers prior to/during the discharge of RO brine to the ocean.

Membrane Fouling: Material slowly accumulates on membranes during operation, such as organic material fouling the feed water, biofilms, and inorganic solutes. The overall effect is a reduction of permeability, which is usually offset by slightly raising pressure to maintain water production. This adds to the energy consumption and cost of water over the full life of the plant. Although membrane cleaning is routine, it takes the plant offline and produces liquid waste to be disposed.

Protecting Marine Life: Harm to marine organisms by seawater intake systems is a major environmental concern. Subsurface intakes can be used to mitigate the effects of intake systems on aquatic communities.

8 BOTTLING WATER PLANT

8.1 Introduction

Bottling water plant can be a potential option to supply water for drinking purpose only. Bottling water plant can be installed in Sabrang Tourism Park beside the desalination plant to produce mineral water. The latest technology for bottling plant is reverse osmosis technology with ultraviolet and ozonize and automatic water filling and packing system (**Figure 8.1**).

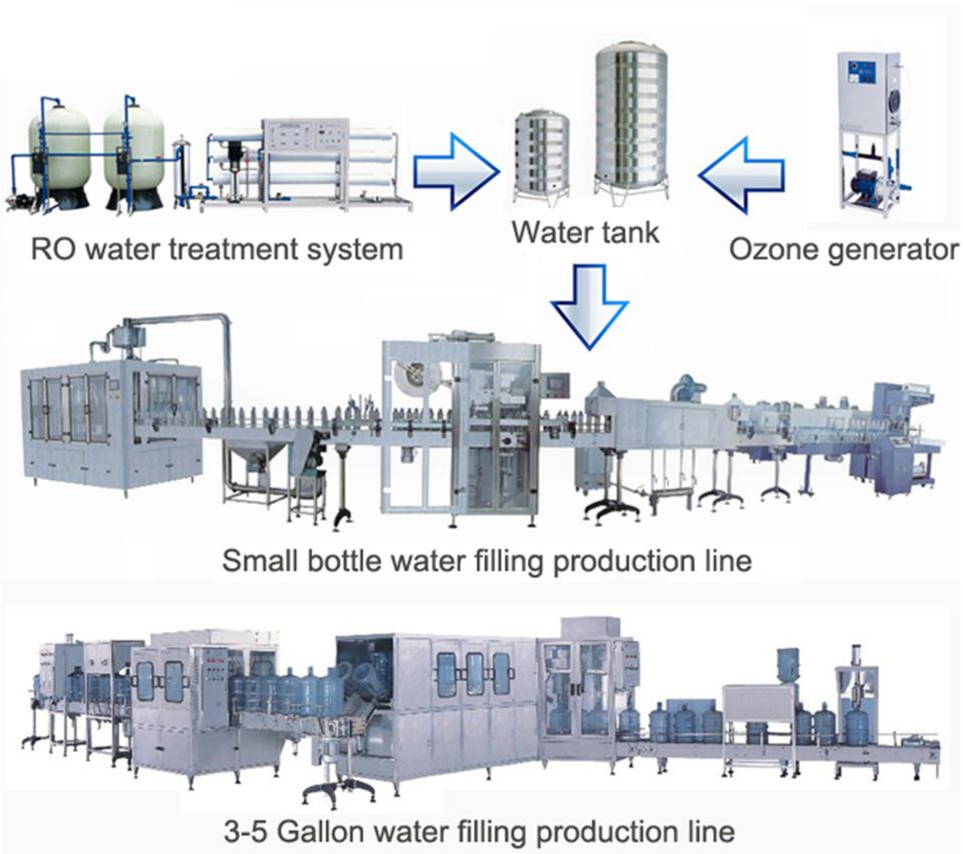


Figure 8.1: Bolting water production system

8.2 Technical Equipment

The different equipment for the bottling plant is presented in **Table 8.1**.

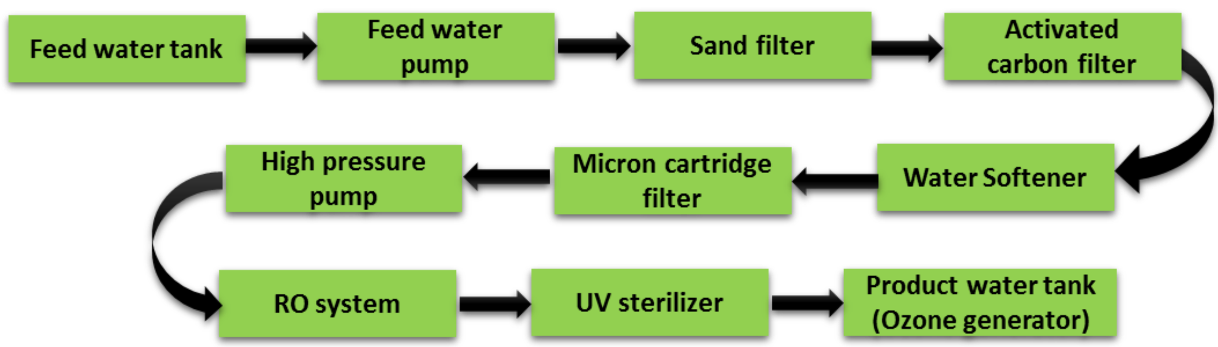
Table 8.1: Different equipment for the bottling plant

Item	Equipment name
Bottle blowing machine	Main machine Preform feeder
	High Air Compressor
	Low Air Compressor
	Air Tank
	HP Air Cooling Dryer
	Air filter
	Water Chiller

Item	Equipment name
	Connector & pipes
	Spare Parts
	Mould 500ml & 1000 ml
	Feed water tank
Pure water treatment system	Raw water pump
	Sand filter
	Activated carbon filter
	Water softener and brine tank
	Precision Filter
	RO System
	UV sterilization
	Ozone Generator
Semiautomatic Bottle Unscrambler	Semiautomatic Bottle Unscrambler
3 In1 High Speed Water Filling Machine	Air Conveyor
	3In1 Washing-Filling-Capping Machine
	Bottle Caps Au toloader
	Changing Parts for 1L PET Bottles
Auxiliary Packing Machines	Lamp Checker
	Automatic Sleeve Labeling Machine
	Inkjet Printer
	Automatic Shrink Film Wrapping Machine
	Belt Conveyor

8.2.1 Pure Water Treatment System

This system is mainly used for getting PURE water and pre-treatment water for all kinds of beverage and drinking water. It can effectively get the rid of suspended mattes, smell and color in raw water source ,also filter substance such as organics, microorganism ,chloride, colloidal particles ,and residual chlorine. Some equipment's of water treatment system is presented **in Figure 8.2** and the process flow diagram of pure water treatment system is shown below:




Raw water tank


Pretreatment filters


Precision Filter


RO system


UV Sterilizer


Ozone generator

Figure 8.2: Some equipment's of water treatment system

8.2.2 Semiautomatic Bottle Unscrambler

Semi-automatic Bottle Unscramblers (**Figure 8.3**) effectively automate packaging production lines affording increased efficiency and productivity.

Figure 8.3: Semi-automatic Bottle Unscrambler

8.2.3 High Speed Water Filling Machine

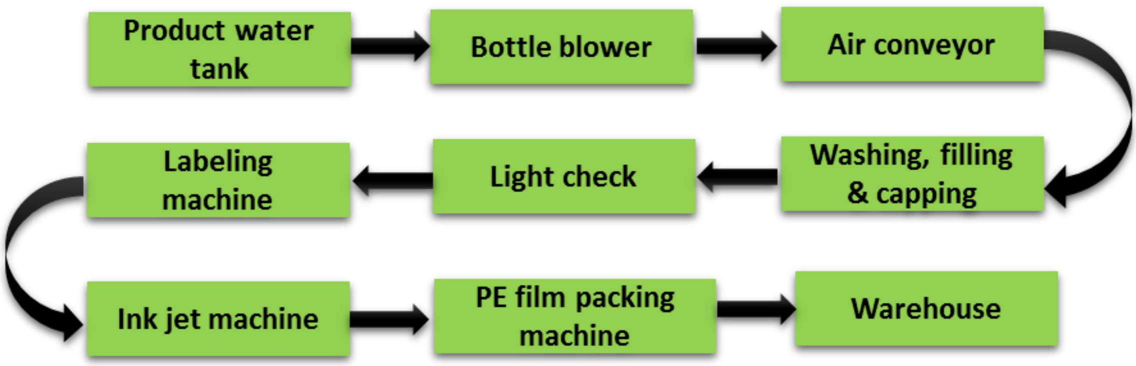
Drinking water filling machine integrates bottle washing, water filling and capping into one monobloc, and the three processes are carried out full automatically (**Figure 8.4**). It is used in the filling of mineral water, pure water, and other non-carbonated beverage. Each machine element that contacts with the liquid is made of high quality stainless steel. The critical components are made by numerically-controlled machine tool, and the whole machine condition is under detection by photoelectric sensor, no bottle no filling, no bottle no capping. It is with advantages of high automation, easy operation, good abrasive resistance, high stability, low failure rate, etc.

Figure 8.4: 3in 1 High Speed Water Filling Machine

8.2.4 Auxiliary Packing Machines

This is a fully automatic machine which can be easily operated. Some auxiliary packing machines are presented in **Figure 8.5**.

The process flow diagram of water filling and packing system is shown below:



Automatic Sleeve Labeling Machine

Inkjet Printer

Automatic Shrink Film Wrapping Machine

Belt Conveyor

Figure 8.5: Auxiliary Packing Machines

8.3 Cost Components of a Bottling Plant

Bottling plant cost components include the following items:

Table 8.2: Bottling plant cost components

Sl. No.	Item	Description
1	Mechanical and equipment	Water treatment system
		Bottling machineries
		Laboratory
2	Civil construction	Factory shed/building
		Interior furniture
		Outer fencing
3	Utilities	Compressor, DG set, cooling tower, AC etc.
4	MEP	Mechanical, electrical and plumbing works
5	Office furniture and software	Computer, networking, management and monitoring system software
6	Legal and consultancy cost	License, renewal, consultancy charges, Annual Maintenance Changes etc.
7	Financial costs	financing fees and other commercial related fees
8	Operational costs	Labor and administrative cost
		equipment and membrane replacement costs
		Power, chemicals, and other consumables

8.4 Consideration for the Tourism Parks

In Sabrang Tourism Park total drinking water requirement is 81,000 liter/day and in Naf Tourism Park is 9,800 liter/day after full development in 2049. To meet the drinking water requirement of Sabrang and Naf Tourism Park, bottling water plant can be installed in Sabrang Tourism Park where the treated water from desalination plant can be used as feed water for bolting water plant.

Several buildings will be required for the factory shed, ware house, office block and officers/staff quarters. Approximately 2 acres of land may be required for the plant. Power is one of the major requirement to run a bottling water plant. The approximate power requirement may be 330volt/60Hz.

9 WATER MANAGEMENT PLAN

9.1 Phasing of Plan

Six and three development phases for Sabrang Tourism Park and Naf Tourism Park has been proposed in its Detailed Master Plan (Draft Final Report). In order to be consistent with the Master Plan, water supply system development plan is divided into six phases, each comprising 5-year period as shown in **Table 9.1**.

Table 9.1: Phasing of water supply system development plan

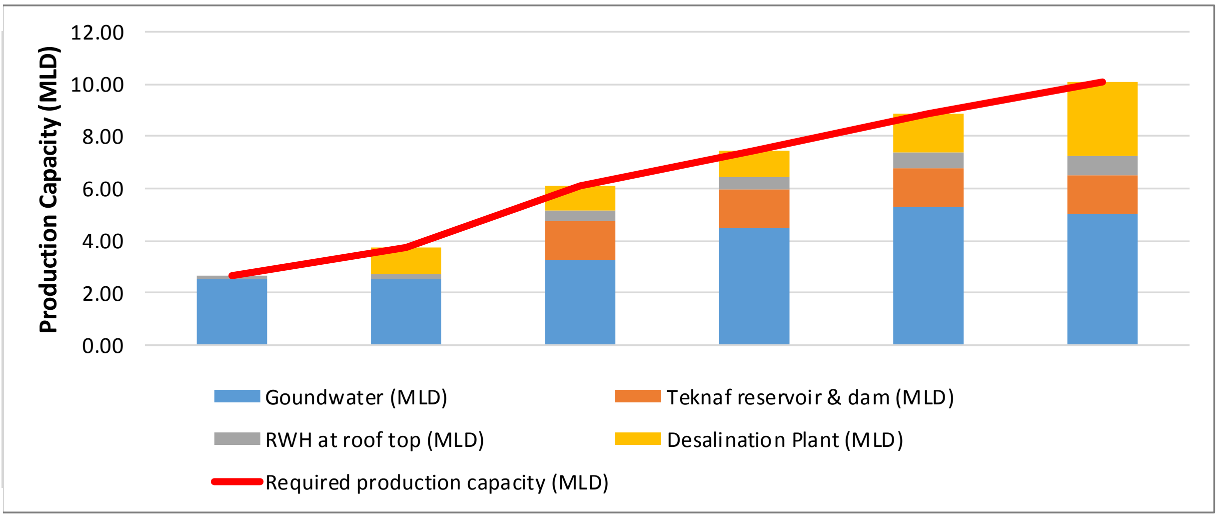
Phase	Period
Phase-1	2020-2024
Phase-2	2025-2029
Phase-3	2030-2034
Phase-4	2035-2039
Phase-5	2040-2044
Phase-6	2045-2049

9.2 Tentative Water Management Plan for Sabrang Tourism Park

The water demand in Sabrang Tourism Park has been estimated based on the total number of tourist and work force required to run the public facilities, utilities, administrations and transportations etc. as mentioned in the Master Plan. The total production capacity required, however, considers physical loss or leakage from the water transmission and distribution pipelines and appurtenances. The estimated total required production capacity will be 10.09 MLD after the completion of full development in 2049. Following different water sources has been considered in fulfilling the estimated water demand:

- Groundwater
- Water stored in dam in Teknaf
- Rainwater harvesting in the roof top of buildings
- Desalination plant

As per the Master Plan the development of Sabrang TP is divided into six main time horizon-2020-2024, 2025-2029, 2030-2034, 2035-2039, 2040-2044 and 2044-2049. Accordingly, the phasing of water supply system has been planned as shown in **Figure 9.1**.



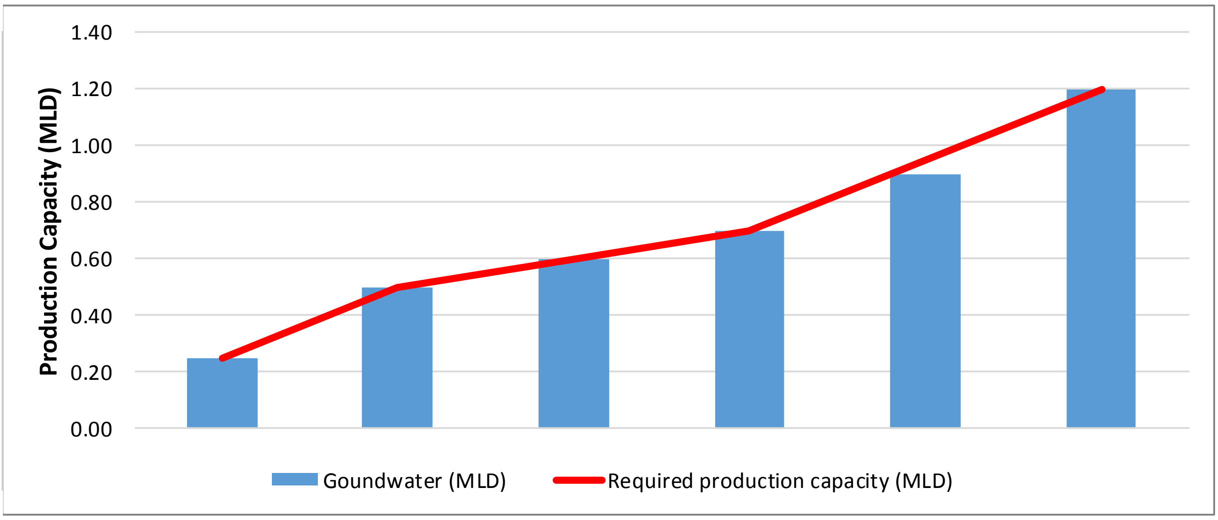
Planning hoizon	2024	2029	2034	2039	2044	2049
Water demand at user end (MLD)	2.01	2.85	4.67	5.69	6.77	7.69
Water lossess (MLD)	0.63	0.89	1.46	1.78	2.12	2.40
Required production capacity (MLD)	2.64	3.74	6.12	7.47	8.89	10.09
Goundwater (MLD)	2.51	2.49	3.28	4.50	5.29	5.03
Teknaf reservoir & dam (MLD)		0.00	1.48	1.48	1.48	1.48
RWH at roof top (MLD)	0.13	0.25	0.37	0.49	0.61	0.73
Gap (MLD)	0.00	1.00	0.99	1.00	1.51	2.85
Desalination Plant (MLD)		1.00	1.00	1.00	1.50	2.85
Production capacity (MLD)	2.64	3.74	6.13	7.47	8.88	10.09

Figure 9.1: Future Sources of Supply for Sabrang Tourism Park

9.3 Tentative Water Management Plan for Naf Tourism Park

The water demand in Naf Tourism Park has been estimated based on the total number of tourist and work force required in different accommodations like hotels, cottages, apartments and central plaza as mentioned in the Master Plan. The total required production capacity considers physical loss or leakage from the treated water transmission and distribution pipelines and appurtenances. The estimated total required production capacity will be 1.2 MLD after completion of full development in 2049. Different water sources has been considered but only groundwater reservoir is considered as the only source for fulfilling the estimated water demand.

As per the Master Plan the development of Naf Tourism Park is divided into three main time horizon- 2020-2029, 2030-2039 and 2040-2049. But the phasing of the water supply system, is considered similar to the Sabrang Economic Zone. Accordingly, the phasing of the water supply system for Naf economic zone is shown in **Figure 9.2**.



Planning hoizon	2024	2029	2034	2039	2044	2049
Water demand at user end (MLD)	0.19	0.39	0.46	0.52	0.70	0.88
Water lossess (MLD)	0.06	0.11	0.14	0.18	0.25	0.32
Required production capacity (MLD)	0.25	0.50	0.60	0.70	0.95	1.20
Goundwater (MLD)	0.25	0.50	0.60	0.70	0.90	1.20
Desalination plant/RWH (MLD)	0.00	0.00	0.00	0.00	0.00	0.00
Production capacity (MLD)	0.25	0.50	0.60	0.70	0.90	1.20

Figure 9.2: Future Sources of Supply for Naf Tourism Park

9.4 Phasing Plan of Different Components

9.4.1 Production Tube well

Groundwater is the main source of water supply for Sabrang Tourism Park and the only source for Naf Tourism Park. Total 8 nos. of production tube well can be installed in Whykhong well field area with production capacity 14.42 l/s (0.5 cusec). The total production would be 6.2 MLD considering maximum of 15 hour operating period.

After the installation of PTW, the shallow tube wells in the surrounding influenced area of about 100m radius may be abandoned due to water table drawdown. To observe the influenced of shallow tube wells and drawdown, monitoring is needed. If the shallow tube wells cannot uplift water, conflict with the existing local water use may arise. In order to avoid conflict BEZA need to construct a new PTW for domestic usage. The supply system of this PTW should be operated and maintained through local administration or under respective authority.

In order to fulfill the water demand into different development phase, the no of PTW and its operation hour has been optimized as shown in **Table 9.2**.

Table 9.2: Production tube wells in different phases

Phase	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6
Total no of PTW	4	4	5	7	8	8
PTW ID to be developed (Figure 4.54)	PTW-08 to PTW-05	PTW-08 to PTW-05	PTW-08 to PTW-04	PTW-08 to PTW-02	PTW-08 to PTW-01	PTW-08 to PTW-01
Operating Hour	13.5	14.5	15	14.5	15	15
Total Production for Tourism Parks (MLD)	2.8	3.0	3.9	5.2	6.2	6.2

9.4.2 Desalination Plant

No desalination plant is considered for Naf Tourism Park. To fulfill water demand in Sabrang Tourism Park total 2.85 MLD production is planned from three desalination plant. The first desalination plant is proposed in Phase-2 with production capacity 1 MLD. The second desalination plant will be required in Phase-5 with production capacity 0.5 MLD and the third one in Phase-6 with production capacity 1.35 MLD.

9.4.3 Roof top Rainwater Harvesting

Roof top rainwater harvesting is considered only in Sabrang Tourism Park. Total 0.73 MLD can be made available in Sabrang Tourism Park after full development and about 180 nos. reservoir will be required to store the rainwater and use throughout the year. In each phase about 30 nos. of rainwater storage reservoir can be constructed. The size of each reservoir would be 16mX16mX4m (including 0.5m freeboard).

9.4.4 Underground Water Reservoir

The underground water reservoirs (UGWR) is proposed in the Tourism Parks that would receive water from production tube well, surface water treatment plant and desalination plant first, and then water will be diverted through distribution network into each plot by pumping. The capacity of the Underground Water Reservoir (CUGWR) would be made adequate to store 2 days water demand. Two days storage has been suggested in the Master Plan to ensure availability of uninterrupted water supply during any maintenance or repairing works.

Water Reservoir capacity = Volume of daily water demand x 2

Moreover, in Whykhong, there would be another underground water reservoirs which will receive water from the production tube wells. Water will be supply to the transmission main from this reservoir through pumping. The capacity of the reservoir would be made adequate to store water for 3-4 hours only.

9.4.4.1 Underground Water Reservoir in Sabrang Tourism Park

Three numbers of underground water reservoir is considered in Sabrang Tourism Park to optimize the cost and operation facilities. Each reservoir will have 2 chamber. The reservoirs will be developed in Phase 1, 3 & 5. The capacity and size of reservoir is given in **Table 9.3**.

Table 9.3: Underground water reservoir capacity and size in Sabrang tourism Park

Item	unit	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6
Maximum Water Requirement in the Distribution System	MLD	2.37	3.36	5.49	6.69	7.97	9.04
Required reservoir capacity for 2 days	m^3	4,474	6,213	10,237	12,410	14,720	16,629
Planned Reservoir Capacity	m^3	6,213	-	6,197	-	4,219	-
	Million Litre	6.21	-	6.20	-	4.22	-
Size of reservoir (height including freeboard)		56m x 56m x 5m		56m x 56m x 5m		46m x 46m x 5m	

9.4.4.2 Underground Water Reservoir in Naf Tourism Park

Two numbers of underground water reservoir is considered in Naf Tourism Park to optimize the cost and operation facilities. Each reservoir will have 1 chamber. The reservoirs will be developed in Phase 1 & 3. The capacity and size of reservoir is given in **Table 9.4**.

Table 9.4: Underground water reservoir capacity and size in Naf tourism Park

Item	unit	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6
Maximum Water Requirement in the Distribution System	MLD	0.5	-	0.6	-	-	-
Required reservoir capacity for 2 days	m^3	916	-	1,234	-	-	-
Planned Reservoir Capacity	m^3	916	-	1151	-	-	-
	Million Litre	0.92	-	1.15	-	-	-
Size of reservoir		22m x 22m x 5m		25m x 25m x 5m			

9.4.4.3 Underground Water Reservoir in Whykhong

One underground water reservoir with 2 chamber is considered in Whykhong area. In Phase-1 one chamber will be operated and the chamber will be operated in Phase-2. The capacity of the reservoir will be 6.2 MLD as equal to the total production from the production wells. Considering 4 hour operation period the size of the reservoir is estimated as 17mX17mX5m.

9.4.5 Water Supply Pump Stations

9.4.5.1 Pump at Underground Water Reservoir in Whykhong

Two pumps is proposed to be installed in Whykhong area to optimized cost and flow in the transmission main. These two pump will be installed in Phase-1 & 3. The capacity of each pumps would be 0.045 m^3/s.

9.4.5.2 Booster pump

The length of transmission line from the well field to Sabrang Tourism Park is about 46 km (from PTW-01). In order to carry the water through this long transmission pipe line, at least two booster pumps will be required to guarantee water pressure to the desired level for uninterrupted supply. The workable capacity of each booster pump would be 0.075m^3/s. Booster pumps will be required to be developed in Phase-1.

(The number of booster pumps and capacity will be finalized in Study Phase-2.)

9.4.5.3 Pumps at Underground Water Reservoirs in Tourism Parks

The capacity of water supply pumps at underground water reservoirs in the Tourism Parks need to be sufficient enough to meet peak water demand. For Sabrang Tourism Park 3 nos. pumps at 3 reservoirs and for Naf Tourism Park 2 nos. pumps at 2 reservoirs will be required. The capacity of these pumps in different phases in given in **Table 9.5**.

Table 9.5: Pump capacity in Sabrang and Naf tourism Park

Pump location	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6
	Pump capacity (m^3/s)					
Sabrang TP	0.045	-	0.045	-	0.03	-
Naf TP	0.005	-	0.01	-	-	-

9.4.6 Water Supply Transmission Main

The water supply transmission main from Whykhong well field (from PTW-01) to Sabrang Tourism Park is about 45km. The transmission line to be developed in Phase-1, would have pipe with 250mm diameter. Moreover, the length of transmission main to carry the water from PTW-01 to PTW-08 is about 4.8 km. The diameter of this portion of transmission main would vary from 100 to 250mm. The design of the transmission main will be finalized in study Phase-2 after conducting topographic and engineering survey.

The length of transmission main from Teknaf water treatment plant to the main transmission main is about 50 m and the required diameter of the pipe line is about 150mm. Water from this treatment plant will be required in Phase-3 and therefore will be developed in Phase-3.

Water will be diverted from the main transmission main to Naf Tourism Park and will be carried through the pipe lines under the proposed tunnel. The length of the pipe line will be about 500m. In phase-1 the required diameter is about 75mm which will be sufficient to carry required amount of water upto phase-3. In phase-4 the pipe line need to be replaced with diameter of 100 mm or another pipe of 75mm need to be installed.

RCC pipe or GI pipe is not available below 400mm diameter. So HDPE pipe is considered for transmission main for these tourism park areas.

9.4.7 Water Supply Distribution Line

Sabrang tourism park area will be developed in 6 planning horizons and accordingly water supply pipe lines will be developed in different phases. The length of the pipe lines in different phases is taken from the Master Plan (Draft Final Report, August 2019).

Naf tourism park area will be developed in 3 planning horizons and the length of the pipe lines in these three phases is taken from the Master Plan (Draft Final Report, August 2019). For water supply planning it is considered that 50% of the length will be developed in the earlier phase.

The required length of distribution line is given in **Table 9.6**. The diameter of the distribution line will vary from 75 to 100mm which will be finalized in the Phase-2 of the study. HDPE pipe material will be used for distribution line in both the tourism parks.

Table 9.6: Water Supply Distribution Line in Sabrang and Naf tourism Park

Location	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	Total
	Length of water supply distribution line (m)						
Sabrang TP	1,996	3,130	2,997	2,360	1,192	1,265	12,940
Naf TP	1,726	1,726	1,868	1,868	1,467	1,467	10,121

9.4.8 Land Acquisition and Land Development

Land will be required outside the tourism park areas for installation of 8 nos. production tube well and 1 no. underground reservoir in Whykhong and for booster pumps along the transmission line. The tentative locations of production tube wells are given in Chapter 4. The location of underground reservoir in Whykgong and booster pumps will be finalized in study Phase-2. If khas land is not available near the proposed locations for PTW and reservoir then land acquisition will be required. All land acquisition should be completed in development Phase-1.

The required area for each production tube well is about 400m^2 (20mX20m) and for underground reservoir is 625m^2 (25mX25m). For each booster pump stations about 225m^2 (15mX15m) area will be required. Moreover, a rest room is required near one of the PTW for visiting the sites or maintenance by expertise and other purposes, so additional 400m^2 area is required.

9.4.9 Bottling Water Plant

To meet the drinking water requirement 3 nos. of bottling water plant can be installed in Phase 1, 3 & 5 as shown in **Table 9.7**.

Table 9.7: Production capacity of bottling water plant in different phases

Phase	Production Capacity (liter/day)	Production Capacity (liter /hour)
Phase-1	26,530	3,200
Phase-3	35,823	4,500
Phase-5	28,396	3,500
Total	**90,749**	

9.5 SWOT Analysis

SWOT analysis is a decision making method that has been widely used in identifying and solving problems related to water resource management and plan which often involve interdisciplinary issues that are difficult to quantify. SWOT analysis for this study is presented in **Table 9.8**.

Table 9.8: SWOT analysis of water management plan

S	W
Strength	**Weakness**
▪ Rooftop rainwater harvesting. ▪ Fund for capital investment is available. ▪ Cost for water supply is recoverable.	▪ Aquifer system is structurally complex for availability of groundwater resources. ▪ Low Safe yield of groundwater resources. ▪ Transmission line through hilly terrain.
O	**T**
Opportunity	**Threat**
▪ Groundwater in deep aquifer is available for use. ▪ Rainwater harvesting in the hilly water shade is possible. ▪ Desalination of sea water ▪ Economic zone establishment is Government priority area. ▪ Investment environment in south Asia is favorable.	▪ Deforestation in the Hilly watershed area could be protested as environmental threat. ▪ Variability in seasonal rainfall (climate change). ▪ Groundwater resources may further deplete due to increase of external demand.

Strength: There is a possibility of generating the water resources within the project area through rainwater harvesting for which appropriate design and methodology would be proposed. In principle enough fund would be available to invest for the rainwater harvesting arrangement. The rainwater harvesting may be planned to accommodate the collected water in underground built storage and use it in the dry season. The cost is expected to be recovered from the establishment to whom the land is allotted.

Weakness: Heterogeneous lithology, dipping stratum due to folding, and presence of faults makes the aquifer system structurally complex for availability of groundwater resources. Due to lack of insufficient data estimated safe yield of groundwater resources is low in the shallow aquifer. Apparently, groundwater safe yield is not enough for meeting future need. Therefore, future investigation and monitoring should be carried out for the revision of groundwater limits. The proposed pipeline for transmission of surface water through hilly terrain might create difficulty during construction.

Opportunity: The Deep aquifer in Whykhong area is expected to abstract only 31% of total calculated storage, leaving the rest for other usages. Rainwater harvesting in the hilly watershed using cross dam is a potential source. Desalination of sea water is also available for future usages. Government policy favors the development of Economic zones, so the externality is expected to be dealt favourably.

Threat: Proposed deforestation in the hilly watershed area for rainwater harvesting could be protested as environmental threat locally. Uncertainty attached with the variability in seasonal rainfall (climate change) might impact the planned rainwater harvesting to meeting future demand. However, the chances of availability through rainwater harvesting is small.

10 TENTATIVE COST ASSESSMENT

10.1 Tentative Cost Estimation

This chapter include the tentative project cost to mitigate total water demand of proposed Sabrang and Naf Tourism Park. The overall project components includes the following items:

- Total 8 nos. production tube wells in Whykhong well field with discharge capacity of 14.42 l/s for each PTW;
- HDPE pipe materials: about 50.6 km transmission main, 13 km distribution network in Sabrang Tourism Park and 10 km distribution network in Naf Tourism Park;
- Total 5 nos. underground water reservoir: 3 nos. in Sabrang tourism park and 2 nos. in Naf Tourism Parks;
- Total 6 nos. pumps: 5 nos. at underground reservoirs & 1 no. booster pump along the transmission main;
- 3 nos. desalination plant of capacity 1, 0.5 and 1.35 MLD;
- 3 nos. Bottling water plant
- General Item for the project components;
- Land acquisition and development cost for production tube wells and booster pump;
- Consultancy cost.

The reservoir cost (180 nos.) for roof top rain water harvesting including the plumbing system would be carried out by the land leaser/developer. That's why this cost is not included in the project cost of BEZA. To meet the water requirement of the Tourism Parks the project works of Phase-1 & 2 is considered as Project-1 and the project works of the remaining phases is considered as Project-2.

The tentative project cost to meet the water requirement in Sabrang and Naf Tourism Park is about 3,308 Million BDT upto Phase-6 (2049) and about 1,572 Million BDT is required in Project-1. The summary of tentative costs in different phases are shown in **Table 10.1** and the detailed is given in **Annex-5** to **Annex-13**. The tentative cost of reservoir cost (180 nos.) for roof top rain water harvesting including the plumbing system is 4,374 Million BDT which will be carried out by the land leaser/developer as shown in **Table 10.2** and the detailed is given in **Annex-14**. The cost of earthen dam, raw water transmission pipeline, surface water treatment plant and water office in Teknaf as shown in **Table 10.3** will be financed by the GoB/Donor agencies and implemented by DPHE.

Table 10.1: Tentative project cost for full filling total water demand

Item No.	Description	Project-1		Project-2				Total
		Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	
		Price in Million BDT (without price escalation)						
1	General Items	19.6	2.8	6.7	2.5	4.4	2.5	38.5
2	Production Tube well	67.1	0.0	16.8	33.6	16.8	0.0	134.3

Item No.	Description	Project-1		Project-2				Total
		Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	
		Price in Million BDT (without price escalation)						
3	Pipe material	377.1	5.1	5.2	5.2	2.8	2.8	398.2
4	Underground Water Reservoirs	256.6	0.0	239.4	0.0	134.9	0.0	630.9
5	Pump Station	179.6	0.0	71.2	0.0	30.1	0.0	280.9
7	Desalination plant	0.0	370.4	0.0	0.0	224.0	425.2	1019.6
8	Bottling water plant	187.5	0.0	238.8	0.0	174.9	0.0	601.2
9	Land Acquisition & development	17.8	0.0	0.0	0.0	0.0	0.0	17.8
10	Consultancy (6%)	65.2	22.7	34.7	2.5	35.3	25.8	186.2
	Total Project Cost	**1,171**	**401**	**613**	**44**	**623**	**456**	
		1,572		**1,736**				**3,308**

Table 10.2: Tentative cost for roof top rainwater harvesting system

Item No.	Description	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	Total
		Price in Million BDT (without price escalation)						
1	Roof Top RWH	687.7	687.7	687.7	687.7	687.7	687.7	4126
2	Consultancy (6%)	41.3	41.3	41.3	41.3	41.3	41.3	248
	Total Cost	**728.9**	**728.9**	**728.9**	**728.9**	**728.9**	**728.9**	**4,374**

Table 10.3: Proposed Contract Packages for DAM and SWTP

Item No.	Description	Total Price in Million BDT
Package-1	**Water retaining dam**	
	6-Earthen dams with protection works	435
	Intake structures	40
	Access bridge for operation of the intake structures	10
	Spillway	14
	Additional cost for mechanical parts, i.e., gate, hoist etc.	1
	Pump house & other electrical works	2
	Environmental Mitigation Cost	2
	Contingency	50.4
	Sub-Total of Package-1	**554.4**
Package-2	Water retaining dam	
	R. W. Transmission Pipeline	4.2
	Surface Water Treatment Plant	70
	Pourashava Water Office & Boundary wall	10

Item No.	Description	Total Price in Million BDT
	Overhead Tank for Teknaf	30
	Diesel Generator	8
	Environmental Mitigation Cost	4
	Contingency	12.6
	Sub-Total of Package-2	**138.8**

11 FINDINGS AND RECOMMENDATIONS

11.1 Findings

11.1.1 Findings for Sabrang Tourism Park

- The total population including tourists that will visit and may stay at night and the service providers in Sabrang Tourism Park is about 40,485 daily.
- For total population in Sabrang Tourism Park the weighted average demand is 165 LPCD.
- Total water demand for Sabrang Tourism Park is 10.09 MLD and drinking water requirement is about 81,000 litre/day after full development in 2049.
- For Sabrang Tourism Park, groundwater, dam-reservoir water, roof top rainwater harvesting and desalination plant are considered for fulfilling water demand.
- From roof top rainwater harvesting about 0.73 MLD can be made available for Sabrang Tourism Park and recommended for water supply.
- From the dam and reservoir system in Teknaf Pourashava 1.48 MLD water will be available for Sabrang Tourism Park and the water will be required in Phase-3.
- Desalination RO plant is required in phase 2, 5 & 6 to fulfill the total water requirement in Sabrang Tourism Park. The capacity of the desalination plant would be 1, 0.5 and 1.35 MLD respectively.
- The tentative cost of roof top rain water harvesting system is 4,374 Million BDT which would be carried out by land leaser/developer.

11.1.2 Findings for Naf Tourism Park

- The total population including tourists that will visit and may stay at night and the service providers in Naf Tourism Park is about 4,890 daily.
- For total population in Naf Tourism Park the weighted average demand is 177 LPCD.
- Total water demand for Naf Tourism Park is 1.15 MLD and drinking water requirement is about 9,800 litre/day after full development in 2049.
- From roof top rainwater harvesting about 0.22 MLD can be made available for Naf Tourism Park. But for water supply roof top rainwater harvesting for Naf Tourism Park is not recommended.
- For Naf Tourism Park, only groundwater source is considered for fulfilling water demand.

11.1.3 Common findings

- The aquifer system is not dependable at Shamlapur, Teknaf so large scale groundwater development for long-term water supply is not advised and thus not considered as water supply source.
- Synthesis analysis of groundwater resource assessment shows that in Whykhong a well field can be developed with 8 nos. of production tube well of capacity 14.42 l/s. The PTWs will be installed in different phases depending on water demand of the tourism parks. About 134 Million BDT is required to construction these PTWs.

- About 6.2 MLD groundwater may be extracted from the Whykhong well field.
- To avoid conflict for local water demand, a new PTW should be constructed by BEZA to be retained for local use (domestic purpose).
- Uncertainty in safe yield assessment will need to be addressed by monitoring of groundwater level.
- The water quality of different exploratory wells in Whykhong area and during aquifer test, indicates that the iron concentration is within the allowable limit of Bangladesh standard and so no treatment plant is required.
- The tidal water level of Naf River varies from -1.8 to 2.5 mMSL in the month of May to September.
- The water quality of Naf River is saline and total dissolve solid concentration and hardness are very high.
- Total about 50.6 km transmission main is required to carry groundwater from Whykhong and hill reservoir near Teknaf Pourashava.
- Two booster pumps would be required along the transmission main to guarantee water pressure to the desired level for uninterrupted supply.
- Tentative total project cost upto Phase-6 (2049) is 3,308 Million BDT and for Project-1 (Phase 1 & 2) is 1,572 Million BDT.
- The summary of the development plan is presented below:

Table 11.1: Summary of water supply system development plan

Project	Phase	Period	Budget (Million BDT)	Water demand (MLD)	Source of water
Project-1	Phase-1	2020-2024	1,171	2.89	• GW • RWH
	Phase-2	2025-2029	401	1.35	• GW • RWH • Desalination Plant
Project-2	Phase-3	2030-2034	613	2.48	• GW • RWH • Desalination Plant • Reservoir
	Phase-4	2035-2039	44	1.45	• GW • RWH • Desalination Plant • Reservoir
	Phase-5	2040-2044	623	1.67	• GW • RWH • Reservoir • Desalination Plant

Project	Phase	Period	Budget (Million BDT)	Water demand (MLD)	Source of water
	Phase-6	2045-2049	456	1.45	• GW • RWH • Reservoir • Desalination Plant
	Total		**3,308**	**11.29**	

11.2 Recommendations

11.2.1 Recommendations for Sabrang Tourism Park

- Sufficient apace shall be kept in the Master Plan for the operation and maintenance of underground water reservoir.
- The provision of roof top rainwater harvesting shall be kept in each building area of roof area >300m^2 from the very beginning. Otherwise extra costing will be needed for re-designing of the plumbing system.
- The water supplied from Teknaf reservoir shall be considered as supplementary water source, as due to rainfall variation in very dry year the storage volume could be lower than design storage volume.
- Metering system shall be installed with the water supply pipeline at every buildings. In that case, BEZA should establish and follow the rules & regulations prepared and approved by the Government of Bangladesh best on WASA Act 1996.
- To meet the drinking water requirement in Sabrang Tourism Park, bottle water industry can be developed.

11.2.2 Recommendations for Naf Tourism Park

- Sufficient apace shall be kept in the Master Plan for the operation and maintenance of underground water reservoir.
- Metering system shall be installed with the water supply pipeline at every buildings. In that case, BEZA should establish and follow the rules & regulations prepared and approved by the Government of Bangladesh best on WASA Act 1996.
- To meet the drinking water requirement in Naf Tourism Park, bottle water industry can be developed.

11.2.3 Recommendations for both Sabrang and Naf Tourism Park

- Monitoring of water level is required to ascertain its decline at different phase of development.
- Monitoring of water quality is required to ascertain any risk of salinity intrusion with development.
- Recharge and safe limit of abstraction is required to be updated reviewing the monitoring as mentioned above.
- Development of production tube wells in phases need to be reviewed based on the groundwater level and quality monitoring data.

- If the shallow tube wells in the surrounding influenced area of PTW's cannot uplift water due to water table drawdown, BEZA need to construct a new PTW for domestic usage to avoid conflict. The supply system of this PTW should be operated and maintained through local administration or under respective authority.

REFERENCES

Alam, M.K., Hasan, A.K.M.S., Khan, M.R., Whitney, J.W., 1990. Geological Map of Bangladesh. Geological Survey of Bangladesh. Dhaka, Scale 1: 1 000 000.

Alam, M., Alam, M.M., Curray, J.R., Chowdhury, M.L.R., and Gani, M.R., 2003. An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. Sedimentary Geology, 155, 179–208.

Bakhtine, M.I., 1966. Major tectonic features of Pakistan: Part II. The Eastern Province. Sci. Ind., 4, 89–100.

BNBC, 2015. Bangladesh National Building Code, Volume I, Final Draft.

Curiale, J.A., Covington, G.H., Shamsuddin, A.H.M., Morelos, J.A., and Shamsuddin, A.K.M., 2002. Origin of petroleum in Bangladesh. AAPG Bulletin, 86(4), 625–652.

Curray, J.R., 1991. Possible green schist metamorphism at the base of a 22 km sedimentary section, Bay of Bengal. Geology, 19, 1097–1100. https://dx.doi.org/10.1130/0091-7613(1991)019<1097:pgmatb>2.3.co;2.

Curray, J.R., and Munasinghe, T., 1991. Origin of the rajmahal traps and the 85° E Ridge: preliminary reconstructions of the trace of the crozet hotspot. Geology, 19(12), 1237-1240. DOI: 10.1130/0091-7613(1991)019<1237:OOTRTA>2.3.CO;2DU (2011), Final Report on Geophysical and Water Point Survey in Teknaf, Department of Geology, University of Dhaka.

DDC-DOHWA, August 2019, Detailed Master Plan for Naf and Sabrang Toirism Park, Draft Final Report

DDC-DOHWA consortium, June 2017, Feasibility Study of Sabrang Tourism Park, Final Report, Bangladesh Economic Zones Authority.

DPHE, BGS, DFID, 2000, Groundwater Studies of Arsenic Contamination in Bangladesh.

ECR, 2017 (Draft), Environmental Conservation Act, 2017, Ministry of Environmental, Forest and Climate Change, Government of Bangladesh.

Hossain, M.S., Khan, M.S.H., Abdullah, R., and Chowdhury, K.R., 2020. Tectonic Development of the Bengal Basin in Relation to Fold-thrust Belt to the East and to the North. In: Biswal, T.K., Ray, S.K., and Grasemann, B. (eds.), Structural Geology of Mobile Belts of the Indian Subcontinent, Society of Earth Scientists Series, Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-030-40593-9_4.

Hossain, M.S., Khan, M.S.H., Chowdhury, K.R. & Afrooz, M., 2014. Morpho-structural classification of the Indo-Burman Ranges and the adjacent regions. In: National conference on Rock Deformation & Structures (RDS-III), Assam, India. Abstract volume, p.31.

Hossain, M.S., Khan, M.S.H., Chowdhury, K.R. & Abdullah, R., 2019. Synthesis of the Tectonic and Structural Elements of the Bengal Basin. In: Mukherjee, S. (eds.) Tectonics & Structural Geology: Indian Context. Springer International Publishing AG, Cham. DOI: 10.1007/978-3-319-99341-6.

IWM and INGO Forum, 2018, Water Resource Potential Assessment of Ukhia and Teknaf Upazila Area, Cox's Bazar, Bangladesh.

IWM, 2009. *Study on Well Field Construction for Immediate Supplement to City Water Supply from Nearby Groundwater Source*, Final Report (Phase-1 & Phase 2), Dhaka Water Supply and Sewerage Authority.

Johnson, S.Y., and Alam, A.M.N., 1991. Sedimentation and tectonics of the Sylhet trough, Bangladesh. Geological Society of America Bulletin, 103, 1513–1527. https://doi.org/10.1130/0016-7606 (1991)103<1513:SATOTS>2.3.CO;2.

JICA, 2012, Data Collection Study on Regional Development in Southeastern Bangladesh, Final Report.

Khan, M.S.H., Haque, M.M., Pati, P., Chowdhury, K.R., and Biswas, S., 2015. OSL derived uplift rate of Dakhin Nhila anticline along the southeastern coast of the Bay of Bengal, Bangladesh. Himalayan Geology, 36(2), 143–152.

Khan, M. S. H., Hossain, M. S. & Uddin M. A., 2018. Geology and Active Tectonics of the Lalmai Hills, Bangladesh – An Overview from Chittagong Tripura Fold Belt Perspective. Journal of the Geological Society of India, 92, 713-720.

Maurin, T., and Rangin, C., 2009. Structure and kinematics of the Indo-Burmese Wedge: Recent and fast growth of the outer wedge. Tectonics, 28, TC2010, doi: 10.1029/2008TC002276.

Najman, Y., Bracciali, L., Parrish, R.R., Chisty, E., and Copley, A., 2016. Evolving strain partitioning in the Eastern Himalaya: The growth of the Shillong Plateau. Earth and Planetary Science Letters, 433, 1-9. https://doi.org/10.1016/j.epsl.2015.10.017.

PwC, June 2016, Environmental Impact Assessment Report for Jaliar Dip Economic Zone, Bangladesh Economic Zones Authority.

PwC, June 2016, Environmental Impact Assessment Report for Sabrang Economic Zone, Bangladesh Economic Zones Authority.

Rahman, M.J.J., Xiao, W., Hossain, M.S., Yeasmin, R., Sayem, A.S.M., Ao, S., Yang, L., Abdullah, R., and Dina, N.T., 2020. Geochemistry and detrital zircon U-Pb dating of Pliocene-Pleistocene sandstones of the Chittagong Tripura Fold Belt (Bangladesh): Implications for provenance. Gondwana Research, 78, 278-290.

Steckler, M.S., Akhter, S.H., and Seeber, L., 2008. Collision of the Ganges-Brahmaputra Delta with the Burma Arc. Earth Planet Sci. Lett., 273, 367–378. doi:10.1016/j.epsl.2008.07.009.

Steckler, M.S., Mondal, D., Akhter, S.H., Seeber, L., Feng, L., and Gale, J., 2016. Locked and loading megathrust linked to active subduction beneath the Indo-Burman ranges. Nat. Geosci., 9, 615–618. doi:10.1038/ngeo2760.

Sultana S, Ahmed KM, Woobaidullah ASM, Rahman M, Alam MJ, Hasan M, Afroz T (2012) Identification of potable water sources in a complex geological terrain- a case study of Teknaf peninsula. Bangladesh J Geol 26:58–69.

Uddin, A., and Lundberg, N., 2004. Miocene sedimentation and subsidence during continent–continent collision, Bengal basin, Bangladesh. Sediment. Geol., 164, 131–146.

UNDP, 1982, Groundwater survey, the hydrogeological condition of Bangladesh. UNDP- United Nations Development Programme DU (2011), Final Report on Geophysical and Water Point Survey in Teknaf, Department of Geology, University of Dhaka.

UNHCR, 2017, Hydrogeological Mission Report (Teknaf Area).

Uniconsult, February 2017, Pre-feasibility Study for Jaliardip Economic Zone, Final Report, Pre-feasibility Studies for Six (6) Economic Zones, World Bank Project: BEZA S-21.

ANNEX-1: HYDRAULIC DATA COLLECTION AND SURVEY

A.1.1 Water Level Data

Tidal water level has been observed in the Naf River adjacent to the proposed Naf Tourism Park from May to September 2019 using manual staff gauge at 1 hour interval. The water level hydrograph is shown in **Figure A.1.1** and the data are presented in **Table A.1.1**.

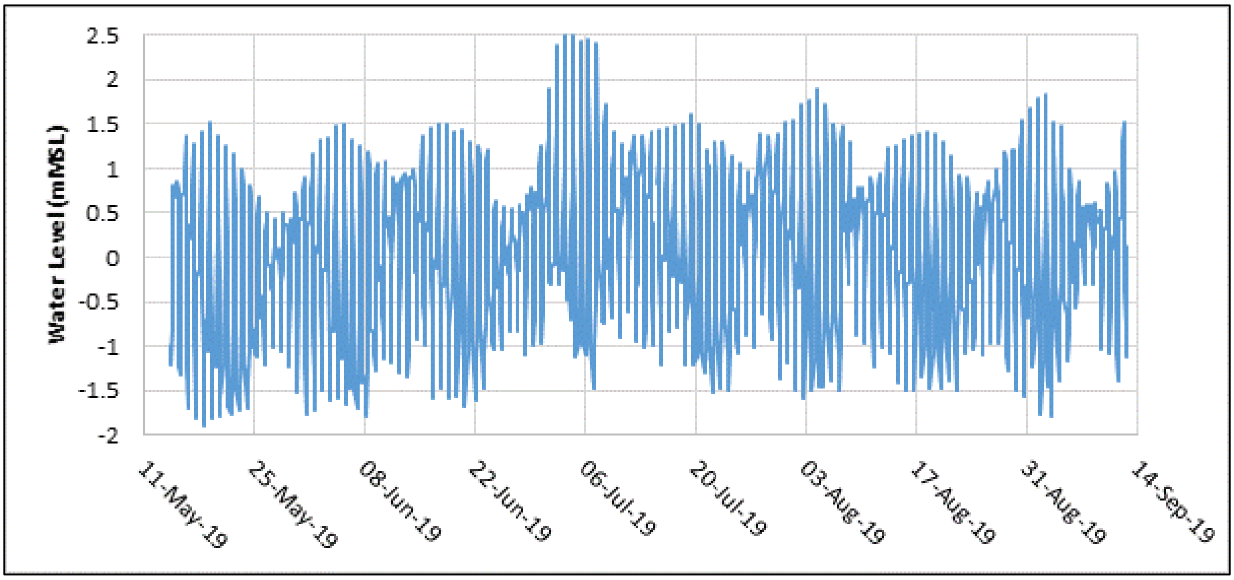


Figure A.1.1: Water Level Hydrograph of Naf River

Table A.1.1: Water Level Data

Date & Time	WL in MSL	Date & Time	WL in MSL	Date & Time	WL in MSL
14/05/2019 9:00	-0.107	23/06/2019 17:00	-0.137	03/08/2019 12:00	1.763
14/05/2019 10:00		23/06/2019 18:00	-0.407	03/08/2019 13:00	1.203
14/05/2019 11:00	-0.997	24/06/2019 6:00	-0.667	03/08/2019 14:00	0.513
14/05/2019 12:00	-1.157	24/06/2019 7:00	-0.967	03/08/2019 15:00	-0.297
14/05/2019 13:00	-1.207	24/06/2019 8:00	-1.037	03/08/2019 16:00	-0.537
14/05/2019 14:00	-0.787	24/06/2019 9:00	-0.597	03/08/2019 17:00	-1.047
14/05/2019 15:00	-0.247	24/06/2019 10:00	-0.167	03/08/2019 18:00	-1.497
14/05/2019 16:00	0.273	24/06/2019 11:00	0.223	04/08/2019 6:00	-1.137
14/05/2019 17:00	0.613	24/06/2019 12:00	0.483	04/08/2019 7:00	-0.577
14/05/2019 18:00	0.803	24/06/2019 13:00	0.543	04/08/2019 8:00	0.073
15/05/2019 6:00	0.673	24/06/2019 14:00	0.633	04/08/2019 9:00	0.763
15/05/2019 7:00	0.853	24/06/2019 15:00	0.343	04/08/2019 10:00	1.023
15/05/2019 8:00	0.773	24/06/2019 16:00	0.133	04/08/2019 11:00	1.513
15/05/2019 9:00	0.473	24/06/2019 17:00	-0.347	04/08/2019 12:00	1.893
15/05/2019 10:00	-0.077	24/06/2019 18:00		04/08/2019 13:00	1.203
15/05/2019 11:00	-0.677	25/06/2019 6:00	-0.367	04/08/2019 14:00	0.803
15/05/2019 12:00	-1.147	25/06/2019 7:00	-0.667	04/08/2019 15:00	0.233
15/05/2019 13:00	-1.227	25/06/2019 8:00	-1.037	04/08/2019 16:00	-0.187
15/05/2019 14:00	-1.327	25/06/2019 9:00	-0.897	04/08/2019 17:00	-0.787
15/05/2019 15:00	-1.007	25/06/2019 10:00	-0.517	04/08/2019 18:00	-1.457

Date & Time	WL in MSL
15/05/2019 16:00	-0.417
15/05/2019 17:00	0.233
15/05/2019 18:00	0.703
16/05/2019 6:00	0.713
16/05/2019 7:00	0.993
16/05/2019 8:00	1.363
16/05/2019 9:00	0.963
16/05/2019 10:00	0.643
16/05/2019 11:00	0.023
16/05/2019 12:00	-0.727
16/05/2019 13:00	-1.267
16/05/2019 14:00	-1.697
16/05/2019 15:00	-1.607
16/05/2019 16:00	-1.027
16/05/2019 17:00	-0.217
16/05/2019 18:00	0.373
17/05/2019 6:00	0.203
17/05/2019 7:00	0.833
17/05/2019 8:00	1.223
17/05/2019 9:00	1.283
17/05/2019 10:00	1.003
17/05/2019 11:00	0.523
17/05/2019 12:00	-0.107
17/05/2019 13:00	-0.917
17/05/2019 14:00	-1.687
17/05/2019 15:00	-1.807
17/05/2019 16:00	-1.607
17/05/2019 17:00	-0.937
17/05/2019 18:00	-0.237
18/05/2019 6:00	-0.127
18/05/2019 7:00	0.433
18/05/2019 8:00	1.133
18/05/2019 9:00	1.413
18/05/2019 10:00	1.253
18/05/2019 11:00	0.893
18/05/2019 12:00	0.423
18/05/2019 13:00	-0.457
18/05/2019 14:00	-1.117
18/05/2019 15:00	-1.617
18/05/2019 16:00	-1.907
18/05/2019 17:00	-1.447
18/05/2019 18:00	-0.707
19/05/2019 6:00	-1.057
19/05/2019 7:00	0.073
19/05/2019 8:00	0.913

Date & Time	WL in MSL
25/06/2019 11:00	-0.287
25/06/2019 12:00	0.083
25/06/2019 13:00	0.333
25/06/2019 14:00	0.453
25/06/2019 15:00	0.573
25/06/2019 16:00	0.433
25/06/2019 17:00	0.203
25/06/2019 18:00	-0.077
26/06/2019 6:00	0.113
26/06/2019 7:00	-0.167
26/06/2019 8:00	-0.207
26/06/2019 9:00	-0.477
26/06/2019 10:00	-0.837
26/06/2019 11:00	-0.507
26/06/2019 12:00	-0.177
26/06/2019 13:00	0.103
26/06/2019 14:00	0.393
26/06/2019 15:00	0.423
26/06/2019 16:00	0.533
26/06/2019 17:00	0.323
26/06/2019 18:00	0.253
27/06/2019 6:00	0.173
27/06/2019 7:00	-0.007
27/06/2019 8:00	-0.207
27/06/2019 9:00	-0.267
27/06/2019 10:00	-0.497
27/06/2019 11:00	-0.837
27/06/2019 12:00	-0.397
27/06/2019 13:00	-0.137
27/06/2019 14:00	-0.137
27/06/2019 15:00	0.303
27/06/2019 16:00	0.423
27/06/2019 17:00	0.593
27/06/2019 18:00	0.503
28/06/2019 6:00	0.503
28/06/2019 7:00	0.383
28/06/2019 8:00	0.173
28/06/2019 9:00	-0.037
28/06/2019 10:00	-0.267
28/06/2019 11:00	-0.787
28/06/2019 12:00	-1.097
28/06/2019 13:00	-0.767
28/06/2019 14:00	-0.287
28/06/2019 15:00	-0.187
28/06/2019 16:00	0.093

Date & Time	WL in MSL
05/08/2019 6:00	-1.457
05/08/2019 7:00	-0.977
05/08/2019 8:00	-0.487
05/08/2019 9:00	0.203
05/08/2019 10:00	0.793
05/08/2019 11:00	1.373
05/08/2019 12:00	1.573
05/08/2019 13:00	1.723
05/08/2019 14:00	1.203
05/08/2019 15:00	0.783
05/08/2019 16:00	0.163
05/08/2019 17:00	-0.397
05/08/2019 18:00	-0.737
06/08/2019 6:00	-1.397
06/08/2019 7:00	-0.947
06/08/2019 8:00	-0.537
06/08/2019 9:00	-0.037
06/08/2019 10:00	0.613
06/08/2019 11:00	1.003
06/08/2019 12:00	1.353
06/08/2019 13:00	1.493
06/08/2019 14:00	1.243
06/08/2019 15:00	0.803
06/08/2019 16:00	0.493
06/08/2019 17:00	-0.137
06/08/2019 18:00	-0.597
07/08/2019 6:00	-1.107
07/08/2019 7:00	-1.507
07/08/2019 8:00	-0.967
07/08/2019 9:00	-0.457
07/08/2019 10:00	0.133
07/08/2019 11:00	0.673
07/08/2019 12:00	1.123
07/08/2019 13:00	1.343
07/08/2019 14:00	1.473
07/08/2019 15:00	1.223
07/08/2019 16:00	1.013
07/08/2019 17:00	0.603
07/08/2019 18:00	0.303
08/08/2019 6:00	0.613
08/08/2019 7:00	0.113
08/08/2019 8:00	-0.207
08/08/2019 9:00	-0.297
08/08/2019 10:00	-0.207
08/08/2019 11:00	0.263

Date & Time	WL in MSL
19/05/2019 9:00	1.513
19/05/2019 10:00	1.333
19/05/2019 11:00	1.003
19/05/2019 12:00	0.723
19/05/2019 13:00	0.083
19/05/2019 14:00	-0.717
19/05/2019 15:00	-1.307
19/05/2019 16:00	-1.627
19/05/2019 17:00	-1.817
19/05/2019 18:00	-1.127
20/05/2019 6:00	-1.227
20/05/2019 7:00	-0.837
20/05/2019 8:00	0.313
20/05/2019 9:00	0.913
20/05/2019 10:00	1.253
20/05/2019 11:00	1.373
20/05/2019 12:00	1.023
20/05/2019 13:00	0.523
20/05/2019 14:00	-0.187
20/05/2019 15:00	-0.907
20/05/2019 16:00	-1.447
20/05/2019 17:00	-1.787
20/05/2019 18:00	-1.597
21/05/2019 6:00	-1.217
21/05/2019 7:00	-0.987
21/05/2019 8:00	-0.017
21/05/2019 9:00	0.573
21/05/2019 10:00	0.993
21/05/2019 11:00	1.253
21/05/2019 12:00	1.173
21/05/2019 13:00	0.863
21/05/2019 14:00	0.243
21/05/2019 15:00	-0.457
21/05/2019 16:00	-1.127
21/05/2019 17:00	-1.547
21/05/2019 18:00	-1.677
22/05/2019 6:00	-1.757
22/05/2019 7:00	-1.357
22/05/2019 8:00	-0.727
22/05/2019 9:00	0.133
22/05/2019 10:00	0.663
22/05/2019 11:00	1.033
22/05/2019 12:00	1.163
22/05/2019 13:00	1.023
22/05/2019 14:00	0.603

Date & Time	WL in MSL
28/06/2019 17:00	0.463
28/06/2019 18:00	0.693
29/06/2019 6:00	0.553
29/06/2019 7:00	0.793
29/06/2019 8:00	0.523
29/06/2019 9:00	0.393
29/06/2019 10:00	0.043
29/06/2019 11:00	-0.177
29/06/2019 12:00	-0.577
29/06/2019 13:00	-0.977
29/06/2019 14:00	-0.677
29/06/2019 15:00	-0.317
29/06/2019 16:00	0.233
29/06/2019 17:00	0.403
29/06/2019 18:00	0.713
30/06/2019 6:00	0.573
30/06/2019 7:00	1.033
30/06/2019 8:00	1.263
30/06/2019 9:00	1.103
30/06/2019 10:00	0.893
30/06/2019 11:00	0.503
30/06/2019 12:00	-0.167
30/06/2019 13:00	-0.967
30/06/2019 14:00	-0.607
30/06/2019 15:00	-0.207
30/06/2019 16:00	-0.187
30/06/2019 17:00	0.193
30/06/2019 18:00	0.503
01/07/2019 6:00	0.693
01/07/2019 7:00	1.183
01/07/2019 8:00	1.363
01/07/2019 9:00	1.903
01/07/2019 10:00	1.453
01/07/2019 11:00	0.933
01/07/2019 12:00	0.523
01/07/2019 13:00	-0.267
01/07/2019 14:00	-0.297
01/07/2019 15:00	-0.207
01/07/2019 16:00	-0.087
01/07/2019 17:00	-0.097
01/07/2019 18:00	-0.092
02/07/2019 6:00	-0.09
02/07/2019 7:00	0.90
02/07/2019 8:00	1.50
02/07/2019 9:00	2.39

Date & Time	WL in MSL
08/08/2019 12:00	0.493
08/08/2019 13:00	0.693
08/08/2019 14:00	1.073
08/08/2019 15:00	1.303
08/08/2019 16:00	0.803
08/08/2019 17:00	0.523
08/08/2019 18:00	0.293
09/08/2019 6:00	0.663
09/08/2019 7:00	0.493
09/08/2019 8:00	-0.037
09/08/2019 9:00	-0.287
09/08/2019 10:00	-0.887
09/08/2019 11:00	-0.347
09/08/2019 12:00	0.083
09/08/2019 13:00	0.173
09/08/2019 14:00	0.393
09/08/2019 15:00	0.613
09/08/2019 16:00	0.783
09/08/2019 17:00	0.543
09/08/2019 18:00	0.413
10/08/2019 6:00	0.793
10/08/2019 7:00	0.693
10/08/2019 8:00	0.493
10/08/2019 9:00	0.113
10/08/2019 10:00	-0.207
10/08/2019 11:00	-0.727
10/08/2019 12:00	-0.967
10/08/2019 13:00	-0.407
10/08/2019 14:00	0.113
10/08/2019 15:00	0.223
10/08/2019 16:00	0.353
10/08/2019 17:00	0.503
10/08/2019 18:00	0.603
11/08/2019 6:00	0.683
11/08/2019 7:00	0.893
11/08/2019 8:00	0.793
11/08/2019 9:00	0.603
11/08/2019 10:00	0.293
11/08/2019 11:00	0.033
11/08/2019 12:00	-0.467
11/08/2019 13:00	-0.807
11/08/2019 14:00	-1.237
11/08/2019 15:00	-0.377
11/08/2019 16:00	0.073
11/08/2019 17:00	0.243

Date & Time	WL in MSL
22/05/2019 15:00	-0.037
22/05/2019 16:00	-0.737
22/05/2019 17:00	-1.187
22/05/2019 18:00	-1.507
23/05/2019 6:00	-1.717
23/05/2019 7:00	-1.427
23/05/2019 8:00	-0.717
23/05/2019 9:00	-0.257
23/05/2019 10:00	0.303
23/05/2019 11:00	0.813
23/05/2019 12:00	0.933
23/05/2019 13:00	0.983
23/05/2019 14:00	0.813
23/05/2019 15:00	0.333
23/05/2019 16:00	-0.417
23/05/2019 17:00	-0.787
23/05/2019 18:00	-1.207
24/05/2019 6:00	-1.687
24/05/2019 7:00	-1.397
24/05/2019 8:00	-1.027
24/05/2019 9:00	-0.597
24/05/2019 10:00	0.023
24/05/2019 11:00	0.373
24/05/2019 12:00	0.673
24/05/2019 13:00	0.803
24/05/2019 14:00	0.693
24/05/2019 15:00	0.493
24/05/2019 16:00	0.023
24/05/2019 17:00	-0.577
24/05/2019 18:00	-1.017
25/05/2019 6:00	-0.817
25/05/2019 7:00	-1.077
25/05/2019 8:00	-1.127
25/05/2019 9:00	-0.777
25/05/2019 10:00	-0.177
25/05/2019 11:00	0.073
25/05/2019 12:00	0.343
25/05/2019 13:00	0.483
25/05/2019 14:00	0.683
25/05/2019 15:00	0.603
25/05/2019 16:00	0.353
25/05/2019 17:00	-0.147
25/05/2019 18:00	-0.687
26/05/2019 6:00	-0.427
26/05/2019 7:00	-0.797

Date & Time	WL in MSL
02/07/2019 10:00	
02/07/2019 11:00	2.00
02/07/2019 12:00	1.09
02/07/2019 13:00	0.52
02/07/2019 14:00	-0.19
02/07/2019 15:00	-0.31
02/07/2019 16:00	-0.22
02/07/2019 17:00	0.01
02/07/2019 18:00	-0.01
03/07/2019 6:00	-0.14
03/07/2019 7:00	0.49
03/07/2019 8:00	1.02
03/07/2019 9:00	1.49
03/07/2019 10:00	2.50
03/07/2019 11:00	1.99
03/07/2019 12:00	1.09
03/07/2019 13:00	0.39
03/07/2019 14:00	-0.21
03/07/2019 15:00	-0.47
03/07/2019 16:00	-0.30
03/07/2019 17:00	-0.11
03/07/2019 18:00	-0.11
04/07/2019 6:00	-0.70
04/07/2019 7:00	0.42
04/07/2019 8:00	0.80
04/07/2019 9:00	1.32
04/07/2019 10:00	2.17
04/07/2019 11:00	2.49
04/07/2019 12:00	1.73
04/07/2019 13:00	1.19
04/07/2019 14:00	0.49
04/07/2019 15:00	-0.28
04/07/2019 16:00	-0.56
04/07/2019 17:00	-0.97
04/07/2019 18:00	-1.13
05/07/2019 6:00	-0.97
05/07/2019 7:00	-0.58
05/07/2019 8:00	0.44
05/07/2019 9:00	0.90
05/07/2019 10:00	1.64
05/07/2019 11:00	2.29
05/07/2019 12:00	2.42
05/07/2019 13:00	1.39
05/07/2019 14:00	0.89
05/07/2019 15:00	0.46

Date & Time	WL in MSL
11/08/2019 18:00	0.483
12/08/2019 6:00	0.513
12/08/2019 7:00	0.813
12/08/2019 8:00	0.933
12/08/2019 9:00	0.803
12/08/2019 10:00	0.683
12/08/2019 11:00	0.493
12/08/2019 12:00	-0.117
12/08/2019 13:00	-0.617
12/08/2019 14:00	-1.007
12/08/2019 15:00	-0.517
12/08/2019 16:00	-0.067
12/08/2019 17:00	0.333
12/08/2019 18:00	0.473
13/08/2019 6:00	0.473
13/08/2019 7:00	0.833
13/08/2019 8:00	1.163
13/08/2019 9:00	1.223
13/08/2019 10:00	1.033
13/08/2019 11:00	0.703
13/08/2019 12:00	0.313
13/08/2019 13:00	-0.187
13/08/2019 14:00	-0.667
13/08/2019 15:00	-1.077
13/08/2019 16:00	-0.517
13/08/2019 17:00	-0.267
13/08/2019 18:00	0.113
14/08/2019 6:00	0.103
14/08/2019 7:00	0.603
14/08/2019 8:00	0.993
14/08/2019 9:00	1.173
14/08/2019 10:00	1.263
14/08/2019 11:00	0.913
14/08/2019 12:00	0.603
14/08/2019 13:00	-0.287
14/08/2019 14:00	-0.617
14/08/2019 15:00	-0.947
14/08/2019 16:00	-1.407
14/08/2019 17:00	-0.727
14/08/2019 18:00	-0.197
15/08/2019 6:00	-0.137
15/08/2019 7:00	0.363
15/08/2019 8:00	0.833
15/08/2019 9:00	1.103
15/08/2019 10:00	1.313

Date & Time	WL in MSL
26/05/2019 8:00	-1.207
26/05/2019 9:00	-1.017
26/05/2019 10:00	-0.687
26/05/2019 11:00	-0.307
26/05/2019 12:00	0.023
26/05/2019 13:00	0.303
26/05/2019 14:00	0.433
26/05/2019 15:00	0.503
26/05/2019 16:00	0.443
26/05/2019 17:00	0.213
26/05/2019 18:00	-0.067
27/05/2019 6:00	-0.107
27/05/2019 7:00	-0.337
27/05/2019 8:00	-0.387
27/05/2019 9:00	-0.617
27/05/2019 10:00	-1.007
27/05/2019 11:00	-0.677
27/05/2019 12:00	-0.267
27/05/2019 13:00	-0.067
27/05/2019 14:00	0.163
27/05/2019 15:00	0.003
27/05/2019 16:00	0.423
27/05/2019 17:00	0.363
27/05/2019 18:00	-0.007
28/05/2019 6:00	0.103
28/05/2019 7:00	-0.007
28/05/2019 8:00	-0.277
28/05/2019 9:00	-0.407
28/05/2019 10:00	-0.697
28/05/2019 11:00	-1.057
28/05/2019 12:00	-0.517
28/05/2019 13:00	-0.287
28/05/2019 14:00	-0.137
28/05/2019 15:00	0.283
28/05/2019 16:00	0.403
28/05/2019 17:00	0.503
28/05/2019 18:00	0.363
29/05/2019 6:00	0.373
29/05/2019 7:00	0.363
29/05/2019 8:00	0.233
29/05/2019 9:00	-0.067
29/05/2019 10:00	-0.327
29/05/2019 11:00	-0.887
29/05/2019 12:00	-1.227
29/05/2019 13:00	-0.917

Date & Time	WL in MSL
05/07/2019 16:00	-0.11
05/07/2019 17:00	-0.57
05/07/2019 18:00	-0.98
06/07/2019 6:00	-1.11
06/07/2019 7:00	-0.67
06/07/2019 8:00	0.09
06/07/2019 9:00	0.79
06/07/2019 10:00	1.42
06/07/2019 11:00	1.99
06/07/2019 12:00	2.44
06/07/2019 13:00	1.89
06/07/2019 14:00	1.12
06/07/2019 15:00	0.52
06/07/2019 16:00	0.13
06/07/2019 17:00	-0.60
06/07/2019 18:00	-0.99
07/07/2019 6:00	-1.47
07/07/2019 7:00	-1.00
07/07/2019 8:00	-0.49
07/07/2019 9:00	0.14
07/07/2019 10:00	0.69
07/07/2019 11:00	1.33
07/07/2019 12:00	1.72
07/07/2019 13:00	2.41
07/07/2019 14:00	1.12
07/07/2019 15:00	0.89
07/07/2019 16:00	0.60
07/07/2019 17:00	0.29
07/07/2019 18:00	-0.01
08/07/2019 6:00	-0.45
08/07/2019 7:00	-0.72
08/07/2019 8:00	-0.74
08/07/2019 9:00	-0.28
08/07/2019 10:00	0.28
08/07/2019 11:00	0.73
08/07/2019 12:00	1.17
08/07/2019 13:00	1.50
08/07/2019 14:00	1.72
08/07/2019 15:00	1.27
08/07/2019 16:00	0.92
08/07/2019 17:00	0.52
08/07/2019 18:00	-0.13
09/07/2019 6:00	0.20
09/07/2019 7:00	-0.31
09/07/2019 8:00	-0.69

Date & Time	WL in MSL
15/08/2019 11:00	1.153
15/08/2019 12:00	0.803
15/08/2019 13:00	0.313
15/08/2019 14:00	-0.337
15/08/2019 15:00	-0.797
15/08/2019 16:00	-1.237
15/08/2019 17:00	-1.497
15/08/2019 18:00	-0.297
16/08/2019 6:00	-0.287
16/08/2019 7:00	0.333
16/08/2019 8:00	0.783
16/08/2019 9:00	1.033
16/08/2019 10:00	1.243
16/08/2019 11:00	1.363
16/08/2019 12:00	0.983
16/08/2019 13:00	0.613
16/08/2019 14:00	-0.097
16/08/2019 15:00	-0.297
16/08/2019 16:00	-0.887
16/08/2019 17:00	-1.397
16/08/2019 18:00	-1.507
17/08/2019 6:00	-0.597
17/08/2019 7:00	0.093
17/08/2019 8:00	0.503
17/08/2019 9:00	0.893
17/08/2019 10:00	1.073
17/08/2019 11:00	1.393
17/08/2019 12:00	1.133
17/08/2019 13:00	0.773
17/08/2019 14:00	0.093
17/08/2019 15:00	-0.377
17/08/2019 16:00	-0.937
17/08/2019 17:00	-1.187
17/08/2019 18:00	-1.337
18/08/2019 6:00	-0.987
18/08/2019 7:00	-0.437
18/08/2019 8:00	0.503
18/08/2019 9:00	0.803
18/08/2019 10:00	1.033
18/08/2019 11:00	1.323
18/08/2019 12:00	1.403
18/08/2019 13:00	1.043
18/08/2019 14:00	0.533
18/08/2019 15:00	-0.107
18/08/2019 16:00	-0.597

Date & Time	WL in MSL	Date & Time	WL in MSL	Date & Time	WL in MSL
29/05/2019 14:00	-0.417	09/07/2019 9:00	-0.51	18/08/2019 17:00	-1.107
29/05/2019 15:00	-0.287	09/07/2019 10:00	-0.48	18/08/2019 18:00	-1.467
29/05/2019 16:00	0.053	09/07/2019 11:00	-0.10	19/08/2019 6:00	-1.097
29/05/2019 17:00	0.313	09/07/2019 12:00	0.58	19/08/2019 7:00	-0.587
29/05/2019 18:00	0.443	09/07/2019 13:00	1.00	19/08/2019 8:00	-0.127
30/05/2019 6:00	0.163	09/07/2019 14:00	1.21	19/08/2019 9:00	0.503
30/05/2019 7:00	0.713	09/07/2019 15:00	1.40	19/08/2019 10:00	0.973
30/05/2019 8:00	0.573	09/07/2019 16:00	1.07	19/08/2019 11:00	1.213
30/05/2019 9:00	0.223	09/07/2019 17:00	0.86	19/08/2019 12:00	1.383
30/05/2019 10:00	0.043	09/07/2019 18:00	0.51	19/08/2019 13:00	1.143
30/05/2019 11:00	-0.617	10/07/2019 6:00	0.533	19/08/2019 14:00	0.693
30/05/2019 12:00	-1.077	10/07/2019 7:00	0.003	19/08/2019 15:00	0.113
30/05/2019 13:00	-1.517	10/07/2019 8:00	-0.337	19/08/2019 16:00	-0.197
30/05/2019 14:00	-0.397	10/07/2019 9:00	-0.577	19/08/2019 17:00	-0.677
30/05/2019 15:00	-0.285	10/07/2019 10:00	-0.897	19/08/2019 18:00	-1.007
30/05/2019 16:00	-0.217	10/07/2019 11:00	-0.617	20/08/2019 6:00	-1.467
30/05/2019 17:00	0.163	10/07/2019 12:00	-0.177	20/08/2019 7:00	-1.117
30/05/2019 18:00	0.423	10/07/2019 13:00	0.323	20/08/2019 8:00	-0.497
31/05/2019 6:00	0.423	10/07/2019 14:00	0.523	20/08/2019 9:00	0.193
31/05/2019 7:00	0.773	10/07/2019 15:00	0.903	20/08/2019 10:00	0.503
31/05/2019 8:00	0.903	10/07/2019 16:00	1.283	20/08/2019 11:00	0.843
31/05/2019 9:00	0.723	10/07/2019 17:00	0.933	20/08/2019 12:00	1.073
31/05/2019 10:00	0.283	10/07/2019 18:00	0.733	20/08/2019 13:00	1.303
31/05/2019 11:00	-0.137	11/07/2019 6:00	0.903	20/08/2019 14:00	0.893
31/05/2019 12:00	-0.817	11/07/2019 7:00	0.693	20/08/2019 15:00	0.503
31/05/2019 13:00	-1.257	11/07/2019 8:00	0.483	20/08/2019 16:00	-0.207
31/05/2019 14:00	-1.767	11/07/2019 9:00	-0.017	20/08/2019 17:00	-0.597
31/05/2019 15:00	-1.147	11/07/2019 10:00	-0.297	20/08/2019 18:00	-0.897
31/05/2019 16:00	-0.707	11/07/2019 11:00	-0.617	21/08/2019 6:00	-1.387
31/05/2019 17:00	-0.077	11/07/2019 12:00	-0.577	21/08/2019 7:00	-0.997
31/05/2019 18:00	0.333	11/07/2019 13:00	-0.107	21/08/2019 8:00	-0.477
01/06/2019 6:00	0.443	11/07/2019 14:00	0.383	21/08/2019 9:00	-0.137
01/06/2019 7:00	0.783	11/07/2019 15:00	0.673	21/08/2019 10:00	0.433
01/06/2019 8:00	0.933	11/07/2019 16:00	0.883	21/08/2019 11:00	0.753
01/06/2019 9:00	1.163	11/07/2019 17:00	1.183	21/08/2019 12:00	1.003
01/06/2019 10:00	0.783	11/07/2019 18:00	1.003	21/08/2019 13:00	1.143
01/06/2019 11:00	0.303	12/07/2019 6:00	1.363	21/08/2019 14:00	0.893
01/06/2019 12:00	-0.277	12/07/2019 7:00	1.223	21/08/2019 15:00	0.513
01/06/2019 13:00	-0.847	12/07/2019 8:00	0.823	21/08/2019 16:00	-0.107
01/06/2019 14:00	-1.347	12/07/2019 9:00	0.463	21/08/2019 17:00	-0.387
01/06/2019 15:00	-1.727	12/07/2019 10:00	-0.157	21/08/2019 18:00	-0.637
01/06/2019 16:00	-1.187	12/07/2019 11:00	-0.757	22/08/2019 6:00	-1.487
01/06/2019 17:00	-0.457	12/07/2019 12:00	-0.937	22/08/2019 7:00	-1.077
01/06/2019 18:00	0.113	12/07/2019 13:00	-0.337	22/08/2019 8:00	-0.827
02/06/2019 6:00	0.063	12/07/2019 14:00	-0.267	22/08/2019 9:00	-0.367

Date & Time	WL in MSL	Date & Time	WL in MSL	Date & Time	WL in MSL
02/06/2019 7:00	0.533	12/07/2019 15:00	-0.007	22/08/2019 10:00	0.093
02/06/2019 8:00	1.123	12/07/2019 16:00	0.333	22/08/2019 11:00	0.403
02/06/2019 9:00	1.313	12/07/2019 17:00	0.633	22/08/2019 12:00	0.753
02/06/2019 10:00	1.193	12/07/2019 18:00	0.893	22/08/2019 13:00	0.863
02/06/2019 11:00	0.783	13/07/2019 6:00	1.033	22/08/2019 14:00	0.913
02/06/2019 12:00	0.203	13/07/2019 7:00	1.373	22/08/2019 15:00	0.763
02/06/2019 13:00	-0.557	13/07/2019 8:00	1.123	22/08/2019 16:00	0.363
02/06/2019 14:00	-1.027	13/07/2019 9:00	0.833	22/08/2019 17:00	-0.227
02/06/2019 15:00	-1.157	13/07/2019 10:00	0.523	22/08/2019 18:00	-0.577
02/06/2019 16:00	-1.487	13/07/2019 11:00	0.063	23/08/2019 6:00	-0.607
02/06/2019 17:00	-0.827	13/07/2019 12:00	-0.737	23/08/2019 7:00	-0.947
02/06/2019 18:00	-0.147	13/07/2019 13:00	-1.007	23/08/2019 8:00	-1.087
03/06/2019 6:00	-0.137	13/07/2019 14:00	-0.807	23/08/2019 9:00	-0.647
03/06/2019 7:00	0.383	13/07/2019 15:00	-0.287	23/08/2019 10:00	-0.177
03/06/2019 8:00	0.973	13/07/2019 16:00	0.003	23/08/2019 11:00	0.203
03/06/2019 9:00	1.333	13/07/2019 17:00	0.363	23/08/2019 12:00	0.493
03/06/2019 10:00	1.293	13/07/2019 18:00	0.693	23/08/2019 13:00	0.553
03/06/2019 11:00	1.103	14/07/2019 6:00	0.673	23/08/2019 14:00	0.893
03/06/2019 12:00	0.603	14/07/2019 7:00	1.143	23/08/2019 15:00	0.663
03/06/2019 13:00	-0.007	14/07/2019 8:00	1.413	23/08/2019 16:00	0.523
03/06/2019 14:00	-1.107	14/07/2019 9:00	1.273	23/08/2019 17:00	0.223
03/06/2019 15:00	-1.417	14/07/2019 10:00	0.823	23/08/2019 18:00	-0.287
03/06/2019 16:00	-1.617	14/07/2019 11:00	0.513	24/08/2019 6:00	-0.257
03/06/2019 17:00	-1.117	14/07/2019 12:00	0.193	24/08/2019 7:00	-0.687
03/06/2019 18:00	-0.787	14/07/2019 13:00	-0.467	24/08/2019 8:00	-1.027
04/06/2019 6:00	-0.837	14/07/2019 14:00	-0.837	24/08/2019 9:00	-0.887
04/06/2019 7:00	0.293	14/07/2019 15:00	-0.977	24/08/2019 10:00	-0.547
04/06/2019 8:00	0.843	14/07/2019 16:00	-0.727	24/08/2019 11:00	-0.237
04/06/2019 9:00	1.363	14/07/2019 17:00	-0.187	24/08/2019 12:00	-0.007
04/06/2019 10:00	1.483	14/07/2019 18:00	0.393	24/08/2019 13:00	0.203
04/06/2019 11:00	1.383	15/07/2019 6:00		24/08/2019 14:00	0.393
04/06/2019 12:00	0.963	15/07/2019 7:00	0.823	24/08/2019 15:00	0.713
04/06/2019 13:00	0.403	15/07/2019 8:00	1.123	24/08/2019 16:00	0.523
04/06/2019 14:00	-0.487	15/07/2019 9:00	1.433	24/08/2019 17:00	0.333
04/06/2019 15:00	-0.857	15/07/2019 10:00	1.223	24/08/2019 18:00	-0.077
04/06/2019 16:00	-1.177	15/07/2019 11:00	0.793	25/08/2019 6:00	0.563
04/06/2019 17:00	-1.587	15/07/2019 12:00	0.093	25/08/2019 7:00	0.303
04/06/2019 18:00	-1.077	15/07/2019 13:00	-0.137	25/08/2019 8:00	-0.037
05/06/2019 6:00	-1.137	15/07/2019 14:00	-0.697	25/08/2019 9:00	-0.287
05/06/2019 7:00	-0.647	15/07/2019 15:00	-1.2	25/08/2019 10:00	-0.867
05/06/2019 8:00	0.333	15/07/2019 16:00		25/08/2019 11:00	-1.107
05/06/2019 9:00	0.873	15/07/2019 17:00	-0.537	25/08/2019 12:00	-0.637
05/06/2019 10:00	1.273	15/07/2019 18:00	0.003	25/08/2019 13:00	-0.137
05/06/2019 11:00	1.503	16/07/2019 6:00	-0.037	25/08/2019 14:00	0.153
05/06/2019 12:00	1.323	16/07/2019 7:00	0.793	25/08/2019 15:00	0.463

Date & Time	WL in MSL	Date & Time	WL in MSL	Date & Time	WL in MSL
05/06/2019 13:00	0.833	16/07/2019 8:00	1.093	25/08/2019 16:00	0.543
05/06/2019 14:00	0.053	16/07/2019 9:00	1.213	25/08/2019 17:00	0.693
05/06/2019 15:00	-0.797	16/07/2019 10:00	1.453	25/08/2019 18:00	0.513
05/06/2019 16:00	-1.227	16/07/2019 11:00	1.153	26/08/2019 6:00	0.863
05/06/2019 17:00	-1.657	16/07/2019 12:00	0.533	26/08/2019 7:00	0.713
05/06/2019 18:00	-1.447	16/07/2019 13:00	0.573	26/08/2019 8:00	0.583
06/06/2019 6:00	-1.477	16/07/2019 14:00	0.35	26/08/2019 9:00	0.243
06/06/2019 7:00	-0.997	16/07/2019 15:00	0.093	26/08/2019 10:00	-0.137
06/06/2019 8:00	-0.017	16/07/2019 16:00	-0.837	26/08/2019 11:00	-0.837
06/06/2019 9:00	0.593	16/07/2019 17:00	-0.277	26/08/2019 12:00	-0.967
06/06/2019 10:00	1.003	16/07/2019 18:00	0.163	26/08/2019 13:00	-0.367
06/06/2019 11:00	1.313	17/07/2019 6:00	-0.207	26/08/2019 14:00	-0.207
06/06/2019 12:00	1.043	17/07/2019 7:00	0.423	26/08/2019 15:00	0.003
06/06/2019 13:00	0.603	17/07/2019 8:00	0.973	26/08/2019 16:00	0.253
06/06/2019 14:00	0.043	17/07/2019 9:00	1.213	26/08/2019 17:00	0.513
06/06/2019 15:00	-0.537	17/07/2019 10:00	1.473	26/08/2019 18:00	0.613
06/06/2019 16:00	-1.117	17/07/2019 11:00	1.183	27/08/2019 6:00	0.803
06/06/2019 17:00	-1.327	17/07/2019 12:00	0.823	27/08/2019 7:00	0.993
06/06/2019 18:00	-1.487	17/07/2019 13:00	0.483	27/08/2019 8:00	0.863
07/06/2019 6:00	-1.707	17/07/2019 14:00	-0.207	27/08/2019 9:00	0.723
07/06/2019 7:00	-1.317	17/07/2019 15:00	-0.477	27/08/2019 10:00	0.273
07/06/2019 8:00	-0.667	17/07/2019 16:00	-0.597	27/08/2019 11:00	-0.267
07/06/2019 9:00	0.023	17/07/2019 17:00	-0.797	27/08/2019 12:00	-0.667
07/06/2019 10:00	0.573	17/07/2019 18:00	-0.007	27/08/2019 13:00	-0.827
07/06/2019 11:00	1.153	18/07/2019 6:00	-0.277	27/08/2019 14:00	-0.967
07/06/2019 12:00	1.243	18/07/2019 7:00	-0.097	27/08/2019 15:00	-0.537
07/06/2019 13:00	1.143	18/07/2019 8:00	0.403	27/08/2019 16:00	-0.287
07/06/2019 14:00	0.703	18/07/2019 9:00	0.903	27/08/2019 17:00	0.123
07/06/2019 15:00	0.293	18/07/2019 10:00	1.313	27/08/2019 18:00	0.413
07/06/2019 16:00	-0.147	18/07/2019 11:00	1.503	28/08/2019 6:00	0.433
07/06/2019 17:00	-0.837	18/07/2019 12:00	0.923	28/08/2019 7:00	0.853
07/06/2019 18:00	-1.407	18/07/2019 13:00	0.703	28/08/2019 8:00	1.183
08/06/2019 6:00	-1.347	18/07/2019 14:00	-0.097	28/08/2019 9:00	1.083
08/06/2019 7:00	-1.797	18/07/2019 15:00	-0.327	28/08/2019 10:00	0.853
08/06/2019 8:00	-1.237	18/07/2019 16:00	-0.777	28/08/2019 11:00	0.383
08/06/2019 9:00	-0.647	18/07/2019 17:00	-1.207	28/08/2019 12:00	-0.297
08/06/2019 10:00	0.043	18/07/2019 18:00	-0.727	28/08/2019 13:00	-0.697
08/06/2019 11:00	0.563	19/07/2019 6:00	-0.487	28/08/2019 14:00	-1.127
08/06/2019 12:00	0.943	19/07/2019 7:00	-0.227	28/08/2019 15:00	-1.267
08/06/2019 13:00	1.193	19/07/2019 8:00	0.413	28/08/2019 16:00	-0.737
08/06/2019 14:00	1.023	19/07/2019 9:00	0.833	28/08/2019 17:00	-0.287
08/06/2019 15:00	0.703	19/07/2019 10:00	1.193	28/08/2019 18:00	0.143
08/06/2019 16:00	0.413	19/07/2019 11:00	1.513	29/08/2019 6:00	0.193
08/06/2019 17:00	-0.117	19/07/2019 12:00	1.613	29/08/2019 7:00	0.713
08/06/2019 18:00	-0.807	19/07/2019 13:00	1.013	29/08/2019 8:00	1.213

Date & Time	WL in MSL
09/06/2019 6:00	-0.857
09/06/2019 7:00	-1.097
09/06/2019 8:00	-1.277
09/06/2019 9:00	-0.967
09/06/2019 10:00	-0.257
09/06/2019 11:00	0.113
09/06/2019 12:00	0.483
09/06/2019 13:00	0.933
09/06/2019 14:00	1.063
09/06/2019 15:00	0.753
09/06/2019 16:00	0.543
09/06/2019 17:00	0.233
09/06/2019 18:00	-0.257
10/06/2019 6:00	-0.097
10/06/2019 7:00	-0.647
10/06/2019 8:00	-0.897
10/06/2019 9:00	-1.147
10/06/2019 10:00	-1.097
10/06/2019 11:00	-0.757
10/06/2019 12:00	-0.097
10/06/2019 13:00	0.503
10/06/2019 14:00	1.083
10/06/2019 15:00	0.953
10/06/2019 16:00	0.653
10/06/2019 17:00	0.443
10/06/2019 18:00	0.333
11/06/2019 6:00	0.463
11/06/2019 7:00	0.263
11/06/2019 8:00	0.063
11/06/2019 9:00	-0.187
11/06/2019 10:00	-0.987
11/06/2019 11:00	-1.197
11/06/2019 12:00	-0.817
11/06/2019 13:00	-0.067
11/06/2019 14:00	0.293
11/06/2019 15:00	0.693
11/06/2019 16:00	0.833
11/06/2019 17:00	0.893
11/06/2019 18:00	0.743
12/06/2019 6:00	0.823
12/06/2019 7:00	0.583
12/06/2019 8:00	0.333
12/06/2019 9:00	-0.117
12/06/2019 10:00	-0.917
12/06/2019 11:00	-1.297

Date & Time	WL in MSL
19/07/2019 14:00	0.613
19/07/2019 15:00	-0.257
19/07/2019 16:00	-0.597
19/07/2019 17:00	-0.957
19/07/2019 18:00	-1.207
20/07/2019 6:00	-1.127
20/07/2019 7:00	-0.507
20/07/2019 8:00	-0.187
20/07/2019 9:00	0.423
20/07/2019 10:00	0.733
20/07/2019 11:00	1.173
20/07/2019 12:00	1.493
20/07/2019 13:00	0.993
20/07/2019 14:00	0.613
20/07/2019 15:00	0.123
20/07/2019 16:00	-0.177
20/07/2019 17:00	-0.687
20/07/2019 18:00	-1.067
21/07/2019 6:00	-1.297
21/07/2019 7:00	-1.167
21/07/2019 8:00	-0.287
21/07/2019 9:00	0.203
21/07/2019 10:00	0.663
21/07/2019 11:00	0.993
21/07/2019 12:00	1.213
21/07/2019 13:00	1.013
21/07/2019 14:00	1.023
21/07/2019 15:00	0.523
21/07/2019 16:00	-0.067
21/07/2019 17:00	-0.627
21/07/2019 18:00	-0.997
22/07/2019 6:00	-1.517
22/07/2019 7:00	-1.167
22/07/2019 8:00	-0.517
22/07/2019 9:00	0.193
22/07/2019 10:00	0.513
22/07/2019 11:00	0.823
22/07/2019 12:00	1.033
22/07/2019 13:00	1.293
22/07/2019 14:00	0.883
22/07/2019 15:00	0.563
22/07/2019 16:00	-0.107
22/07/2019 17:00	-0.527
22/07/2019 18:00	-0.837
23/07/2019 6:00	-1.467

Date & Time	WL in MSL
29/08/2019 9:00	
29/08/2019 10:00	1.203
29/08/2019 11:00	0.763
29/08/2019 12:00	0.323
29/08/2019 13:00	-0.187
29/08/2019 14:00	-0.617
29/08/2019 15:00	-1.087
29/08/2019 16:00	-1.507
29/08/2019 17:00	-0.497
29/08/2019 18:00	-0.167
30/08/2019 6:00	-0.107
30/08/2019 7:00	0.583
30/08/2019 8:00	1.233
30/08/2019 9:00	1.423
30/08/2019 10:00	1.533
30/08/2019 11:00	1.193
30/08/2019 12:00	0.723
30/08/2019 13:00	0.093
30/08/2019 14:00	-0.427
30/08/2019 15:00	-0.897
30/08/2019 16:00	-1.317
30/08/2019 17:00	-1.567
30/08/2019 18:00	-0.317
31/08/2019 6:00	-0.677
31/08/2019 7:00	0.153
31/08/2019 8:00	0.793
31/08/2019 9:00	1.403
31/08/2019 10:00	1.603
31/08/2019 11:00	1.683
31/08/2019 12:00	1.203
31/08/2019 13:00	0.763
31/08/2019 14:00	-0.207
31/08/2019 15:00	-0.467
31/08/2019 16:00	-0.787
31/08/2019 17:00	-1.007
31/08/2019 18:00	-1.237
01/09/2019 6:00	-0.777
01/09/2019 7:00	-0.457
01/09/2019 8:00	0.263
01/09/2019 9:00	1.023
01/09/2019 10:00	1.493
01/09/2019 11:00	1.793
01/09/2019 12:00	1.503
01/09/2019 13:00	0.933
01/09/2019 14:00	0.313

Date & Time	WL in MSL	Date & Time	WL in MSL	Date & Time	WL in MSL
12/06/2019 12:00	-1.117	23/07/2019 7:00	-1.197	01/09/2019 15:00	-0.367
12/06/2019 13:00	-0.727	23/07/2019 8:00	-0.587	01/09/2019 16:00	-0.987
12/06/2019 14:00	-0.177	23/07/2019 9:00	-0.067	01/09/2019 17:00	-1.527
12/06/2019 15:00	0.133	23/07/2019 10:00	0.393	01/09/2019 18:00	-1.767
12/06/2019 16:00	0.413	23/07/2019 11:00	0.723	02/09/2019 6:00	-1.137
12/06/2019 17:00	0.803	23/07/2019 12:00	0.973	02/09/2019 7:00	-0.697
12/06/2019 18:00	0.883	23/07/2019 13:00	1.293	02/09/2019 8:00	-0.137
13/06/2019 6:00	0.933	23/07/2019 14:00	1.103	02/09/2019 9:00	0.603
13/06/2019 7:00	0.843	23/07/2019 15:00	0.733	02/09/2019 10:00	1.403
13/06/2019 8:00	0.703	23/07/2019 16:00	0.423	02/09/2019 11:00	1.603
13/06/2019 9:00	0.423	23/07/2019 17:00	-0.107	02/09/2019 12:00	1.823
13/06/2019 10:00	0.313	23/07/2019 18:00	-0.607	02/09/2019 13:00	1.473
13/06/2019 11:00	-0.587	24/07/2019 6:00	-1.107	02/09/2019 14:00	0.803
13/06/2019 12:00	-0.927	24/07/2019 7:00	-1.507	02/09/2019 15:00	0.123
13/06/2019 13:00	-1.347	24/07/2019 8:00	-1.087	02/09/2019 16:00	-0.497
13/06/2019 14:00	-1.097	24/07/2019 9:00	-0.457	02/09/2019 17:00	-1.017
13/06/2019 15:00	-0.477	24/07/2019 10:00	0.133	02/09/2019 18:00	-1.447
13/06/2019 16:00	0.143	24/07/2019 11:00	0.403	03/09/2019 6:00	-1.417
13/06/2019 17:00	0.553	24/07/2019 12:00	0.673	03/09/2019 7:00	-1.797
13/06/2019 18:00	0.903	24/07/2019 13:00	0.873	03/09/2019 8:00	-0.507
14/06/2019 6:00	0.893	24/07/2019 14:00	1.133	03/09/2019 9:00	0.133
14/06/2019 7:00	0.983	24/07/2019 15:00	0.993	03/09/2019 10:00	0.793
14/06/2019 8:00	0.813	24/07/2019 16:00	0.613	03/09/2019 11:00	1.193
14/06/2019 9:00	0.563	24/07/2019 17:00	0.303	03/09/2019 12:00	1.403
14/06/2019 10:00	0.023	24/07/2019 18:00	-0.577	03/09/2019 13:00	1.513
14/06/2019 11:00	-0.167	25/07/2019 6:00	-0.617	03/09/2019 14:00	1.203
14/06/2019 12:00		25/07/2019 7:00	-0.937	03/09/2019 15:00	0.603
14/06/2019 13:00		25/07/2019 8:00	-1.077	03/09/2019 16:00	0.093
14/06/2019 14:00		25/07/2019 9:00	-0.557	03/09/2019 17:00	-0.437
14/06/2019 15:00	-0.917	25/07/2019 10:00	-0.207	03/09/2019 18:00	-0.797
14/06/2019 16:00	-0.457	25/07/2019 11:00	0.293	04/09/2019 6:00	-1.397
14/06/2019 17:00	0.153	25/07/2019 12:00	0.503	04/09/2019 7:00	-0.997
14/06/2019 18:00	0.493	25/07/2019 13:00	0.663	04/09/2019 8:00	-0.507
15/06/2019 6:00	0.413	25/07/2019 14:00	0.903	04/09/2019 9:00	-0.277
15/06/2019 7:00	0.983	25/07/2019 15:00	1.063	04/09/2019 10:00	0.193
15/06/2019 8:00	1.373	25/07/2019 16:00	0.863	04/09/2019 11:00	0.643
15/06/2019 9:00	1.293	25/07/2019 17:00	0.523	04/09/2019 12:00	1.123
15/06/2019 10:00	1.023	25/07/2019 18:00	0.143	04/09/2019 13:00	1.473
15/06/2019 11:00	0.513	26/07/2019 6:00	0.583	04/09/2019 14:00	0.793
15/06/2019 12:00	-0.067	26/07/2019 7:00	0.023	04/09/2019 15:00	0.613
15/06/2019 13:00	-0.537	26/07/2019 8:00	-0.197	04/09/2019 16:00	0.383
15/06/2019 14:00	-0.767	26/07/2019 9:00	-0.647	04/09/2019 17:00	-0.177
15/06/2019 15:00	-0.977	26/07/2019 10:00	-0.887	04/09/2019 18:00	-0.467
15/06/2019 16:00	-0.727	26/07/2019 11:00	-0.367	05/09/2019 6:00	-0.657
15/06/2019 17:00	-0.137	26/07/2019 12:00	0.073	05/09/2019 7:00	-0.907

Date & Time	WL in MSL
15/06/2019 18:00	0.393
16/06/2019 6:00	0.303
16/06/2019 7:00	0.853
16/06/2019 8:00	1.263
16/06/2019 9:00	1.453
16/06/2019 10:00	1.033
16/06/2019 11:00	0.553
16/06/2019 12:00	0.193
16/06/2019 13:00	-0.257
16/06/2019 14:00	-0.697
16/06/2019 15:00	-1.027
16/06/2019 16:00	-1.587
16/06/2019 17:00	-0.537
16/06/2019 18:00	-0.027
17/06/2019 6:00	-0.117
17/06/2019 7:00	0.463
17/06/2019 8:00	0.893
17/06/2019 9:00	1.393
17/06/2019 10:00	1.503
17/06/2019 11:00	1.093
17/06/2019 12:00	0.593
17/06/2019 13:00	0.223
17/06/2019 14:00	-0.487
17/06/2019 15:00	-0.977
17/06/2019 16:00	-1.467
17/06/2019 17:00	-0.927
17/06/2019 18:00	-0.337
18/06/2019 6:00	-0.287
18/06/2019 7:00	0.143
18/06/2019 8:00	0.693
18/06/2019 9:00	1.333
18/06/2019 10:00	1.493
18/06/2019 11:00	1.383
18/06/2019 12:00	0.903
18/06/2019 13:00	-0.237
18/06/2019 14:00	-0.697
18/06/2019 15:00	-1.027
18/06/2019 16:00	-1.377
18/06/2019 17:00	-1.597
18/06/2019 18:00	-0.797
19/06/2019 6:00	-0.407
19/06/2019 7:00	0.243
19/06/2019 8:00	0.803
19/06/2019 9:00	1.003
19/06/2019 10:00	1.323

Date & Time	WL in MSL
26/07/2019 13:00	0.403
26/07/2019 14:00	0.563
26/07/2019 15:00	0.773
26/07/2019 16:00	0.973
26/07/2019 17:00	0.793
26/07/2019 18:00	0.613
27/07/2019 6:00	0.703
27/07/2019 7:00	0.563
27/07/2019 8:00	0.333
27/07/2019 9:00	0.033
27/07/2019 10:00	-0.777
27/07/2019 11:00	-1.007
27/07/2019 12:00	-0.657
27/07/2019 13:00	-0.047
27/07/2019 14:00	0.203
27/07/2019 15:00	0.493
27/07/2019 16:00	0.663
27/07/2019 17:00	0.893
27/07/2019 18:00	0.713
28/07/2019 6:00	1.383
28/07/2019 7:00	1.103
28/07/2019 8:00	0.873
28/07/2019 9:00	0.603
28/07/2019 10:00	0.163
28/07/2019 11:00	-0.487
28/07/2019 12:00	-0.627
28/07/2019 13:00	-0.507
28/07/2019 14:00	0.093
28/07/2019 15:00	0.393
28/07/2019 16:00	0.503
28/07/2019 17:00	0.683
28/07/2019 18:00	0.873
29/07/2019 6:00	1.213
29/07/2019 7:00	1.363
29/07/2019 8:00	1.123
29/07/2019 9:00	0.593
29/07/2019 10:00	0.323
29/07/2019 11:00	0.023
29/07/2019 12:00	-0.327
29/07/2019 13:00	-0.677
29/07/2019 14:00	-0.917
29/07/2019 15:00	-0.697
29/07/2019 16:00	-0.107
29/07/2019 17:00	0.293
29/07/2019 18:00	0.693

Date & Time	WL in MSL
05/09/2019 8:00	-1.167
05/09/2019 9:00	-0.827
05/09/2019 10:00	-0.137
05/09/2019 11:00	0.203
05/09/2019 12:00	0.663
05/09/2019 13:00	0.883
05/09/2019 14:00	0.993
05/09/2019 15:00	0.753
05/09/2019 16:00	0.513
05/09/2019 17:00	0.193
05/09/2019 18:00	-0.287
06/09/2019 6:00	0.163
06/09/2019 7:00	-0.307
06/09/2019 8:00	-0.577
06/09/2019 9:00	-0.347
06/09/2019 10:00	-0.287
06/09/2019 11:00	0.073
06/09/2019 12:00	0.403
06/09/2019 13:00	0.503
06/09/2019 14:00	0.693
06/09/2019 15:00	0.863
06/09/2019 16:00	0.583
06/09/2019 17:00	0.413
06/09/2019 18:00	0.123
07/09/2019 6:00	0.563
07/09/2019 7:00	0.393
07/09/2019 8:00	0.033
07/09/2019 9:00	-0.297
07/09/2019 10:00	-0.267
07/09/2019 11:00	-0.307
07/09/2019 12:00	-0.007
07/09/2019 13:00	0.203
07/09/2019 14:00	0.303
07/09/2019 15:00	0.463
07/09/2019 16:00	0.583
07/09/2019 17:00	0.553
07/09/2019 18:00	0.413
08/09/2019 6:00	0.583
08/09/2019 7:00	0.513
08/09/2019 8:00	0.353
08/09/2019 9:00	0.123
08/09/2019 10:00	-0.207
08/09/2019 11:00	-0.307
08/09/2019 12:00	-0.277
08/09/2019 13:00	-0.057

Date & Time	WL in MSL
19/06/2019 11:00	1.403
19/06/2019 12:00	0.863
19/06/2019 13:00	0.623
19/06/2019 14:00	0.093
19/06/2019 15:00	-0.347
19/06/2019 16:00	-0.897
19/06/2019 17:00	-1.407
19/06/2019 18:00	-1.567
20/06/2019 6:00	-0.817
20/06/2019 7:00	-0.267
20/06/2019 8:00	0.563
20/06/2019 9:00	0.893
20/06/2019 10:00	1.143
20/06/2019 11:00	1.323
20/06/2019 12:00	1.423
20/06/2019 13:00	1.173
20/06/2019 14:00	0.423
20/06/2019 15:00	-0.597
20/06/2019 16:00	-1.287
20/06/2019 17:00	-1.547
20/06/2019 18:00	-1.677
21/06/2019 6:00	-1.097
21/06/2019 7:00	-0.667
21/06/2019 8:00	-0.177
21/06/2019 9:00	0.443
21/06/2019 10:00	0.693
21/06/2019 11:00	0.963
21/06/2019 12:00	1.293
21/06/2019 13:00	1.123
21/06/2019 14:00	0.903
21/06/2019 15:00	0.473
21/06/2019 16:00	0.223
21/06/2019 17:00	-0.507
21/06/2019 18:00	-0.967
22/06/2019 6:00	-1.607
22/06/2019 7:00	-1.197
22/06/2019 8:00	-0.577
22/06/2019 9:00	-0.107
22/06/2019 10:00	0.433
22/06/2019 11:00	0.723
22/06/2019 12:00	0.993
22/06/2019 13:00	1.253
22/06/2019 14:00	1.143
22/06/2019 15:00	0.803
22/06/2019 16:00	0.523

Date & Time	WL in MSL
30/07/2019 6:00	0.793
30/07/2019 7:00	1.163
30/07/2019 8:00	1.393
30/07/2019 9:00	1.203
30/07/2019 10:00	0.693
30/07/2019 11:00	0.403
30/07/2019 12:00	-0.327
30/07/2019 13:00	-0.547
30/07/2019 14:00	-0.907
30/07/2019 15:00	-1.367
30/07/2019 16:00	-0.747
30/07/2019 17:00	-0.157
30/07/2019 18:00	0.323
31/07/2019 6:00	0.683
31/07/2019 7:00	0.933
31/07/2019 8:00	1.403
31/07/2019 9:00	1.513
31/07/2019 10:00	1.233
31/07/2019 11:00	0.903
31/07/2019 12:00	0.293
31/07/2019 13:00	-0.187
31/07/2019 14:00	-0.757
31/07/2019 15:00	-1.177
31/07/2019 16:00	-1.117
31/07/2019 17:00	-0.697
31/07/2019 18:00	0.293
01/08/2019 6:00	0.203
01/08/2019 7:00	0.683
01/08/2019 8:00	1.153
01/08/2019 9:00	1.403
01/08/2019 10:00	1.543
01/08/2019 11:00	1.203
01/08/2019 12:00	0.673
01/08/2019 13:00	0.093
01/08/2019 14:00	-0.477
01/08/2019 15:00	-0.987
01/08/2019 16:00	-1.507
01/08/2019 17:00	-0.087
01/08/2019 18:00	-0.327
02/08/2019 6:00	-0.337
02/08/2019 7:00	0.273
02/08/2019 8:00	0.743
02/08/2019 9:00	1.403
02/08/2019 10:00	1.503
02/08/2019 11:00	1.713

Date & Time	WL in MSL
08/09/2019 14:00	0.073
08/09/2019 15:00	0.133
08/09/2019 16:00	0.293
08/09/2019 17:00	0.603
08/09/2019 18:00	0.503
09/09/2019 6:00	0.393
09/09/2019 7:00	
09/09/2019 8:00	0.523
09/09/2019 9:00	0.523
09/09/2019 10:00	0.183
09/09/2019 11:00	-0.187
09/09/2019 12:00	-0.677
09/09/2019 13:00	-1.027
09/09/2019 14:00	-0.787
09/09/2019 15:00	-0.277
09/09/2019 16:00	0.033
09/09/2019 17:00	0.193
09/09/2019 18:00	0.303
10/09/2019 6:00	0.333
10/09/2019 7:00	0.563
10/09/2019 8:00	0.833
10/09/2019 9:00	0.693
10/09/2019 10:00	0.423
10/09/2019 11:00	0.123
10/09/2019 12:00	-0.287
10/09/2019 13:00	-0.707
10/09/2019 14:00	-1.087
10/09/2019 15:00	-0.577
10/09/2019 16:00	-0.247
10/09/2019 17:00	0.023
10/09/2019 18:00	0.223
11/09/2019 6:00	0.093
11/09/2019 7:00	0.513
11/09/2019 8:00	0.973
11/09/2019 9:00	0.713
11/09/2019 10:00	0.463
11/09/2019 11:00	0.113
11/09/2019 12:00	-0.287
11/09/2019 13:00	-0.687
11/09/2019 14:00	-1.107
11/09/2019 15:00	-1.377
11/09/2019 16:00	-0.627
11/09/2019 17:00	-0.177
11/09/2019 18:00	0.423
12/09/2019 6:00	0.463

Date & Time	WL in MSL
22/06/2019 17:00	-0.287
22/06/2019 18:00	-0.717
23/06/2019 6:00	-1.467
23/06/2019 7:00	-1.067
23/06/2019 8:00	-0.797
23/06/2019 9:00	-0.277
23/06/2019 10:00	0.133
23/06/2019 11:00	0.543
23/06/2019 12:00	0.823
23/06/2019 13:00	1.103
23/06/2019 14:00	1.213
23/06/2019 15:00	0.893
23/06/2019 16:00	0.493

Date & Time	WL in MSL
02/08/2019 12:00	1.193
02/08/2019 13:00	0.773
02/08/2019 14:00	-0.207
02/08/2019 15:00	-0.467
02/08/2019 16:00	-0.957
02/08/2019 17:00	-1.437
02/08/2019 18:00	-1.597
03/08/2019 6:00	-0.767
03/08/2019 7:00	-0.207
03/08/2019 8:00	0.373
03/08/2019 9:00	1.003
03/08/2019 10:00	1.503
03/08/2019 11:00	1.613

Date & Time	WL in MSL
12/09/2019 7:00	0.803
12/09/2019 8:00	1.313
12/09/2019 9:00	1.513
12/09/2019 10:00	1.223
12/09/2019 11:00	0.923
12/09/2019 12:00	0.293
12/09/2019 13:00	-0.167
12/09/2019 14:00	-0.397
12/09/2019 15:00	-0.797
12/09/2019 16:00	-1.127
12/09/2019 17:00	-0.397
12/09/2019 18:00	0.113

A.1.2 Discharge Data

Tidal discharge data of Naf River has been measured for the month of July to October forth nightly as given in **Table A.1.2** to **Table A.1.5**.

Table A.1.2: Discharge measurement on dated 08/07/2019

Time	Total Q	Velocity	Flow Direction
	m^3/s	m/s	Degree
7:33:13	1126.111	0.606	128.63
8:10:17	896.619	0.502	130.36
8:47:21	559.894	0.277	126.37
9:24:25	-181.136	-0.083	311.64
9:57:22	-534.105	-0.248	313.43
10:51:59	-1159.677	-0.366	305.98
11:59:44	-1158.453	-0.443	308.56
12:51:54	-1065.638	-0.403	305.6
13:41:01	-907.705	-0.328	309.34
14:23:28	-493.863	-0.191	305.12
14:58:48	-175.819	-0.066	127.21
15:54:44	1396.619	0.532	130.36
16:25:04	1726.111	0.686	128.63
16:56:04	2073.98	0.887	129.09
17:31:30	1976.377	0.873	129.8
18:08:28	1793.158	0.877	129.25

Table A.1.3: Discharge measurement on dated 28/08/2019

Time	Total Q	Velocity	Flow Direction
	m^3/s	m/s	Degree
8:40:51	-862.354	-0.238	288.5
9:27:36	-11.526	-0.003	166.92
10:10:07	815.193	0.242	121.52
10:55:55	1876.128	0.632	124.37
11:33:19	2123.711	0.814	127.05
12:15:03	2083.52	0.898	127.4
13:02:59	1828.341	0.853	127.93
13:47:40	1604.62	0.809	127.24
14:33:46	1214.295	0.63	128.96
15:13:29	754.247	0.368	117.85
15:19:40	697.46	0.335	127.9
16:10:46	-741.368	-0.303	308.01
16:55:24	-1519.298	-0.545	304.47
17:11:34	-1236.17	-0.468	314.07

Table A.1.4: Discharge measurement on dated 12/09/2019

Time	Total Q	Velocity	Flow Direction
	m^3/s	m/s	Degree
9:12:48	-415.671	-0.129	295.23
9:19:37	-311.615	-0.103	297.92
10:05:21	333.27	0.111	135.57
10:10:46	475.191	0.155	127.37

Time	Total Q	Velocity	Flow Direction
	m³/s	m/s	Degree
10:47:09	1191.194	0.429	135.76
10:52:47	1330.038	0.446	129.78
11:42:08	2041.865	0.774	132.32
11:48:16	2010.254	0.754	130.23
12:39:27	2338.81	0.909	130.11
12:44:22	2355.581	0.947	129
13:30:35	2332.982	1.057	130.72
13:35:23	2239.753	1.005	128.21
14:10:54	2012.152	0.882	129.96
14:16:15	1956.669	0.95	127.9
15:12:54	1744.301	0.846	129.75
15:16:59	1671.829	0.83	127.75
15:48:56	1447.622	0.744	130.26
15:52:42	1345.686	0.696	129.1
16:25:15	929.47	0.494	134
16:29:19	813.727	0.412	127.55
17:01:37	375.796	0.182	154.38
17:08:53	106.394	0.049	100.6
17:41:03	-546.388	-0.226	317.72
17:45:11	-572.345	-0.237	321.02
17:55:39	-703.067	-0.339	316.11
17:59:01	-783.957	-0.349	317.78

Table A.1.5: Discharge measurement on dated 15/10/2019

Time	Total Q	Velocity	Flow Direction
	m³/s	m/s	Degree
7:09	-1756.576	-0.784	309.4
7:14	-1753.187	-0.778	313.49
7:28	-1752.533	-0.756	308.42
7:32	-1732.109	-0.732	313.22
8:01	-1595.292	-0.678	308.51
8:06	-1619.597	-0.639	311.54
8:34	-1553.542	-0.627	307.13
8:39	-1536.707	-0.591	310.14
9:03	-1446.504	-0.542	306.98
9:09	-1427.401	-0.536	313.26
9:37	-1286.891	-0.465	304.05
9:41	-1276.469	-0.444	307.97
10:07	-1081.249	-0.36	300.81
10:11	-1061.16	-0.338	310.2
10:33	-809.813	-0.272	295.98
10:37	-724.197	-0.218	311.8
11:04	-385.539	-0.121	282.44
11:08	-338.586	-0.077	339.05
11:37	295.886	0.132	143.6
11:41	381.165	0.191	119.64
12:06	990.301	0.365	132.43
12:10	1131.93	0.48	125.43
12:32	1523.502	0.597	133.11
12:35	1623.369	0.674	126.35
13:02	2017.225	0.848	132.66
13:05	2050.018	0.892	127.43

Time	Total Q	Velocity	Flow Direction
	m^3/s	m/s	Degree
13:33	2186.45	0.984	131.82
13:36	2168.763	1.015	128.18
14:02	2170.218	0.992	131.87
14:06	2133.01	1.052	127.6
14:33	1980.276	1.011	131.6
14:36	1959.296	1.025	128.59
14:59	1822.437	0.98	132.91
15:03	1785.541	0.99	128.41
15:32	1680.653	0.921	132.95
15:35	1612.114	0.937	128.12
16:03	1471.952	0.828	134.23
16:06	1425.348	0.855	127.62
16:32	1258.487	0.743	134.19
16:35	1225.289	0.775	129.7
17:01	945.544	0.551	135.17
17:05	890.282	0.583	128.04
17:27	466.952	0.276	138.98
17:31	428.735	0.267	125.89
17:45	57.137	0.068	174.59
17:55	-66.603	-0.039	328.35
17:55	-66.603	-0.039	328.35

ANNEX-2: WATER DEMAND ESIMATION IN SABRANG TOURISM PARK

Table A.2.1: Estimated water demand for Sabrang Tourism Park in Phase-1

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6	2	500	1000	50	100	1100	300	300000	3000	303000
	1A	5	2	500	1000	50	100	1100	300	300000	3000	303000
	1B	4		500	0	50	0	0	300	0	0	0
	1B	3		500	0	50	0	0	300	0	0	0
	1C	2		270	0	30	0	0	135	0	0	0
	1C	1.7		270	0	30	0	0	135	0	0	0
	1C	1.5	1	270	270	30	30	300	135	36450	900	37350
	1C	1.3	2	270	540	30	60	600	135	72900	1800	74700
	1C	1.2		270	0	30	0	0	135	0	0	0
	1C	1	8	270	2160	30	240	2400	135	291600	7200	298800
	1D	0.5		225	0	25	0	0	135	0	0	0
	1D	0.3		210	0	20	0	0	135	0	0	0
Studio Apartment	25	29		7740	0	860	0	0	135	0	0	0
Old Age Home	26	7.5		500	0	50	0	0	100	0	0	0
Welfare center	22	6		90	0	10	0	0	100	0	0	0
Golf course & Golf club	21	57		90	0	10	0	0	10	0	0	0
Amusement park	15	9		450	0	50	0	0	10	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	16	3.5		450	0	50	0	0	10	0	0	0
	17			450	0	50	0	0	10	0	0	0
	18			450	0	50	0	0	10	0	0	0
Eco park & Jhaw Forest	27	60		180	0	20	0	0	10	0	0	0
Shopping district & Cable car station	13	7		315	0	35	0	0	30	0	0	0
Central Green & Park	9B	22	0.5	90	45	10	5	50	10	450	50	500
	9A			90	45	10	5	50	10	450	50	500
Bus depot	8	3	1		0	10	10	10	10	0	100	100
Transportation Hub	19A	3			0	25	0	0	10	0	0	0
	19B				0	25	0	0	10	0	0	0
Administration	2	1.5	1		0	50	50	50	30	0	1500	1500
Fire station	5	1.5	1		0	50	50	50	30	0	1500	1500
Tourist police station	3	1.5	1		0	50	50	50	30	0	1500	1500
Hospital	4	1.5	1	180	180	20	20	200	135	24300	600	24900
Jetty station	20	3			0	100	0	0	30	0	0	0
Security		2			0	50	0	0	30	0	0	0
Bio gas plant	7	1	1		0	50	50	50	30	0	1500	1500
Gas plant station	23	3			0	50	0	0	30	0	0	0
Power plant station	24	6.5			0	25	0	0	30	0	0	0
Electrical Substation	10A	2			0	25	0	0	30	0	0	0
	10B	1			0	80	0	0	30	0	0	0
STP	6B	4			0	25	0	0	30	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	6A	2.5	1		0	25	25	25	30	0	750	750
Helipad	11A	1.5	1		0	25	25	25	10	0	250	250
	11B	0.2			0	50	0	0	10	0	0	0
Garbage disposal station	12	3.6	1		0	200	200	200	10	0	2000	2000
Water Reservoir & Treatment Plant	14	2			0	**50**	0	0	30	0	0	0
Total domestic water demand					**5,240**		**1,020**	**6,260**		**1,026,150**	**25,700**	**1,051,850**
Water demand for Amusement Park												-
Water demand for Sub Station PP												960,000
Total Water demand Requirement												**2,011,850**
Water Requirement at source												**2,514,813**

Table A.2.2: Estimated water demand for Sabrang Tourism Park in Phase-2

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6	2	500	1000	50	100	1100	300	300000	3000	303000
	1A	5	1	500	500	50	50	550	300	150000	1500	151500
	1B	4		500	0	50	0	0	300	0	0	0
	1B	3		500	0	50	0	0	300	0	0	0
	1C	2	1	270	270	30	30	300	135	36450	900	37350
	1C	1.7	1	270	270	30	30	300	135	36450	900	37350
	1C	1.5	1	270	270	30	30	300	135	36450	900	37350
	1C	1.3	1	270	270	30	30	300	135	36450	900	37350
	1C	1.2	1	270	270	30	30	300	135	36450	900	37350
	1C	1	5	270	1350	30	150	1500	135	182250	4500	186750
	1D	0.5		225	0	25	0	0	135	0	0	0
	1D	0.3		210	0	20	0	0	135	0	0	0
Studio Apartment	25	29		7740	0	860	0	0	135	0	0	0
Old Age Home	26	7.5		500	0	50	0	0	100	0	0	0
Welfare center	22	6		90	0	10	0	0	100	0	0	0
Golf course & Golf club	21	57		90	0	10	0	0	10	0	0	0
Amusement park	15	9		450	0	50	0	0	10	0	0	0
	16	3.5		450	0	50	0	0	10	0	0	0
	17			450	0	50	0	0	10	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	18			450	0	50	0	0	10	0	0	0
Eco park & Jhaw Forest	27	60		180	0	20	0	0	10	0	0	0
Shopping district & Cable car station	13	7	1	315	315	35	35	350	30	9450	1050	10500
Central Green & Park	9B	22	0.5	90	45	10	5	50	10	450	50	500
	9A			90	45	10	5	50	10	450	50	500
Bus depot	8	3			0	10	0	0	10	0	0	0
Transportation Hub	19A	3			0	25	0	0	10	0	0	0
	19B				0	25	0	0	10	0	0	0
Administration	2	1.5			0	50	0	0	30	0	0	0
Fire station	5	1.5			0	50	0	0	30	0	0	0
Tourist police station	3	1.5			0	50	0	0	30	0	0	0
Hospital	4	1.5		180	0	20	0	0	135	0	0	0
Jetty station	20	3			0	100	0	0	30	0	0	0
Security		2			0	50	0	0	30	0	0	0
Bio gas plant	7	1			0	50	0	0	30	0	0	0
Gas plant station	23	3			0	50	0	0	30	0	0	0
Power plant station	24	6.5			0	25	0	0	30	0	0	0
Electrical Substation	10A	2	1		0	25	25	25	30	0	750	750
	10B	1			0	80	0	0	30	0	0	0
STP	6B	4	1		0	25	25	25	30	0	750	750

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	6A	2.5			0	25	0	0	30	0	0	0
Helipad	11A	1.5			0	25	0	0	10	0	0	0
	11B	0.2			0	50	0	0	10	0	0	0
Garbage disposal station	12	3.6			0	200	0	0	10	0	0	0
Water Reservoir & Treatment Plant	14	2			0	**50**	0	0	30	0	0	0
Total domestic water demand					**4,605**		**545**	**5,150**		**824,850**	**16,150**	**841,000**
Water demand for Amusement Park												**-**
Water demand for Sub Station PP												-
Total Water demand Requirement												**841,000**
Water Requirement at source												**1,051,250**

Table A.2.3: Estimated water demand for Sabrang Tourism Park in Phase-3

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6	3	500	1500	50	150	1650	300	450000	4500	454500
	1A	5		500	0	50	0	0	300	0	0	0
	1B	4	1	500	500	50	50	550	300	150000	1500	151500
	1B	3	2	500	1000	50	100	1100	300	300000	3000	303000
	1C	2		270	0	30	0	0	135	0	0	0
	1C	1.7		270	0	30	0	0	135	0	0	0
	1C	1.5		270	0	30	0	0	135	0	0	0
	1C	1.3		270	0	30	0	0	135	0	0	0
	1C	1.2		270	0	30	0	0	135	0	0	0
	1C	1		270	0	30	0	0	135	0	0	0
	1D	0.5	2	225	450	25	50	500	135	60750	1500	62250
	1D	0.3	29	210	6090	20	580	6670	135	822150	17400	839550
Studio Apartment	25	29		7740	0	860	0	0	135	0	0	0
Old Age Home	26	7.5		500	0	50	0	0	100	0	0	0
Welfare center	22	6		90	0	10	0	0	100	0	0	0
Golf course & Golf club	21	57		90	0	10	0	0	10	0	0	0
Amusement park	15	9		450	0	50	0	0	10	0	0	0
	16	3.5		450	0	50	0	0	10	0	0	0
	17			450	0	50	0	0	10	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	18			450	0	50	0	0	10	0	0	0
Eco park & Jhaw Forest	27	60		180	0	20	0	0	10	0	0	0
Shopping district & Cable car station	13	7		315	0	35	0	0	30	0	0	0
Central Green & Park	9B	22		90	0	10	0	0	10	0	0	0
	9A			90	0	10	0	0	10	0	0	0
Bus depot	8	3			0	10	0	0	10	0	0	0
Transportation Hub	19A	3			0	25	0	0	10	0	0	0
	19B				0	25	0	0	10	0	0	0
Administration	2	1.5			0	50	0	0	30	0	0	0
Fire station	5	1.5			0	50	0	0	30	0	0	0
Tourist police station	3	1.5			0	50	0	0	30	0	0	0
Hospital	4	1.5		180	0	20	0	0	135	0	0	0
Jetty station	20	3			0	100	0	0	30	0	0	0
Security		2			0	50	0	0	30	0	0	0
Bio gas plant	7	1			0	50	0	0	30	0	0	0
Gas plant station	23	3			0	50	0	0	30	0	0	0
Power plant station	24	6.5			0	25	0	0	30	0	0	0
Electrical Substation	10A	2			0	25	0	0	30	0	0	0
	10B	1			0	80	0	0	30	0	0	0
STP	6B	4			0	25	0	0	30	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	6A	2.5			0	25	0	0	30	0	0	0
Helipad	11A	1.5			0	25	0	0	10	0	0	0
	11B	0.2			0	50	0	0	10	0	0	0
Garbage disposal station	12	3.6			0	200	0	0	10	0	0	0
Water Reservoir & Treatment Plant	14	2	1		0	**50**	50	50	30	0	1500	1500
Total domestic water demand					**9,540**		**980**	**10,520**		**1,782,900**	**29,400**	**1,812,300**
Water demand for Amusement Park												**-**
Water demand for Sub Station PP												-
Total Water demand Requirement												**1,812,300**
Water Requirement at source												**2,265,375**

Table A.2.4: Estimated water demand for Sabrang Tourism Park in Phase-4

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6	2	500	1000	50	100	1100	300	300000	3000	303000
	1A	5		500	0	50	0	0	300	0	0	0
	1B	4		500	0	50	0	0	300	0	0	0
	1B	3	4	500	2000	50	200	2200	300	600000	6000	606000
	1C	2		270	0	30	0	0	135	0	0	0
	1C	1.7		270	0	30	0	0	135	0	0	0
	1C	1.5		270	0	30	0	0	135	0	0	0
	1C	1.3		270	0	30	0	0	135	0	0	0
	1C	1.2		270	0	30	0	0	135	0	0	0
	1C	1		270	0	30	0	0	135	0	0	0
	1D	0.5		225	0	25	0	0	135	0	0	0
	1D	0.3		210	0	20	0	0	135	0	0	0
Studio Apartment	25	29		7740	0	860	0	0	135	0	0	0
Old Age Home	26	7.5	1	500	500	50	50	550	100	50000	1500	51500
Welfare center	22	6		90	0	10	0	0	100	0	0	0
Golf course & Golf club	21	57		90	0	10	0	0	10	0	0	0
Amusement park	15	9	1	450	450	50	50	500	10	4500	500	5000
	16	3.5	1	450	450	50	50	500	10	4500	500	5000
	17		1	450	450	50	50	500	10	4500	500	5000

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	18		1	450	450	50	50	500	10	4500	500	5000
Eco park & Jhaw Forest	27	60	1	180	180	20	20	200	10	1800	200	2000
Shopping district & Cable car station	13	7		315	0	35	0	0	30	0	0	0
Central Green & Park	9B	22		90	0	10	0	0	10	0	0	0
	9A			90	0	10	0	0	10	0	0	0
Bus depot	8	3			0	10	0	0	10	0	0	0
Transportation Hub	19A	3	1		0	25	25	25	10	0	250	250
	19B				0	25	25	25	10	0	250	250
Administration	2	1.5			0	50	0	0	30	0	0	0
Fire station	5	1.5			0	50	0	0	30	0	0	0
Tourist police station	3	1.5			0	50	0	0	30	0	0	0
Hospital	4	1.5		180	0	20	0	0	135	0	0	0
Jetty station	20	3			0	100	0	0	30	0	0	0
Security		2			0	50	0	0	30	0	0	0
Bio gas plant	7	1			0	50	0	0	30	0	0	0
Gas plant station	23	3			0	50	0	0	30	0	0	0
Power plant station	24	6.5			0	25	0	0	30	0	0	0
Electrical Substation	10A	2			0	25	0	0	30	0	0	0
	10B	1	1		0	80	80	80	30	0	2400	2400
STP	6B	4			0	25	0	0	30	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	6A	2.5			0	25	0	0	30	0	0	0
Helipad	11A	1.5			0	25	0	0	10	0	0	0
	11B	0.2			0	50	0	0	10	0	0	0
Garbage disposal station	12	3.6			0	200	0	0	10	0	0	0
Water Reservoir & Treatment Plant	14	2			0	**50**	0	0	30	0	0	0
Total domestic water demand					**5,480**		**700**	**6,180**		**969,800**	**15,600**	**985,400**
Water demand for Amusement Park												40,000
Water demand for Sub Station PP												-
Total Water demand Requirement												**1,025,400**
Water Requirement at source												**1,281,750**

Table A.2.5: Estimated water demand for Sabrang Tourism Park in Phase-5

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6		500	0	50	0	0	300	0	0	0
	1A	5		500	0	50	0	0	300	0	0	0
	1B	4		500	0	50	0	0	300	0	0	0
	1B	3		500	0	50	0	0	300	0	0	0
	1C	2		270	0	30	0	0	135	0	0	0
	1C	1.7		270	0	30	0	0	135	0	0	0
	1C	1.5		270	0	30	0	0	135	0	0	0
	1C	1.3		270	0	30	0	0	135	0	0	0
	1C	1.2		270	0	30	0	0	135	0	0	0
	1C	1		270	0	30	0	0	135	0	0	0
	1D	0.5		225	0	25	0	0	135	0	0	0
	1D	0.3		210	0	20	0	0	135	0	0	0
Studio Apartment	25	29	1	7740	7740	860	860	8600	135	1044900	25800	1070700
Old Age Home	26	7.5		500	0	50	0	0	100	0	0	0
Welfare center	22	6	1	90	90	10	10	100	100	9000	300	9300
Golf course & Golf club	21	57		90	0	10	0	0	10	0	0	0
Amusement park	15	9		450	0	50	0	0	10	0	0	0
	16	3.5		450	0	50	0	0	10	0	0	0
	17			450	0	50	0	0	10	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	18			450	0	50	0	0	10	0	0	0
Eco park & Jhaw Forest	27	60		180	0	20	0	0	10	0	0	0
Shopping district & Cable car station	13	7		315	0	35	0	0	30	0	0	0
Central Green & Park	9B	22		90	0	10	0	0	10	0	0	0
	9A			90	0	10	0	0	10	0	0	0
Bus depot	8	3			0	10	0	0	10	0	0	0
Transportation Hub	19A	3			0	25	0	0	10	0	0	0
	19B				0	25	0	0	10	0	0	0
Administration	2	1.5			0	50	0	0	30	0	0	0
Fire station	5	1.5			0	50	0	0	30	0	0	0
Tourist police station	3	1.5			0	50	0	0	30	0	0	0
Hospital	4	1.5		180	0	20	0	0	135	0	0	0
Jetty station	20	3			0	100	0	0	30	0	0	0
Security		2	1		0	50	50	50	30	0	1500	1500
Bio gas plant	7	1			0	50	0	0	30	0	0	0
Gas plant station	23	3	1		0	50	50	50	30	0	1500	1500
Power plant station	24	6.5	1		0	25	25	25	30	0	750	750
Electrical Substation	10A	2			0	25	0	0	30	0	0	0
	10B	1			0	80	0	0	30	0	0	0
STP	6B	4			0	25	0	0	30	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	6A	2.5			0	25	0	0	30	0	0	0
Helipad	11A	1.5			0	25	0	0	10	0	0	0
	11B	0.2			0	50	0	0	10	0	0	0
Garbage disposal station	12	3.6			0	200	0	0	10	0	0	0
Water Reservoir & Treatment Plant	14	2			0	**50**	0	0	30	0	0	0
Total domestic water demand					**7,830**		**995**	**8,825**		**1,053,900**	**29,850**	**1,083,750**
Water demand for Amusement Park												-
Water demand for Sub Station PP												-
Total Water demand Requirement												**1,083,750**
Water Requirement at source												**1,354,688**

Table A.2.6: Estimated water demand for Sabrang Tourism Park in Phase-6

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
		(Acre)	(no)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Accommodation/Residential	1A	6	6	500	3000	50	300	3300	300	900000	9000	909000
	1A	5		500	0	50	0	0	300	0	0	0
	1B	4		500	0	50	0	0	300	0	0	0
	1B	3		500	0	50	0	0	300	0	0	0
	1C	2		270	0	30	0	0	135	0	0	0
	1C	1.7		270	0	30	0	0	135	0	0	0
	1C	1.5		270	0	30	0	0	135	0	0	0
	1C	1.3		270	0	30	0	0	135	0	0	0
	1C	1.2		270	0	30	0	0	135	0	0	0
	1C	1		270	0	30	0	0	135	0	0	0
	1D	0.5		225	0	25	0	0	135	0	0	0
	1D	0.3		210	0	20	0	0	135	0	0	0
Studio Apartment	25	29		7740	0	860	0	0	135	0	0	0
Old Age Home	26	7.5		500	0	50	0	0	100	0	0	0
Welfare center	22	6		90	0	10	0	0	100	0	0	0
Golf course & Golf club	21	57	1	90	90	10	10	100	10	900	100	1000
Amusement park	15	9		450	0	50	0	0	10	0	0	0
	16	3.5		450	0	50	0	0	10	0	0	0
	17			450	0	50	0	0	10	0	0	0

Land Use	Plot Category	Plot Size	Number of Plots	Tourist		Work Force		Total Population	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
Heritage Museum, Convention Centre, Amphitheatre	18			450	0	50	0	0	10	0	0	0
Eco park & Jhaw Forest	27	60		180	0	20	0	0	10	0	0	0
Shopping district & Cable car station	13	7		315	0	35	0	0	30	0	0	0
Central Green & Park	9B	22		90	0	10	0	0	10	0	0	0
	9A			90	0	10	0	0	10	0	0	0
Bus depot	8	3			0	10	0	0	10	0	0	0
Transportation Hub	19A	3			0	25	0	0	10	0	0	0
	19B		1		0	25	0	0	10	0	0	0
Administration	2	1.5			0	50	0	0	30	0	0	0
Fire station	5	1.5			0	50	0	0	30	0	0	0
Tourist police station	3	1.5			0	50	0	0	30	0	0	0
Hospital	4	1.5		180	0	20	0	0	135	0	0	0
Jetty station	20	3	1		0	100	100	100	30	0	3000	3000
Security		2			0	50	0	0	30	0	0	0
Bio gas plant	7	1			0	50	0	0	30	0	0	0
Gas plant station	23	3			0	50	0	0	30	0	0	0
Power plant station	24	6.5			0	25	0	0	30	0	0	0
Electrical Substation	10A	2			0	25	0	0	30	0	0	0
	10B	1			0	80	0	0	30	0	0	0
STP	6B	4			0	25	0	0	30	0	0	0

Land Use	**Plot Category**	**Plot Size**	**Number of Plots**	**Tourist**		**Work Force**		**Total Population**	**Water demand**	**Water Requirement for Tourist**	**Water Requirement for Work Force**	**Total Water Requirement for Population**
	6A	2.5			0	25	0	0	30	0	0	0
Helipad	11A	1.5			0	25	0	0	10	0	0	0
	11B	0.2	1		0	50	50	50	10	0	500	500
Garbage disposal station	12	3.6			0	200	0	0	10	0	0	0
Water Reservoir & Treatment Plant	14	2			0	**50**	0	0	30	0	0	0
Total domestic water demand					**3,090**		**460**	**3,550**		**900,900**	**12,600**	**913,500**
Water demand for Amusement Park												-
Water demand for Sub Station PP												-
Total Water demand Requirement												**913,500**
Water Requirement at source												**1,141,875**

ANNEX-3: WATER DEMAND ESIMATION IN NAF TOURISM PARK

Table A.3.1: Estimated water demand for Naf Tourism Park in Phase-1

Facilities	Area		Plot Number	Footprint percentage	Tourist (Nos.)		Work Force (Nos.)		Total population (Nos.)	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	(Acre)	(sqm)	(no)	(%)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Hotels	10	40469	2	16.68	500	1000	50	100	1100	300	300000	4500	304500
Cottages	0.05	191	52	52.63	5	260	1.9	99	358.8	135	35100	2964	38064
Apartments	0.316	1278	10	25.83	20	200	3.86	39	238.6	135	27000	1158	28158
BGB	1.2	4856	1	40			70	70	70	30		2100	2100
Central Plaza & Shopping District	50	202343	0.5	13.2			15	7.5	7.5	30		225	225
STP	0.06	243	0	80			15	0	0	30		0	0
Fire Station	0.7	2857	0	40			30	0	0	30		0	0
Power House	0.7	2857	1	60			20	20	20	30		600	600
Service Staff	0.7	2857	0	40			170	0	0	30		0	0
Security Staff	0.7	2857	0	40			95	0	0	30		0	0
Gas & Pump House	0.7	2857	1	2			15	15	15	30		450	450
Garbage Sorting Station & STS	1	4047	0	15			15	0	0	30		0	0

Facilities	**Area**		**Plot Number**	**Footprint percentage**	**Tourist (Nos.)**		**Work Force (Nos.)**		**Total population (Nos.)**	**Water demand**	**Water Requirement for Tourist**	**Water Requirement for Work Force**	**Total Water Requirement for Population**
	(Acre)	**(sqm)**	**(no)**	**(%)**	**(no Per Plot)**	**(no Total)**	**(no Per Plot)**	**(no Total)**	**(no)**	**(Lpcd)**	**(Litre/day)**	**(Litre/day)**	**(Litre/day)**
Cable Car Station	1.2	4856	1	15			25	25	25	30		750	750
Parking & Tunnel Access Station	21.5	87008	0	40			50	0	0	30		0	0
Helipad	0.05	200	0	2			5	0	0	30		0	0
Restaurants	0.33	1336	0	60			12	0	0	30		0	0
Water Reservoir & Treatment Plant	0.22	900	1	90			20	20	20	30		600	600
Total domestic water demand	**89.426**	**362012**				**1460**		**395**	**1855**		**362,100**	**13,347**	**375,447**
Water demand for CCPP													14,000
Total Water demand Requirement													**389,447**

Facilities	Area		Plot Number	Footprint percentage	Tourist (Nos.)		Work Force (Nos.)		Total population (Nos.)	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	(Acre)	(sqm)	(no)	(%)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Water Requirement at source													**486,809**

Table A.3.2: Estimated water demand for Naf Tourism Park in Phase-2

Facilities	Area		Plot Number	Footprint percentage	Tourist (Nos.)		Work Force (Nos.)		Total population (Nos.)	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	(Acre)	(sqm)	(no)	(%)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Hotels	10	40469	0	16.68	500	0	50	0	0	300	0	0	0
Cottages	0.05	191	0	52.63	5	0	1.9	0	0	135	0	0	0
Apartments	0.316	1278	47	25.83	20	940	3.86	181	1121.42	135	126900	5442.6	132342.6
BGB	1.2	4856	0	40			70	0	0	30		0	0
Central Plaza & Shopping District	50	202343	0	13.2			15	0	0	30		0	0
STP	0.06	243	1	80			15	15	15	30		450	450
Fire Station	0.7	2857	0	40			30	0	0	30		0	0
Power House	0.7	2857	0	60			20	0	0	30		0	0
Service Staff	0.7	2857	0	40			170	0	0	30		0	0
Security Staff	0.7	2857	0	40			95	0	0	30		0	0
Gas & Pump House	0.7	2857	0	2			15	0	0	30		0	0
Garbage Sorting Station & STS	1	4047	1	15			15	15	15	30		450	450
Cable Car Station	1.2	4856	0	15			25	0	0	30		0	0

Facilities	Area		Plot Number	Footprint percentage	Tourist (Nos.)		Work Force (Nos.)		Total population (Nos.)	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	(Acre)	(sqm)	(no)	(%)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Parking & Tunnel Access Station	21.5	87008	0	40			50	0	0	30		0	0
Helipad	0.05	200	0	2			5	0	0	30		0	0
Restaurants	0.33	1336	5	60			12	60	60	30		1800	1800
Water Reservoir & Treatment Plant	0.22	900	0	90			20	0	0	30		0	0
Total domestic water demand	**89.426**	**362012**				**940**		**271**	**1211**		**126,900**	**8,143**	**135,043**
Water demand for CCPP													-
Total Water demand Requirement													**135,043**
Water Requirement at source													**168,803**

Table A.3.3: Estimated water demand for Naf Tourism Park in Phase-3

Facilities	Area		Plot Number	Footprint percentage	Tourist (Nos.)		Work Force (Nos.)		Total population (Nos.)	Water demand	Water Requirement for Tourist	Water Requirement for Work Force	Total Water Requirement for Population
	(Acre)	(sqm)	(no)	(%)	(no Per Plot)	(no Total)	(no Per Plot)	(no Total)	(no)	(Lpcd)	(Litre/day)	(Litre/day)	(Litre/day)
Hotels	10	40469	2	16.68	500	1000	50	100	1100	300	300000	4500	304500
Cottages	0.05	191	53	52.63	5	265	1.9	101	365.7	135	35775	3021	38796
Apartments	0.316	1278	0	25.83	20	0	3.86	0	0	135	0	0	0
BGB	1.2	4856	0	40			70	0	0	30		0	0
Central Plaza & Shopping District	50	202343	0.5	13.2			15	7.5	7.5	30		225	225
STP	0.06	243	0	80			15	0	0	30		0	0
Fire Station	0.7	2857	1	40			30	30	30	30		900	900
Power House	0.7	2857	0	60			20	0	0	30		0	0
Service Staff	0.7	2857	1	40			170	170	170	30		5100	5100
Security Staff	0.7	2857	1	40			95	95	95	30		2850	2850
Gas & Pump House	0.7	2857	0	2			15	0	0	30		0	0
Garbage Sorting Station & STS	1	4047	0	15			15	0	0	30		0	0
Cable Car Station	1.2	4856	0	15			25	0	0	30		0	0

Facilities	**Area**		**Plot Number**	**Footprint percentage**	**Tourist (Nos.)**		**Work Force (Nos.)**		**Total population (Nos.)**	**Water demand**	**Water Requirement for Tourist**	**Water Requirement for Work Force**	**Total Water Requirement for Population**
	(Acre)	**(sqm)**	**(no)**	**(%)**	**(no Per Plot)**	**(no Total)**	**(no Per Plot)**	**(no Total)**	**(no)**	**(Lpcd)**	**(Litre/day)**	**(Litre/day)**	**(Litre/day)**
Parking & Tunnel Access Station	21.5	87008	1	40			50	50	50	30		1500	1500
Helipad	0.05	200	1	2			5	5	5	30		150	150
Restaurants	0.33	1336	0	60			12	0	0	30		0	0
Water Reservoir & Treatment Plant	0.22	900	0	90			20	0	0	30		0	0
Total domestic water demand	**89.426**	**362012**				**1265**		**558**	**1823**		**335,775**	**18,246**	**354,021**
Water demand for CCPP													-
Total Water demand Requirement													**354,021**
Water Requirement at source													**442,526**

ANNEX-4: DATA FOR GROUNDWATER INVESTIGATION

A.4.1 Secondary Lithology Information

An intensive exploratory program had been carried out in Ukhiya and Teknaf jointly by DPHE-INGO Forum, Bangladesh and IWM for Water Resources Potential Assessment of Ukhia and Teknaf Upazila Area, Cox's bazar, Bangladesh. Project in 2017-2018. In the above mentioned project 22 number of exploratory well was drilled and most of the well drill depth was up to 300 meter. 10 number of well (2 in Ukhiya and 8 in Teknaf) are located within the present study area and information of these wells is used for further analysis of assessment of aquifer and water potential zone.

A.4.1.1 Granular Formation Evidenced in Ukhia

At **IWM TTU-13 (GL2294035)** site**,** single granular layer has been encountered, which is 15.24 to 48.78 m (thickness 33.54m) having fine to medium sand layer. At **IWM TTU-14 (GL2294023)** site, six granular layers have been found: (i) 3.05 to 18.29m (thickness 15.24m) having alternation of fine sand and fine to medium sand layer, and (ii) 24.39 to 30.49 m (thickness 6.1m) having very fine sand layer, (iii) 36.59 to 42.68 m (thickness 6.09 m) having very fine to fine sand layer, (iv) 54.88 to 201.22 m (thickness 146.34m) having alternation of fine sand and fine to medium sand and medium to coarse sand layer, (v) 219.51 to 228.66 m (thickness 9.15m) having fine sand layer, and (vi) 243.9 to 250 m (thickness 6.1m) having very fine to fine sand layer. The entire aquifer thickness of Ukhia from the individual borelog is compiled below on **Table A.4.1.**

Table A.4.1: Aquifer thickness evidenced in test borehole of the study area (Ukhia)

Well ID	Depth		Thickness (m)	Hydrostratigraphic Unit
	From (m)	To (m)		
IWM TTU--13 GL-2294035	0	6.1	6.1	Aquiclude
	6.1	15.24	9.14	Aquitard
	15.24	**48.78**	**33.54**	**Aquifer**
	48.78	182.93	134.15	Aquiclude
IWM TTU--14 GL-2294023	0	3.05	3.05	Aquitard
	3.05	**18.29**	**15.24**	**Aquifer**
	18.29	24.39	6.1	Aquiclude
	24.39	**30.49**	**6.1**	**Aquifer**
	30.49	36.59	6.1	Aquitard
	36.59	**42.68**	**6.09**	**Aquifer**
	42.68	54.88	12.2	Aquitard
	54.88	**201.22**	**146.34**	**Aquifer**
	201.22	219.51	18.29	Aquiclude
	219.51	**228.66**	**9.15**	**Aquifer**
	228.66	243.9	15.24	Aquiclude
	243.9	**250**	**6.1**	**Aquifer**
	250	256.1	6.1	Aquitard
	256.1	304.88	48.78	Aquiclude

A.4.1.2 Granular Formation Evidenced in Teknaf

Granular formations evidenced on individual test boreholes in Teknaf area are described here. **IWM TTT-01 (GL-2290021)** site shows that there are three granular layers: (i) 42.68 to 79.27 m (thickness 36.59m) having fine to medium sand, (ii) 88.41 to 97.56 m (thickness 9.15m) having fine to medium sand, and (iii)128 to 134.15 m (thickness 6.15m) having fine to medium sand layer. At **IWM TTT-02 (GL2290019)** site, six granular layers has been found: (i) 12.20 to 18.29 m (thickness 6.09m) consisting medium to fine sand, (ii) 24.39 to 30.49 m (thickness 6.1m) having fine to medium sand layer, (iii) 51.83 to 79.27 m (thickness 27.44m) comprising alternation of medium to fine sand and fine to medium sand, (iv) 91.46 to 121.95 m (thickness 30.49m) having fine to medium sand layer, (v) 128.05 to 170.73 m (thickness 42.68m) consisting fine to medium sand layer, and (vi) 195.12 to 204.27 m (thickness 9.15m) consisting fine to medium sand layer. At **IWM TTT-03 (GL2290020)** site, four granular layers has been found: (i) 54.88 to 57.93 m (thickness 3.05m) having medium to fine sand, (ii) 67.07 to 109.76 m (thickness 42.69m) having medium to coarse sand to fine to medium sand, (iii) 118.90 to 143.29 m (thickness 24.39m) having medium to coarse sand, and lastly (iv) 170.73 to 179.44 m (thickness 8.71m) having medium to fine sand layer. At **IWM TTT-05 (GL2290022)** site, four granular layer has been found: (i) 6.10 to 12.20 m (thickness 6.1m) having fine to medium sand, (ii) 42.68 to 60.98 m (thickness 18.3m) having fine to medium sand layer, (iii) 70.12 to 79.27 m (thickness 9.15m) having medium to fine sand, and lastly (iv) 134.15 to 158.54 m (thickness 24.39m) having fine to medium sand layer. At **IWM TTT-06 (GL2290026),** 304.88m drilling has completed and two granular layer has been found: (i) 3.05 to 12.20 m (thickness 9.15m) having very fine sand to fine sand, and (ii) 97.56 to 115.85 m (thickness 18.29m) having fine sand with little medium sand. At **IWM TTT-08 (GL2290023)** site, 304.88 meter drilling has been encountered but no productive layer found. At **IWM TTT-09 (GL2290024)** site, five granular layers have been found: (i) 12 to 24 m (thickness 12m) having fine to very fine sand layer, (ii) 30.49 to 60.98 m (thickness 30.49m) comprising fine to medium sand, (iii) 67.07 to 70.12 m (thickness 3.05m) consisting fine to medium sand, (iv) 76.22 to 79.27 m (thickness 3.05m) having fine to medium sand, and finally (v) 85.37 to 91.46 m (thickness 6.09m) having fine to medium sand layer. At **IWM TTT-11 (GL2290025)** site, two granular layers have been found: (i) 0 to 3.05 m (thickness 3.05m) having fine sand layer, and (ii) 3.05 to 12.20 m (thickness 9.15m) consisting fine to medium sand. The **Figure A.4.1** and **Figure A.4.2** represents the exploratory well drilling information. The entire aquifer thickness of the Teknaf Upazila from the individual borelog is compiled below in **Table A.4.2**.

Table A.4.2: Granular formation thickness evidenced in test borehole in Teknaf

Well ID	Depth		Thickness (m)	Hydrostratigraphic Unit
	From (m)	To (m)		
IWM TTT--01 GL-2290021	0	18.29	18.29	Aquiclude
	18.29	30.49	12.2	Aquitard
	30.49	**79.27**	**48.78**	**Aquifer**
	79.27	88.41	9.14	Aquitard
	88.41	**97.56**	**9.15**	**Aquifer**
	97.56	128.05	30.49	Aquiclude
	128.05	**137.2**	**9.15**	**Aquifer**

Well ID	Depth		Thickness (m)	Hydrostratigraphic Unit
	From (m)	To (m)		
	137.2	146.34	9.14	Aquitard
	146.34	179.88	33.54	Aquiclude
IWM TTT--02 GL-2290019	0	12.2	12.2	Aquitard
	12.2	**18.29**	**6.09**	**Aquifer**
	18.29	24.39	6.1	Aquitard
	24.39	**30.49**	**6.1**	**Aquifer**
	30.49	51.83	21.34	Aquitard
	51.83	**79.27**	**27.44**	**Aquifer**
	79.27	85.37	6.1	Aquitard
	85.37	91.46	6.09	Aquiclude
	91.46	**121.95**	**30.49**	**Aquifer**
	121.95	128.05	6.1	Aquitard
	128.05	**170.73**	**42.68**	**Aquifer**
	170.73	195.12	24.39	Aquitard
	195.12	**204.27**	**9.15**	**Aquifer**
	204.27	240.85	36.58	Aquitard
	240.85	262.2	21.35	Aquiclude
	262.2	280.49	18.29	Aquitard
	280.49	304.88	24.39	Aquiclude
IWM TTT--03 GL-2290020	0	6.1	6.1	Aquiclude
	6.1	15.24	9.14	Aquitard
	15.24	21.34	6.1	Aquiclude
	21.34	48.78	27.44	Aquitard
	48.78	54.88	6.1	Aquiclude
	54.88	**60.98**	**6.1**	**Aquifer**
	60.98	67.07	6.09	Aquiclude
	67.07	**109.76**	**42.69**	**Aquifer**
	109.76	118.9	9.14	Aquitard
	118.9	**143.29**	**24.39**	**Aquifer**
	143.29	146.34	3.05	Aquitard
	146.34	158.54	12.2	Aquiclude
	158.54	170.73	12.19	Aquitard
	170.73	**179.88**	**9.15**	**Aquifer**
	179.88	234.76	54.88	Aquiclude
	234.76	240.85	6.09	Aquitard
	240.85	289.63	48.78	Aquiclude
	289.63	292.68	3.05	Aquitard
	292.68	304.88	12.2	Aquiclude
IWM TTT--05 GL-2290022	0	3.05	3.05	Aquiclude
	3.05	**12.2**	**9.15**	**Aquifer**
	12.2	24.39	12.19	Aquitard
	24.39	33.54	9.15	Aquiclude
	33.54	42.68	9.14	Aquitard
	42.68	**60.98**	**18.3**	**Aquifer**

Well ID	Depth		Thickness (m)	Hydrostratigraphic Unit
	From (m)	To (m)		
	60.98	70.12	9.14	Aquitard
	70.12	**91.46**	**21.34**	**Aquifer**
	91.46	134.15	42.69	Aquitard
	134.15	**158.54**	**24.39**	**Aquifer**
	158.54	182.93	24.39	Aquitard
	182.93	271.34	88.41	Aquiclude
	271.34	304.88	33.54	Aquitard
IWM TTT--06 GL-2290026	0	6.1	6.1	Aquiclude
	6.1	**18.29**	**12.19**	**Aquifer**
	18.29	36.59	18.3	Aquitard
	36.59	67.07	30.48	Aquiclude
	67.07	70.12	3.05	Aquitard
	70.12	91.46	21.34	Aquiclude
	91.46	**94.51**	**3.05**	**Aquifer**
	94.51	97.56	3.05	Aquitard
	97.56	**115.85**	**18.29**	**Aquifer**
	115.85	219.51	103.66	Aquiclude
	219.51	234.76	15.25	Aquitard
	234.76	304.88	70.12	Aquiclude
IWM TTT--08 GL-2290023	0	30.49	30.49	Aquiclude
	30.49	36.59	6.1	Aquitard
	36.59	42.68	6.09	Aquiclude
	42.68	54.88	12.2	Aquitard
	54.88	60.98	6.1	Aquiclude
	60.98	67.07	6.09	Aquitard
	67.07	76.22	9.15	Aquiclude
	76.22	91.46	15.24	Aquitard
	91.46	170.73	79.27	Aquiclude
	170.73	176.83	6.1	Aquitard
	176.83	179.88	3.05	Aquiclude
	179.88	189.02	9.14	Aquitard
	189.02	268.29	79.27	Aquiclude
	268.29	277.44	9.15	Aquitard
	277.44	304.88	27.44	Aquiclude
IWM TTT--09 GL-2290024	**0**	**6.1**	**6.1**	**Aquifer**
	6.1	12.2	6.1	Aquiclude
	12.2	**24.39**	**12.19**	**Aquifer**
	24.39	30.49	6.1	Aquiclude
	30.49	**60.98**	**30.49**	**Aquifer**
	60.98	67.07	6.09	Aquiclude
	67.07	**70.12**	**3.05**	**Aquifer**
	70.12	76.22	6.1	Aquiclude
	76.22	**79.27**	**3.05**	**Aquifer**
	79.27	85.37	6.1	Aquiclude

Well ID	Depth		Thickness (m)	Hydrostratigraphic Unit
	From (m)	To (m)		
	85.37	**91.46**	**6.09**	**Aquifer**
	91.46	152.44	60.98	Aquiclude
IWM TTT--11 GL-2290025	**0**	**12.2**	**12.2**	**Aquifer**
	12.2	36.59	24.39	Aquitard
	36.59	85.37	48.78	Aquiclude
	85.37	103.66	18.29	Aquitard
	103.66	274.39	170.73	Aquiclude
	274.39	304.88	30.49	Aquitard

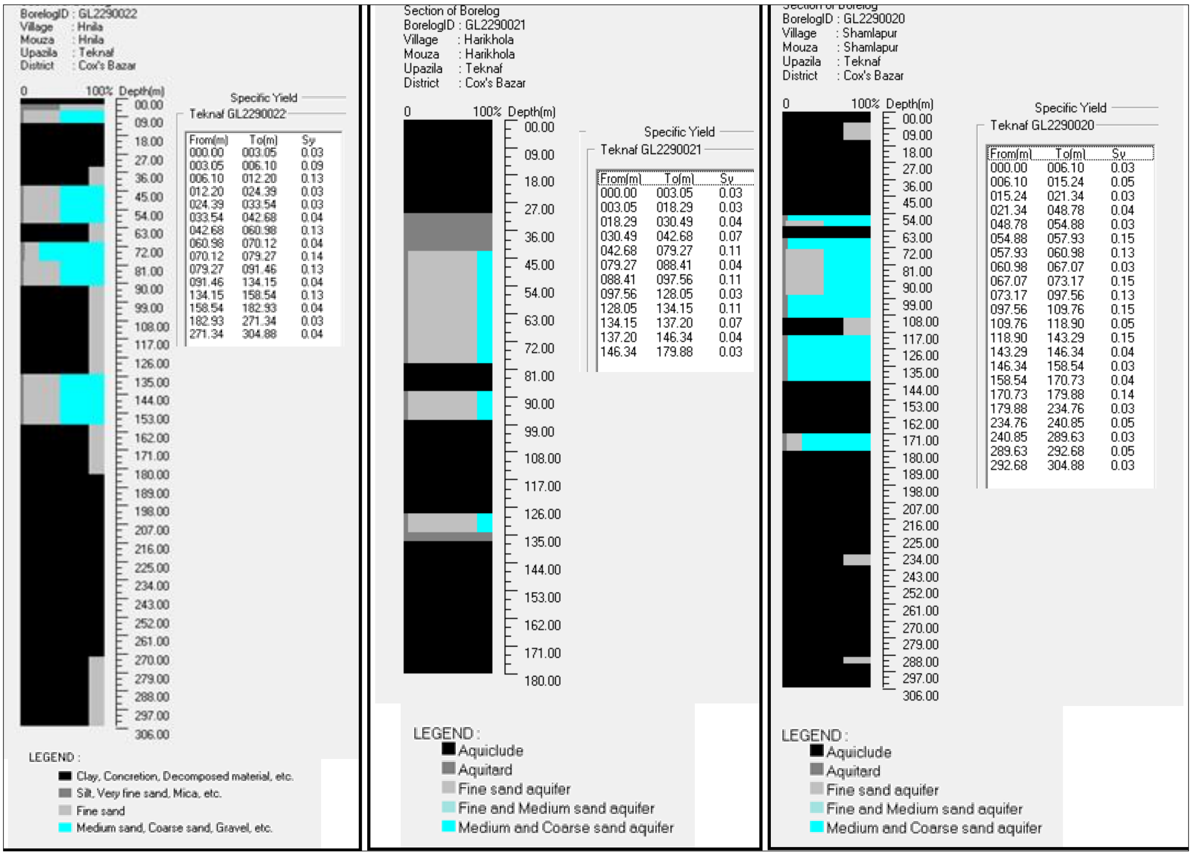


Figure A.4.1: Specific yield values of the exploratory well borehole

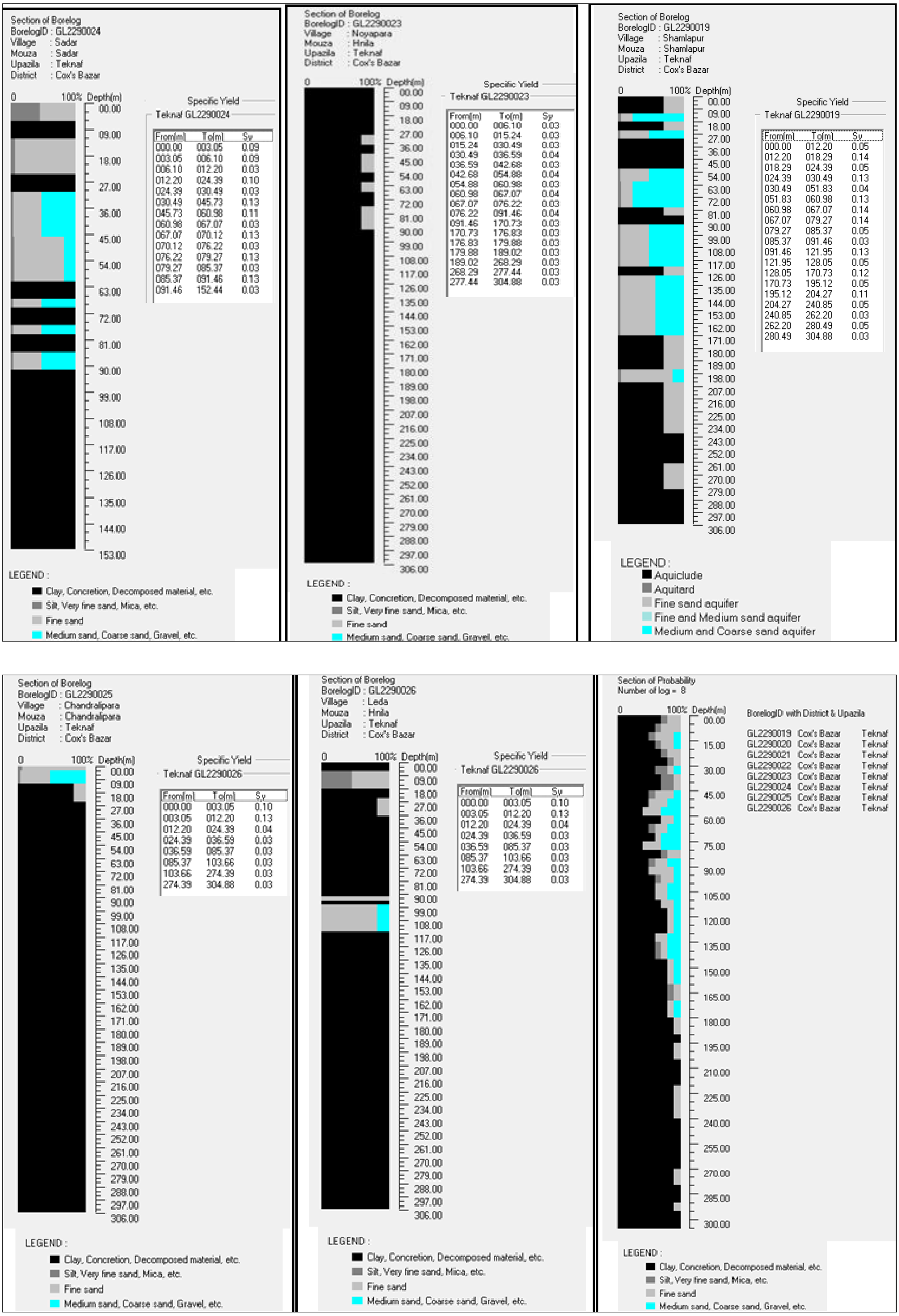


Figure A.4.2: Specific yield values of the exploratory well borehole

A.4.1.3 Probable Potential Zone of Aquifer

Hydrostratigraphic strip log from exploratory well's lithology revealing the lithological evidence of hydrogeological complexity for instance: major and minor faulting squeeze the lateral extension of individual layer, saline water intrusion from the coast in shallow aquifer, periodical saline intrusion line oscillation in inland part, inaccessible hill and hillock of the study area etc. Lithological information collected upto 304 m depth in 16 no wells and for rest of the borehole's depth ranges from 75 m to 180 m depth. Lithological information has been analyzed and hydrostratigraphic layers are defined based on these 22 no strip logs (**Figure A.4.3**). Using these strip-logs profiles have been prepared to view spatial distribution of hydrostratigraphic system throughout the study area.

Aquifer layer is very limited in most of the test well, which are constructed in the southern part of the Teknaf area. When these logs are plotted with the surface geology (**Figure A.4.4**) of the study area (**Figure A.4.5** and **Figure A.4.6**) it is found that most probably drilling encountered in Boka Bil Formation which is mainly constitute of shale, fine to very fine sand, silt and their alternation. However, this needs to be reconfirmed by further study. Fine sand aquifer of IWM TTT-09 (Teknaf) is comprises of beach and dune sand.

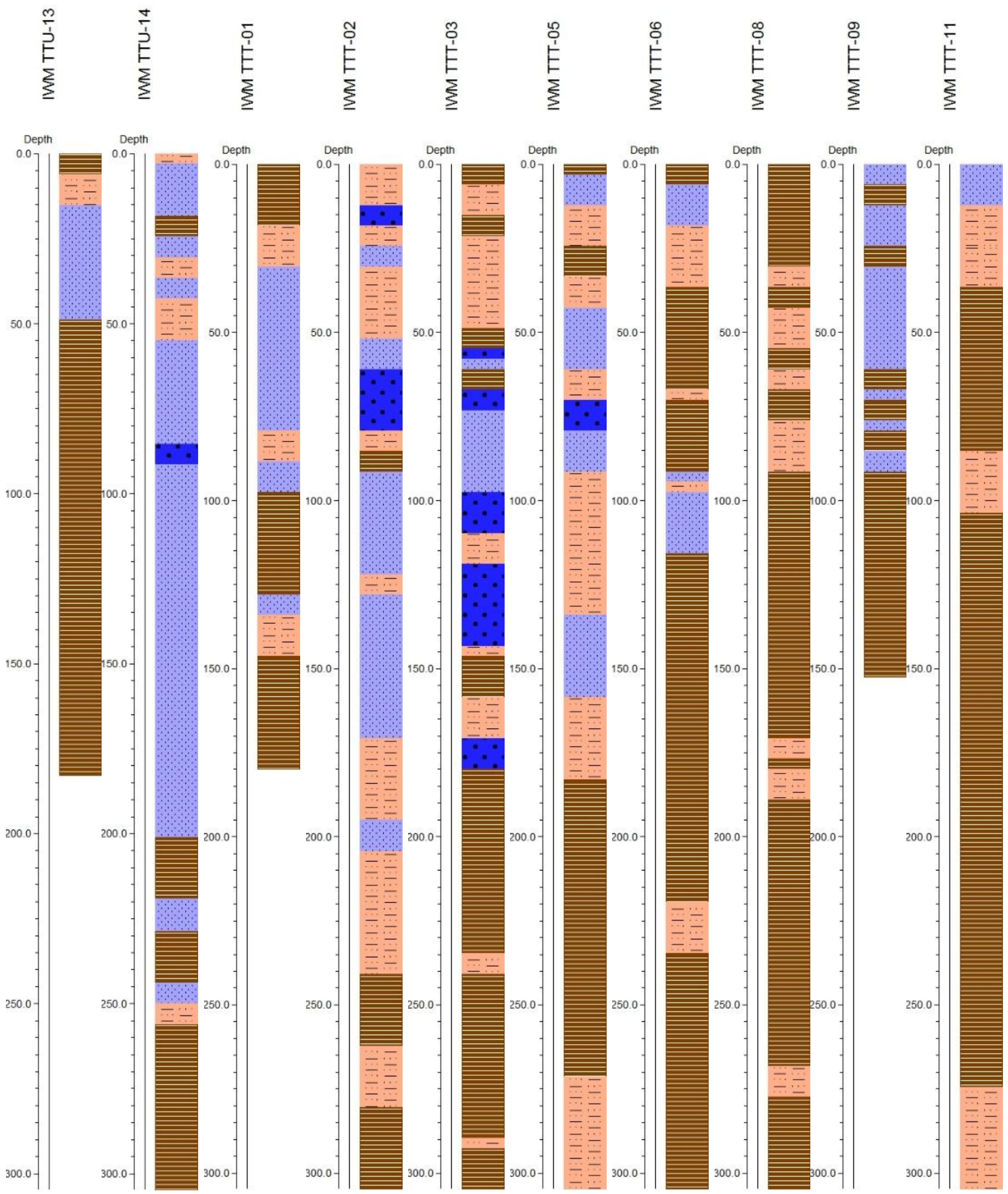


Figure A.4.3: Strip log (Hydrostratigraphic) of Ukhia and Teknaf Area

(Note: TTU-Striplog in Ukhia, TTT-Striplog in Teknaf)

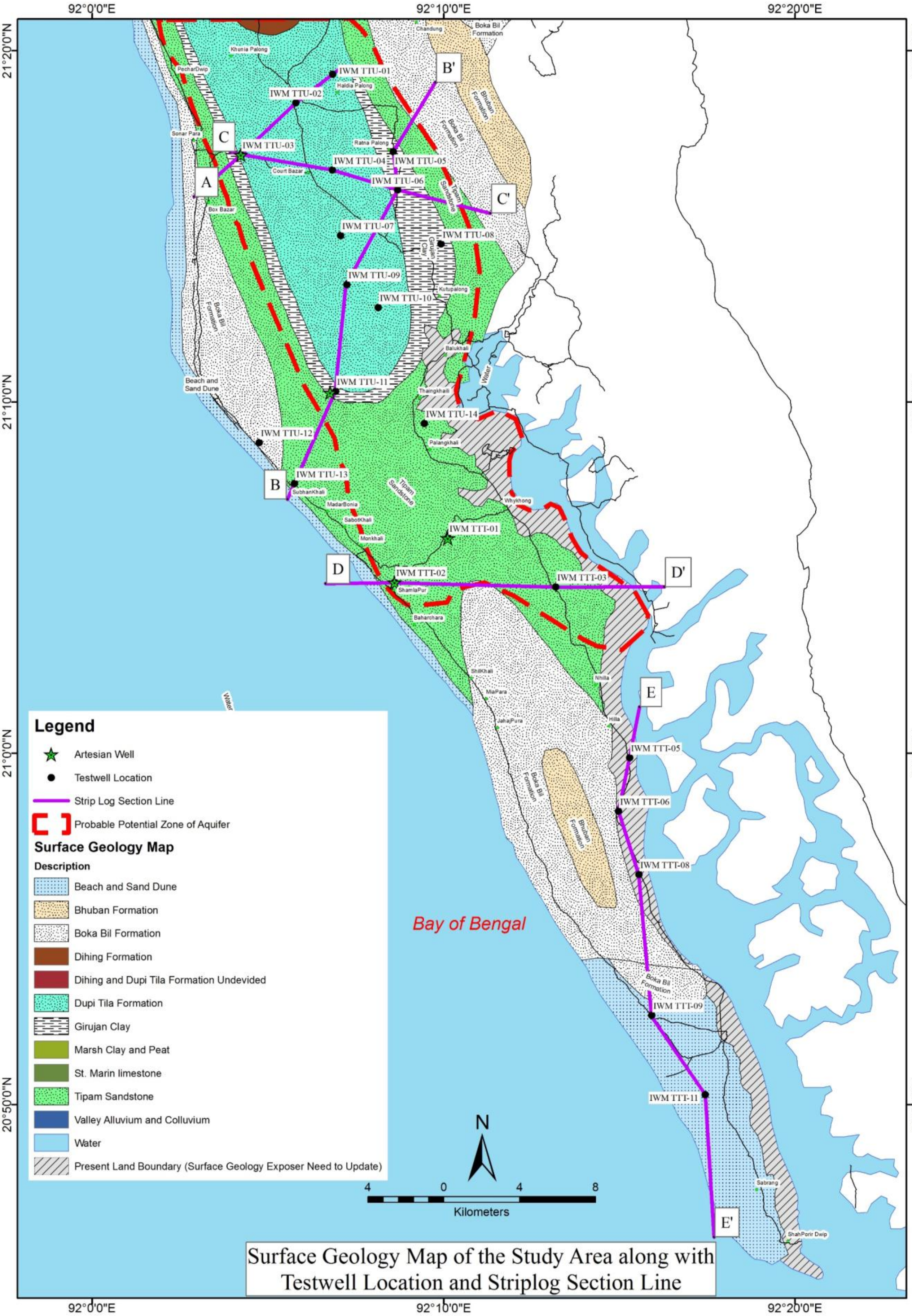


Figure A.4.4: Surafce geological map of the Study area with striplog section and test well location which suggest preliminary potential zone of aquifer

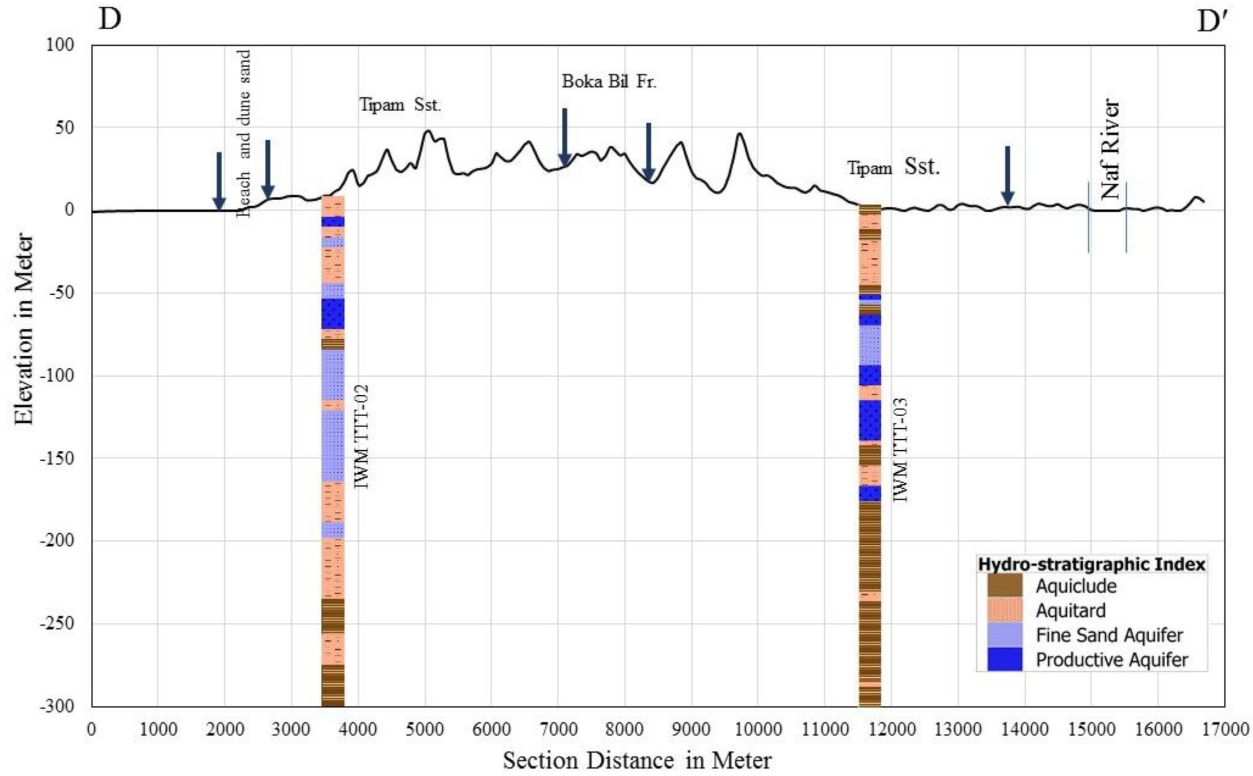


Figure A.4.5: Surface elevation profile with surface geology of the area and together with hydrostrtaigraphic striplog along the line DD′

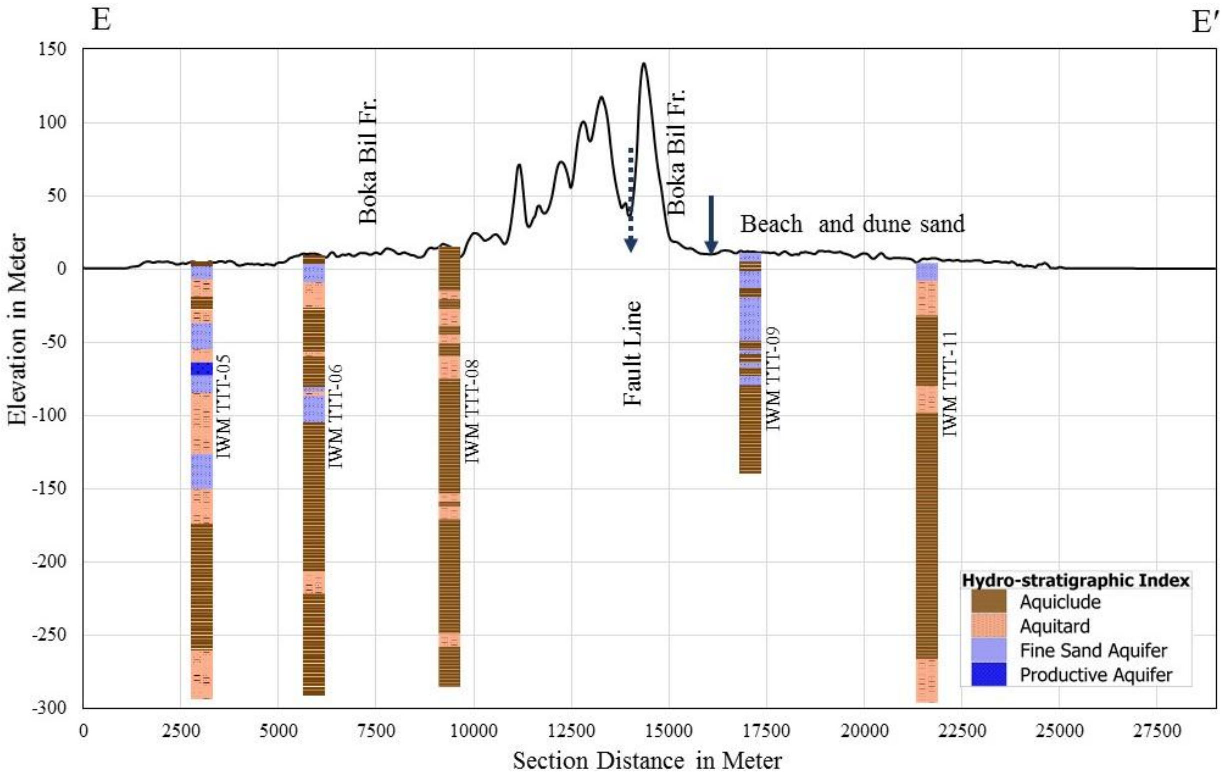


Figure A.4.6: Surface elevation profile with surface geology of the area and together with hydrostrtaigraphic striplog along the line EE'

A.4.2 Analysis of Aquifer Test Data

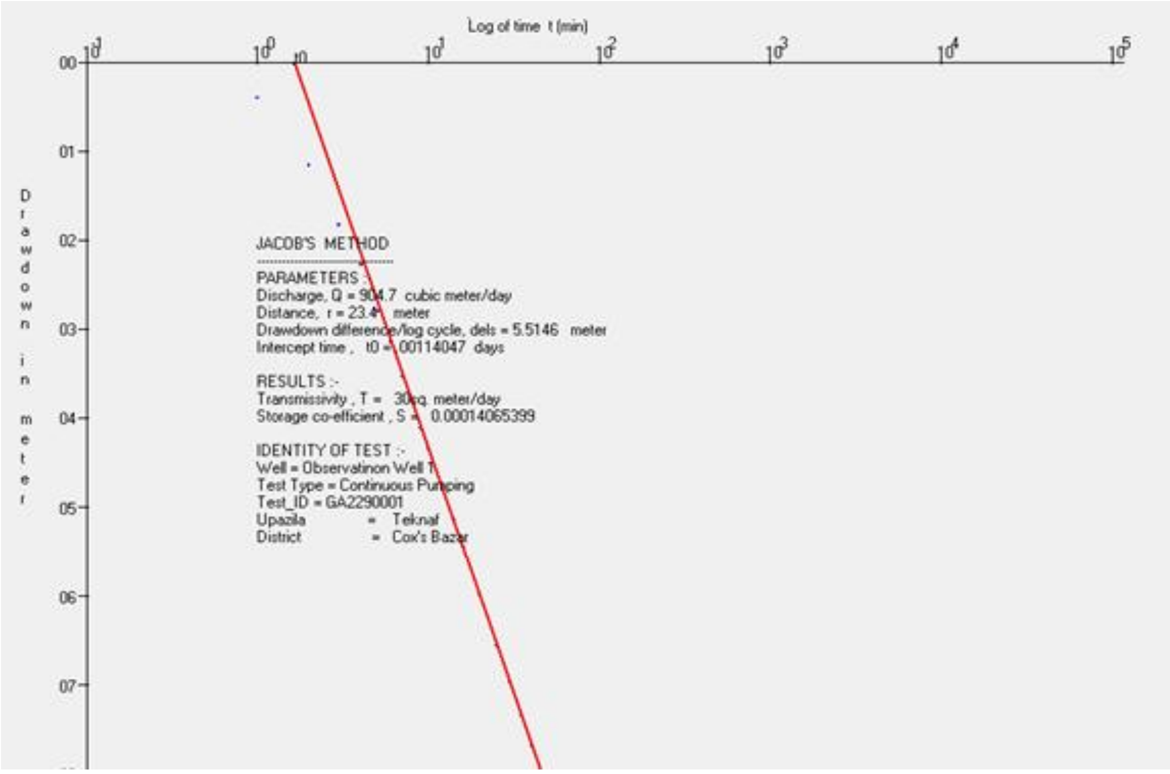


Figure A.4.7: Jacobs method of analysis for Observation wel1

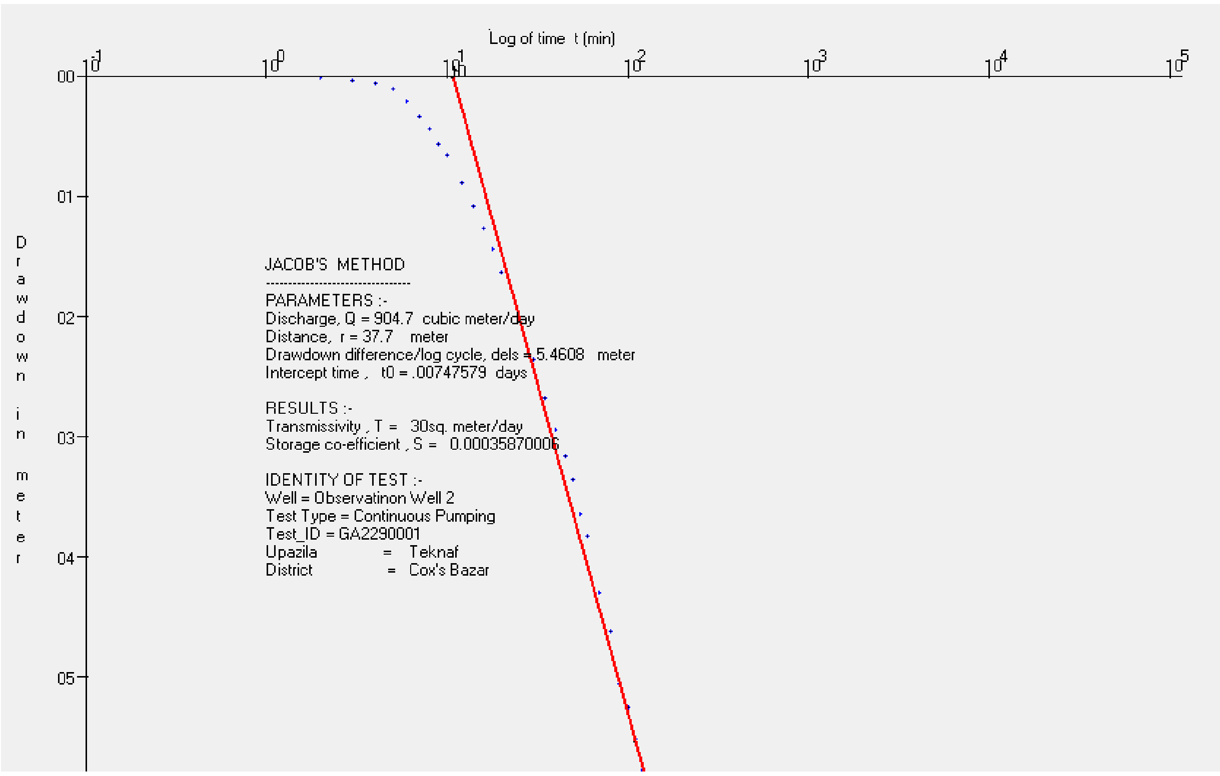


Figure A.4.8: Jacobs method of analysis for Observation well 2

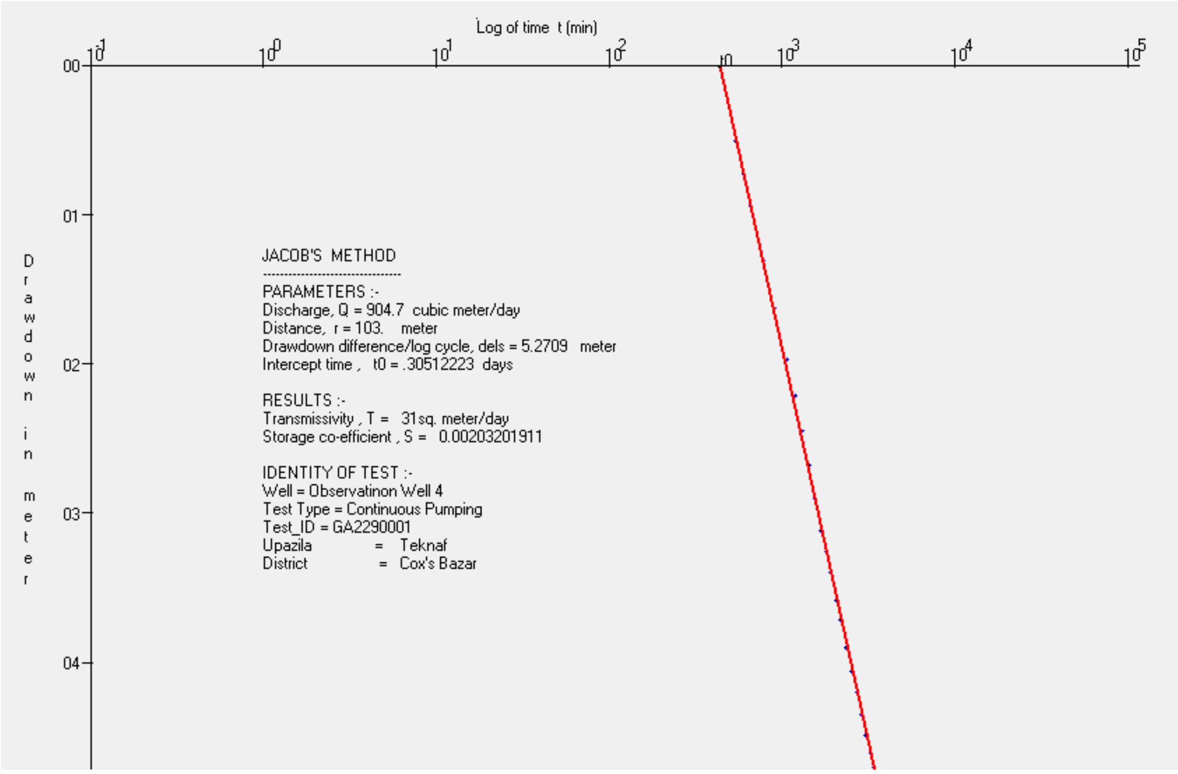


Figure A.4.9: Jacobs method of analysis for Observation well 4

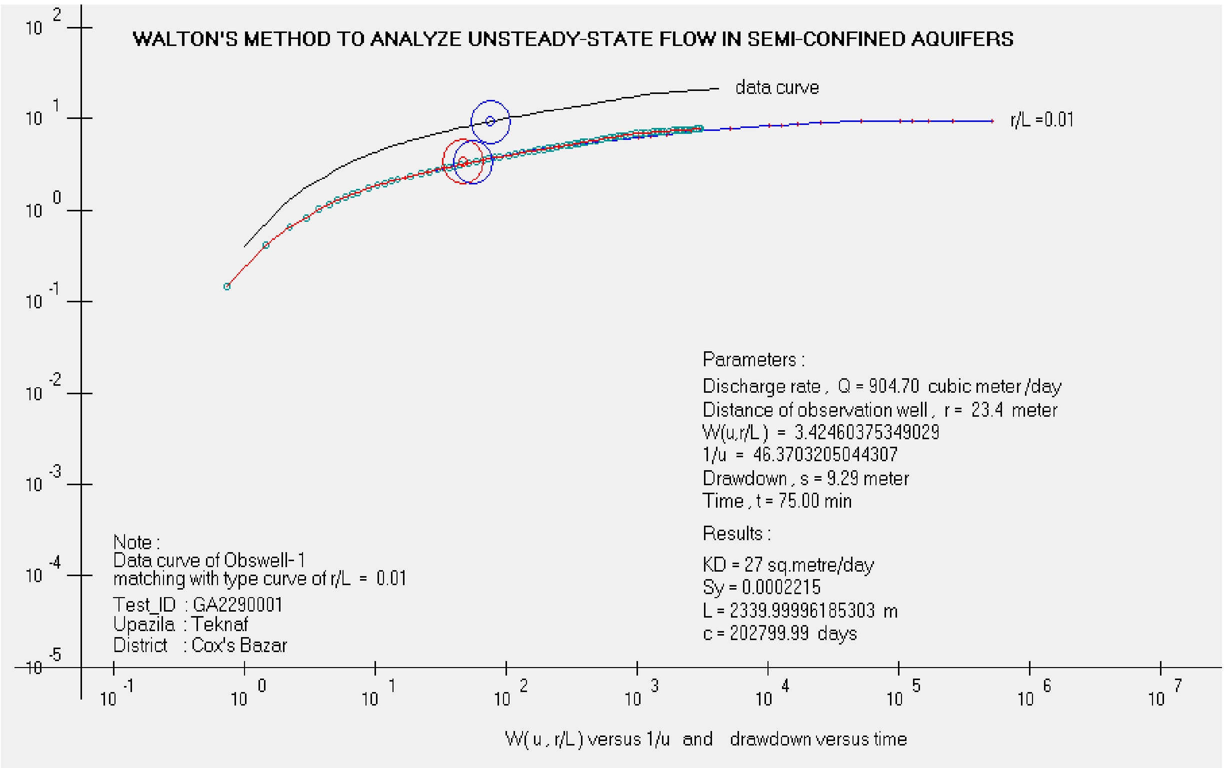


Figure A.4.10: Waltons method of analysis for unsteady state of flow, Observation well 1

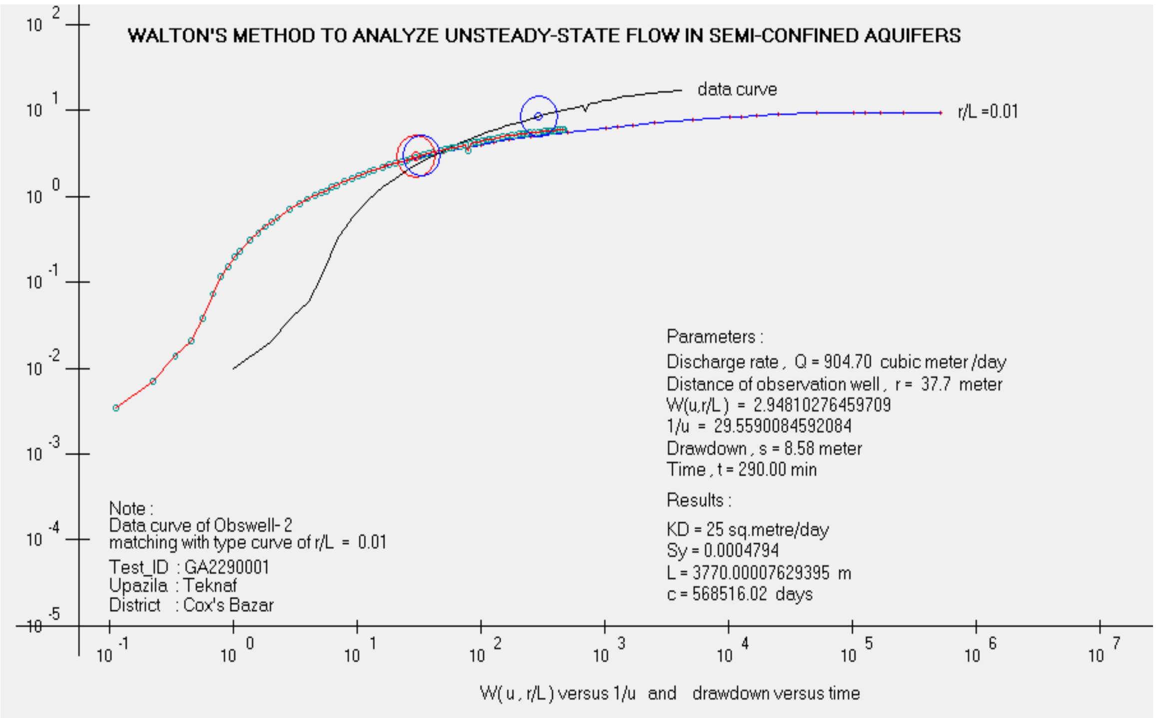


Figure A.4.11: Waltons method of analysis for unsteady state of flow, Observation well 2

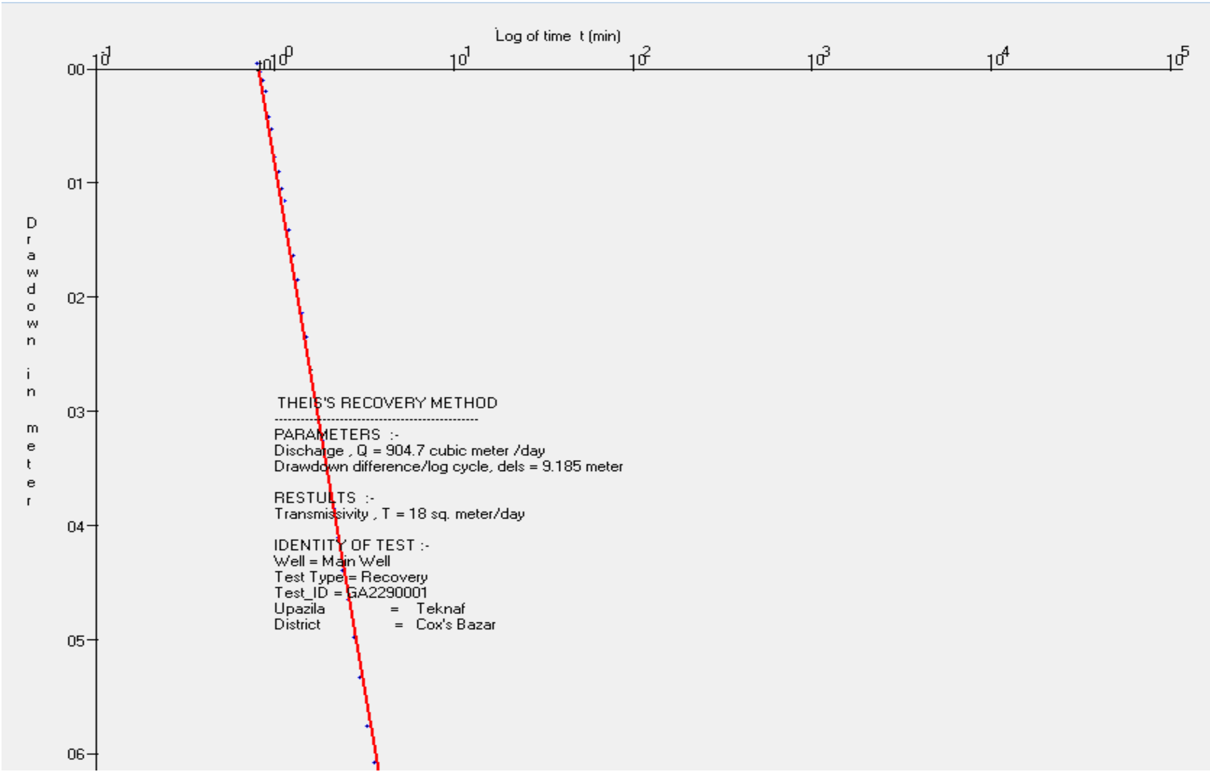


Figure A.4.12: Theis's Recovery method for analysis of main well

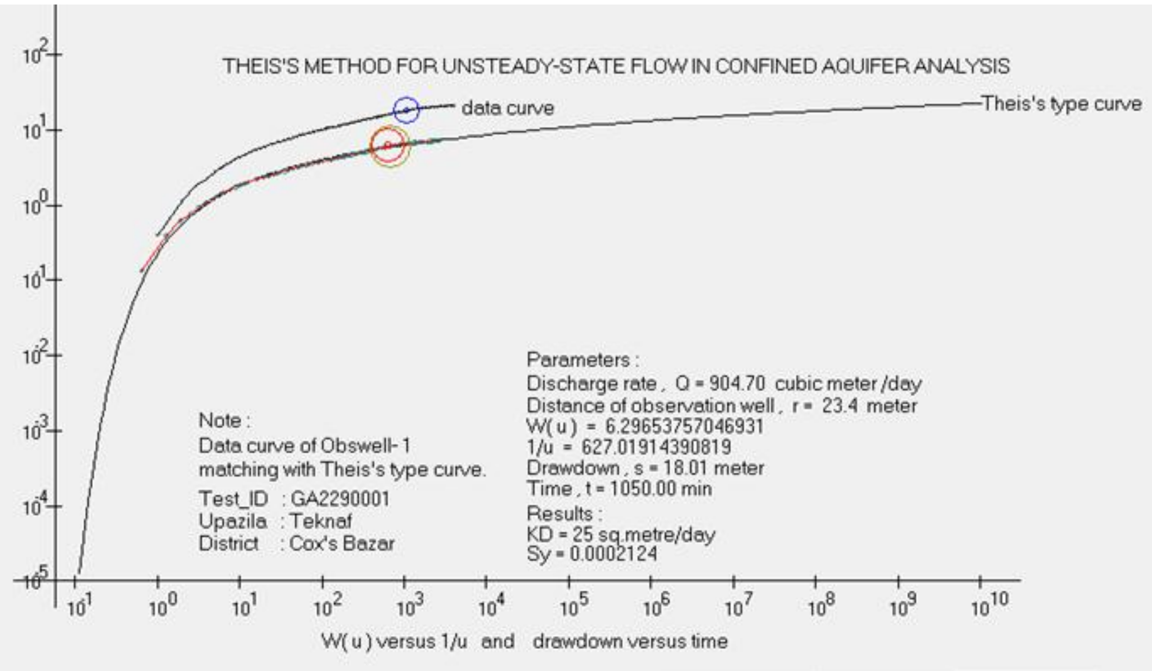


Figure A.4.13: Theis's method for unsteady state flow for analysis of observation well 1

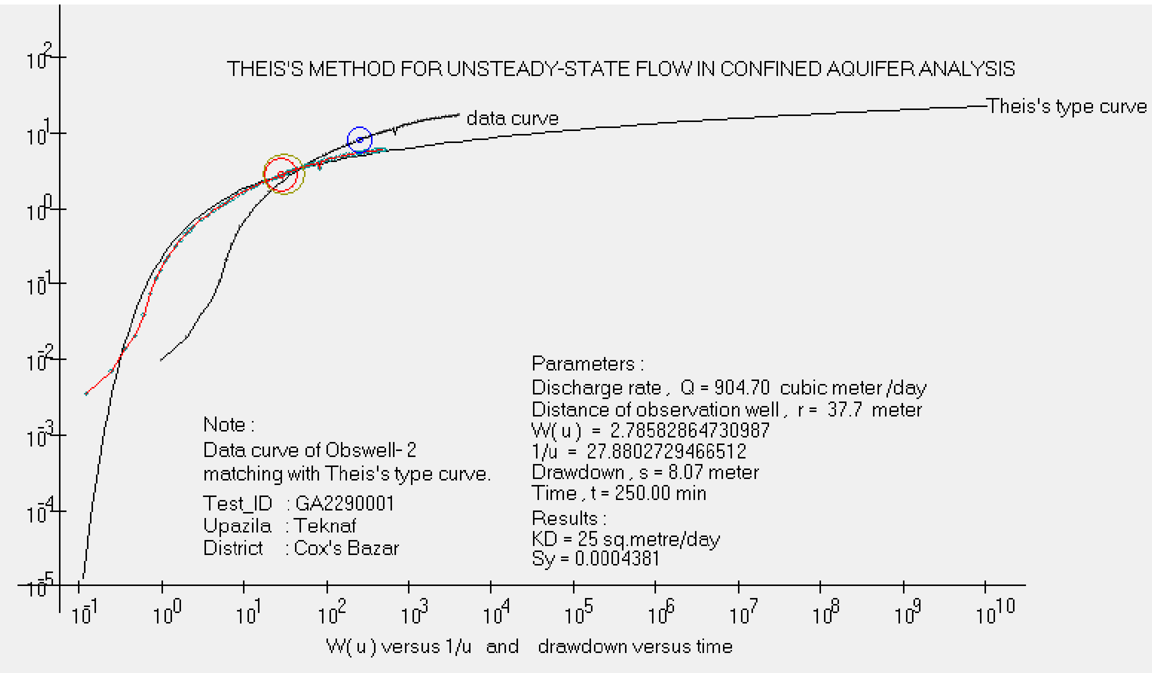


Figure A.4.14: Theis's method for unsteady state flow for analysis of observation well 2

A.4.3 Aquifer Test Data

Table A.4.3: Aquifer test data of Production Well PTW-01

Aquifer Test Duration: 72 Hour
Test Date: 27/01/2020
Start time: 10:00 AM
Location Information
Village : Puran Shamlapur
Union: Shamlapur
Upazila: Teknaf
District : Cox's Bazar

Well ID **PTW-01**
Latitude: 21° 4'17.42"N
Longitude: 92° 8'53.73"E
Well Depth: 150.39 m
Discharge Rate: 0.375 cusec

Pumping Well					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
0	5.35	0	46.15	40.8	SWL = 5.35 m
1	22.26	16.91	34.69	29.34	
2	24.45	19.1	32.68	27.33	Maximum
3	26.3	20.95	31.46	26.11	PWL= 46.15 m
4	27.68	22.33	30.37	25.02	
5	29.27	23.92	29.41	24.06	
6	29.86	24.51	28.7	23.35	
7	30.35	25	28.06	22.71	
8	30.85	25.5	27.6	22.25	
9	31.05	25.7	27.24	21.89	
10	31.3	25.95	26.77	21.42	
12	31.4	26.05	26.06	20.71	
14	31.85	26.5	25.57	20.22	
16	32.26	26.91	25.15	19.8	
18	32.59	27.24	24.8	19.45	
20	32.79	27.44	24.49	19.14	
25	33.48	28.13	23.82	18.47	
30	33.84	28.49	23.39	18.04	
35	34.24	28.89	23.05	17.7	
40	34.5	29.15	22.64	17.29	
45	34.55	29.2	22.29	16.94	
50	35.12	29.77	22.05	16.7	
55	35.42	30.07	21.83	16.48	
60	35.59	30.24	21.58	16.23	
70	35.95	30.6	21.25	15.9	
80	36.25	30.9	21.81	16.46	
90	36.53	31.18	20.49	15.14	
100	36.78	31.43	20.2	14.85	
110	37.09	31.74	12.17	6.82	
120	37.31	31.96	19.95	14.6	
140	37.68	32.33	19.73	14.38	
160	38.07	32.72	19.3	13.95	
180	38.49	33.14	18.85	13.5	
200	38.68	33.33	18.5	13.15	

Pumping Well					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
220	38.93	33.58	18.15	12.8	
240	39.21	33.86	17.85	12.5	
260	39.44	34.09	17.62	12.27	
280	39.66	34.31	17.35	12	
300	39.91	34.56	17.08	11.73	
330	40.15	34.8	16.87	11.52	
360	40.48	35.13	16.5	11.15	
390	40.74	35.39	16.24	10.89	
420	41.09	35.74	15.93	10.58	
450	41.26	35.91	15.67	10.32	
480	41.51	36.16	15.4	10.05	
510	41.8	36.45	15.15	9.8	
540	41.87	36.52	14.9	9.55	
600	42.23	36.88	14.69	9.34	
660	42.53	37.18	14.25	8.9	
720	43.88	38.53	13.89	8.54	
780	44.22	38.87	13.55	8.2	
840	44.41	39.06	13.23	7.88	
900	44.7	39.35	12.93	7.58	
960	44.95	39.6	12.64	7.29	
1020	45.19	39.84	12.4	7.05	
1080	45.47	40.12	11.92	6.57	
1200	45.84	40.49	11.43	6.08	
1320	46.15	40.8	11.11	5.76	
1440	46.15	40.8	10.68	5.33	
1560	46.15	40.8	10.33	4.98	
1680	46.15	40.8	10	4.65	
1800	46.15	40.8	9.74	4.39	
1920	46.15	40.8	9.46	4.11	
2040	46.15	40.8	9.2	3.85	
2160	46.15	40.8	8.91	3.56	
2340	46.15	40.8	8.6	3.25	
2520	46.15	40.8	8.27	2.92	
2700	46.15	40.8	7.99	2.64	
2880	46.15	40.8	7.7	2.35	
3060	46.15	40.8	7.49	2.14	
3240	46.15	40.8	7.2	1.85	
3420	46.15	40.8	6.98	1.63	
3600	46.15	40.8	6.76	1.41	
3780	46.15	40.8	6.5	1.15	
3960	46.15	40.8	6.4	1.05	
4140	46.15	40.8	6.25	0.9	
4320	46.15	40.8	6.12	0.77	
4500	-	-	5.88	0.53	
4680	-	-	5.77	0.42	
4860	-	-	5.55	0.2	
5040	-	-	5.45	0.1	

Pumping Well					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
5220	-	-	5.38	0.03	
5400	-	-	5.3	-0.05	

Table A.4.4: Aquifer test data of Observation Well 01

Aquifer Test Duration: 72 Hour
Test Date: 27/01/2020
Start time: 10:00 AM

Well ID **Observation Well 01**

Location Information
Village : Puran Shamlapur
Union: Shamlapur
Upazila: Teknaf
District : Cox's Bazar

Well Depth: 126.98 m
Discharge Rate: 0.375 cusec
Distance from PTW: 23.4 m

Observation Well 01					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
0	4.14	0	25.54	21.4	SWL = 4.14 m
1	4.54	0.4	25.21	21.07	
2	5.3	1.16	24.6	20.46	Maximum
3	5.96	1.82	24.11	19.97	PWL= 25.54 m
4	6.41	2.27	23.71	19.57	
5	6.94	2.8	23.43	19.29	
6	7.28	3.14	23.12	18.98	
7	7.67	3.53	22.94	18.8	
8	7.95	3.81	22.67	18.53	
9	8.25	4.11	22.43	18.29	
10	8.48	4.34	22.27	18.13	
12	8.91	4.77	21.91	17.77	
14	9.28	5.14	21.59	17.45	
16	9.59	5.45	21.35	17.21	
18	9.88	5.74	21.11	16.97	
20	10.12	5.98	20.91	16.77	
25	10.7	6.56	20.43	16.29	
30	11.11	6.97	20.08	15.94	
35	11.48	7.34	19.77	15.63	
40	11.81	7.67	19.45	15.31	
45	12.13	7.99	19.2	15.06	
50	12.36	8.22	18.99	14.85	
55	12.62	8.48	18.77	14.63	
60	12.89	8.75	18.58	14.44	
70	13.25	9.11	18.22	14.08	
80	13.61	9.47	17.9	13.76	

Observation Well 01					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
90	13.91	9.77	17.62	13.48	
100	14.22	10.08	17.65	13.51	
110	14.51	10.37	17.05	12.91	
120	14.76	10.62	16.92	12.78	
140	15.21	11.07	16.49	12.35	
160	15.47	11.33	16.12	11.98	
180	15.83	11.69	15.8	11.66	
200	16.16	12.02	15.51	11.37	
220	16.47	12.33	45.34	41.2	
240	16.77	12.63	15.12	10.98	
260	16.98	12.84	14.87	10.73	
280	17.24	13.1	14.66	10.52	
300	17.47	13.33	14.43	10.29	
330	17.78	13.64	14.14	10	
360	18.06	13.92	13.86	9.72	
390	18.34	14.2	13.59	9.45	
420	18.46	14.32	13.35	9.21	
450	18.82	14.68	13.15	9.01	
480	19.04	14.9	12.92	8.78	
510	19.25	15.11	12.72	8.58	
540	19.44	15.3	12.52	8.38	
600	19.78	15.64	12.15	8.01	
660	20.11	15.97	11.82	7.68	
720	20.62	16.48	11.52	7.38	
780	20.99	16.85	11.25	7.11	
840	21.26	17.12	10.99	6.85	
900	21.57	17.43	10.75	6.61	
960	21.81	17.67	10.53	6.39	
1020	22.01	17.87	10.34	6.2	
1080	22.29	18.15	10.1	5.96	
1200	22.7	18.56	9.72	5.58	
1320	23.07	18.93	9.26	5.12	
1440	23.3	19.16	9.03	4.89	
1560	23.51	19.37	8.74	4.6	
1680	23.67	19.53	8.45	4.31	
1800	23.83	19.69	8.22	4.08	
1920	23.96	19.82	7.95	3.81	
2040	24.1	19.96	7.71	3.57	
2160	24.22	20.08	7.5	3.36	
2340	24.39	20.25	7.2	3.06	
2520	24.54	20.4	6.92	2.78	
2700	24.67	20.53	6.66	2.52	
2880	24.81	20.67	6.41	2.27	
3060	24.92	20.78	6.21	2.07	
3240	25.03	20.89	6	1.86	
3420	25.12	20.98	5.78	1.64	
3600	25.22	21.08	5.56	1.42	

Observation Well 01					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
3780	25.32	21.18	5.38	1.24	
3960	25.39	21.25	5.2	1.06	
4140	25.45	21.31	5.12	0.98	
4320	25.54	21.4	5.04	0.9	
4500	-	-	4.78	0.64	
4680	-	-	4.66	0.52	
4860	-	-	4.57	0.43	
5040	-	-	4.45	0.31	
5220	-	-	4.32	0.18	
5400	-	-	4.17	0.03	

Table A.4.5: Aquifer test data of Observation Well 02

Aquifer Test Duration: 72 Hour
Test Date: 27/01/2020
Start time: 10:00 AM
Location Information
Village : Puran Shamlapur
Union: Shamlapur
Upazila: Teknaf
District : Cox's Bazar

Well ID **Observation Well 02**

Well Depth: 121.8 m
Discharge Rate: 0.375 cusec
Distance from PTW: 37.7 m

Observation Well 02					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
0	2.5	0	-	-	SWL = 2.5 m
1	2.51	0.01	-	-	
2	2.52	0.02	-	-	Maximum
3	2.54	0.04	-	-	PWL= 19.76 m
4	2.56	0.06	-	-	
5	2.61	0.11	-	-	
6	2.71	0.21	-	-	
7	2.84	0.34	-	-	
8	2.94	0.44	-	-	
9	3.07	0.57	-	-	
10	3.16	0.66	-	-	
12	3.39	0.89	-	-	
14	3.58	1.08	-	-	
16	3.77	1.27	-	-	
18	3.94	1.44	-	-	
20	4.13	1.63	-	-	
25	4.52	2.02	-	-	
30	4.86	2.36	-	-	
35	5.18	2.68	-	-	

Observation Well 02					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
40	5.44	2.94	-	-	
45	5.66	3.16	-	-	
50	5.85	3.35	-	-	
55	6.14	3.64	-	-	
60	6.32	3.82	-	-	
70	6.8	4.3	-	-	
80	7.12	4.62	-	-	
90	7.55	5.05	-	-	
100	7.75	5.25	-	-	
110	8.01	5.51	-	-	
120	8.27	5.77	-	-	
140	8.71	6.21	-	-	
160	9.13	6.63	-	-	
180	9.49	6.99	-	-	
200	9.83	7.33	-	-	
220	10.13	7.63	-	-	
240	10.44	7.94	-	-	
260	10.7	8.2	-	-	
280	10.97	8.47	-	-	
300	11.19	8.69	-	-	
330	11.52	9.02	-	-	
360	11.82	9.32	-	-	
390	12.38	9.88	-	-	
420	12.6	10.1	-	-	
450	12.82	10.32	-	-	
480	13.02	10.52	-	-	
510	13.23	10.73	-	-	
540	13.57	11.07	-	-	
600	13.89	11.39	-	-	
660	12.13	9.63	-	-	
720	14.26	11.76	-	-	
780	14.64	12.14	-	-	
840	14.93	12.43	-	-	
900	15.21	12.71	-	-	
960	15.46	12.96	-	-	
1020	15.7	13.2	-	-	
1080	15.93	13.43	-	-	
1200	16.35	13.85	-	-	
1320	16.73	14.23	-	-	
1440	17.02	14.52	-	-	
1560	17.27	14.77	-	-	
1680	17.49	14.99	-	-	
1800	17.67	15.17	-	-	
1920	17.84	15.34	-	-	
2040	18	15.5	-	-	
2160	18.18	15.68	-	-	
2340	18.38	15.88	-	-	

Observation Well 02					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
2520	18.55	16.05	-	-	
2700	18.71	16.21	-	-	
2880	18.87	16.37	-	-	
3060	19.01	16.51	-	-	
3240	19.14	16.64	-	-	
3420	19.25	16.75	-	-	
3600	19.38	16.88	-	-	
3780	19.5	17	-	-	
3960	19.6	17.1	-	-	
4140	19.67	17.17	-	-	
4320	19.76	17.26	-	-	

Table A.4.6: Aquifer test data of Observation Well 03

Aquifer Test Duration: 72 Hour
Test Date: 27/01/2020
Start time: 10:00 AM
Location Information
Village : Puran Shamlapur
Union: Shamlapur
Upazila: Teknaf
District : Cox's Bazar

Well ID **Observation Well 03**

Well Depth: 127 m
Discharge Rate: 0.375 cusec
Distance from PTW: 84.2 m

Observation Well 03					
Elapsed time (Minute)	**Pumping State**		**Recovery State**		**Remarks**
	Depth to water table (m)	**Drawdown (m)**	**Depth to water Table (m)**	**Recovered level (m)**	
0	1.08	0	-	-	SWL = 1.08 m
1	1.08	0	-	-	
2	1.08	0	-	-	Maximum
3	1.08	0	-	-	PWL= 3.0 m
4	1.08	0	-	-	
5	1.08	0	-	-	
6	1.08	0	-	-	
7	1.08	0	-	-	
8	1.08	0	-	-	
9	1.08	0	-	-	
10	1.08	0	-	-	
12	1.08	0	-	-	
14	1.08	0	-	-	
16	1.08	0	-	-	
18	1.08	0	-	-	
20	1.08	0	-	-	
25	1.08	0	-	-	
30	1.08	0	-	-	
35	1.08	0	-	-	
40	1.08	0	-	-	
45	1.08	0	-	-	
50	1.08	0	-	-	
55	1.08	0	-	-	
60	1.08	0	-	-	
70	1.08	0	-	-	
80	1.08	0	-	-	
90	1.08	0	-	-	
100	1.08	0	-	-	
110	1.08	0	-	-	
120	1.08	0	-	-	
140	1.08	0	-	-	
160	1.08	0	-	-	
180	1.26	0.18	-	-	
200	1.28	0.2	-	-	
220	1.3	0.22	-	-	
240	1.33	0.25	-	-	

Observation Well 03					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
260	1.35	0.27	-	-	
280	1.36	0.28	-	-	
300	1.37	0.29	-	-	
330	1.39	0.31	-	-	
360	1.41	0.33	-	-	
390	1.44	0.36	-	-	
420	1.47	0.39	-	-	
450	1.49	0.41	-	-	
480	1.52	0.44	-	-	
510	1.545	0.465	-	-	
540	1.57	0.49	-	-	
600	1.625	0.545	-	-	
660	1.66	0.58	-	-	
720	1.73	0.65	-	-	
780	1.79	0.71	-	-	
840	1.83	0.75	-	-	
900	1.86	0.78	-	-	
960	1.89	0.81	-	-	
1020	1.91	0.83	-	-	
1080	1.93	0.85	-	-	
1200	1.99	0.91	-	-	
1320	2.02	0.94	-	-	
1440	2.09	1.01	-	-	
1560	2.05	0.97	-	-	
1680	2.21	1.13	-	-	
1800	2.26	1.18	-	-	
1920	2.28	1.2	-	-	
2040	2.32	1.24	-	-	
2160	2.37	1.29	-	-	
2340	2.45	1.37	-	-	
2520	2.5	1.42	-	-	
2700	2.51	1.43	-	-	
2880	2.58	1.5	-	-	
3060	2.64	1.56	-	-	
3240	2.69	1.61	-	-	
3420	2.72	1.64	-	-	
3600	2.77	1.69	-	-	
3780	2.89	1.81	-	-	
3960	2.95	1.87	-	-	
4140	2.95	1.87	-	-	
4320	3	1.92	-	-	

Table A.4.7: Aquifer test data of Observation Well 04

Aquifer Test Duration: 72 Hour
Test Date: 27/01/2020
Start time: 10:00 AM
Location Information
Village : Puran Shamlapur
Union: Shamlapur
Upazila: Teknaf
District : Cox's Bazar

Well ID **Observation Well 04**

Well Depth: 136.16 m
Discharge Rate: 0.375 cusec
Distance from PTW: 103 m

Observation Well 04					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
0	0	0	-	-	SWL = 0 m
1	0	0	-	-	
2	0	0	-	-	Maximum
3	0	0	-	-	PWL= 5.18 m
4	0	0	-	-	
5	0	0	-	-	
6	0	0	-	-	
7	0	0	-	-	
8	0	0	-	-	
9	0	0	-	-	
10	0	0	-	-	
12	0	0	-	-	
14	0	0	-	-	
16	0	0	-	-	
18	0	0	-	-	
20	0	0	-	-	
25	0	0	-	-	
30	0	0	-	-	
35	0	0	-	-	
40	0	0	-	-	
45	0	0	-	-	
50	0	0	-	-	
55	0	0	-	-	
60	0	0	-	-	
70	0	0	-	-	
80	0	0	-	-	
90	0	0	-	-	
100	0	0	-	-	
110	0	0	-	-	
120	0	0	-	-	
140	0	0	-	-	
160	0	0	-	-	
180	0	0	-	-	
200	0	0	-	-	
220	0	0	-	-	
240	0	0	-	-	

Observation Well 04					
Elapsed time (Minute)	Pumping State		Recovery State		Remarks
	Depth to water table (m)	Drawdown (m)	Depth to water Table (m)	Recovered level (m)	
260	0	0	-	-	
280	0	0	-	-	
300	0	0	-	-	
330	0	0	-	-	
360	0	0	-	-	
390	0	0	-	-	
420	0	0	-	-	
450	0	0	-	-	
480	0	0	-	-	
510	0	0	-	-	
540	0.51	0.51	-	-	
600	0.73	0.73	-	-	
660	0.95	0.95	-	-	
720	1.17	1.17	-	-	
780	1.31	1.31	-	-	
840	1.48	1.48	-	-	
900	1.63	1.63	-	-	
960	1.75	1.75	-	-	
1020	1.86	1.86	-	-	
1080	1.97	1.97	-	-	
1200	2.21	2.21	-	-	
1320	2.45	2.45	-	-	
1440	2.68	2.68	-	-	
1560	2.9	2.9	-	-	
1680	3.12	3.12	-	-	
1800	3.26	3.26	-	-	
1920	3.4	3.4	-	-	
2040	3.58	3.58	-	-	
2160	3.71	3.71	-	-	
2340	3.9	3.9	-	-	
2520	4.06	4.06	-	-	
2700	4.2	4.2	-	-	
2880	4.35	4.35	-	-	
3060	4.49	4.49	-	-	
3240	4.6	4.6	-	-	
3420	4.7	4.7	-	-	
3600	4.83	4.83	-	-	
3780	4.98	4.98	-	-	
3960	5.05	5.05	-	-	
4140	5.1	5.1	-	-	
4320	5.18	5.18	-	-	

A.4.4. Production Well Time Series Water Quality

Table A.4.8: Time series water quality laboratory analysis result in PTW-01

Sl. No.	Parameters	Bangladesh Standard for Drinking Water (ECR,97)	WHO Guideline Value, 2004	Unit	Concentration value			
					1 Hour	24 Hour	48 Hour	72 Hour
1	Sodium (Na)	200	200	mg/L	24.20	25.70	29.80	23.70
2	Chloride (Cl)	150-600	250	mg/L	10.00	14.00	12.00	12.00
3	Bi-Carbonate (HCO_3)	-	-	mg/L	182.90	182.40	182.20	180.90
4	Iron (Fe)	0.3-1.0	0.3	mg/L	0.08	0.10	0.02	0.02
5	Arsenic (As)	0.05	0.01	mg/L	<MDL	<MDL	<MDL	<MDL
6	Manganese (Mn)	0.1	0.4	mg/L	0.223	0.209	0.203	0.220

**MDL = Minimum Detection Limit; As=0.001 mg/l*

Table A.4.9: Time series water quality laboratory analysis result in PTW-02

Sl. No.	Parameters	Bangladesh Standard for Drinking Water (ECR,97)	WHO Guideline Value, 2004	Unit	Concentration value			
					1 Hour	24 Hour	48 Hour	72 Hour
1	Sodium (Na)	200	200	mg/L	163.60	141.90	174.00	136.70
2	Chloride (Cl)	150-600	250	mg/L	12.00	10.00	12.00	13.00
3	Bi-Carbonate (HCO_3)	-	-	mg/L	341.60	353.60	353.20	351.40
4	Iron (Fe)	0.3-1.0	0.3	mg/L	0.08	0.05	0.05	0.05
5	Arsenic (As)	0.05	0.01	mg/L	<MDL	<MDL	<MDL	<MDL
6	Manganese (Mn)	0.1	0.4	mg/L	0.029	0.028	0.027	0.029

**MDL = Minimum Detection Limit; As=0.001 mg/l*

ANNEX-5: COST ASSESSMENT FOR GENERAL ITEM

The cost in general item includes costing for performance security and advance payment guarantee, Insurances, different management plans for the project, site preparation and removal after project completion, test of different components, O&M during defect liability period etc.

Table A.5.1: Cost summary of General Items

Sl. No	Project Components	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	Total
		Estimated Value (Million BDT) (without price escalation)						
1	Interest payable for performance security and advance payment guarantee	1.1	0.2	0.4	0.1	0.3	0.1	2.2
2	Insurances for contractor's equipment, injury to persons and damage to property, contractor's personnel and other insurances	2.0	0.3	0.7	0.2	0.4	0.2	3.8
3	Preparation of i) health & safety plan, ii) environment management plan, iii) traffic management plan etc.	0.7	0.1	0.2	0.1	0.2	0.1	1.4
4	Preparation of as-built documents-PTW, transmission mains, pumping stations etc.	0.5	0.1	0.2	0.1	0.1	0.1	1.1
5	Preparation of O&M manuals -PTW, transmission mains, pumping stations etc.	0.5	0.1	0.2	0.1	0.1	0.1	1.1
6	Site establishment, operation and removal							
6.1	Supply and erect signboard, establish contractor's main site offices, welfare facilities, site access and miscellaneous services including transports etc.	1.1	0.1	0.4	0.1	0.2	0.1	2.0
6.2	Management of site and above facilities during the construction period including health, safety and security measures during the construction period	1.2	0.2	0.4	0.2	0.3	0.2	2.5
6.3	Removal at the completion of the works of all the established facilities	0.4	0.1	0.1	0.1	0.1	0.1	0.9
7	Test on and after completion of PTW, transmission main & distribution network including trial operation	0.9	0.1	0.3	0.1	0.2	0.1	1.7
8	Operation and maintenance of all components of PTW, transmission & distribution mains during defect liability period	11.2	1.5	3.8	1.4	2.5	1.4	21.8
	Total	**19.6**	**2.8**	**6.7**	**2.5**	**4.4**	**2.5**	**38.5**

ANNEX-6: COST ASSESSMENT FOR PRODUCTION TUBEWELL

About 8 nos. of deep well will be constructed in Whykhong well field for supply water in Sabrang and Naf Tourism Park. The production wells will be constructed with 14.42l/s production capacity and 17-hour maximum operation window, to extract about 7.0 MLD groundwater. The summary of cost estimation is given in **Table A.6.1** and costing in different phases in **Table A.6.2.**

Table A.6.1: Summary of Capital Cost for Construction of 7nos. Deep Well

Schedule No.	Description	Total Price in Million BDT
1	Construction of 350mmx150mm diameter Deep Tube Well with related works including supply of all necessary materials	7.96
2	Construction of Delivery main and wash out line of DTW with related works including supply of all necessary materials	0.87
3	Construction of Pump house, Chlorine Room of DTW with related works including supply of all necessary materials	1.43
4	Construction of Boundary wall and approach road of DTW compound with related works including supply of all necessary materials	1.40
5	Construction of RCC Column with R.S. Joist of DTW with related works including supply of all necessary materials	0.18
6	Construction of 11/0.415KV 200KVA Pad Mounted Sub-Station of DTW Compound with related works including supply of all necessary materials	2.87
7	Installation of Submersible Pump Set and Chlorine Set with related works including supply of all necessary materials	2.07
	Total for 01 Deep Tube well (BDT)	**16.78**
	Grand Total for 08 Deep Tube wells (BDT)	**134.3**

Table A.6.2: Costing of Deep Wells in different phases

Item	Phase-1	Phase-2	Phase-3	Phase-4	Phase-5	Phase-6	Total
	Estimated Value (Million BDT) (without price escalation)						
No of PTW to be constructed	4	0	1	2	1	0	**8**
Costing (million BDT)	67.1	0.0	16.8	33.6	16.8	0.0	**134.3**

ANNEX-7: COST ASSESSMENT FOR DESALINATION PLANT

To fulfill water demand in Sabrang Tourism Park 3 nos. desalination plant is proposed to be constructed in Phase 2, 5 & 6 in with production capacity 1 MLD, 0.5 MLD and 1.35 MLD respectively. The summary of cost estimation with the estimated production capacity is given in **Table A.7.1**.

Table A.7.1: Cost summary of desalination plant

	Phase-2		**Phase-5**		**Phase-6**	
	Estimated Value (without price escalation)					
Item	**Million USD**	**Million BDT**	**Million USD**	**Million BDT**	**Million USD**	**Million BDT**
Equipment cost	1.36	115.9	0.68	58.0	1.84	156.5
CD & VAT	0.48	40.6	0.24	20.3	0.64	54.8
Transportation						
Sea Fred	0.15	12.8	0.08	6.4	0.20	17.2
Port to site		0.4		0.3		0.4
Installation charge		23.2		11.6		31.3
Sludge management unit		15.0		15.0		15.0
Civil works						
Factory building		150.0		112.5		150.0
Office building		12.6				
Total		**370.4**		**224.0**		**425.2**

ANNEX-8: COST ASSESSMENT FOR TRANSMISSION MAIN WATER SUPPLY PIPE MATERIALS

HDPE pipe material is proposed for the water supply transmission main. The total length of transmission line is about 50.6 km as describe below:

- The proposed transmission main from Whykhong well field will follow Dhaka-Chittagong Highway (N1) and then Cox's Bazar-Teknaf Marine drive road. The total length of this line is about 50 km (including the length of transmission main from PTW-08 to PTW-1) upto near Sabrang Tourism Park. After travelling about 29km (from PTW-01) this transmission main will supply water in Naf Tourism Park crossing the Naf River. This Transmission main will be developed in Phase-1.
- The treated water from the Teknaf SWTP will carry the treated water and will be intersected with the ground water transmission main from Whykhong well field and the network will carry combined water from Whykhong well field and reservoir treated water to Sabrang Tourism Park. The length of transmission main for the treated water from the SWTP is only about 50m. This portion of transmission main will be developed in Phase-3.
- The transmission main will cross the Naf River through the proposed tunnel and the length is about 500m. In phase-1 the required diameter is about 75mm which will be sufficient to carry required amount of water upto phase-3. In phase-4 the pipe line need to be replaced with diameter of 100 mm or another pipe of 75mm need to be installed.

The pipe diameter for the transmission line varies from 100 to 250mm. The length and cost of pipe in different phases are given in **Table A.8.1** to **Table A.8.3**.

Table A.8.1: Pipe cost for transmission line in Phase-1

Pipe Diameter (mm)	Length (m)	Total Cost (Million BDT)
75	500	0.4
100	600	0.9
150	1,227	3.9
200	1,410	7.0
250	46,752	361.0
Total	**50,489**	**373.2**

*Without considering price escalation

(Note: The rate is collected from ongoing projects of DWASA)

Table A.8.2: Additional Pipe cost for transmission line in Phase-3

Pipe Diameter (mm)	Length (m)	Total Cost (Million BDT)
150	50	0.2
Total	**50**	**0.2**

*Without considering price escalation

Table A.8.3: Additional Pipe cost for transmission line in Phase-4

Pipe Diameter (mm)	Length (m)	Total Cost (Million BDT)
100	500	0.8
Total	**500**	**0.8**

*Without considering price escalation

ANNEX-9: COST ASSESSMENT FOR DISTRUBUTION LINE WATER SUPPLY PIPE MATERIALS

HDPE pipe material is proposed for the water supply distribution network. The length of distribution network in Sabrang TP is about 13 km and in Naf TP is about 10 km and the pipe diameter varies from 75 to 100mm. The length and cost of pipes for water supply distribution system in Sabrang and Naf Tourism Park in different phases are given in **Table A.9.1** to **Table A.9.2**.

Table A.9.1: Pipe cost for distribution line in Sabrang Tourism Park

Phase	Length (m)	Total Cost (Million BDT)
Phase-1	1,996	2.1
Phase-2	3,130	3.3
Phase-3	2,997	3.1
Phase-4	2,360	2.5
Phase-5	1,192	1.2
Phase-6	1,265	1.3
Total	**12,940**	**13.5**

*Without considering price escalation

Table A.9.2: Pipe cost for distribution line in Naf Tourism Park

Phase	Length (m)	Total Cost (Million BDT)
Phase-1	1,381	1.4
Phase-2	2,071	2.2
Phase-3	1,494	1.6
Phase-4	2,242	2.3
Phase-5	1,173	1.2
Phase-6	1,760	1.8
Total	**10,121**	**10.6**

*Without considering price escalation

ANNEX-10: COST ASSESSMENT FOR UNDERGROUND RESERVOIR

Total 6 nos. underground water reservoir is proposed for water supply in Sabrang and Naf Tourism Park.

- One reservoir is proposed in Khykhong area to reserve the water from the production tube well for 3-4 hours and then supply to the transmission main. The reservoir will be developed in Phase 1. The cost estimations are given in **Table A.10.1**.
- Three reservoirs is proposed in Sabrang Tourism Park to store water for 48 hours and facilitated water supply in different development zones. The reservoirs will be developed in Phase 1, 3 & 5. The cost estimations are given in **Table A.10.2** to **Table A.10.4**.
- Two reservoirs is proposed in reservoir in Naf Tourism Park to store water for 48hours and facilitated water supply in different development zones. The reservoirs will be developed in Phase 2 & 4. The cost estimations are given in **Table A.10.5** to **Table A.10.6**.

Table A.10.1: Underground water reservoir cost in Khykhong area in Phase-1

Required storage volume = 1,040 m^3 for 4 hours (2 chambers)				
Size of reservoir (height including freeboard)= 17m x 17m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	1,620	0.35
2	RCC Concrete	m^3	565	14.85
3	MS Road	Kg	133,105	10.91
			Total	**26.11**

Table A.10.2: Underground water reservoir cost in Sabrang for Phase-1

Required storage volume = 6,234 m^3 for 2 days (2 chambers)				
Size of reservoir (height including freeboard)= 56m x 56m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	16,245	3.53
2	RCC Concrete	m^3	4,124	108.33
3	MS Road	Kg	971,190	79.64
			Total	**191.49**

*Without considering price escalation

Table A.10.3: Underground water reservoir cost in Sabrang for Phase-3

Required storage volume = 6,214 m^3 for 2 days (2 chambers)				
Size of reservoir (height including freeboard)= 56m x560m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	16,245	3.53
2	RCC Concrete	m^3	4,124	108.33
3	MS Road	Kg	971,190	79.64
			Total	**191.49**

*Without considering price escalation

Table A.10.4: Underground water reservoir cost in Sabrang for Phase-5

Required storage volume = 4,229 m^3 for 2 days (2 chambers)				
Size of reservoir (height including freeboard)= 33m x 33m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	11,045	2.40
2	RCC Concrete	m^3	2,907	76.36
3	MS Road	Kg	684,587	56.14
			Total	**134.89**

*Without considering price escalation

Table A.10.5: Underground water reservoir cost in Naf for Phase-1

Required storage volume = 1,002 m^3 for 2 days (1 chamber)				
Size of reservoir (height including freeboard)= 22m x 22m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	2,645	0.57
2	RCC Concrete	m^3	843	22.14
3	MS Road	Kg	198,515	16.28
			Total	**38.99**

*Without considering price escalation

Table A.10.6: Underground water reservoir cost in Naf for Phase-3

Required storage volume = 1,203 m^3 for 2 days (1 chamber)				
Size of reservoir (height including freeboard)= 25m x 25m x 5m				
Sl. No.	**Item**	**Unit**	**Quantity**	**Total cost (Million BDT)**
1	Earth work	m^3	3,380	0.73
2	RCC Concrete	m^3	1,035	27.18
3	MS Road	Kg	243,695	19.98
			Total	**47.9**

*Without considering price escalation

ANNEX-11: COST ASSESSMENT FOR PUMP STATIONS

Four pump stations is required in the five reservoirs and two booster pumps is required along the transmission line. The cost of pump stations and booster pumps is given in **Table A.11.1**.

Table A.11.1: Pump stations at underground reservoir and booster pump cost

Location	Capacity (m^3/s)	Cost (Million BDT)	Phasing
Reservoir in Whykong	0.045	13.1	Phase-1
Reservoir in Whykong	0.045	13.1	Phase-3
Reservoir-1 in Sabrang	0.045	36.1	Phase-1
Reservoir-2 in Sabrang	0.045	36.1	Phase-3
Reservoir-3 in Sabrang	0.03	30.1	Phase-5
Reservoir-1 in Naf	0.005	22.1	Phase-1
Reservoir-2 in Naf	0.01	22.1	Phase-3
Booster Pump 1	0.075	54.2	Phase-1
Booster Pump 2	0.075	54.2	Phase-1
Total		**280.9**	

*Without considering price escalation

ANNEX-12: COST ASSESSMENT FOR LAND ACQUISITION AND LAND DEVELOPMENT

The required area for each production tube well is about 400m^2 (20mX20m). For booster pump stations about 225m^2 (15mX15m) area will be required. For the reservoit in Whykhong about 625m^2 (25mX25m) area will be required. Moreover, a rest room is required near one of the PTW for visiting the sites or maintenance by expertise and other purposes, so additional 400m^2 area is required.

If khas land is not available near the proposed locations for PTW and reservoit, then land acquisition will be require. The booster pump stations will be built beside the Dhaka-Chittagong Highway (N1). The land is Government property so land acquisition may not be required for building the booster pump station. All land acquisition should be completed in Phase-1.

The tentative cost required for land acquisition and land development is given in **Table A.12.1**.

Table A.12.1: Tentative cost of land acquisition and land development

Sl. No.	Item	Unit	Total Amount
1	Required amount of land	m^2	4225
3	Land Costing	million BDT	11.9
4	Development costing	million BDT	5.9
	Total		**17.8**

ANNEX-13: COST ASSESSMENT FOR BOTTLE WATER PLANT

About 3 nos. bottle water plant is proposed to be constructed in Phase 1, 3 & 5 in Sabrang Tourism Park to meet the drinking water requirement in Sabrang and Naf Tourism Park. The production capacity would be 3,200, 4,500 and 3,500 liter/hour in Phase 1, 3 % 5 respectively. The summary of cost estimation with the estimated production capacity is given in **Table A.13.1**.

Table A.13.1: Cost summary of bottle water plant

Sl/ No.	Items	Phase-1		Phase-3		Phase-5	
		Estimated Value (without price escalation)					
		USD	Million BDT	USD	Million BDT	USD	Million BDT
1	**Different Equipment**						
1.1	Treatment plant unit	25,000	2.1	35,000	3.0	25,000	2.1
1.2	Semiautomatic Bottle Unscrambler	2,200	0.2	3,080	0.3	2,200	0.2
1.3	3 In1 High Speed Water Filling Machine	18,500	1.6	25,900	2.2	18,500	1.6
1.4	Downstream Auxiliary Packing Machines	28,500	2.4	39,900	3.4	28,500	2.4
1.5	Bottle blowing machine	39,000	3.3	54,600	4.6	39,000	3.3
2	**CD & VAT**						0.0
2.1	Treatment unit	15,083	1.3	21,116	1.8	15,083	1.3
2.2	Other units	24,299	2.1	34,019	2.9	24,299	2.1
3	**Transportation**				0.0		0.0
3.1	Sea Fred	8,000	0.7	11,200	1.0	8,000	0.7
3.2	Port to site		0.3		0.4		0.3
4	**Installation charge**	22,640	1.9	31,696	2.7	22,640	1.9
5	**Sludge management**		15.0		15.0		15.0
6	**Civil works**						
6.1	Factory building		144.0		201.6		144.0
6.2	Office building		12.6				
	Total		**187.5**		**238.8**		**174.9**

ANNEX-14: COST ASSESSMENT FOR ROOF TOP RWH

In Sabrang Tourism Park 180 nos. of reservoir of capacity 860 m^3 is required to store the roof top storm water and use the water or non-potable usage throughout the year. The size of each reservoir would be 16mX16mX4m (including 0.5m freeboard). The cost of roof top rain water harvesting for one reservoir and plumbing system is given in **Table A.14.1** and the cost required in different phases is given in **Table A.14.2.**

Table A.14.1: Cost of roof top RWH system in Sabrang Tourism Park

Sl. No.	Item	Unit	Quantity	Total cost (Million BDT)
1	Earth work	m^3	1,156	0.25
2	RCC Concrete	m^3	473	12.44
3	MS Road	Kg	111,497	9.14
4	Plumbing	LS		1.09
Cost of 1 no. roof top RWH system				**22.92**

Table A.14.2: Cost of roof top RWH system in different phases

Different Phase	Potential RWH volume (MLD)	No. of RWH reservoir	Total cost (Million BDT)
Phase-1	0.13	30	687.7
Phase-2	0.12	30	687.7
Phase-3	0.12	30	687.7
Phase-4	0.12	30	687.7
Phase-5	0.12	30	687.7
Phase-6	0.12	30	687.7
Total	**0.73**	**180**	**4125.9**

*Without considering price escalation

ANNEX-15: COMMENTS FROM CLIENTS AND DPHE

Comments received from Mr. Md. Abdul Quader Khan, Social Specialist, Support to Capacity Building of BEZA Project, BEZA through e-mail.

1. Phasing of Water Supply System Development Plan (Page XIX) : Table E.3 need to be update according to following information :

Phase	Period	Budget	Water demand	Source

2. Please attach the details information in the final report
3. In the recommendation the consultancy firm has mentioned that monitoring of water level and water quality are required but in the report I don't found any monitoring indicators or plan. Please incorporate the monitoring indicators and pan in the reporting including its budget
4. The consultancy firm suggested that "The provision of roof top rainwater harvesting should be kept in each building area of roof from the very beginning. Otherwise extra costing will be needed for the re-design the plumbing system. BEZA may incorporate this sentence in the land lease agreement.
5. There is no specific head of budget for internal water connectivity in the report. The consultancy firm may incorporate the line item for internal water connectivity
6. The consultancy firm suggested for ensuring metering system within the water supply pipeline at every building but there is no details budget for this.
7. There is no SWOT analysis in the report. Please incorporate the SWOT analysis in the report
8. The consultancy firm has given costing of desalination plant but what is the major challenge and source of information didn't mention. The firm also can provide details technical specification for similar type of desalination plant.
9. The consultancy firm may consider the feasibility study of BEZA for Sabrang and Naf Tourism Park for identifying total demand of water

Comments received from Department of Public Health Engineering through e-mail.

1. In the design criteria, please provide the estimated water usages on a weighted average basis, expressing single LPCD;
2. Other than the commons, please split the findings and recommendation for Sabrang & Naf separately.
3. Please consider the system operation hours not more than 15 hours a day;
4. The individual discharge of PTW needs to be limited to 50 cum/h;
5. Count the unaccounted for water as 25%;
6. Total population to be served by 2049 needs to be mentioned distinctly;
7. The diameter of transmission water mains (250 mm) needs to be revisited.

ANNEX-16: MEETING MINUTES OF DRAFT FINAL REPORT (PHASE-1) PRESENTATION WORKSHOP

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
বাংলাদেশ অর্থনৈতিক অঞ্চল কর্তৃপক্ষ
প্রধানমন্ত্রীর কার্যালয়
www.beza.gov.bd

বিষয়ঃ পরামর্শক প্রতিষ্ঠান IWM কর্তৃক প্রস্তুতকৃত Total Water Demand and Water Availability Assessment for Naf and Sabrang Tourism Park এর Draft Final Report (Phase-1) এর উপর পর্যালোচনা সভার কার্যবিবরণী

সভাপতি : জনাব পবন চৌধুরী, নির্বাহী চেয়ারম্যান, বেজা।
তারিখ : ১৩/১০/২০২০ খ্রি:।
সময় : সকাল ১১.০০ টায়।
স্থান : বেজা'র সভাকক্ষে।

বাংলাদেশ অর্থনৈতিক অঞ্চল কর্তৃপক্ষ (বেজা) এর নিজস্ব অর্থায়নে গৃহীত 'Total Water Demand and Water Availability Assessment for Naf and Sabrang Tourism Park' সমীক্ষা কাজের আওতায় পরামর্শক প্রতিষ্ঠান Institute of Water Modelling (IWM) কর্তৃক দাখিলকৃত Draft Final Report (Phase-1) এর উপর গত ১৩ অক্টোবর ২০২০ তারিখে বেজা'র সম্মেলন কক্ষে একটি Workshop অনুষ্ঠিত হয়। উক্ত Workshop-এ সভাপতিত্ব করেন বেজা'র নির্বাহী চেয়ারম্যান **জনাব পবন চৌধুরী**।

০২। সভার শুরুতে উপস্থিত সকলকে স্বাগত জানিয়ে নির্বাহী চেয়ারম্যান সভার কাজ শুরু করেন। সভাপতির অনুমতিক্রমে বেজা'র নির্বাহী সদস্য (পরি: ও উন্ন:) জনাব মোহাম্মদ ইরফান শরীফ সভাকে অবহিত করেন যে, প্রাকৃতিক পরিবেশ নষ্ট না করে বেজা সাবরাং ও নাফ এলাকায় দু'টি ট্যুরিজম পার্ক গঠন করার পরিকল্পনা হাতে নিয়েছে। IWM কর্তৃক দাখিলকৃত Report-টি বিশেষজ্ঞের মতামতের ভিত্তিতে সুপরিকল্পিতভাবে প্রস্তুত করা হয়েছে বলে তিনি মন্তব্য করেন। অতঃপর তিনি IWM-কে দাখিলকৃত Draft Final Report এর উপর Presentation প্রদানের আহ্বান জানান।

০৩। অতঃপর IWM কর্তৃক Draft Final Report-টি Power Point Presentation এর মাধ্যমে উপস্থাপন করা হয় এবং নিম্নরূপ বিষয়াদি নিয়ে বিস্তারিত আলোচনা করা হয়:

৩.১। হোয়াইকং এলাকায় Deep Tube Well স্থাপন করা হলে উক্ত এলাকায় অবস্থিত Shallow Tube Well এর মাধ্যমে পানি উত্তোলন বাঁধাগ্রস্ত হবে কিনা জানতে চাওয়া হলে IWM-এর পক্ষ হতে জানানো হয় যে, Deep Tube Well এর Zone of Influence এর ৩০ মিটারের মধ্যে অবস্থিত Shallow Tube Well এর পানি উত্তোলন বাঁধাগ্রস্ত হতে পারে। এ বিষয়ে Monitoring এর প্রয়োজন আছে। এছাড়া IWM কর্তৃক অবহিত করা হয় যে, Deep Tube Well স্থাপনের কারনে Zone of Influence এর Shallow Tube Well এর পানি উত্তোলনে বাঁধাগ্রস্ত হতে পারে বিধায় উত্তোলনকৃত পানির ১০ শতাংশ পানি উক্ত এলাকায় সরবরাহ করার বিষয়টি সমীক্ষায় উল্লেখ করা হয়েছে। এ বিষয়ে BEZA ও DPHE এর পক্ষ হতে মতামত

1

৪৮

প্রদান করা হয় যে, প্রতিটি Deep Tube Well হতে ১০ শতাংশ পানি বরাদ্দ না রেখে একটি পৃথক Deep Tube Well স্থাপন করে তা হতে প্রয়োজনীয় পানি Zone of Influence এলাকায় সরবরাহ করা যুক্তিযুক্ত হবে। অধিকন্তু, সমীক্ষায় উল্লেখকৃত Deep Tube Well এর Operating Hour ১৭ ঘন্টার পরিবর্তে সর্বোচ্চ ১৫ ঘণ্টা রাখা যেতে পারে বলে DPHE হতে অভিমত ব্যক্ত করা হয়।

৩.২। সমীক্ষায় Naf and Sabrang Tourism Park-এ পানি সরবরাহের জন্য Rainwater Harvesting-এর উৎস বাবদ যে প্রাক্কলন করা হয়েছে এ বিষয়ে জানতে চাওয়া হলে IWM কর্তৃক অবহিত করা হয় যে, বৃষ্টিপাতের পরিমাণ বিভিন্ন বছরে বিভিন্ন হওয়ায় অপেক্ষাকৃত কম বৃষ্টি পাতের বছরে Reservoir-এ ধারণকৃত পানি প্রাক্কলিত পানির চেয়ে কম হতে পারে। এ বিষয়ে DPHE হতে অভিমত ব্যক্ত করা হয় যে, Wet Season-এর বৃষ্টির পানি নির্ধারিত জায়গায় জমা রেখে তা Lean Period-এ সরবরাহ করা যেতে পারে এবং এ পানি ট্যুরিজম পার্কের জন্য Supplementary হিসাবে বিবেচিত হতে পারে। এছাড়া Rainwater Harvesting এর জন্য প্রস্তাবিত প্রকল্পে যে ব্যয় প্রাক্কলন করা হয়েছে তা Project Cost হতে বাদ দেয়ার বিষয়ে সভাপতি মহোদয় পরামর্শ প্রদান করেন এবং অবহিত করেন যে, যেসকল প্রতিষ্ঠান জোন/ট্যুরিজম পার্কে জমি বরাদ্দ নিবে সেসকল প্রতিষ্ঠান তাদের নিজ দায়িত্বে Rainwater Harvesting System স্থাপন করবে।

৩.৩। অত:পর ট্যুরিজম পার্কে মোট পানির চাহিদা নিরূপণে এবং Distribution Pipe Line এর Design প্রণয়নে Peak Factor বিবেচনা করা হয়েছে কিনা জানতে চাওয়া হলে IWM কর্তৃক জানানো হয় যে, পানির চাহিদা নিরূপণ এবং Distribution Pipe Line এর Design করার সময় Peak Factor বিবেচনা করা হয়েছে। এছাড়া ট্যুরিজম পার্কের Underground Reservoir এর Design দুই দিনের চাহিদার সমপরিমান পানির ধারণ ক্ষমতা বিবেচনা নিয়ে করা হয়েছে।

৩.৪। Desalination Plant এর বিষয়ে সভায় আলোচনাকালে সভাপতি পরামর্শ প্রদান করেন যে, ট্যুরিজম পার্কের বোতলজাতকৃত পানির চাহিদা পূরণ করতে প্রস্তাবিত Desalination Plant হতে পানি বোতলজাত করে তা সরবরাহ করার সম্ভাবনা যাচাই করতে হবে। এ বিষয়ে IWM হতে অবহিত করা হয় যে, Final Report (Phase-1)-এ শুধুমাত্র Drinking Water বাবদ যে পরিমাণ পানির প্রয়োজন হবে তা হিসাব করে উল্লেখ করা হবে। এছাড়া Drinking Water বাবদ প্রাক্কলিত পানি বোতলজাত করে সরবরাহ করা যেতে পারে মর্মে পরামর্শক প্রতিষ্ঠান কর্তৃক অভিমত ব্যক্ত করা হয়।

৪। বিস্তারিত আলোচনা শেষে সভায় নিম্নলিখিত সিদ্ধান্তসমূহ গৃহীত হয়:

(ক) Deep Tube Well স্থাপনের কারণে Shallow Tube Well এর পানি উত্তোলন বাঁধাগ্রস্ত হওয়ার সম্ভাবনা থাকায় Zone of Influence এলাকায় পানি সরবরাহের জন্য একটি পৃথক Deep Tube Well স্থাপনের সংস্থান রাখতে হবে এবং সে অনুযায়ী Final Report চূড়ান্ত করতে হবে।

(খ) Rainwater Harvesting হিসেবে Reservoir এ ধারণকৃত পানি ট্যুরিজম পার্কের জন্য Supplementary হিসাবে ব্যবহারের সুযোগ রাখতে হবে।

(গ) ট্যুরিজম পার্কে শুধুমাত্র পান করার জন্য যে পরিমাণ পানির (Drinking Water) প্রয়োজন হবে তা সমীক্ষাপূর্বক Final Report-এ উল্লেখ করতে হবে এবং তা বোতলজাতের মাধ্যমে সরবরাহের বিষয়ে প্রয়োজনীয় সংস্থান থাকতে হবে।

(ঘ) Deep Tube Well এর Operating Hour কত হবে তা DPHE এর সাথে পরামর্শ করে নির্ধারণ করতে হবে এবং সে অনুযায়ী Final Report চূড়ান্ত করতে হবে।

(ঙ) Naf and Sabrang Tourism Park-এ Rainwater Harvesting এর মাধ্যমে পানি সরবরাহের জন্য প্রস্তাবিত প্রকল্পে যে ব্যয় প্রাক্কলন করা হয়েছে তা প্রাক্কলিত ব্যয় হতে বাদ দিয়ে আলাদাভাবে হিসাব করে Final Report-এ উল্লেখ করতে হবে।

০৫। পরিশেষে আর কোন আলোচ্য বিষয় না থাকায় সভাপতি উপস্থিত সকলকে ধন্যবাদ জানিয়ে সভার সমাপ্তি ঘোষণা করেন।

২২/০৭/২০২০

(পবন চৌধুরী)
নির্বাহী চেয়ারম্যান (সচিব)

3

ANNEX-17: RESPONSE TO THE COMMENTS ON DRAFT FINAL REPORT (PHASE-1)

Table A.17.1: Response to the comments received from Mr. Md. Abdul Quader Khan, Social Specialist, Support to Capacity Building of BEZA Project, BEZA

<table>
<tr><th>Sl. No.</th><th>Comments</th><th>Response of IWM</th></tr>
<tr><td>1</td><td>Phasing of Water Supply System Development Plan (Page XIX) : Table E.3 need to be update according to following information :<table><tr><th>Phase</th><th>Period</th><th>Budget</th><th>Water demand</th><th>Source</th></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td><td>Phasing of Water Supply System Development Plan is incorporated in Table E.5 and Table 11.1 of Final Report including information of phase, period, budget, water demand and source of water.</td></tr>
<tr><td>2</td><td>Please attach the details information in the final report.</td><td>The detail information is already included in Sec. 9.4 and the summary table is given in Table E.3 and Table 10.1 of Final Report.</td></tr>
<tr><td>3</td><td>In the recommendation the consultancy firm has mentioned that monitoring of water level and water quality are required but in the report I don't found any monitoring indicators or plan. Please incorporate the monitoring indicators and plan in the reporting including its budget</td><td>The monitoring plan and budget will be prepared and given under Phase-2.</td></tr>
<tr><td>4</td><td>The consultancy firm suggested that "The provision of roof top rainwater harvesting should be kept in each building area of roof from the very beginning. Otherwise extra costing will be needed for the re-design the plumbing system. BEZA may incorporate this sentence in the land lease agreement.</td><td>The cost of rainwater harvesting is excluded from the project cost and mentioned separately in Final Report. BEZA should consider this suggestion in the land lease agreement.</td></tr>
<tr><td>5</td><td>There is no specific head of budget for internal water connectivity in the report. The consultancy firm may incorporate the line item for internal water connectivity.</td><td>Water connectivity plan and the phase wise tentative budget is already mentioned in sec 9.4.7 and Annex-9.</td></tr>
<tr><td>6</td><td>The consultancy firm suggested for ensuring metering system within the water supply pipeline at every building but there is no details budget for this.</td><td>The budget for metering system will be prepared and incorporated under Phase-2.</td></tr>
</table>

7	There is no SWOT analysis in the report. Please incorporate the SWOT analysis in the report.	SWOT analysis is done and incorporate in sec. 9.5 of Final Report and will be finalized in Phase-2.
8	The consultancy firm has given costing of desalination plant but what is the major challenge and source of information didn't mention. The firm also can provide details technical specification for similar type of desalination plant.	• The source of water for desalination plant is sea water which is already mentioned in the report. • The quality of the source water is surveyed and already given in Table 2.2. • The major challenge is given in Sec 7.9, of Final Report.
9	The consultancy firm may consider the feasibility study of BEZA for Sabrang and Naf Tourism Park for identifying total demand of water.	Water demand is calculated based on the population as mentioned in the Master Plan Report of Sabrang and Naf Tourism Park (Master Plan, August 2019). The consultants also have considered Feasibility Study of Sabrang Tourism Park (June 2017) and Pre-feasibility Study for Jaliardip Economic Zone (February 2017).

Table A.17.2: Response to the comments received from DPHE.

Sl. No.	Comments	Response of IWM
1	In the design criteria, please provide the estimated water usages on a weighted average basis, expressing single LPCD.	Weighted average water demand is given in sec. 3.2.3 for Sabrang Tourism Park and in sec. 3.3.3 for Naf Tourism Park rather in design criteria table (Table 3.1) of Final Report. This is because the weighted average demand is different in different Tourism Parks due to variation of population and workforce ratio.
2	Other than the commons, please split the findings and recommendation for Sabrang & Naf separately.	The findings and recommendation for Sabrang and Naf Tourism Park are split and incorporate in the Final Report.
3	Please consider the system operation hours not more than 15 hours a day;	The maximum operation hour is considered 15 hour for each production tube well and accordingly water management plan is revised and presented in Chapter 8.
4	The individual discharge of PTW needs to be limited to 50 cum/h;	The individual discharge of PTW is considered maximum to 50 cum/h (14.42 l/s/0.5 cusec).
5	Count the unaccounted for water as 25%;	Unaccounted For Water in transmission and distribution system is considered 20% and loss through WTP is considered 5% and mentioned in Table 3.1 of Final Report. Accordingly total water demand has been estimated and water

		management plant has been revised. All the information are given in Final Report.
6	Total population to be served by 2049 needs to be mentioned distinctly;	Total population to be served by 2049 is already mentioned distinctly in Sec. 3.2.2 and 3.3.2 for both Sabrang and Naf Tourism Park.
7	The diameter of transmission water mains (250 mm) needs to be revisited.	The diameter of transmission water mains is considered 250 mm and will be finalized after modelling under Phase-2.

Table A.17.3: Response to the comments given in DFR presentation meeting

গত ১৩ অক্টোবর ২০২০ তারিখে বেজা'র সম্মেলন কক্ষে অনুষ্ঠিত Workshop- এ গৃহীত সিদ্ধান্ত মোতাবেক পরামর্শক প্রতিষ্ঠান কর্তৃক প্রয়োজনীয় পরিবর্তন এবং সংশোধন করা হয়েছে । নিম্নে ছক আকারে সিদ্ধান্তসমূহের উপর গৃহীত কার্যক্রম সদয় অবাগতির জন্য প্রদত্ত হলোঃ

ক্রমিক নং	সভার সিদ্ধান্ত	পরামর্শক প্রতিষ্ঠান কর্তৃক গৃহীত কার্যক্রম
(ক)	Deep Tube Well স্থাপনের কারণে Shallow Tube Well এর পানি উত্তোলন বাধাগ্রস্ত হওয়ার সম্ভাবনা থাকায় Zone of Influence এলাকায় পানি সরবরাহের জন্য একটি পৃথক Deep Tube Well স্থাপনের সংস্থান রাখতে হবে এবং সে অনুযায়ী Final Report চূড়ান্ত করতে হবে।	Deep Tube Well স্থাপনের কারণে Shallow Tube Well এর পানি উত্তোলন বাধাগ্রস্ত হওয়ার সম্ভাবনা থাকায় Zone of Influence এলাকায় পানি সরবরাহের জন্য একটি পৃথক Deep Tube Well স্থাপনের সংস্থান রাখা হয়েছে এবং সে অনুযায়ী Final Report (Phase-1) চূড়ান্ত করা হয়েছে।
(খ)	Rainwater Harvesting হিসেবে Reservoir এ ধারণকৃত পানি ট্যুরিজম পার্কের জন্য Supplementary হিসেবে ব্যবহারের সুযোগ রাখতে হবে।	Rainwater Harvesting হিসেবে Reservoir এ ধারণকৃত পানি ট্যুরিজম পার্কের জন্য Supplementary হিসেবে ব্যবহারের সুযোগ রাখা হয়েছে।
(গ)	ট্যুরিজম পার্কে শুধুমাত্র পান করার জন্য যে পরিমাণ পানির (Drinking Water) প্রয়োজন হবে তা সমীক্ষাপূর্বক Final Report- এ উল্লেখ করতে হবে এবং তা বোতলজাতের মাধ্যমে সরবরাহের বিষয়ে প্রয়োজনীয় সংস্থান থাকতে হবে।	(i) ট্যুরিজম পার্কে শুধুমাত্র পান করার জন্য যে পরিমাণ পানির (Drinking Water) প্রয়োজন হবে তা সমীক্ষার Final Report (Phase-1) - এ Section 3.24 ও Section 3.3.4 এ উল্লেখ করা হয়েছে। (ii) বোতলজাতের মাধ্যমে শুধুমাত্র পান করার জন্য প্রয়োজনীয় সংস্থান সমীক্ষার Final Report (Phase-1) এ রাখা হয়েছে।
(ঘ)	Deep Tube Well এর Operating Hour কত হবে তা DPHE এর সাথে পরামর্শ করে নির্ধারণ করতে হবে এবং সে অনুযায়ী Final Report চূড়ান্ত করতে হবে।	Deep Tube Well এর Operating Hour, DPHE এর সাথে পরামর্শ করে নির্ধারণ করা হয়েছে এবং সে অনুযায়ী সমীক্ষার Final Report (Phase-1) চূড়ান্ত করা হয়েছে।
(ঙ)	Naf and Sabrang Tourism Park- এ Rainwater Harvesting এর মাধ্যমে পানি সরবরাহের জন্য প্রস্তাবিত প্রকল্পে যে ব্যয় প্রাক্কলন করা হয়েছে তা প্রাক্কলিত ব্যয় হতে বাদ দিয়ে আলাদাভাবে হিসাব করে Final Report- এ উল্লেখ করতে হবে।	Rainwater Harvesting শুধুমাত্র Sabrang Tourism Park এর জন্য প্রস্তাব করা হয়েছে। Rainwater Harvesting এর জন্য প্রাক্কলন ব্যয় Project Cost থেকে বাদ দিয়ে আলাদা ভাবে Final Report (Phase-1)এর Sec. 10.1 এ উল্লেখ

ক্রমিক নং	সভার সিদ্ধান্ত	পরামর্শক প্রতিষ্ঠান কর্তৃক গৃহীত কার্যক্রম
		করা হয়েছে। উল্লেখ্য যে Rainwater Harvesting এর ব্যয় যে সকল প্রতিষ্ঠান জোন/ ট্যুরিজম পার্কে জমি বরাদ্দ নিবে সে সকল প্রতিষ্ঠান তাদের নিজ দায়িত্বে Rainwater Harvesting System স্থাপন করবে যা Tabl e 10. 2, Final Report (Phase-1)এ উল্লেখ করা হয়েছে। ।