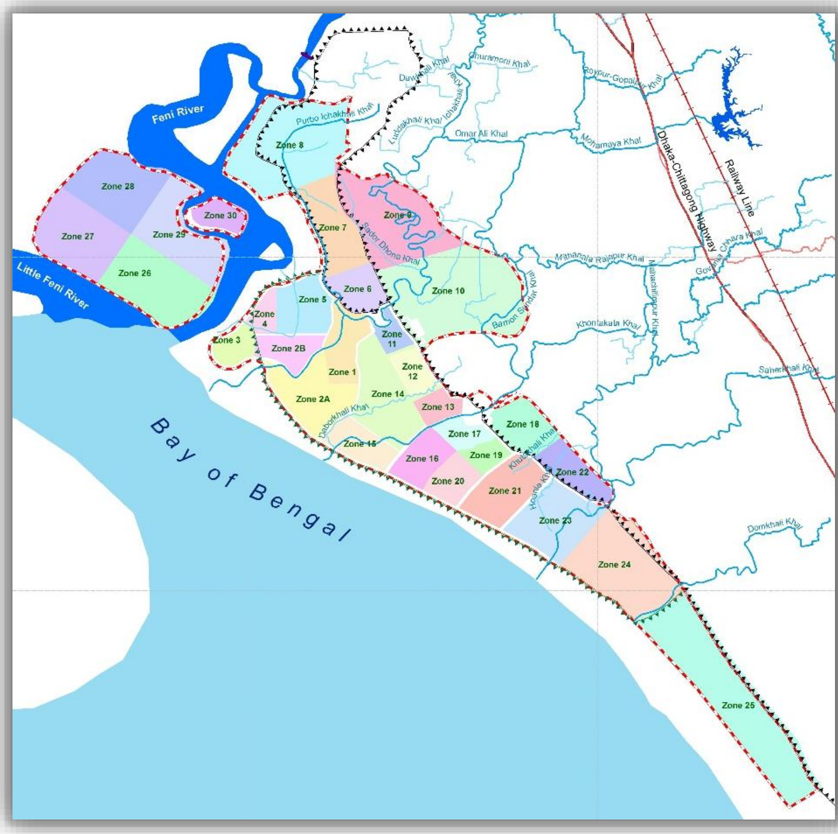
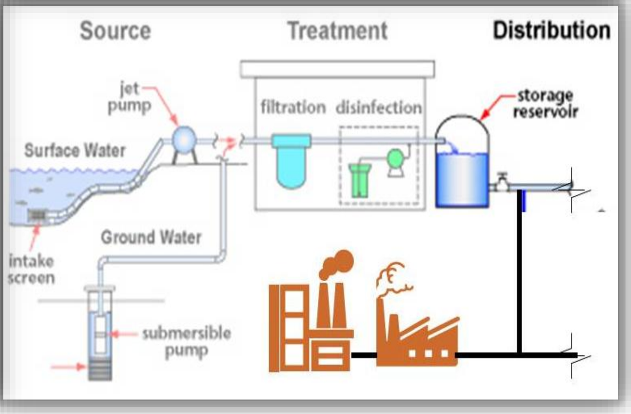
Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR





Final Report

Volume I: Executive Summary

February, 2020

Water Environment & Climate

INSTITUTE OF WATER MODELLING

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Contents of Final Report

Executive Summary

Introduction

The proposed Bangabandhu Sheikh Mujib Shilpanagar (BSMSN) will be the first multi sector economic zone comprising an area of around 30,000 acres, located in Mirsharai Upazilla of Chittagong district and Sonagazi Upazilla of Feni district (**Figure E.1**) BSMSN will be situated at the mouth of Feni river, covering 25 KMs of coast lines of Sandweep channel of the Bay of Bengal. Bangladesh Economic Zone Authority (BEZA) is in the process of developing a comprehensive master plan including incorporation of sea port, rail connectivity, marine drive, residential area, power plant, hospital, school and university for developing this self-sustained industrial city. The entire area is divided into 30 sub-zones. Sub-zones 2A, 2B, 3, 4 and 5, comprising an area of around 2,382 acres will be developed first as priority. The area is very strategically located for its water way connectivity. However due to non-availability of sufficient water resources, water supply solution for the area will have to depend on the use of surface water, groundwater and also sea water conjunctively.

Demand Assessment

Assessment of industrial rate of utility demand is expressed in practicing unit of demand per day per unit of area. Preliminary unit rate of water demand for BSMSN, in absence of its detailed industrial allocation plan, has been assessed, reviewing yearly water consumption of eight EPZs of BEPZA and other reports. It may be mentioned that Master Plan of BSMSN and its land use plan is conducted jointly by Sheltech Consultants (Pvt.) Limited and STUP Consultants Private Limited.

Total water demand is divided into two major portions: 1. Industrial Water Demand, and 2. Domestic and non-domestic water demand. Unit rate of demand of 97 m^3/d/ha (0.0392 MLD/acre) of gross industrial land or 162 m^3/d/ha (0.066 MLD/acre) of operating industrial land has been considered for present purpose. Considering total industrial area of about14606 acre in 2040, the projected water demand for industrial part is about 665 million liter daily. Domestic and non-domestic water demand is estimated based on the total population living in BSMSN area and in-direct employee which is about 174 million liter daily. Considering some losses in distribution system the required production capacity is 965 million liter daily. Also there will be some losses at treatment plant, so total water withdrawal is about 1013 million liter daily. Based on the assumption the water required production capacity will be 343 million liter in 2025, 482 million liter in 2030, 683 million liter in 2035 and 965 million liter in 2040.

Surface Water Resource Assessment

Feni River

Existing surface water reservoir in the Feni River is a potential source of water supply for the BSMSN area. The reservoir was built at Sonapur, by constructing Feni Regulator to supply the irrigation water during dry season (December to April) in the Muhuri Irrigation Project (MIP) area. The gates are designed to allow flood flow, prevent sea water intrusion and to maintain appropriate water levels for irrigation water supply from the reservoir. The effective storage of the reservoir depends on the combined upstream supply of water from Muhuri, Selonia and

Feni River. Originally the irrigation was planned for a net irrigable area of 23,067 ha. Presently the available active storage of Feni reservoir is about 17.4 Mm^3. Under average rainfall and stream flow conditions use of 100 MLD water from the reservoir to meet the industrial requirement of BSMSN after meeting crop water requirements would be a problem. However, withdrawal of 100 MLD for industrial requirement during dry condition in February and March would reduce a bit the minimum reservoir storage for use in the later part.

Figure E.1: Base Map of BSMSN Study Area

Little Feni River

The existing surface water reservoir on the Little Feni River is also a potential source of water supply for the BSMSN area. A surface water reservoir was built on the little Feni River by constructing Musapur Regulator and a dam closure at about 1 km north of Sandwip channel. The main purpose of the regulator is to protect the area from saline water intrusion, drainage control and facilitate small scale irrigation in the area. The effective storage volume in the reservoir is estimated to be about 20.14Mm^3. The analysis shows that about 40MLD water can be withdrawn for BSMSN industrial requirement without disturbing minimum reservoir storage requirement.

Other Khals and Reservoir

There are other khal and reservoir in the area. Analysis shows that year-round water available in Ichakhali & Bamon Sundor Khal and water available in Mohamaya, Bawa Chhara, Boro-Komoldoho and Sahasradhara reservoir is not sufficient for BSMSN area, therefore not considered as potential source of surface water.

Groundwater Investigation and Resource Assessment

Hydrogeological Investigation and Aquifer Properties Determination

10 VES (Vertical Electrical Sounding) of Schlumberger configuration with 600 m spread were carried out at different sites of the study area. Hydrogeological investigation shows that the top soil in the study area is composed of mainly ~~by~~ silty clay. The shallow (10m to 121m) aquifer consists of very fine to fine sand is mainly brackish in nature and showing a resistivity range between 0.9 Ωm to 12 Ωm. The aquitard thickness is highly variable and varies from ~15m to ~100m. The resistivity of the aquitard range between 1.24 Ωm to 17 Ωm, and composed of clay or silty clay.

The deep aquifer shows resistivity range varying between 23 Ωm to 73 Ωm and confirms having fine to medium sand with fresh pore water. The depth to the deep aquifer varies between ~50m to ~150m and is increasing towards southeast.

It is observed that shallow or deep aquifers in the study area are interrupted by discontinuous clay deposition at multiple depth levels of different thickness.

Aquifers containing saline water show low resistivity value and it is difficult to identify lithology or pore water quality unless direct information about the texture of the formation or the water quality of the formation water is available.

For aquifer system analysis, 10 (Ten) exploratory drilling and test well construction up to a depth 300m were carried out in the study area. For this purpose of identifying hydrogeological parameters of the aquifer, the area was divided into four zones: Zone A, B, C & D. One production well (near CP More), 8 (eight) observation well boreholes were drilled and 2 (two) long term (72 hrs) aquifer test carried out (one at CP more PTW and another in DPHE well) for this purpose.

At DPHE PTW, average transmissivity and storage coefficient is found 1282 m^2/day and 0.000175514 respectively, indicating that the aquifer is confined in nature and suitable for groundwater development.

At BEZA PTW, average transmissivity and storage coefficient is found 1333 m^2/day and 0.0016872 respectively, indicating that the aquifer is semi confine in nature and also suitable for development.

The **Figure E.2** shows area of influence of pumping is 285 m (935 ft) at DPHE well, and 405 m (1328 ft) at CP More well surrounding the above pumps.

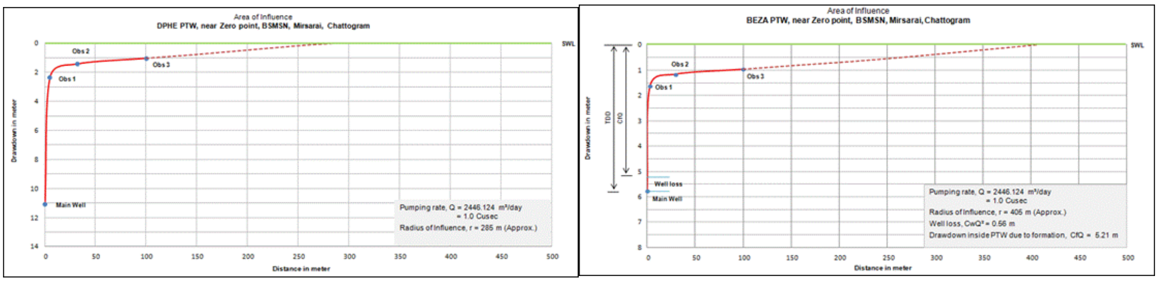


Figure E.2: Area of influence due to pumping at DPHE PTW (left) and CP More PTW (right)

Groundwater Resource Assessment

Groundwater resources available is estimated based on the targated drawdown of 10m in the Mirsharai area using the Depth-Storage Model for the purpose. **Figure E.3** shows the Depth-Storage relationship used for the estimation of groundwater resources availability.

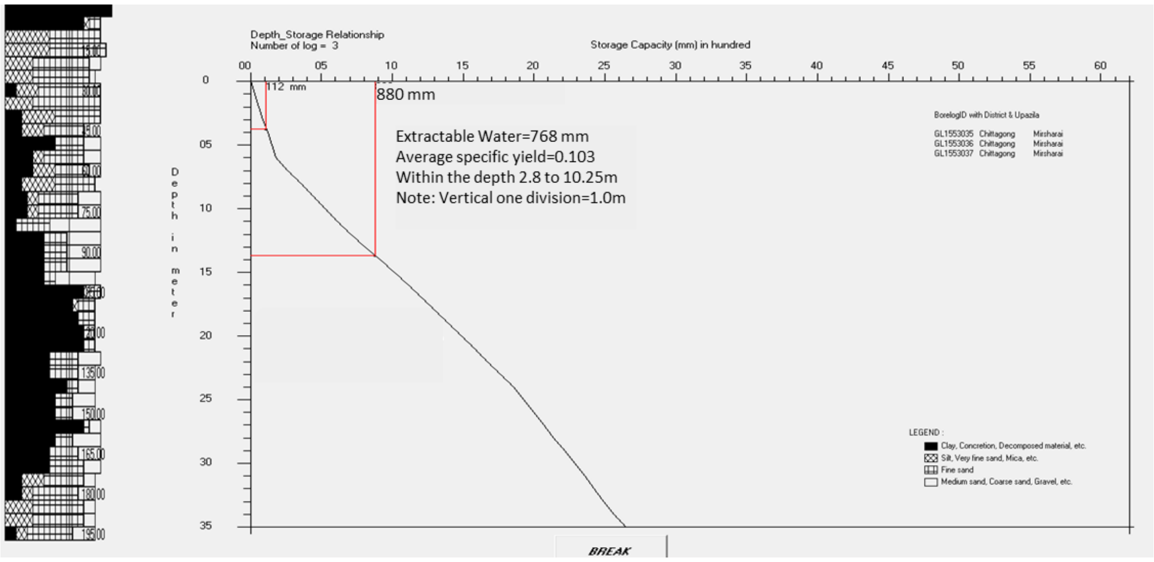


Figure E.3: Depth-storage relationship of the study area

The drainable storage volume estimated is about 205 MLD that can be obstructed from the deep aquifer and total of 100 nos of 1 cusec pumps (28.414 litre/sec), operating for 20 hours per day will be required for its development.

Rainwater harvesting

Annual rainfall of the study area is about 3300mm and 90% rainfall is received between the months from May to October. Rainwater harvesting is considered as a very potential source for water supply in this economic zone. If 50% of the area is considered as catchment area for rainwater harvesting and 60% of rainfall from May to October can be utilized, then about 65,487 million liters volume rain water will be available from potential area annually, which is equivalent to about 179 MLD. This huge amount of harvested rainwater can be utilized as non-potable usage.

Feni Surface Water treatment plant

Selection of Intake Site

The intake site for raw water collection has been selected at Osmanpur, which is about 2.5 km upstream of the Feni Regulator near confluence of the Azampur Khal and the Feni River. This intake site has been found feasible in terms of availability of land, water and long term stability of the river bank. Water quality analysis for both dry and wet seasons has been conducted for the treatment plant. Maximum water level in the Feni River at Sonapur during dry season is maintained by BWDB at 4.5 mPWD while corresponding minimum water level during wet season is 0.6 mPWD. The bed level of the river at intake point is -5.27 mPWD. The pipe intake solution appears to be the most effective considering initial and recurrent operation and maintenance cost. The capacity of the intake will be 105 MLD considering two phase development of the surface water treatment plant. The land acquisition required at the intake site is about 15.44 acre.

Selection of Sites for Surface Water Treatment Plant

Based on the study, treatment plant site at Poshchim Ichakhali Mouza on the east side of CDSP embankment has been selected. The site is free from social disturbance. The capacity of the treatment plant will be 50 MLD in Phase-1. The land required for treatment plant is about 9.26 acre (3.75 ha). Another 9.26 acre (3.75 ha) area need to be preserved for Phase-2 of the treatment plant. As the location is within the project area so land acquisition is not required.

Process Selection of WTP

A detailed study for the proposed water treatment plant has been carried out by BUET expert team to select the treatment processes. Coagulation-flocculation-sedimentation with PAC was found to be very effective in removing turbidity, suspended solids, and color from the raw water. Provision of a rapid sand filtration unit will be beneficial for removing suspended and floating flocs of turbidity, and suspended solids.

Pre-chlorination is required to remove fecal/total coliforms from raw water, prevent growth of microorganisms. The model process studies indicate that post-chlorination is not necessary prior to feeding the treated water into the water distribution network. However, in actual plant operation, the microbial quality may vary at different conditions, which may require a post-chlorination process for effective disinfection. The proposed treatment process flow diagram is depicted in **Figure E.4**.

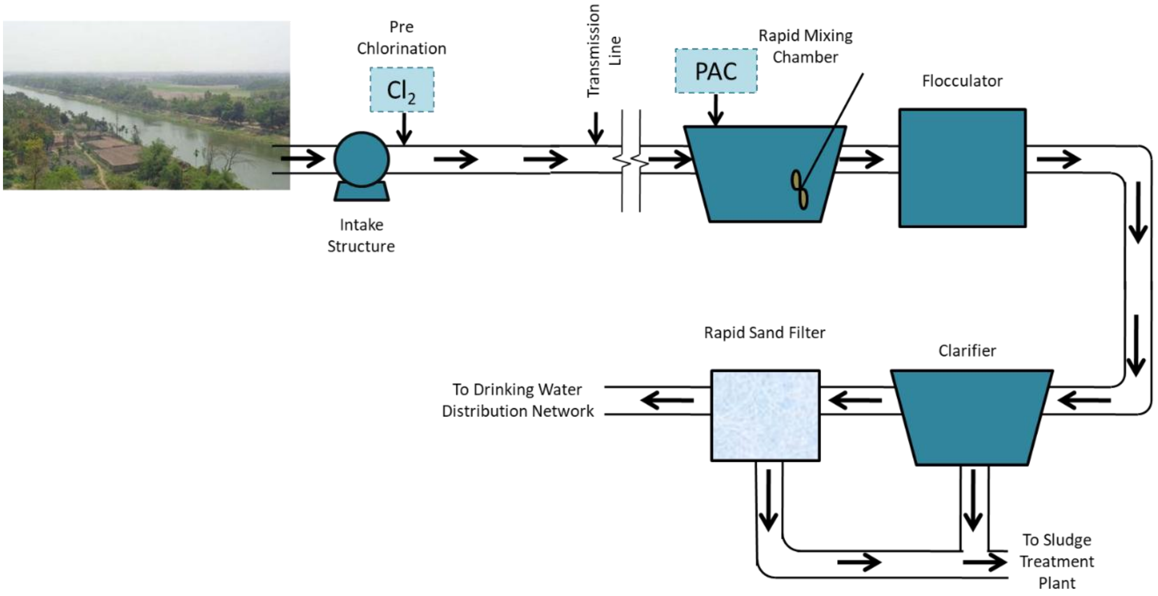


Figure E.4: Treatment process flow diagram of the Water Treatment Plant for treating raw water from the Feni River to supply water to the BSMSN

Raw Water Transmission Mains

RAW water of 52.5 MLD (Phase-1) will be transported from the intake site to the treatment plant along the existing Vanghani road (BWDB old embankment) and then along proposed BEZA project road by diameter 800mm ductile iron pipe. The length of the raw water transmission main is about 9.56 km. The land acquisition required for raw water transmission main from intake site to Vanghani road is about 7.71 acre.

Treated Water Transmission and Secondary Distribution Mains

About 50 MLD treated water will be carried from the proposed SWTP to the priority area. The transmission main length is about 10.44 km. The treated water transmission main will follow the CDSP embankment road and then Vanghani road. Ductile iron pipe~~s~~ is recommended for treated water transmission main as well. The diameter of transmission main and distribution pipe line has been considered from 800mm to 300mm and 300 mm to 100mm respectively.

Outline Design of Infrastructures

A Conventional treatment plants including its related structures have been prepared. The general layout of the water treatment plant is shown in **Figure E.5.**

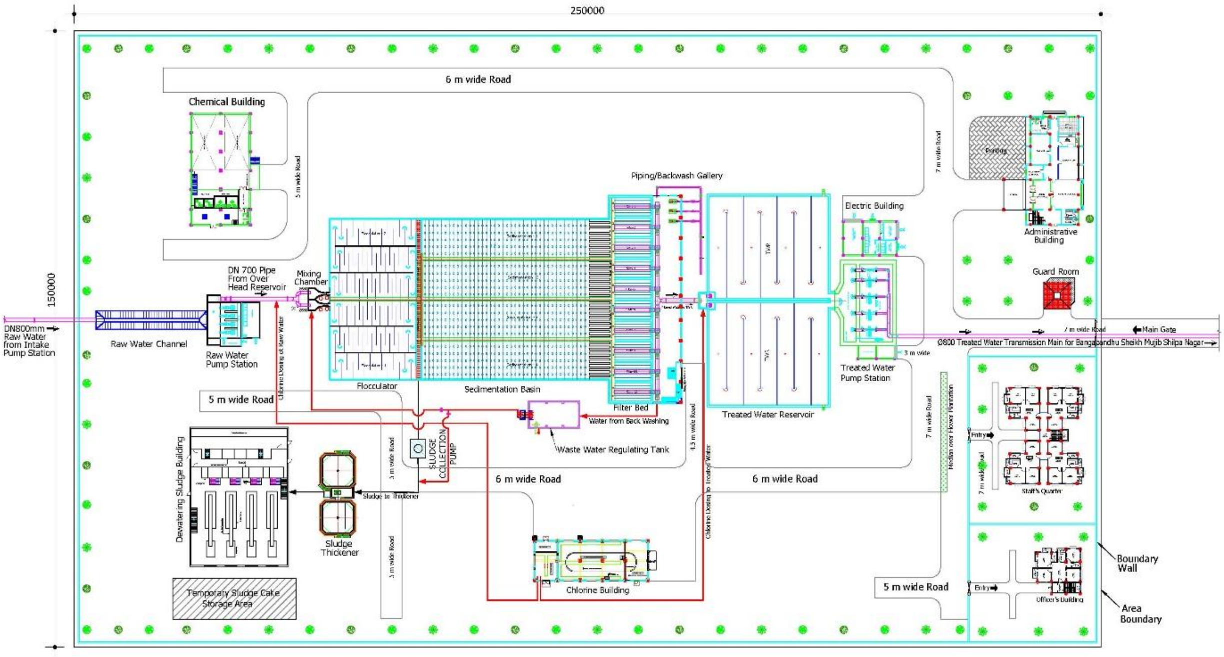


Figure E.5: Layout of Surface Water Treatment Plant at Poshchim Inhakhali

Geotechnical Investigation and Foundation Design

The exploratory work involves drilling through cohesive and non-cohesive soil on firm ground upto 20m depth. Standard penetration tests and permeability tests have been executed in the boreholes. According to geotechnical report the cast in situ of 50cm diameter of piles at intake and treatment plant recommended are listed as follows.

Sl. No.	Description	Depth (m)	Average ultimate pile capacity
1	Intake pumping station	**15**	1154kN
	Clarifier	15	1189kN
	Filter	15	1119kN
	Storage tank	18	1450kN
2	Treated water pumping station	18	1400kN

Cost of SWTP

The estimated capital cost for the surface water treatment plant of 50MLD capacity (Phase-1), transmission and distribution network and road & bridge cost along the transmission line is about 5879.37 Million BDT as given in **Table E.1**.

Table E.1: Summary of Capital Cost for SWTP and pipeline

Sl. No.	Description	Total Price in Million BDT
A)	**SWTP and water supply network**	
	I) Civil Works for SWTP and Intake (including general cost items structure)	1375.24
	ii) Water supply network (Transmission and Distribution pipeline)	1552.26
	iIi) Mechanical Equipment	754.04
	iv) Electricity Equipment	378.56

Sl. No.	Description	Total Price in Million BDT
	v) Land development for intake and SWTP site	115.26
	Sub-total of A=	**4175.76**
B)	**CD & VAT for pipe materials, mechanical and electrical equipment**	**988.06**
	Sub-total of B=	**988.06**
C)	**Linking road**	
	ii) Approach road	131.57
	i) Bridge (62.5m)	78.90
	Sub-total of C=	**210.47**
D)	**Land Acquisition & Purchase**	
	i) Land acquisition for intake and approach road	166.85
	Sub-total of D=	**166.85**
E)	**Consultancy**	
	i) Consultant for Design Supervision and Construction Supervision of Treatment Plant including Intake and Transmission Main and Tertiary Network	75.10
	Sub-total of E=	**75.10**
F)	**Contingency**	
	i) Physical contingency (1% of A+C cost)	43.86
	ii) Price contingency (5% of A+C cost)	219.31
	Sub-total of F=	**263.17**
	Total cost (A+B+C+D+E+F)	**5879.41**

Operation and Maintenance Cost

Annual operating costs of the SWTP have been estimated separately for labor, chemicals, electricity & miscellaneous costs based on current rate. It is found that 104.36 Million BDT Per year is required for O&M of SWTP and related structures.

Groundwater Wells

Design of PTW

According to the resource estimation a sample well design and its component dimension has been given. It is considered that the rated drawdown would be 5m and capacity of each pump is 1 cusec. If the pump is operated for 20hours a day, about 2MLD water will be available from each well.

Cost of PTW

Cost Estimate for 25nos. deep tube well is about 414 million BDT as given in **Table E.2**.

Table E.2: Summary of Capital Cost

Sl. No.	Description	Total Price in Million BDT
A)	**25 nos. Production Well**	
	i) Construction of Tube well and ancillary structures	303.66
	a) Construction of 350mmx200mm diameter Deep Tube Well with related works including supply of all necessary materials	146.46

Sl. No.	Description	Total Price in Million BDT
	b) Construction of Pump house, Chlorine Room of DTW with related works including supply of all necessary materials	35.64
	c) Construction of RCC Column with R.S. Joist of DTW with related works including supply of all necessary materials	4.22
	d) Construction of 11/0.415KV 200KVA Pad Mounted Sub-Station of DTW Compound with related works including supply of all necessary materials	56.22
	e) Installation of Submersible Pump Set and Chlorine Set with related works including supply of all necessary materials	26.49
	f) Construction of boundary wall and approach road of DTW compound with related works including supply of all necessary materials	34.63
	ii) Land Development of PWT site	80.00
	Sub-total of A=	**383.66**
B)	**Consultancy**	
	i) Consultant for Design Supervision and Construction Supervision of Deep Tube Well (25nos.)	7.53
	Sub-total of B=	**7.53**
C)	**Contingency**	
	i) Physical contingency (1% of A cost)	3.84
	ii) Price contingency (5% of A cost)	19.18
	Sub-total of C=	**23.02**
	Total cost (A+B+C)	**414.21**

Operation and Maintenance Cost

Annual operating costs of the PTWs have been estimated separately for labor, electricity & miscellaneous costs based on current rate. It is found that 16.66 Million BDT Per year required for O&M of 25nos. PTW and related structures.

Project Implementation & Operation (Phase I)

Bangladesh Economic Zone Authority (BEZA) will be the Executing Agency of the water supply project, responsible for the overall technical supervision and execution of the projects. A Project Implementation Unit (PIU) headed by a Project Director (PD) will be set up at in BEZA and will be responsible for day to day management of the project including but not limited to the following:

- Prepare overall Project Implementation Plan (PIP)
- Provide overall construction supervision works of the project components
- Initiate tendering and executing contracts
- Monitor and supervise all project management activities
- Organize monitoring and evaluation activities
- Prepare Project Progress Report (PPR) and Project Completion Report (PCR)
- Ensure full compliance with resettlement, environmental and other safe guard issues and policies.

- The PIU will be assisted by the consultants for design supervision and construction supervision.
- PIU will continue the O&M of the project up to defect liability period and then PIU will hand over the operation and maintenance of the project to the Executive Engineer O&M division for proper operation and maintenance of the Project.

A proposed organizational structure for Project Implementation unit (PIU) has been given **Figure E.6**.

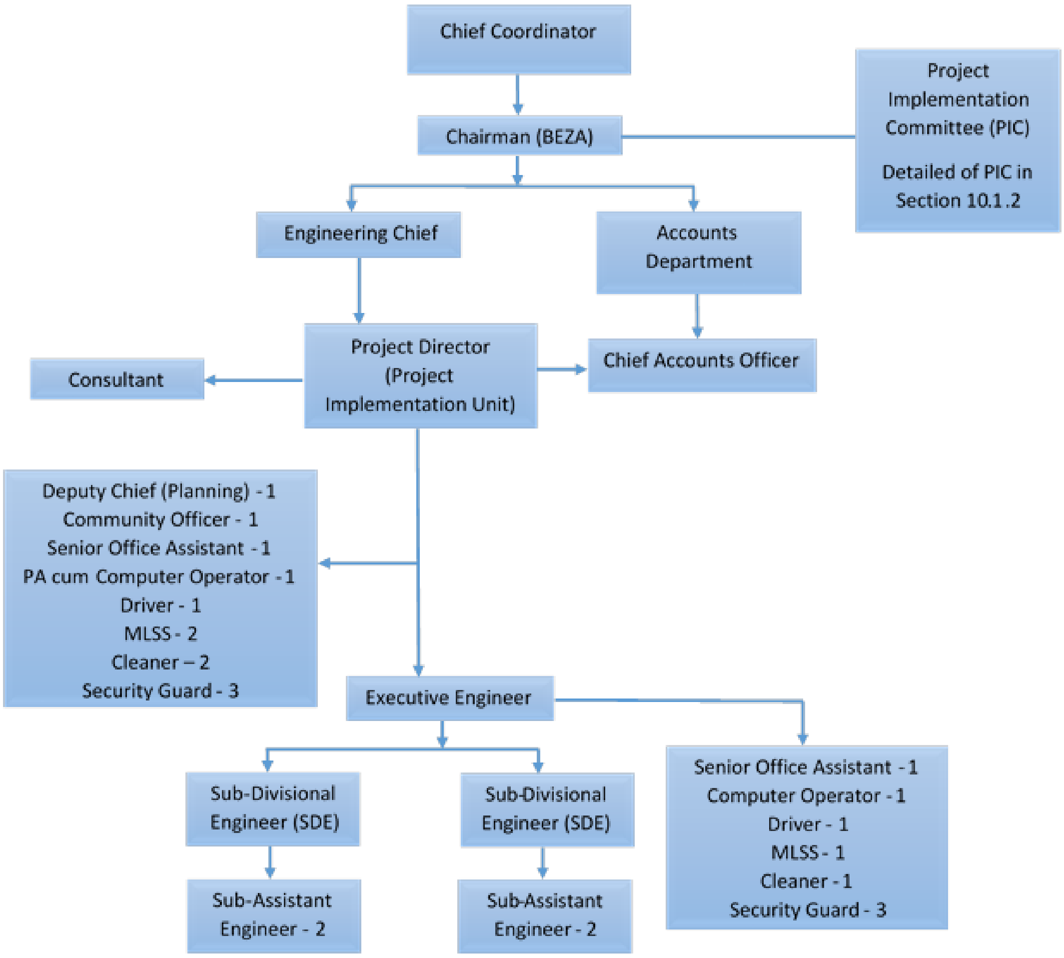


Figure E.6: Proposed organizational structure for Project Implementation Unit (PIU)

BEZA will setup a Unit for operation and maintenance (O&M) of Water Treatment Plants and Ground Water Wells including Transmission and Distribution System by an Executive Engineer. The O&M unit will be responsible for

a) Procurement of chemicals, operation and maintenance of different units of SWTP

b) Operation and maintenance of

– raw water transmission main

– treated water transmission

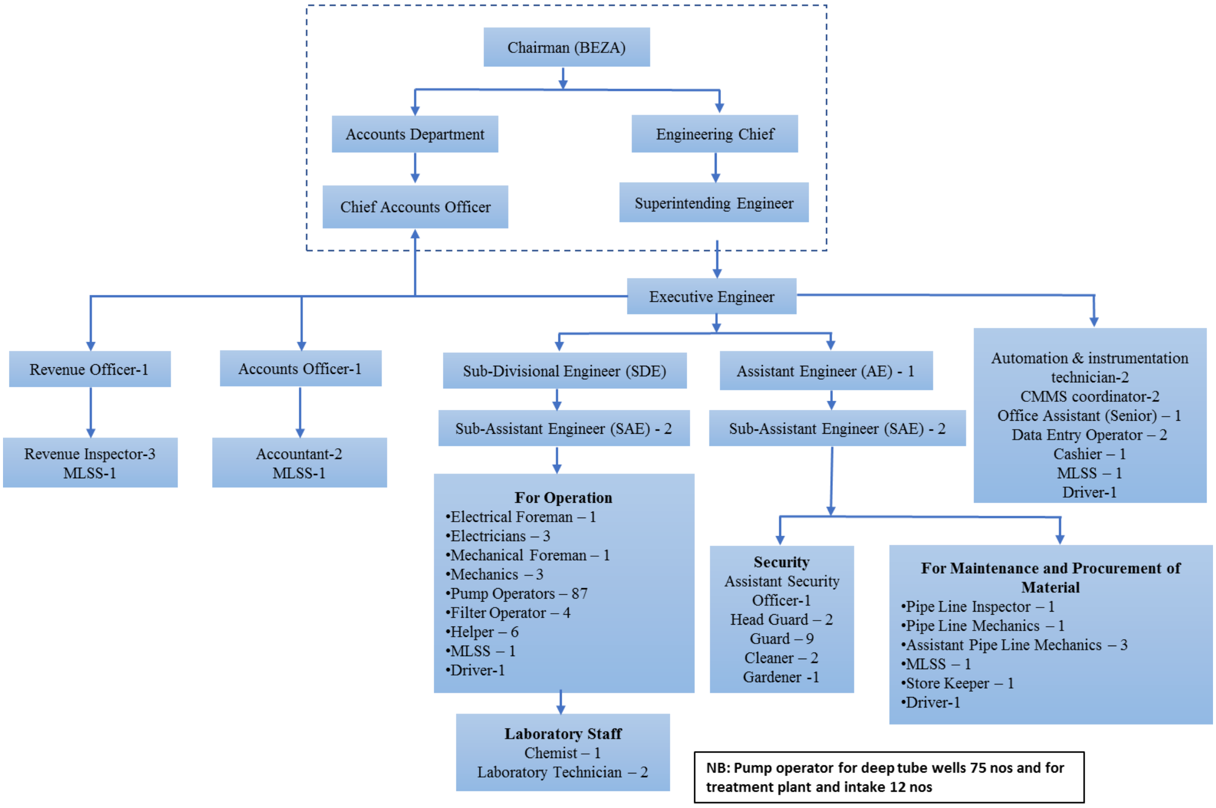
– distribution network

– groundwater wells

c) Providing service connection to the consumers

d) Receive complains and provide emergency services

Proposed Organizational Structure for O&M unit of the overall water supply system is shown in **Figure E.7.**



NB: Pump operator for deep tube wells 75 nos and for treatment plant and intake 12 nos

Figure E.7: Proposed Organogram for O&M Unit of Water Supply System

Water Quality of Sea Water and Desalination Plant

Water quality of sea water

To assess the marine pollution marine and design of desalination plant water sample has been collected from the Sandwip channel at the downstream of Shaherkhali khal. The water sample has been tested in BUET laboratory and are shown in **Table E.3**.

Table E.3: Water quality data of Sandwip channel

Sl. No.	Parameter	Unit	Concentration
1	pH	--	7.90
2	Turbidity	NTU	616
3	Electrical Conductivity (EC)	mS/cm	30.5
4	Dissolved Oxygen (DO)	mg/l	7.81
5	Temperature	°C	23.8
6	Total Dissolved Solids (TDS)	mg/l	22,068
7	Total Suspended Solids	mg/l	712
8	Total Hardness	mg/l as $CaCO_3$	3,750
9	Chloride	mg/l	12,275
10	Manganese (Mn)	mg/l	0.12
11	Total Iron (Fe)	mg/l	6.80

Sl. No.	Parameter	Unit	Concentration
12	Nitrate (NO_3-N)	mg/l	0.40
13	Orthophosphate (PO_4^{3-})	mg/l	0.17
14	Sulfate (SO_4^{2-})	mg/l	1,340
15	Biochemical Oxygen Demand (BOD_5)	mg/l	0.4
16	Chemical Oxygen Demand (COD)	mg/l	60
17	Magnesium(Mg)	mg/l	789.6
18	Lead (Pb)	mg/l	< 0.001
19	Cadmium (Cd)	mg/l	< 0.001
20	Chromium (Cr)	mg/l	< 0.001
21	Zinc (Zn)	mg/l	0.071
22	Mercury (Hg)	mg/l	< 0.001
23	Copper (Cu)	mg/l	0.006
24	Nickel (Ni)	mg/l	0.011
25	Total Organic Carbon (TOC)	mg/l	1.69

Desalination plant for BSMSN

With current technology trend a sea water reverse osmosis (SWRO) plant would be suitable for BSMSN area 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

Approximately 15 acres of land may be required for the plant. The approximate power requirement for a 50 MLD plant can be 200 MWh/day. Based on similar project and assessment of current study the following approximate costs can be assumed for the 50MLD desaliation

- Capital Cost - $50 million
- Operating Cost - $6 million/yr
- Cost of Water – 50 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.

Project Cost

The overall project components includes 2 nos. 50 MLD surface water treatment plant from Feni River, 90 MLD surface water treatment plant from Halda river (Mohra), 40 MLD surface water treatment plant from Little Feni river, installation of 100 nos. DTW each of 2.0 MLD , 11 nos @50 MLD desalination plant and transmission main & distribution networks. The tentative total cost to meet the water requirement for 30,000 acre area of BSMSN is about 83,387 Million BDT. The summary of tentative cost is shown in **Table E.4.**

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

SL. No.	Description	Total Price in Million BDT
1	50 MLD Surface Water Treatment Plant (Phase I) including Intake for 105 MLD	5,676
2	50 MLD Surface Water Treatment Plant (Phase II)	4,898
3	90 MLD Surface Water Treatment Plant (Mohra)	5,565
3.1	About 65 km Transmission Main with 2 nos. Booster Pump from Mohra to BSMSN	10,022
4	40 MLD Surface Water Treatment Plant (Little Feni River)	2,968
4.1	12 Km Raw &T Water Transmission for 40 MLD SWTP	828
5	205 MLD Groundwater (100 nos. DTW)	1,657
6	11 nos @ 50 MLD Sea Water Desalination Plant	46,750
7	About 380 km water distribution networks	5,022
Total		**83,387**

Water management plan

Use of Available Resources and Phasing

About 100 MLD water can be supplied from Feni river reservoir and the plant has been proposed to be construct in two phases. In the 1st phase, 50 MLD treatment plant with 25 nos. DTW will be constructed for supplying water in priority zone 2A, 2B, 3, 4 & 5.

In the 2nd phase, another surface water treatment plant from Feni River will be constructed for next priority zones. The location for 50 MLD water treatment plant (phase II) has been selected adjacent to the phase I.

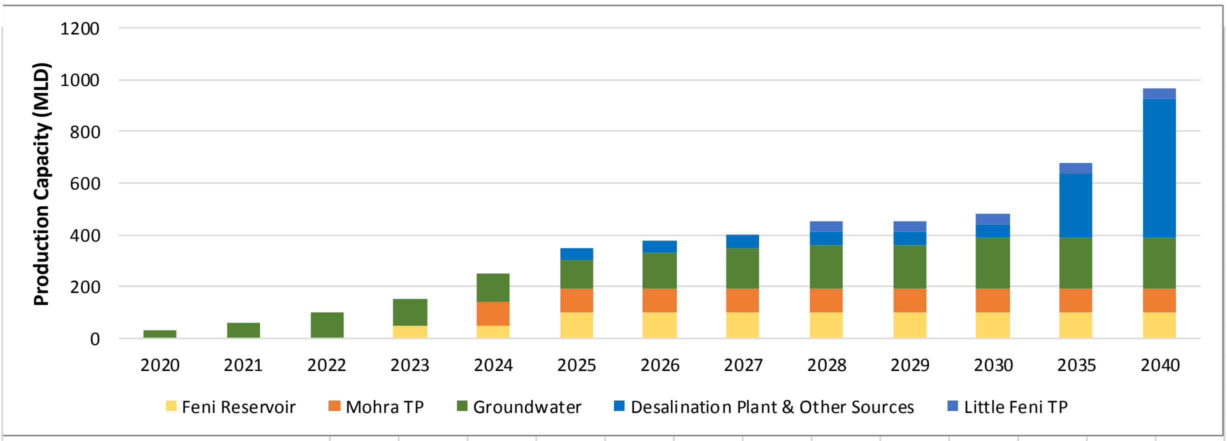
Another potential source of surface water is Mohra treatment plant Phase-2. The source of this treatment plant is Halda River in Chittagong. About 65km transmission line is required to carry the treated water from the treatment plant to BSMSN area. A treated water transmission main of 1000 mm diameter Ductile Iron pipe or steel pipe with 2 (two) number booster pump stations will be required.

Little Feni river is another source of surface water which can provide 40MLD water to meet water demand of BSMSN area. A surface water treatment plant is required in this regard and the water can be distributed in the western zones beside the right bank of Feni River. About 6km raw water transmission line is required to carry the river water to the treatment plant in BSMSN area. The raw water transmission main of 800 mm diameter Ductile Iron pipe or steel pipe will be required.

Detailed groundwater investigation in BSMSN area reveals that average thickness of deeper aquifer in this area varies between 120m to 205m. The available water that can be extracted from groundwater is maximum 205 MLD.

The total amount of water that will be available from surface water and groundwater source is about 430 MLD. The additional water that will be required to fulfil the water demand of the whole project area will be about 535MLD. This amount of water will need to be managed by using treatment of sea water and other sources.

In the Master Plan the development of BSMSN area has been divided into four main time horizon- 2020-2025, 2026-2030. 2031-2035 and 2036-2040. Accordingly, the production water from surface water, groundwater and desalination plant has been planned for BSMSN as shown in **Figure E.8**.



Planning hoizone	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040
Water Demand	**30**	**60**	**100**	**150**	**250**	**344**	**380**	**400**	**450**	**450**	**482**	**682**	**965**
Feni Reservoir - Phase I				50	50	50	50	50	50	50	50	50	50
Feni Reservoir - Phase II						50	50	50	50	50	50	50	50
Total Feni Reservoir	**0**	**0**	**0**	**50**	**50**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Goundwater Phase I	30	50	50	50	50	50	50	50	50	50	50	50	50
Goundwater Phase II		10	50	50	50	50	50	50	50	50	50	50	50
Goundwater Phase III					10	10	40	60	70	70	100	100	100
Total Groundwater	**30**	**60**	**100**	**100**	**110**	**110**	**140**	**160**	**170**	**170**	**200**	**200**	**200**
Mohra Treatment Plant					90	90	90	90	90	90	90	90	90
Little Feni Treatment Plant									40	40	40	40	40
Offstream Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0
Mahamaya Reservoir	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total (SW+GW)	**30**	**60**	**100**	**150**	**250**	**300**	**330**	**350**	**400**	**400**	**430**	**430**	**430**
Gap	0	0	0	0	0	44	50	50	50	50	52	252	535
Desalination Plant (sea water) & other sources				**0**	**0**	**50**	**50**	**50**	**50**	**50**	**50**	**250**	**535**
Required Production Capacity	**30**	**60**	**100**	**150**	**250**	**350**	**380**	**400**	**450**	**450**	**480**	**680**	**965**

Figure E.8: Future Sources of Supply for BSMSN

Uncertainties in Resource Availability and Management

There could be several uncertainties associated with availability of water from surface water sources or groundwater sources. Also issues such as reduced water demand or damage to the infrastructures due to natural disaster can immerge. Therefore, it is necessary to have a management plan to overcome the uncertainties as follows.

1. Decrease in Surface Water and Groundwater Availability

Over the years, availability of freshwater in the Feni river reservoir can get hampered due to Trans-boundary withdrawal, extended draught governed by climate change and water quality issue such as river pollution. Besides availability of groundwater can get reduced over the time due to excessive withdrawal, reduced natural recharge governed by climate change impacts and quality issues such groundwater pollution, salinity instruction etc.

Impacts: The probable impact would be less production in the surface water treatment plants and less production or shutdown of the deep tube wells.

Mitigation Measures: Following measures shall be taken to mitigate the impacts:

- Signing water sharing treaties or MoU with the neighboring countries.
- Establishing a monitoring mechanism both for surface water and groundwater sources.
- In case the reduction in water availability is emerged as a result of quantity issues, the probable deficiency in supply requirement shall be managed by installing additional desalination plants.
- Waste water with or without treatment from the industries, domestic and non-domestic should not be discharged from upstream of Intake to Feni regulator.
- However, in case of quality issues additional treatment steps shall be added to the SWTPs for maintaining treated water quality standard. Additional treatment facilities (RO, chlorination, aeration etc.) shall be installed for DTWs in groundwater quality issue arises.
- Efficient management of produced water from SWTPs and DTWs such as reducing system loss, installing water recycling facilities in industries where feasible.

2. Reduction in Water Requirement

Requirement of water is likely to decrease during vacations such as Eid festivals or during labour strikes and shutdown of industries due to financial or other implications. This will lead to shortfall in requirement for a limited period. In addition, the future growth in industries may not follow the projected pattern which will result reduction in long term water requirement.

Impacts: Financial loss of the investments for water production

Mitigation Measures: Following measures shall be taken to mitigate the impacts:

- Limited operation of the SWTPs and DTWs during vacation or period of labour strike
- Periodical updating of the implementation plans of different phases based on the actual water requirement at different time frames.

3. Natural Disasters

Natural disasters in the form of cyclone, earthquake etc. may occur and cause longer time power failure, partial damage to the infrastructures related to SWTP, DTW and transmission and distribution network.

Mitigation Measures:

Following measures shall be taken to mitigate the impacts:

- Design of structures shall include consideration of seismic load according to the guidelines of BNBC
- Warning system shall be established in the industrial park to limit probable damage due to natural disasters.
- Rapid action shall be taken for restoration of power supply and damaged infrastructures.
- The officer in charge of the industrial park will take immediate actions with the assistance from the O&M team. In case he is unable to act by his own capacity, he will involve the top management of BEZA to undertake the matter.
- The damage shall be considered as an act of God and immediate action for assessment of damage and restoration of the same shall be taken.

Findings and Recommendations

The Final Report has covered water demand estimation, resource assessment of surface water and groundwater, water management plant, project cost estimation, selection of sites and outline design of SWTP and related structures and production tube wells.

Findings

- Total water demand for the Bangabandhu Sheikh Mujib Shilpanagar will likely to be around 839 MLD in 2040 after the full development of the economic zone. Considering losses, the required production capacity is about 965 MLD.
- Average thickness of deeper aquifer in the project area varies between 120m to 205m.
- Estimated maximum drainable storage volume stands at 205 MLD for the whole project area.
- Discharge of the production well should not be more than 1 cusec (28.3 litre/sec).
- Maximum of 100 wells can be installed for 20 hours operation/ day.
- Feni reservoir is suitable for water abstraction for surface water treatment plant.
- Considering the shortage of water in dry period, a maximum of 100 MLD plant can be constructed for BSMSN.
- Osmanpur, located 2.5 km upstream of the Feni Regulator, has been selected as intake location point based on field verification and discussion with stakeholder, local people and BEZA.
- Pipe intake solution appears to be feasible considering initial and recurrent operation and maintenance cost.
- Route of raw water transmission main has been chosen along the existing Vanghani road (BWDB old embankment) and proposed project road. The length of raw water transmission main from intake site to treatment plant is about 9.56 km.
- The proposed surface water treatment plant will be located at Poshchim Ichakhali Mouza in the east side of CDSP embankment. The capacity of the treatment plant will be 50 MLD in Phase-1 and another 50 MLD in Phase-2. The location is finalized after field verification and discussion with BEZA.
- Route of treated water transmission main has been chosen along the existing CDSP embankment cum road and then Vanghani road (BWDB old embankment). The length of treated water transmission main is about 10.44 km.

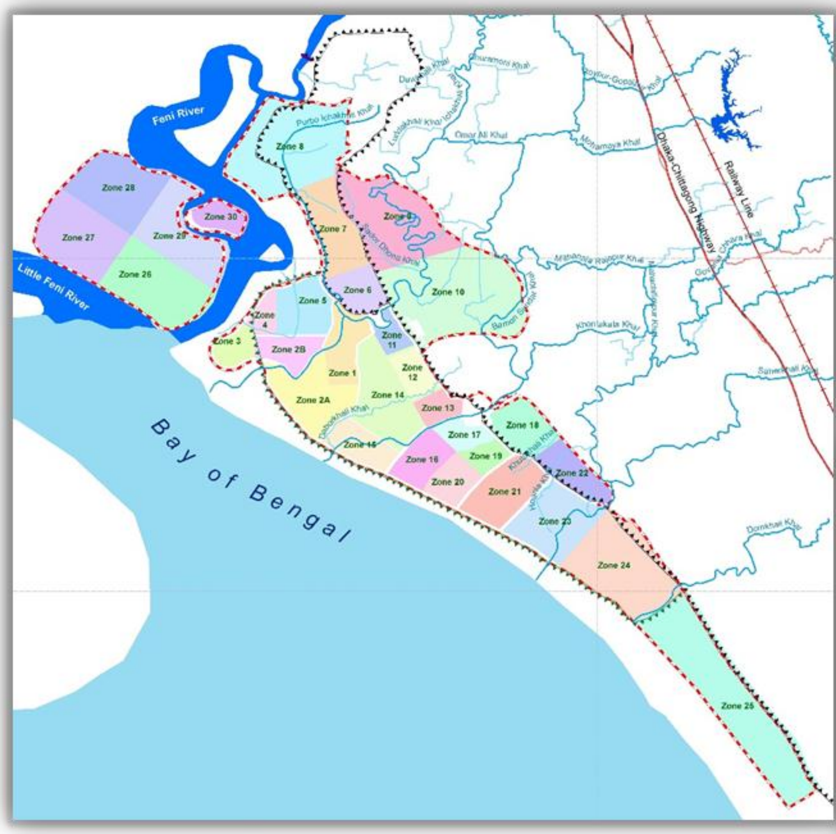
- The project would require acquisition of land of about 23.15 acre for intake and raw water transmission main.
- Preliminary cost of the SWTP including transmission and distribution of 50MLD capacity has been estimated to be about 5,879.41 million BDT.
- Preliminary cost of 25 nos. Production well field system has been estimated to be about 414 million BDT.
- Mohra surface water treatment plant is a potential water source which production capacity is 90MLD.
- Little Feni River is another potential water source to supply water of about 40MLD after proper treatment.
- Desalination RO plant is required in future to fulfill the water requirement of the economic zone. A 50MLD desaliation may require $50 million as capital cost.
- The tentative total cost to meet the water requirement for 30,000 acre area of BSMSN is about 83,387 Million BDT.

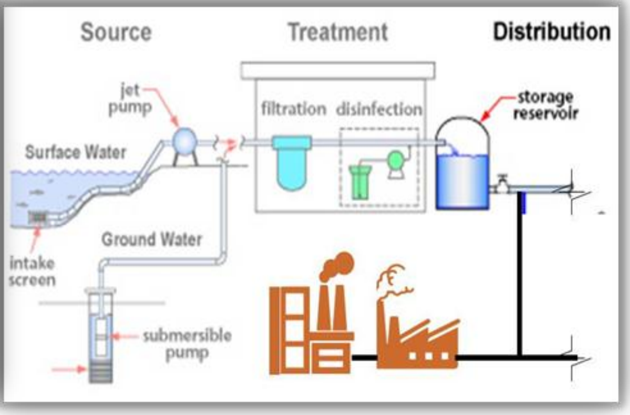
Recommendations

- Maintenance dredging arrangement will need to be kept assuring water availability in the Feni River at intake point throughout the design life of the treatment plant.
- Continuous monitoring and maintenance of the river training works are important for the safety of intake.
- Preparation of Sewerage Master Plan for the BSNSN area and engagement of relevant consultant is recommended strongly for proper management of waste water.
- For appropriate technology transfer and maintenance of the plant, the required staffs need to be-trained adequately (training both on the job and at abroad).
- Necessary MoU need to be signed between the Ministry of Water Resources and BEZA to abstract water from the Feni River and use of land for laying of raw water transmission main owned by Bangladesh Water Development Board (BWDB).
- If needed in future, water sharing treaties or MoU should be signed with neighboring countries.
- Waste water with or without treatment from the industries, domestic and non-domestic should not be discharged, at upstream of Intake to Feni regulator.
- The surface water quality monitoring should be included at discharge monitoring stations. Besides there should be a monitoring wells for observing periodical changes in groundwater level and groundwater quality.
- The monitoring of river function requires specialization, BEZA may borrow the services of BWDB under some long-term contract.
- Further study is necessary to check whether the option carrying treated water from Mohra water treated plant to the BSMSN area is technically and financially acceptable.
- A detail study is necessary for withdrawn and supply water from Little Feni River.
- Metering system should be installed with the water supply pipeline at every industry and other 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.

Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR





Final Report

Volume II: Main Report

February, 2020

INSTITUTE OF WATER MODELLING

Bangladesh Economic Zones Authority
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DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR

Final Report

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INSTITUTE OF WATER MODELLING

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List of Acronyms and Abbreviations

ADCP	Acoustic Doppler Current Profiler
AE	Assistant Engineer
APHA	American Public Health Association
ASTER	Advanced Spaceborne Thermal Emission and Reflection
BETS	Bangladesh Engineering and Technological Services
BEZA	Bangladesh Economic Zone Authority
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BOD	Biological Oxygen Demand
BOD_5	5 Day BOD
BOQ	Bill of Quantities
BSMSN	Bangabandhu Sheikh Mujib Shipla Nagar
BTM	Bangladesh Transverse Mercator projection
BUET	Bangladesh University of Engineering and Technology
BWA	Bangladesh Water Act
BWDB	Bangladesh Water Development Board
BWFMS	Bangladesh Water and Flood Management Strategy
CDMP	Comprehensive Disaster Management Plan
CETP	Common Effluent Treatment Plant
CIP	Clean-In-Place
COD	Chemical Oxygen Demand
CPA	Chittagong Port Authority
CPHEEO	Central Public Health and Environmental Engineering Organization (India)
CPU	Central Processing Unit
CSTP	Common Sewage Treatment Plant
DEM	Digital Elevation Model
DFR	Draft Final Report
DI	Ductile Iron
DHI	Danish Hydraulic Institute
DO	Dissolved Oxygen
DPHE	Department of Public Health Engineering
DSL	Dead Storage Level
DWASA	Dhaka Water Supply and Sewerage Authority
EC	Electrical Conductivity
ECA	Environmental Conservation Act
ECNWRC	Executive Committee of National Water Resources Council
ECR	Environmental Conservation Rule
ETP	Effluent Treatment Plant
FAP	Flood Action Plan
FC	Fecal Coliform
FRL	Full Reservoir Level
GoB	Government of Bangladesh

GPS	Global Positioning System
GIS	Geographic information system
GMS	Galvanized Mild Steel
GNSS	Global Navigation Satellite System
GRP	Glass Fiber Reinforced Plastic
GSB	Geological Survey of Bangladesh
GW	Ground Water
HD	Hydrodynamic
HDP	Gross Domestic Products
IIFC	Infrastructure Investment Facilitation Company
IRP	Iron Removal Plant
IWM	Institute of Water Modelling
JDI	Japan Development Institute
Km	Kilometre
KVA	Kilovolt Ampere
KW	Kilowatt
m	Metre
MDDL	Minimum Drawdown Level
MED	Multi-effect Distillation
METI	Ministry of Economy, Trade, and Industry
MEZ	Mirsharai Economic Zone
MGD	Million Gallon per Day
MLD	Million Litter per Day
MSF	Multi-stage Flash Evaporation
MSL	Mean Sea Level
MWL	Maximum Water Level
NAM	Nedbør-Afstrømnings-Model (precipitation-runoff-model)
NASA	National Aeronautics and Space Administration
NWMP	National Water Management Plan
NWPo	National Water Policy
NWRC	National Water Resources Council
O&M	Operation and Maintenance
PDB	Power Development Board
PIU	Project Implementation Unit
PLC	Programmable Logic Controller
PTW	Production Tube Well
PWD	Public Works Department
Q	Discharge
RDA	Rural Development Authority
REB	Rural Electrification Board
RO	Reverse Osmosis
RR	Rainfall-Runoff
RTK	Real Time Kinematic
RTU	Remote Control Unit

SCADA	Supervisory Control and Data Acquisition
SCPL	Sheltech Consultants (Pvt.) Ltd.
SE	Superintendent Engineer
SERM	South East Regional Model
SoB	Survey of Bangladesh
SRTM	Shuttle Radar Topography Mission
SW	Surface Water
SWSMP	Surface Water Simulation Modelling Programme
SWTP	Surface Water Treatment Plant
TBM	Temporary Bench Mark
TC	Total Coliform
TDS	Total dissolved solids
TSS	Total suspended solids
TTW	Test Tube Well
TRDI	Teledyne RD Instruments
UDD	Urban Development Directorate
UPS	Uninterruptible Power Supply
uPVC	Unplasticized polyvinyl chloride
USA	United States of America
UTM	Universal Transverse Mercator
VES	Vertical Electrical Sounding
WHO	World Health Organization
WL	Water Level
WMP	Water Management Plan
WS	Water Supply
WQ	Water Quality
WRP	Water Recourses Planning
WTP	Water Treatment Plant
ZoI	Zone of Influenced

1 Introduction

1.1 Background

Bangladesh Economic Zones Authority (BEZA) is providing an overall framework for 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 with a view to encourage rapid economic development through increase and diversification of industry, employment, production and export. BEZA aims to establish 100 economic zones in the country over the next fifteen years. Development of these economic zones is expected to create employment opportunities, contribute to poverty reduction and higher standard of living.

The proposed Bangabandhu Sheikh Mujib Shilpanagar (BSMSN) will be the first multi sector economic zone comprising an area of around 30,000 acres, located in Mirsharai Upazilla of Chittagong district and Sonagazi Upazilla of Feni district. The BSMSN area is divided into several sub-zones. The BSMSN area is very potential due to its strategic location. It is only 10 Km west of the national highway (Dhaka-Chittagong highway) and 11.5 Km west of the nearby railway station. There are ten Mouzas in the Mirsharai Upazilla and six Mouzas in the Sonagazi Upazilla.

1.2 Objective and Scope of the Study

The main objective of the study is to prepare a Water Supply Master Plan to fulfill water demand for BSMSN requirement in the context with water availability and demand.

To accomplish the objective the following tasks were identified and have been done by the consultant:

1) Examine the project site and document the existing condition of the project site.
2) Review the policy and plans of the project site and meet with water related stakeholders.
3) Prepare water related baselines and base maps for the project site in order to document the existing aquatic conditions and features of the land, community, infrastructure and utilities.
4) Marine, surface water survey and groundwater investigation.
5) Identify all possible source with relevant water quality and validate water availability in the context of development program for the project area.
6) Prepare a water zoning and phasing plan for the project area.
7) Conduct a stakeholder workshop to share the water supply related utility planning for the project area and obtain feedback.
8) Prepare a water management plan for the project on the point of environmental context.
9) Arrange training programme for capacity building of BEZA officials.

1.3 Expected Outputs

The expected outputs of the study are as follows:

- Assessment of surface water and groundwater resources;
- Water demand estimation for the economic zone;
- Identified source of water for fulfilling the demand of the industries and other uses;
- Water quality and geotechnical data sets related to construction of the river intake structure and the SWTP;
- Map showing the suitable area demarcated for intake structure and primary and secondary water distribution network;
- Water zoning and phasing plans ;
- Water Management Plan (WMP);
- Process design of treatment plant and related issues;
- Detail design of the all structures and transmission and distribution main;
- Preparation of BOQ and cost estimation;
- Tender documents.

1.4 Study Area

The proposed Bangabandhu Sheikh Mujib Shilpanagar (BSMSN) is located (**Figure 1.1**) at the end of the eastern side of the Bay of Bengal, surrounded by the coast at the north-western. The nearby town is Mirsharai Pourashava, and Sonagazi Pourashava, located about 10km and 4.5km from the proposed area respectively. It is situated only 10 Km west of the national highway (Dhaka-Chittagong highway) and 11.5 Km west of the nearby railway station. The Shah Amanat International Airport at Chittagong is located, south of the BSMSN area at a distance of 79 Km. Chittagong seaport is located 67 Km south of BSMSN area. BWDB embankment is aligned almost parallel to the Dhaka-Chittagong National highway and create the south-eastern boundary of the BSMSN area. Muhuri irrigation project embankment creates the northern boundary of BSMSN and the CDSP embankment is within the project area boundary.

Figure 1.1: Base Map of BSMSN Study Area

1.4.1 Climate and Hydrology

Bangladesh is located at the central part within the Asiatic monsoon region where the climate is tropical. Relatively small size of the country and generally low-lying area cause moderate spatial variation of temperature, precipitation, relative humidity, wind speeds and other climatic variables. However, the climate of Bangladesh exhibits pronounced temporal variability. This is because of the moisture-laden monsoon winds flowing predominantly from the south-west during summer and the comparatively dry and colder north-western winds during winter.

Three seasons are generally recognized in the project area: a hot, muggy summer from March to June; a hot, humid and rainy monsoon; and a moderately cold, dry winter from December to February. 85% of the total annual rainfall occurs during June to November. The beginning of the rainy season varies from year to year; heavy rains may commence anywhere between mid-April and early June and ends anywhere between the end of September and mid-November. Usually winter season is dry with occasional rains. The summer season ranges between March to April. During summer, the air becomes hot with very low humidity. Early summer is also dominated by Sitakundu cyclone and rains.

1.4.1.1 Precipitation

The general pattern of precipitation (which consists entirely of rain) follows the monsoon pattern with the cooler, drier months of November to March, increasing rains in April and May, and highest rainfall in the months of June to September (**Figure 1.2**) when the prevailing wind direction from the southwest brings moisture-laden air from the Bay of Bengal. Annual rainfall of Sitakunda is about 3,300mm. About 62% of the rainfall occurs in the months of June, July and August.

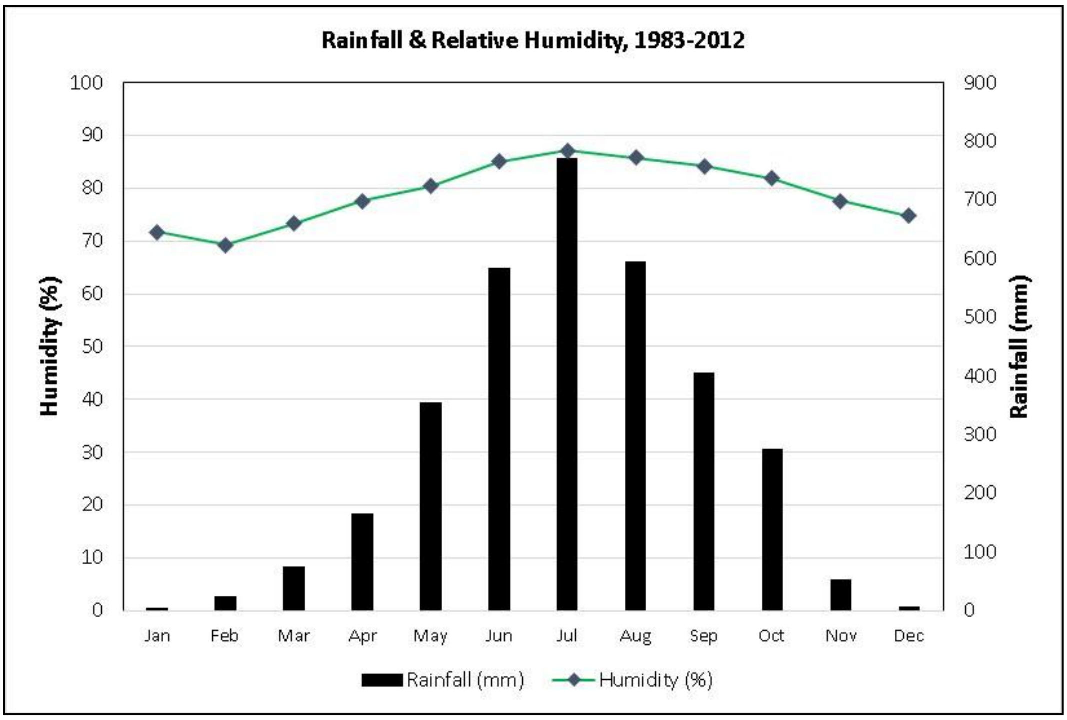


Figure 1.2: Average monthly rainfall and relative humidity pattern during 1983-2012

1.4.1.2 Relative Humidity

As would be expected, humidity during the wet season is significantly higher, as shown in **Table 1.1** and **Figure 1.2** than those occurring at other times of the year. Maximum average relative humidity for the project area is found as 87.1% in the month of July, whereas minimum relative humidity is 69.3% in the month of February.

Table 1.1: Monthly averages of climatic variables at the Sitakunda BMD Station, 1983-2012

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	5.2	24.5	74.7	165.1	355.6	583.8	771.6	595.7	405.6	275.6	54.4	6.8
Mean Temp (°C)	19.3	22.0	25.7	28.0	28.6	28.5	28.0	28.4	28.5	27.9	24.6	20.8
Max Temp (°C)	26.7	29.1	31.5	32.4	32.5	31.4	30.7	31.3	31.9	32.2	30.4	27.9
Min Temp (°C)	11.9	14.8	19.8	23.6	24.7	25.5	25.4	25.4	25.2	23.6	18.8	13.8
Humidity (%)	71.6	69.3	73.3	77.6	80.4	85.0	87.1	85.8	84.2	81.9	77.5	74.8
Avg. Wind speed(knots)	3.2	3.7	4.2	4.7	4.4	4.6	4.4	4.0	3.6	2.8	2.6	2.6
Max Wind Speed(knots)	6.0	7.1	8.1	9.7	9.7	9.4	8.0	7.8	7.4	7.3	5.9	4.9
Sunshine (Hours)	5.8	6.8	7.1	7.1	5.9	3.9	3.6	4.1	4.8	5.9	6.0	5.8
Evaporation (mm/D)*	3.3	3.6	3.8	3.5	3.3	2.7	1.9	2.2	2.6	3.0	3.5	3.6
Solar Radiation (MJ/m^{2}day)	13.2	16.2	18.7	20.0	18.9	15.9	15.3	15.7	15.7	15.5	13.8	12.7

1.4.1.3 Ambient Air Temperature

The temperature of the country is related to the period of rainfall. In general, cool seasons coincide with the period of lowest rainfall. **Figure 1.3** shows the monthly average mean, maximum and minimum temperature of the project area. Maximum average temperature of 32.5°C was observed in May and minimum average temperature was 11.9°C in January (**Table 1.1**).

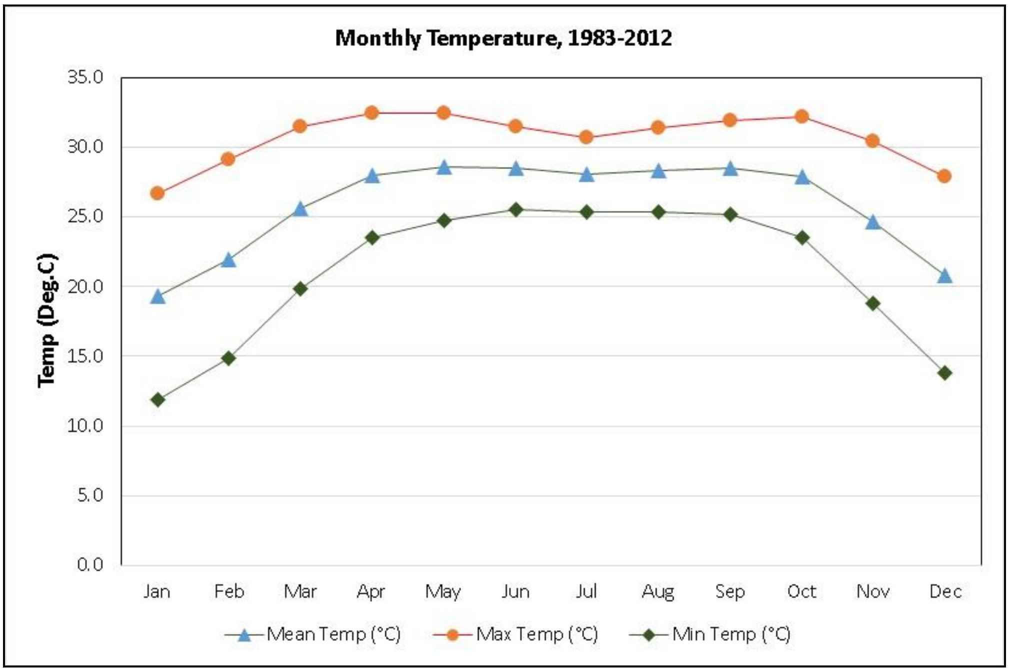


Figure 1.3: Monthly Average maximum, minimum and average temperature during 1983-2012

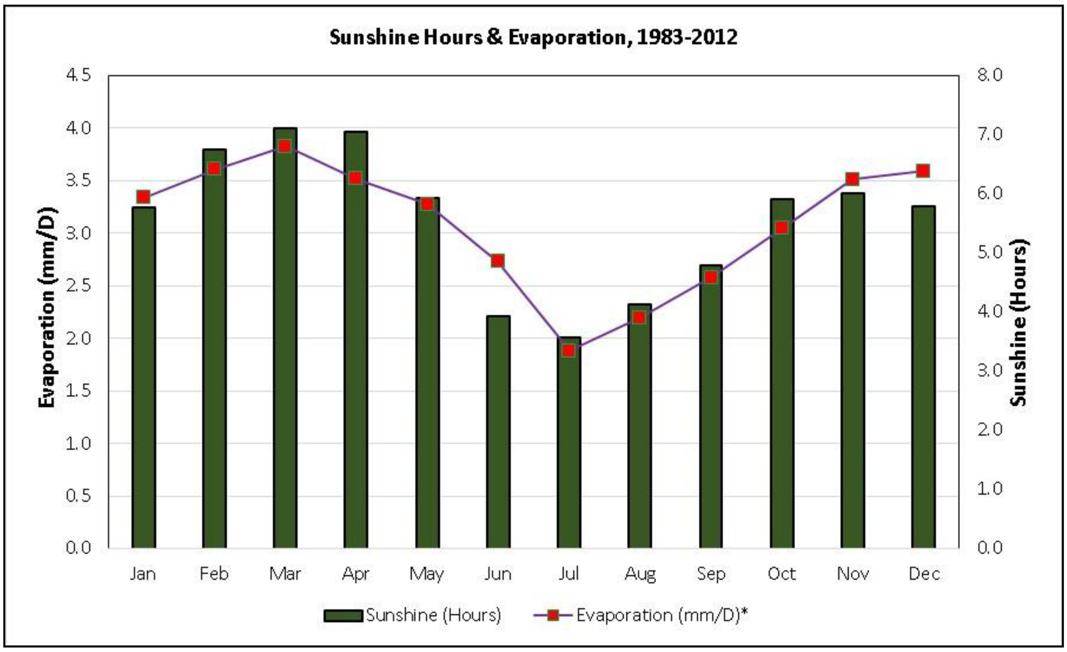


Figure 1.4: Average monthly sunshine hours and evaporation during 1983-2012

1.4.1.4 Sunshine and Evaporation

The average incident solar radiation is comparatively higher during the period between February to May than the other months of the year. Consequently the amount of evaporation is also higher during that period **(Figure 1.4).**

1.4.1.5 Wind Speeds and Direction

The predominant wind directions at the project site are from to south and southeast. During November to February the wind directions are from north to northeast and during March to October it is from south to southeast. It can be observed from **Table 1.1** that the maximum wind speed prevails during the month of May which is about 9.7 Knots.

1.4.2 Topography

The topography data of the BSMSN area has been collected from Master Plan Report conducted by Sheltech Consultants (Pvt.) Ltd. (SCPL). They have collected about 46,080 spot level data during the Master Plan Study where the lowest spot height is -3.33 mMSL and the highest +8.71 mMSL. Based on the collected spot level data they have generated Digital Elevation Model (DEM) (**Figure 1.5**) for the study area. It is observed from the DEM that the elevation varies from -2.91 mMSL to 7.87mMSL with average elevation 3.62mMSL. The slope of the study area is from north-east towards south-west.

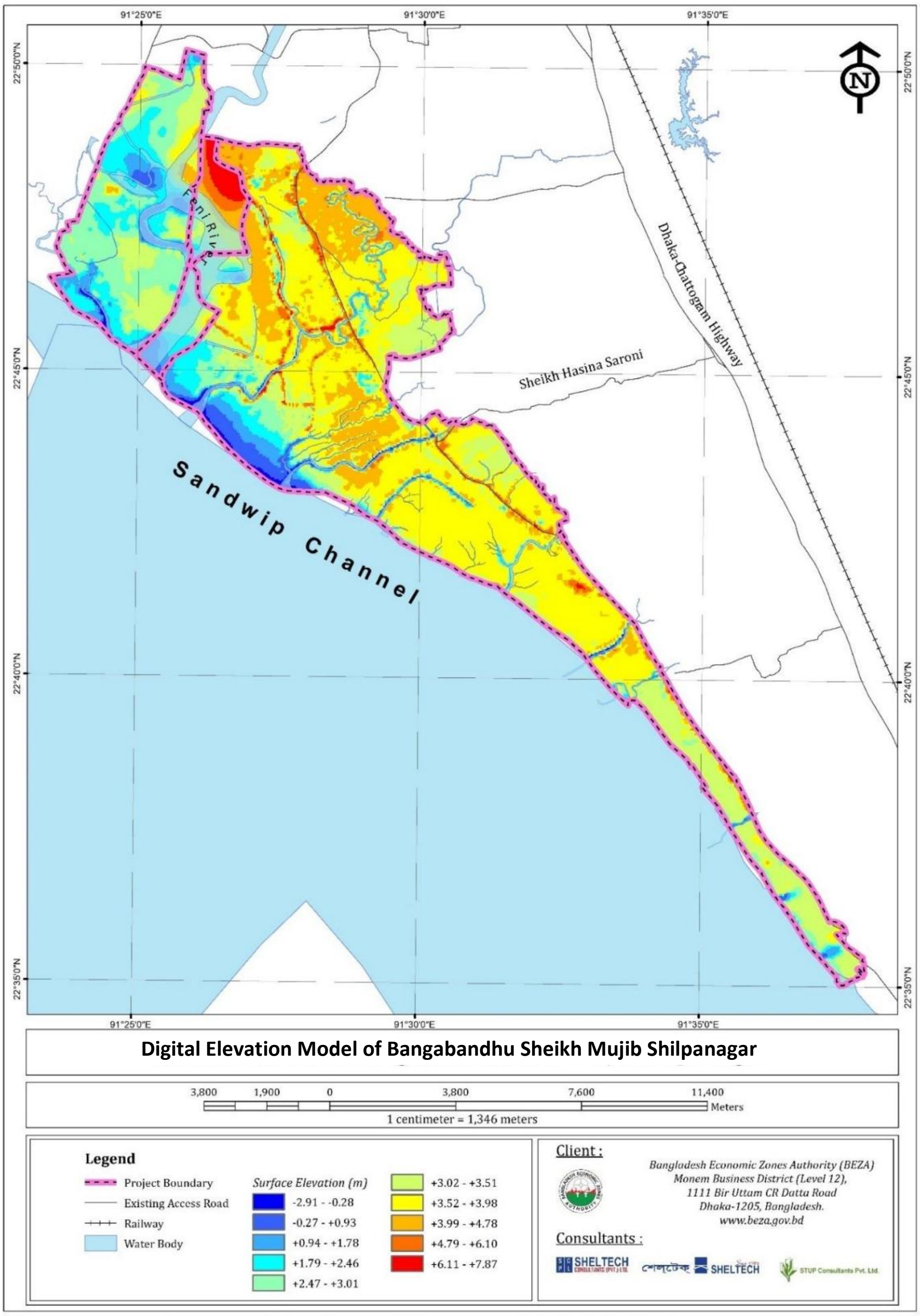


Figure 1.5: Digital Elevation Model of Bangabandhu Sheikh Mujib Shilpanagar

1.5 Approach, Methodology and Activities

A clear understanding of the river/khal system of the surrounding area of BSMSN area and their flowing pattern is vital for assessing the surface water resources in quantity and quality terms. Knowledge about the aquifer system, salinity intrusion into the aquifer is important for groundwater resource assessment. After assessing the total availability of freshwater, the plan for meeting the water demand of the BSMSN area has been formulated.

For detail surface water and groundwater resource assessment and demand calculation for the BSMSN area, scientifically comprehensive following approach has been adopted:

- Field survey and data acquisition (from primary as well as secondary sources);
- A clear understanding of the river/khal system in and around the BSMSN area and ascertain their flowing pattern;
- Selection of possible locations of impounding reservoir and to calculate their storage capacity based on hydrology, hydraulic and soil characteristics;
- Knowledge about the aquifer system, salinity intrusion possibility into aquifer to calculate the safe yield capacity of groundwater;
- Demand calculation of the BSMSN zones based on the Master Plan;
- Planning for proper water zoning;
- Selection of treatment plant sites based on field verification and consultation with BEZA;
- Selection of appropriate treatment process and design of the water treatment plant to produce acceptable quality of treated water from rivers and reservoirs;
- Outline design of the intake, water treatment plant and transmission mains for Phase-1;
- Develop a water management plan for utilization of available water resources to meet present and future water demand.

A schematic diagram showing the approach and methodology to achieve the objective of the study is presented in **Figure 1.6.**

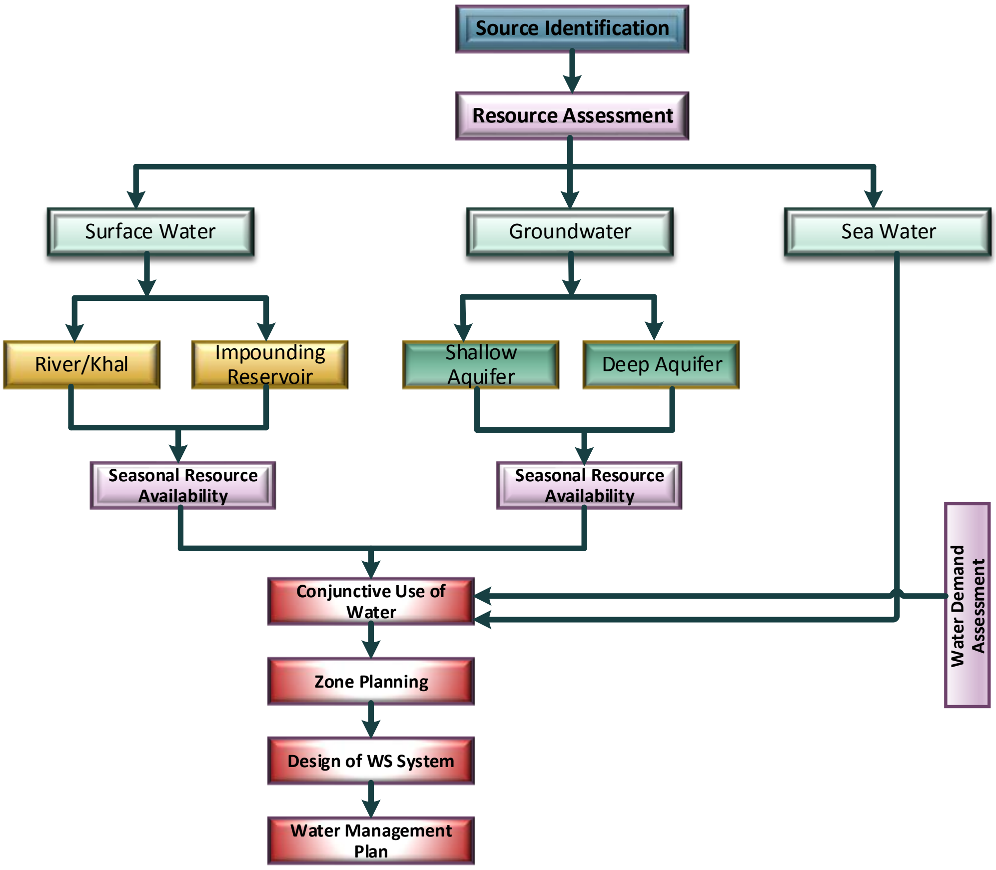


Figure 1.6: Schematic Diagram of Approach and Methodology

1.6 Review of Relevant Policies, Plans and Acts in Water Sector

There has been a series of policy documents issued in 1990's and 2000's for different key sectors to accelerate the balanced way of water resources use and development. The policies, plans and legislations relevant for conservation of water resources and its usages may be as follows:

a. National Water Policy (1999);
b. National Industrial Policy, 2016;
c. National Environmental Policy, 2013 (draft);
d. Coastal Zone Policy (2005);
e. Environmental Conservation Act (2005) ;
f. Bangladesh Water Act 2013;
g. National Water Management Plan (2001);
h. Coastal Development Strategy (2006).

1.6.1 National Water Policy (1999)

Issuance of Bangladesh Water and Flood Management Strategy (BWFMS) in 1996, as an outcome of Flood Action Plan (FAP) process led the GoB to issue National Water Policy (NWPo) in 1999. Preparation of National Water Management Plan (NWMP) started in 1999 and ended in 2001. NWMP was approved by National Water Resources Council (NWRC) in 2004. NWRC is the apex organization, responsible for coordinated implementation of policy and plan as per NWPo.

The NWPo is essentially the key document describing the need for a coherent water strategy for water resource exploration, use and management. The broad objectives of the policy are as follows:

a) Development of all forms of surface and ground water management through equitable manner;
b) Ensuring the availability of water to all level people of the society emphasizing on women and children;
c) Accelerating sustainable public and private water delivery systems with legal and financial measures;
d) Bringing institutional changes to decentralize the water management and to enhance the role of women;
e) Formulating a legal and regulatory environment in water management systems;
f) Developing a state of knowledge to design future water resource management plans with economic efficiency and social justice.

Important clause of the document relevant to the water resources availability, use and conservation are as follows:

- "Prepare National Water Code by revising and consolidating the laws governing ownership, development, appropriation, utilization, conservation and protection of water resources" (GoB, 1999, p. 16).

- " Water will be considered an economic resource and priced to convey its scarcity value to all users and provide motivation for its conservation” (GoB, 1999, p. 16);
- “The rates for surface and groundwater will reflect, to the extent possible, their actual cost of delivery." (GoB, 1999, p. 16);
- “Appropriate financial incentives will be introduced for water re-use and conservation, responsible use of groundwater, and for preventing overexploitation and pollution”(GoB, 1999, p. 16)

1.6.2 Coastal zone policy (2015) and Coastal Strategy (2006)

The coastal zone policy was prepared and accepted in 2005; Coastal strategy was issued in 2006. The main objective of the policy is to protect the livelihood and ecosystem of the coastal zone. The strategy focused on regular maintenance of the coastal embankments for protection against storm surges during cyclones, maintenance of the coastal mangroves for protection against cyclones, coordinate with the Comprehensive Disaster Management Plan (CDMP) considering the coastal zones.

1.6.3 National Industrial Policy, 2016

The prime objectives of the National Industrial Policy 2016 are to accelerate industrial growth led by private sector investment and production.

In general it has no contradiction with the policies relevant to water policy and Environmental policy. To promote environment friendly industrial management the policy encourage industrial units [under Chapter 14] to establish effluent treatment plant (ETP), common effluent treatment plant (CETP) and waste recycling process and committed to provide financial subsidies and other facilities for that. It is also committed to ensure enforcement of provision under Environmental Conservation Act (ECA) 1995 and Bangladesh Water Act 2013.

However presently there is no representation of Ministry of Industry or association of industries in the apex National consultative bodies’ i.e. National Water Resources Council (NWRC) and its executive committee (ECNWRC) to facilitate an integrated approach in industrial zoning and pollution control so far water resources and environment protection is concerned.

1.6.4 National Environmental Policy, 2013 (draft)

The Bangladeshi Government issued the National Environmental Policy in 1992 to reflect its worries as regard impact of development on environment.

The draft National Environment Policy 2013 is yet to be adopted but it has set forth policies [Clause 3.2] for water resource to protect rivers, canals, lake, wetlands and water resource from pollution and to corrective measure to purify polluted wetlands.

As activities for environmental conservation (clause 5.8) the policy direct Ministry of Industry, Ministry of Forest and Environment; Ministry of Agriculture; Ministry of Water Resources; Ministry of Jute and Textile; DoE; Investment Board; WASA; City Corporation; Pourashova; Department of agricultural Extension to strictly regulating not to dump industrial wastes directly to the river, canal or wetland before retreat it in the effluent treatment plant.

1.6.5 Environmental Conservation Act (2005) and Rules (2006)

The Bangladesh Environmental Conservation Act of 1995 and Rules 1997 was promulgated, are currently the main legislation in relation to environmental protection of the country.

Environment Conservation Rule of 1997 gives a framework for issuance of environmental clearance for new industries/projects that include the assessment of the project area and the pollutants to be emitted or discharged by the industries/projects.

For highly polluting industries environmental clearance is given only after an Effluent Treatment Plant (ETP) has been constructed and commissioned. It is also obligatory to issue a site clearance for the site of the industry first and then only owner can proceed for the construction of the site and ETP to get final clearance

However, despite its strict adherence to safe environment, untreated industrial waste, including heavy metals are discharged unregulated and water bodies are being polluted. The enforcement of the environmental conservation law and rules are yet to strengthen for a sustainable environmental protection.

The Environmental Standards established in the Rules need to be revised in line with the other international standard and enforcement of the rules set need to be strictly monitored. Environmental Conservation Act 1995 may need additional rules for an effective integrated pollution control for a sustainable water management in the country.

1.6.6 Bangladesh Water Act 2013

The Bangladesh Water Act 2013 has been issued for an integrated development, management, extraction, distribution, usage, protection and conservation of water resources in Bangladesh. Bangladesh Water Act (BWA) is a framework Law to integrate and coordinate the water resources management in the country.

As per the Water Act, all forms of water (e.g. surface water, ground water, sea water, rain water and atmospheric water) within the territory of Bangladesh belong to the Government on behalf of the people.

The Bangladesh Water Act has established the right to access water by everyone. However certain area may be declared as stressed area and abstraction may be restricted to safe yield to protect the resources for future generation. Any over abstraction, overuse, and contamination would be controlled through protection, compliance order.

Water quality would be maintained to certain set standards as per Environmental conservation rules (ECR) 2006. The industrial effluent discharge would be monitored, and necessary enforcement would be done as per ECA and ECR.

However, there are several Acts that can be related to cross cutting issues with water and environment. Groundwater ordinance for abstraction (1985), is now suspended. Thana Irrigation Committees as per ordinance can be reintroduced to advise the Thana Parishads (Councils) on the granting of permits as per rules (draft) under Bangladesh Water Act. In order to achieve a balance between the existing acts/rules and BWA, it would need to harmonize with some of the principal Acts/rules, ordinance, policy and plan with those of

Bangladesh Water Act and its rules (under development). WARPO is also preparing additional rules for coast in line with Coastal Zone Policy within the framework of BWA. The Water Act will establish a new, integrated approach to the protection, improvement and sustainable use of Countries Rivers, lakes, estuaries, coastal waters and groundwater.

1.6.7 National Water Management Plan (2001)

Bangladesh embarked upon preparation of a National Water Management Plan (NWMP) in 1998, in parallel with the process of drafting National Water Policy which started in 1997. The NWMP, a framework plan to implement the policies by the government. NWMP is also a guiding framework to formulate projects by the line agencies and invest and support development with integrated management of water resources.

The plan assumed that population would increase by 218 million by 2025, GDP would increase @ of 6-7%; as a result, there would be pressure on water resources and its quality primarily as a result of population and economic growth.

The plan assumed both groundwater surface water uses would expand but identified groundwater resources has knowledge gap as regard its availability assessment.

The document is a rolling plan which is required to be updated periodically to incorporate the changes in the drivers and knowledge gaps. The Plan included is a firm plan for the next five years (2001-2006), an indicative plan for the subsequent five years (2006-2011), and a perspective plan up to 2025. The plan is regards as the first step forward introducing integrated water resources management in the country in light of the principles of NWPo.

As per Bangladesh water Act 2013, the update of NWMP would be done as National Water Resources Plan. The update of the plan may include among others the water resources availability, present and future water use and analysis on water impact incorporating elements concerning economic, natural, social, political, environmental, and ecological and institutional aspects.

1.6.8 Regulatory Authorities of Water

There are several regulatory authorities to implement and supervise the noted activities according to various policies and acts on water resources management.

National Water Resources Council (NWRC) is the apex body to provide policy guidance to the implementation of water resources NWPo, NWMP and BWA. The Executive Committee of National Water Resources Council (ECNWRC) is to carry out the implementation of the decision of the NWRC in terms of planning, management and inter-sectoral coordination on water resources. WARPO as secretariat to ECNWRC is responsible for coordinating the implementation of BWA. Coordination and interactions between different institutions are one of the biggest challenges for implementing BWA.

Water Resources Planning Organization (WARPO), established in 1992 as the Apex planning organization in the Water sector. The Water Resources Planning Act (Act No. 12 of 1992) provides the legal framework for WARPO as a statutory body. During 1998 to 2000, WARPO under took the preparation of National Water Resources Management Plan (NWMP), a framework Plan to translate the National Water Policy into 84 programs within the framework of Integrated Water Resources Management (IWRM). As per Bangladesh Water Act WARPO has the role to prepare National Water Resources Plan (update of NWMP) and act as 'Clearing house' providing technical support to planning commission in the approval process of development proposals. As secretariat to ECNWRC, WARPO is responsible for coordinating the implementation of BWA through a decentralized institutional setting.

2 Reconnaissance Survey and Existing Situation Analysis

Several reconnaissance visits have been made in the BSMSN proposed area and its surrounding concerning water resource assessment. The first visit took place during 4 –6 January, 2018. The team headed by Hydrologist and comprising, Survey Specialist and Hydrogeologist visited the sites. The team visited the Feni regulator, test tube well (TTW) and production tube well (PTW) sites, planned 100acre reservoir site and Ichakhali khal.

The second visit took place during 12 –15 February 2018. IWM surface water resources expert team has made useful discussions with BWDB officials in Feni and Chittagong. The team visited the Musapur regulator and closure site, Mohamaya lake and visited surrounding area comprehensively to get a clear picture of the khals system and their flow pattern during this field visit.

The third visit was made by a team of Hydrogeologists during 26-27 February 2018. The consultants' team visited the entire area for selection of exploratory drilling sites and to investigate the existing production tube wells.

2.1 Overview of Present River/Khal in BSMSN & Its Peripheral Area

Feni and Little Feni are the two major rivers which flow down to the Bay of Bengal on the north-west of proposed BSMSN area. These two major rivers make a confluence near Char Chandia. The char land at the confluence of these two major rivers has been considered as part of BSMSN. The major khals/ chharas which flow through the proposed BSMSN area are Ichakhali Khal, Bamon Sundar khal, Saherkhali Khal and Domkhali Khal. Others are Daborkhali, Khutakhali, Hoania and Donakhali khals. Most of the khals/ chharas receive water from hills on the east of Dhaka-Chittagong highway.

2.1.1 Little Feni River

Little Feni River is a trans-boundary rivers of Bangladesh. It originates from the Hill Tripura in India and enters in Bangladesh near Comilla district and after running over the southeastern direction it cross over Noakhali district. Flowing further south, the Little Feni debouches into falling into the Bay of Bengal at 22°45'49"N and 91°23'16"E. The river contains a lot of meanders. A number of streams eg the Dakatia, Gumti meet the river on its course.

Little Feni closely flows along the west and south border of Sonagazi Upazilla. The original course of Little Feni River has a closure on it and a 23 vent regulator on its diversion channel at Musapur. Upstream of the Musapur closure serves as a reservoir and recreation place as well.

2.1.2 Feni River

Feni River originates from the hill ranges of the Indian state of Tripura at nearly 23°20'N and 91°47'E, flows southwest through Silachari, Sabroom town and marking the boundary with the chittagong hill tracts, then flows west, separating Tripura from Chittagong up to Aliganj and then emerges out of the hills and passes through the plains dividing Chittagong from Noakhali before falling into the Bay of Bengal at 22°45'9"N and 91°25'5"E. This river belongs to Bangladesh as it used to form the demarcation line between Chittagong, Noakhali and

Tripura State of India. The river is about 116 km long from the source to the Bay of Bengal. Inside Bangladesh the river is navigable throughout the year by small boats. During monsoon flash flood occur in this river and it becomes furious with rapid currents and whirling eddies at sharp turns. The Feni River gets inflow from a basin of 645 sq. km located in India. Its drainage area inside Bangladesh is only 181 sq. km.

The river has a closure near the sea with a 40 vent regulator on it near Muhurighat bazar. The structures are commonly known as Feni regulator and Dam. Upstream of the Muhuri dam serves as a reservoir and recreation place as well.

2.1.3 Domkhali khal

Domkhali khal originates from Komoldoho waterfalls in eastern hills and crosses the Dhaka-Chitagong highway near Choto Komoldoho (**Figure 2.1**). Domkhali khal bifurcates at upstream of existing BWDB embankment and they again meet immediate downstream of embankment. A three vent regulator (**Figure 2.2**) has been constructed on main channel and a two vent regulator (**Figure 2.3**) on its branch channel. Regulators are provided with flap gates at downstream to prevent intrusion of sea water.

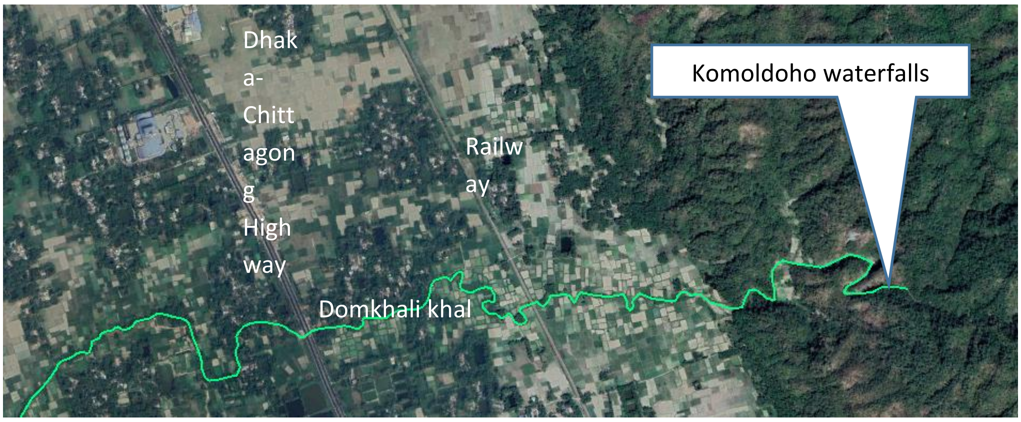


Figure 2.1: Origin of Domkhali khal

Figure 2.2: 3 vent regulator on Domkhali khal

Figure 2.3: 2 vent regulator on branch Domkhali khal

2.1.4 Shaherkhali khal

Gobania Chhara and Shaherkhali khal, are the two major Khals which make the Shaherkhali Khal system with some other secondary khals. Gobania chhara originates from Boalia waterfall in eastern hills. The valley in the hills surrounding the Boalia waterfall may be considered as a reservoir subject to its study for viability. The Gobania khal crosses the Dhaka-Chittagong highway at Mirsharai Bazar. After crossing the Dhaka-Chittagong highway, the khal traverses about 5 km over the land. Thereafter, Gobania khal flows along the north side of the proposed Sheikh Hasina Avenue and crosses the avenue at Abutorab bazar. Gobania khal meets Shaherkhali khal near upstream of existing embankment. Gobania khal has a distributary, Haonia with a one vent regulator on it (**Figure 2.4**).

Shaherkhali khal, the main course originates from Napittachora waterfalls at Ujainnapara and crosses the Dhaka-Chitagong highway at 1 km south of Boro Takia Bazar. A six vent regulator (**Figure 2.5**) with flap gates has been constructed on Shaherkhali khal crossing the embankment. In stream storage in Shaherkhali khal is observed significant (**Figure 2.6**). A small khal namely Golla Donakhali Khal originates from open land and meets with Shaherkhali khal after crossing the embankment. A one vent regulator (**Figure 2.7**) has been constructed on Golla Donakhali khal.

Figure 2.4: 6 vent regulator of Shaherkhali khal

Figure 2.5: Upstream of Shaherkhali khal at regulator site

Figure 2.6: 1 vent regulator of Howani khal

Figure 2.7: 1 vent regulator of Golla Donakhali khal

2.1.5 Bamon Sundar khal

Mohamaya khal, Mithanala Rajapur khal and Khontakata khal are the major tributaries of Bamon Sundar khal. These tributaries convey water from eastern hills to Bamon Sundar khal.

Mohamaya khal conveys its catchment runoff and release from Mohamaya lake to Bamon Sundar khal at Sattar Bhuiyar Hat. Mithanala Rajapur khal conveys its catchment runoff extending from the vicinity of Mohamaya lake and flows to Bamon Sundar khal near Sufia Bazar (**Figure 2.8)**. Khontakata khal takes the distributary flows from Mithanala Rajapur khal through Mohachilimpur Khal and that from Gobania Khal through Moghadia Khal, and the Khontakata khal conveys the total flow to Bamon Sundar (**Figure 2.9**).

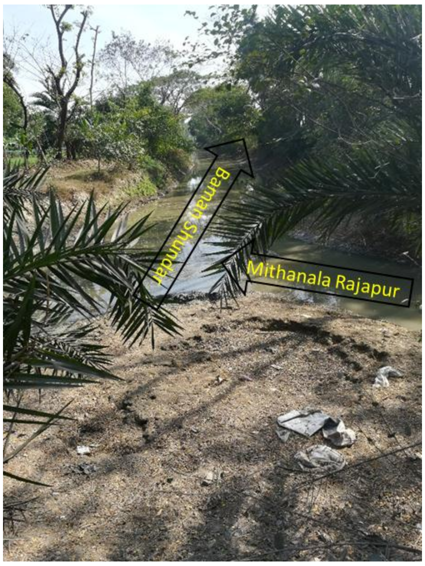


Figure 2.8: Confluence of Bamonsundar & Mithanala Rajapur khal

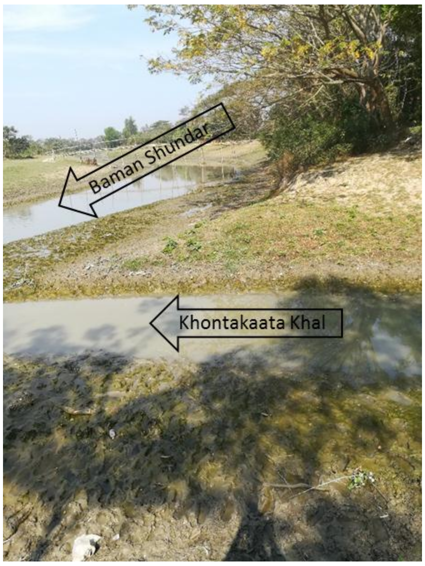


Figure 2.9: Confluence of Bamonsundar & Khontakata khal

The Mohamaya khal originates from Mohamaya lake (**Figure 2.10**) which releases its irrigation water through an under sluice during dry season and a spillway during wet season. A rubber dam (**Figure 2.11**) has been constructed on Mohamaya khal. Bamon Sundar khal traverses through Sattar Bhuiyar hat, Bamon Darogar hat, Sufia Bazar and flows down across the existing BWDB embankment. A nine vent regulator with flap gates (**Figure 2.12**) has been constructed on Bamon Sundar khal. In stream storage in Bamon Sundar khal is observed significant (**Figure 2.13**)

Figure 2.10: Mohamaya lake

Figure 2.11: Rubber dam on Mohamaya lake

Figure 2.12: 9 vent regulator of Bamon Sundar khal

Figure 2.13: Upstream of Bamon Sundar khal at regulator site

2.1.6 IchaKhali Khal

IchaKhali Khal receives water from Feni reservoir site for irrigation purpose (**Figure 2.14**). Excess water at the reservoir site may be considered to pass to the Ichakhali khal for meeting its additional requirement. Barmai Chhara, Roypur Gopalpur Khal and Mohamaya Khal convey water from eastern hills and make distributary contributions in Ichakhali khal. Ichamoti khal, Gopinathpur khal and Omar Ali khal are relatively significant distributaries of Barmai Chhara, Roypur Gopalpur khal and Mohamaya khal respectively which make contribution to Ichakhali khal.

Figure 2.14: Flows in Ichakhali sourcing from Muhuri Irrigation project at Jhulonpul Bazar

The main course of Ichakhali khal has been closed off with BWDB embankment and a diversion channel has been made with a construction of 9 vent regulator (**Figure 2.15**) on the diversion. The abandoned course of Ichakhali khal, both upstream and downstream of the embankment shows a pool of water (**Figure 2.16**) and can be considered for a planned reservoir. Purba Ichakhali khal is a major drainage khal on country side which crosses the embankment and flows down to Ichakhali khal. It has a 5 vent regulator on it (**Figure 2.17**).

Figure 2.15: 9 vent regulator of Ichakhali khal

Figure 2.16: Reservoir at Ichakhali khal regulator site

Figure 2.17: 5 vent regulator of Purba Ichakhali khal

2.2 Existing Structures and Operation Rules

Existing coastal embankment in BSMSN and its associated regulators on different khals were constructed by BWDB for drainage, prevention of salinity intrusion and inundation during periods of high sea level. All these regulators have flap gates on the sea side and the gates get closed when the sea level is higher than the water level in khals on country side. Flap gets are opened for drainage of country side the sea level is lower than the water level in khals on country side. These regulators also have vertical gates on country side which are operated as and when necessary for storage of freshwater in stream of country side and drainage of excess water from country side.

There are three major structures and sites in connection with likely possible sources of surface water for BSMSN. These are i) Musapur closure and regulator, ii) Feni closure and regulator and iii) Mohamaya lake.

2.2.1 Musapur closure and regulator

Musapur closure and regulator has been constructed on Little Feni River at Musapur objectively for drainage. The original course of the river has been closed off with an earthen closure. Its course has been diverted and a 23 vent regulator has been constructed on it (**Figure 2.18**). Upstream gates of the regulator are radial type and those on the downstream are flap gates. Radial gates are generally closed in the dry months of November through April. This makes a significant storage provision upstream of closure for dry season use of freshwater. Radial gates are kept opened during other months. However, the radial gates are opened whenever rising storage level is considered a danger for crops land when drainage is allowed through automatic opening of flap gates depending on stage difference between country and sea side.

Figure 2.18: 23 vent regulator at Musapur on Little Feni River

Figure 2.19: 40 vent regulator on Feni River

2.2.2 Feni closure and regulator

Feni closure and regulator (**Figure 2.19**) has been constructed on Feni River at Sonagazi union objectively for irrigation. The original course of Feni River has been partly closed off with an earthen closure. A 40 vent regulator has been constructed on rest part of it. Upstream gates of the regulator are radial type and those on the downstream are flap gates. Radial gates are generally closed in the dry months of November through April. This makes a significant storage provision upstream of closure for dry season use of freshwater, dominantly for irrigation. Radial gates are kept opened during other months. Design highest storage level at Feni regulator site is 3.89 mPWD and dead storage level is 2.59 mPWD. Radial gates are designed such that storage water starts spilling over the radial gates when storage level exceeds the design highest level. However, the radial gates are opened whenever rising storage level exceeds the design highest water level when drainage is allowed through automatic opening of flap gates depending on stage difference between country and sea side.

2.2.3 Mohamaya lake

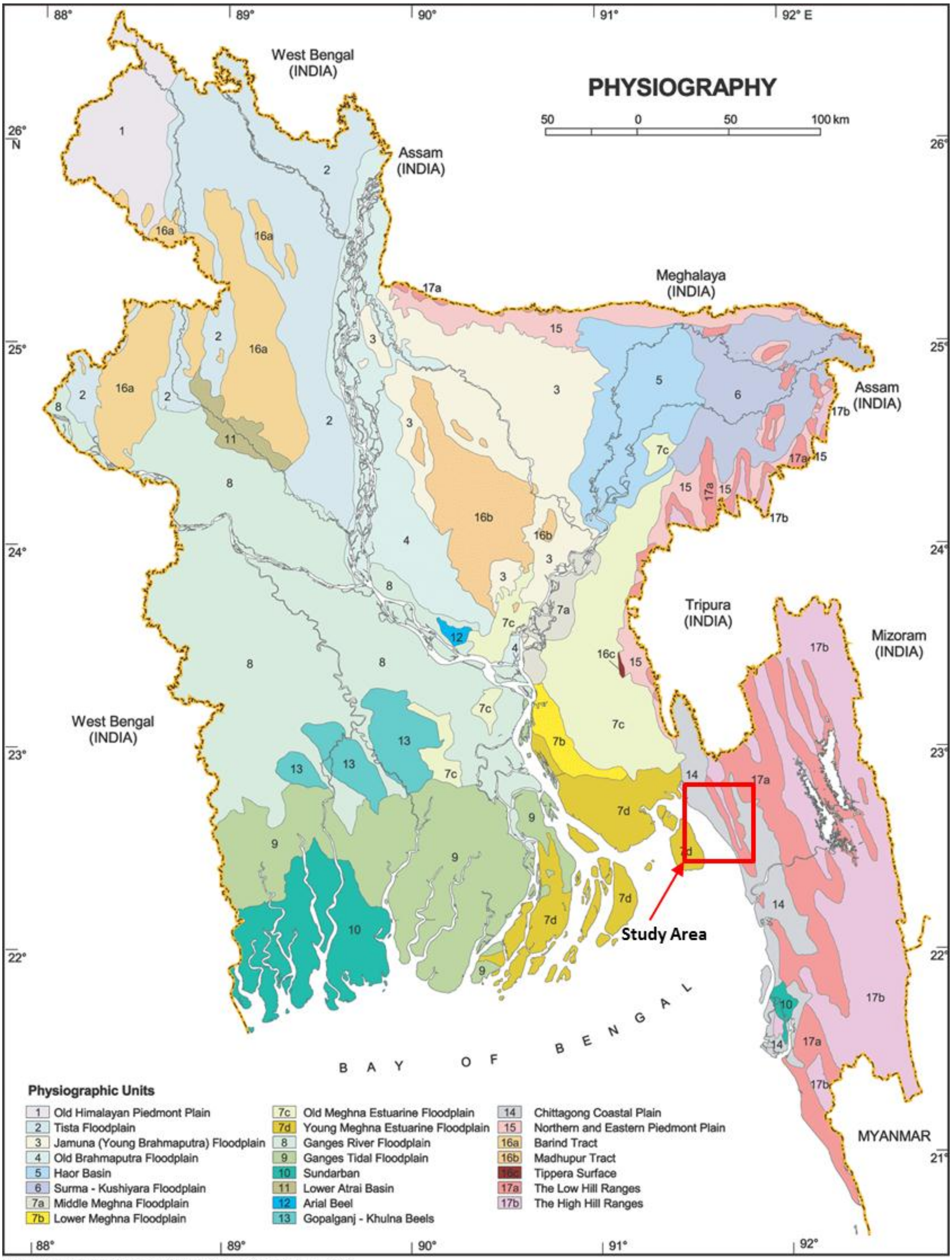
Mohamaya lake is the second largest one in Bangladesh in the valley of eastern hills of Mirsharai objectively for irrigation. Release of water from Mohamaya lake is made through an intake structure (0.9m x 0.9m, invert 11.45 mPWD) and a spillway (12.00m wide). The maximum and minimum storage level of the lake is 26.83 mPWD and 15.50 mPWD respectively. Crest level of dam is 29.88 mPWD. Release water from Mohamaya lake flows down to Bamon Sundar khal through Mohamaya khal (Mohamaya New Chhara) and Mithanala Rajapur khal (Mohamaya Old Chhara) near Sattar Bhuiyar hat and Sufia bazar. Irrigation water in dry season is released through intake structure while spillway is activated mostly in monsoon or when the water level in lake exceeds the maximum storage level. There is a rubber dam for heading up distribution of chhara water in dry season for irrigation.

2.3 Hydrogeological Setting of the Study Area

Available lithological information of various explorations reveals that the depth and variable thickness of the aquifer in the study area conforms the resemblance of local hydrogeology to regional geology. Hydrogeological parameters of this area are governed by the litho-stratigraphic and prevailing tectonic activities, which is also part of regional hydrogeological setting and tectonic features.

The study area is under the physiographic unit of Chittagong coastal plain of Bangladesh. It represents gently sloping piedmont plains near the hills. It is bounded by a small area of a young estuarine flood plain in the north, adjoining sub-regional young Meghna estuarine floodplain and sandy beach ridges adjoining the coast in the south. Sediments of the study area are mainly silt, locally sandy with clays more extensive in floodplain basins. The delta building activities are still going on in the south which is attributed to the GBM river system. **Figure 2.20** shows the tentative location of the study area in Physiographical map of Bangladesh.

The aquifers are generally thick multi-layered with high transmissivity and storage coefficient. And the aquifer systems can broadly be distinguished in the study area is recent sand forming both confine and semi-confine aquifer.



Source: Modified From *SRDI,1997; Rashid, 1991; Reimann, 1993*

Figure 2.20: Location of the study area in physiographical map of Bangladesh

[Source: SRDI]

3 Water Demand Assessment

3.1 Introduction

Feni and Little Feni are the two major rivers which flow down to the Bay of Bengal on the north-west of proposed BSMSN area. Both the rivers have closures at their estuaries with gated regulations. The water resources projects on Feni River is Muhuri Irrigation Project and that on Little Feni River is Dakatia-Little Feni Drainage Project. Upstream of their closures serve as freshwater reservoirs and recreation places as well. There is an irrigation demand at Feni reservoir while storage at Little Feni reservoir is not defined for uses but facilitate public purposes. Mohamaya lake is a large valley reservoir in the eastern hills which mainly serve for meeting the irrigation demand.

The above existing sources of surface water are identified for meeting the BSMSN demand to the possible extent. The allocation of these water resources will be an important issue for BSMSN, looking into the growth of industrial and municipal demand especially. However, sustaining and meeting future growth aspirations in industrial sector of BSMSN will require a befitting approach (combination of surface, ground and sea water) to managing the emerging water demand, quality and availability risks.

3.2 Demand at Existing Surface Water Sources

3.2.1 Muhuri Irrigation Project

The original feasibility study of the Muhuri Irrigation Project (MIP) was done in 1973 and construction completed in 1986. In addition to irrigation, the MIP provides flood control and protection against the intrusion of tidal water. The design enabled dry season irrigation as well as supplemental wet season irrigation by constructing the Feni Closure Dam and Regulator to create a reservoir upstream of the dam.

The main issue in recent years for MIP is the gradual loss of area under irrigation. The main causes of the reduction in irrigated area are complex but include: i) siltation of khals, rivers and reservoirs, ii) apparent reduction of river flows as a result of increased abstractions in upstream India and partly reduction of baseflow contribution due to groundwater abstraction, iii) high prices of irrigation water as pump operators find it too expensive to provide water to plots located far from the pumps, iv) There is a significant drop in the number of operational pumps and the irrigated areas. However, the on-going Irrigation Management Improvement Project (IMIP, funded by ADB) is supporting for rehabilitation and modernization of Muhuri Irrigation Project. The existing cropped area for boro rice is about 9,800 ha (ADB, 2016) and the project is expected to increase the target area 17,000 ha through phase development.

Feni reservoir is a source of water and the balance of its water after securing all demand on it may be considered for BSMSN. One of the significant demands on Feni reservoir is irrigation requirement. Monthly irrigation requirement at Feni reservoir for dry and average year for existing and two alternative future cropping scenarios are given in **Table 3.1**. The existing and two alternative future scenarios are:

- Scenario 1: Existing condition, 100% Boro
- Scenario 2: Future condition, 85% Boro
- Scenario 3: Future condition, 60% Boro

Table 3.1: Monthly Irrigation Demand (Mm^3) for different scenario

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Scenario 1: dry year	29.6	40.6	35.5	20.1	1.1	13.3	13.3	0.0	0.2	6.4	0.0	23.2
Scenario 1: average year	29.4	37.9	24.4	6.9	0.0	13.3	13.3	0.0	0.0	0.0	0.0	23.2
Scenario 2: dry year	33.4	46.1	42.4	23.7	1.1	15.7	15.7	0.0	0.2	7.6	0.0	22.1
Scenario 2: average year	33.2	42.8	29.0	7.6	0.0	15.7	15.7	0.0	0.0	0.0	0.0	22.1
Scenario 3: dry year	29.3	40.7	42.7	20.6	0.7	15.7	15.7	0.0	0.2	7.6	0.0	20.4
Scenario 3: average yea	29.0	37.2	28.7	5.7	0.0	15.7	15.7	0.0	0.0	0.0	0.0	20.4

[Source: IMIP Report for MIP, March 2016]

3.2.2 Mohamaya Irrigation Project

Mohamaya Reservoir Lake is the second largest reservoir in Bangladesh in the valley of eastern hills under Mirsharai District. The reservoir is purposely constructed for irrigation in the valley. The Mohamaya Irrigation Project is implemented during 2006-7 through 2009-10 which provides irrigation to an area of 1295 hectare. Release of water from Mohamaya lake is made through an intake and a spillway structure. Irrigation water in dry season is released through intake structure while spillway is activated mostly in monsoon or when the water level in the lake exceeds the maximum storage level.

Monthly irrigation requirement assessment at Mohamaya reservoir is given in **Table 3.2**.

Table 3.2: Monthly Irrigation Demand (m^3/s) for Cultivable Area (1295 ha) of Mohamaya Irrigation Project

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010-11 (base yr.)	0.01	0.33	0.45	0.64	0.04	0.00	0.00	0.00	0.00	0.38	0.51	0.01
2035-36 (in trend)	0.01	0.42	0.57	0.93	0.31	0.00	0.00	0.00	0.00	0.38	0.51	0.01
*2035-36 (scenario)	0.13	0.58	0.70	0.93	0.31	0.00	0.00	0.00	0.00	0.38	0.51	0.12

* 50% of seasonal fallow land might be brought under suitable crops.

[Source: WARPO, 2016]

3.2.3 Dakatia-Little Feni Drainage Project

Musapur closure and regulator, under the project has been constructed, objectively for drainage, at Musapur on Little Feni River. This makes a significant storage facility upstream of closure for dry season use of freshwater. This storage is left for public facilitation which is at present locally used for drinking purpose, localized irrigation and local economic activities (recreation, vending at site etc.). Local people at the site is not aware of any large and precise demand plan on the freshwater storage reservoir upstream of the Musapur closure. The available storage capacity of the reservoir and excess water to be used for BSMSN area is estimated in sec.4.4. Making available of water for BSMSN from this source, Memorandum of Understanding (MoU) is required in between BWDB and BEZA.

3.3 Land Use Plan of BSMSN

According to the Master Plan of BSMSN conducted by Sheltech Consultants (Pvt.) Limited and STUP Consultants Private Limited (SCPL-STUP), the total area is divided by 15 main category of land use as shown in **Figure 3.1**. The amount of area allocated for each land use type is given in **Table 3.3**.

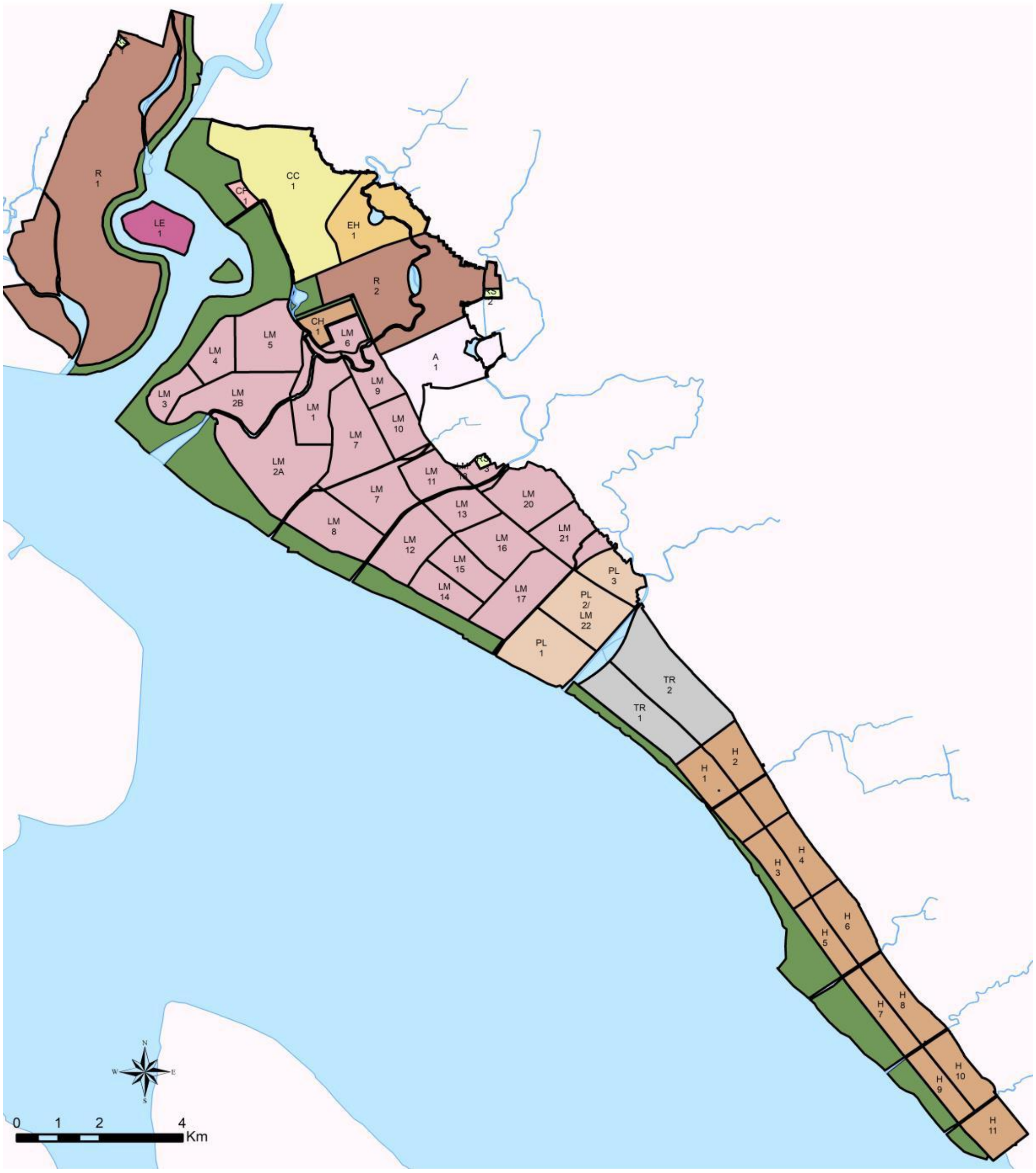


Figure 3.1: Land use map of Bangabandhu Sheikh Mujib Shilpanagar

[Source: SPCL-STUP (June 2019)]

Table 3.3: Area under each category of land use

Sl. No.	Land use Type	Parcel ID	Area (Acre)
1	Residential/ Mixed Residential/ Retail/ Educational	R1-2	6079.24
2	City Center (Commercial/ Retail/ Tech Hub)	CC1	1701.27
3	Educational/ Health	EH1	755.65
4	Cultural Facilities	CF1	63.86
5	Leisure/ Entertainment	LE1	350.89
6	Administrative/ Institutional	A1	841.69
7	Resettlement	RS1-3	56.26
8	Light/ Medium Industrial	LM1-21	9936.3
9	Port/ Logistics	PL1 & 3	946.12
10	Port/ Logistics/ Light/ Medium Industrial	PL2/LM22	584.82
11	Transitional	TR1-2	1613.33
12	Heavy Industrial	H1-11	3918.58
13	Chemical Hub	CH1	166.35
14	Open Space	-	5821.8
15	Water body	-	-

In the land use plan, about 14,606 acre area is preserved for light, medium and heavy industries including area preserved for chemical hub. Thus about 44.5% area is allocated for industrial usage. Other areas are allocated for residential, commercial, community, administrative, port/logistic and other usage.

3.4 Water Demand Assessment for BSMSN

Assessment of industrial rate of utility demand is expressed in practicing unit of demand per day per unit of area. Master Plan of BSMSN and its detailed land use plan is now being conducted by SHELTECH. Preliminary unit rate of water demand for BSMSN, in absence of its detailed land use plan, has been assessed by reviewing yearly water consumption of eight EPZs of BEPZA; Feasibility Study of Mirsharai Economic Zone, JDI-MAXWELL-SHELTECH, 2014; and Pre-feasibility Report, Mirsharai 2 Economic Zone, IIFC-BETS, 2017.

Unit rate of demand of 97 m^3/d/ha (0.039 MLD/acre) of gross industrial land or 162 m^3/d/ha (0.066 MLD/acre) of operating industrial land is considered from the reviews of BEPZA data **(Table 3.4)**. The review estimates of unit rate of water demand and hence the total water demand for the BSMSN is given in **Table 3.4**. Estimates from demand data of EPZs and review of feasibility study of JDI show fairly close to the above. Both estimates consider operating industrial land is about 60% of gross industrial land. A factor of 1.15 is considered at this assessment.

Table 3.4: Review on Water Demand of EPZs of BEPZA

Reference	Approach	Unit Rate of Demand			Remarks
		(m3/d/ha)	(MLD/ha)	(MLD/ac)	
Yearly consumption of Water in Different EPZs of BEPZA	Gross Industrial Land	97	0.097	0.039	Estimate is made from 4 substantially developed EPZs (CEPZ, AEPZ, CoEPZ, KEPZ) and their yearly consumption data. Considerations are made as 60% of EPZs is operating land and 300 operating days a year.
	Operating Industrial Land	162	0.162	0.066	
Feasibility Study for MIRERSHORAI ECONOMIC ZONE, August 2014 JDI-MAXWELL-SHELTECH	Gross Industrial Land	108	0.108	0.044	It considered 58.6% of land as operating land and made their land use accordingly. The estimation is based on unit rate of demand for different operating land uses, and thereby estimated total water demand for industrial zone area of concern. The zone area was 7195 acre (2913 ha) and reported demand for the operating land was 161 m^3/d/ha which is found requiring correction during review, and is revised to 185 m^3/d/ha.
	Operating Industrial Land	185	0.185	0.075	
Pre-feasibility Report, Mirsharai 2 Economic Zone, June 2017, IIFC-BETS	Gross Industrial Land	254	0.254	0.103	It considered 71% of land (Zone 2, 1310 ac (530 ha)) as operating land and made the operating land uses. It also considered unit rate of demand as that of JDI for operating land uses regardless of influence of percentage of operating land on unit rate of demand. Operating area in vertical direction of operating land is generally influenced with the consideration of percentage of operating land. This has likely resulted excess estimation of unit rate of demand for the Zone 2.
	Operating Industrial Land	358	0.358	0.145	

3.4.1 Industrial Water Demand

3.4.1.1 Land Demand for Industrial Purpose

About 14606 acre of land is conserved for industrial development. According to the Master Plan full development of BSMSN will be completed within 2040. **Table 3.5** shows the land amount that will be required up to 2040 in BSMSN area.

Table 3.5: Demand Projection for Industrial Land

Type of Industries		Cumulative land requirement (Acre)			
		2025	**2030**	**2035**	**2040**
Light and Medium Industries	Textiles and Garments	738	1177	1896	3039
	Food & Beverage	304	454	682	1018
	Other Light and Medium Industries	46	57	70	86
	Pharmaceuticals	434	599	832	1149
	Total Light and Medium	**1,522**	**2,286**	**3,480**	**5,293**
Heavy Industries	Steel& Steel Products	1642	2334	3291	4551
	Energy & Power	1321	1658	2090	2622
	Chemicals	46	57	70	86
	Other Heavy Industries	775	1070	1487	2054
	Total Heavy	**3,784**	**5,119**	**6,938**	**9,313**
	Grand Total	**5,306**	**7,406**	**10,417**	**14,606**

3.4.1.2 Industrial Water Demand Assessment

Industrial water demand has been estimated based on the following consideration:

- Unit rate of demand 0.066 MLD/acre of operating industrial land;
- Operating industrial land is about 60% of gross industrial land;
- For water demand uncertainty a factor 1.15 is considered.

There are many uncertainly factors for calculating the industrial water demand as shown below:

- Interviews and data gathering are an inherently derived facts, due to lack of accurate and reliable data which is critical to assess the demand;
- Some industries (viz. garments, electrical, electronic etc.) grow vertically and floor adjustment factor needs to be considered;
- Progressive growth of industrial capacity will increase demand with time;
- BSMSN will be an industrial city, unlike EPZs; weightage of wet industries like that in EPZs may be reduced while some more industries with greater water requirement may be installed;
- Reduction in water demand with more efficient industrial water usage pattern:
- Reuse of water will decrease the water demand.

Considering the uncertainty factors, the water demand for industrial water usage will be about 665 after full development in 2040. The industrial water demand in different development horizon is given in **Table 3.6.**

Table 3.6: Demand Projection for Industrial Land

Type of Industries		**Cumulative Estimation of water demand (MLD)**			
		2025	**2030**	**2035**	**2040**
Light and Medium Industries	Textiles and Garments	34	54	86	138
	Food & Beverage	14	21	31	46
	Other Light and Medium Industries	2	3	3	4
	Pharmaceuticals	20	27	38	52
	Total Light and Medium	**69**	**104**	**158**	**241**
Heavy Industries	Steel& Steel Products	75	106	150	207
	Energy & Power	60	75	95	119
	Chemicals	2	3	3	4
	Other Heavy Industries	35	49	68	94
	Total Heavy	**172**	**233**	**316**	**424**
	Grand Total	**242**	**337**	**474**	**665**

3.4.2 Residential and Non-residential Water Demand in BSMSN

Employment and population projection has been collected from the Master Plan conducted by SCPL-STUP. SPCL has done the projection for three cases: Base case, Conservative Case and Aggressive Case (Cumulative Scenario). For water demand estimation the number of employee and other populations that will live inside BSMSN area, base case has been taken into consideration.

3.4.2.1 Employee Projection

According to the Master Plan, the total employment opportunity created by different industries, transport, commercial, health, education sector etc. will be about 1,441,566 (Base case) as shown in **Table 3.7**.

Table 3.7: Estimated employment for the BSMSN Area

Cases	**Type of Employee**	**Cumulative Estimation of Employment**			
		2025	**2030**	**2035**	**2040**
Base Case	Direct	*328,525*	*473,779*	*689,968*	*1,002,829*
	Indirect (25% of Direct Employee)	*82,131*	*118,445*	*172,492*	*250,707*
	Informal Sector (15% of the Direct and Indirect Employee)	61,598	88,834	129,369	188,030
	Total	***472,254***	***681,058***	***991,829***	***1,441,566***
Conservative Case	Direct	*328,525*	*457,183*	*641,511*	*898,000*
	Indirect (25% of Direct Employee)	*82,131*	*114,296*	*1,60,378*	*224,500*

	Informal Sector (15% of the Direct and Indirect Employee)	61,598	85,722	120,283	168,375
	Total	***472,254***	***657,201***	***922,172***	***1,290,875***
Aggressive Case	Direct	*328,525*	*490,875*	*741,849*	*1,119,540*
	Indirect (25% of Direct Employee)	*82,131*	*122,719*	*1,85,462*	*279,885*
	Informal Sector (15% of the Direct and Indirect Employee)	61,598	92,039	139,097	209,914
	Total	***472,254***	***705,633***	***1,066,408***	***1,609,339***

3.4.2.2 Population Projection

Population estimation in the BSMSN area has been made estimated by SPCL based on certain assumptions. These are:

- Assuming 30% total job holders in Bangabandhu Sheikh Mujib Shilpanagar will live within project area.
- Among them 60% will live with their families and remaining 40% without family.
- Average family size has been considered as 3.25.

It is estimated that about 1,441,000 employees will work in Bangabandhu Sheikh Mujib Shilpanagar industrial area (base case). Based on the above assumption about 438,740 employees (30%) will live within the industrial area. Moreover, about 175,500 employees (40%) will live single and 263,500 employees (60%) will live with their family. The final population for this city will be 1,031,000 at the end of the 2040. The estimated population for BSMSN area at different cases and phases are shown in **Table 3.8** and **Table 3.9**.

Table 3.8: Estimation of population at Bangabandhu Sheikh Mujib Shilpanagar

Case	**Estimated Employees that will live at *BSMSN* Area**				**Total Population**
	Employee	Single	Family	Family Population	
Base Case	438,738	175,495	263,243	855,539	1,031,034
Conservative Case	392,875	157,150	235,725	766,107	923,257
Aggressive Case	489,799	195,920	293,879	955,108	1,151,027

Table 3.9: Year wise cumulative population at Bangabandhu Sheikh Mujib Shilpanagar

Case	**Events**	**Year**			
		2025	**2030**	**2035**	**2040**
Base Case	Employee	143730	207278	301861	438738
	Single	57492	82911	120744	175495
	Family	86238	124367	181117	263243
	Family Population	280273	404193	588629	855539
	Total Population	***3,37,765***	***4,87,104***	***7,09,373***	***10,31,034***
Conservative Case	Employee	143730	200018	280661	392875
	Single	57492	80007	112264	157150
	Family	86238	120011	168397	235725
	Family Population	280273	390034	547289	766107

	Total Population	***3,37,765***	***4,7,0042***	***6,59,553***	***9,23,257***
Aggressive Case	Employee	143730	214758	324559	489799
	Single	57492	85903	129824	195920
	Family	86238	128855	194735	293879
	Family Population	280273	418778	632890	955108
	Total Population	***3,37,765***	***5,04,681***	***7,62,713***	***11,51,027***

3.4.2.3 Domestic & Non-domestic Water Demand Assessment

For calculating the domestic and non-domestic water demand the considerations are as follows:

- Water demand for residents live within BSMSN area is 150 lpcd
- Water demand for non-domestic purpose for the working force (In-direct) will not live within the BSMSN area is 45lpcd
- Water demand is 5% of domestic water demand for miscellaneous usage

Accordingly the domestic and non-domestic water demand has been estimated as given in **Table 3.10**. It is observed that 155 MLD water is required to fulfil the water demand for the residents that will live within the economic zone area. For the other employees those will not live within the economic zone area is about 56 MLD. Including water usage for other miscellaneous purpose the total domestic and non-domestic water demand become 214 MLD.

Table 3.10: Domestic and non-domestic water demand estimation (cumulative)

Year	Domestic Usage		Non-domestic Usage		Water Demand for Miscellaneous Usage (MLD)	Domestic and Non-domestic Water Demand (MLD)
	No. of Population	Water Demand (MLD)	No of In-direct Employees	Water Demand (MLD)		
2025	337765	51	82131	3.7	2.5	57
2030	487104	73	118445	5.3	3.7	82
2035	709373	106	172492	7.8	5.3	119
2040	1031034	155	250707	11.3	7.7	**174**

3.4.3 Gross Water Demand in BSMSN

For the evaluation of gross water demand (**Table 3.11, Figure 3.1**) an additional provision of the following losses has been considered over the net water requirement for industrial, domestic and non-domestic water usages:

- Loss along the raw water transmission main and distribution system: 15%
- Loss at water treatment plant and along the raw water transmission main: 5.0%

Table 3.11: Gross water demand for Bangabandhu Sheikh Mujib Shilpanagar

Description	**Cumulative water requirement (MLD)**			
	2025	**2030**	**2035**	**2040**
Industrial water demand	242	337	474	665
Domestic & non-domestic water demand	57	82	119	174
Net water requirement at user end	299	419	594	839
Required production Capacity	343	482	683	965
Water required to be withdrawal for treatment	360	506	717	1013
Gross water demand	**360**	**506**	**717**	**1013**

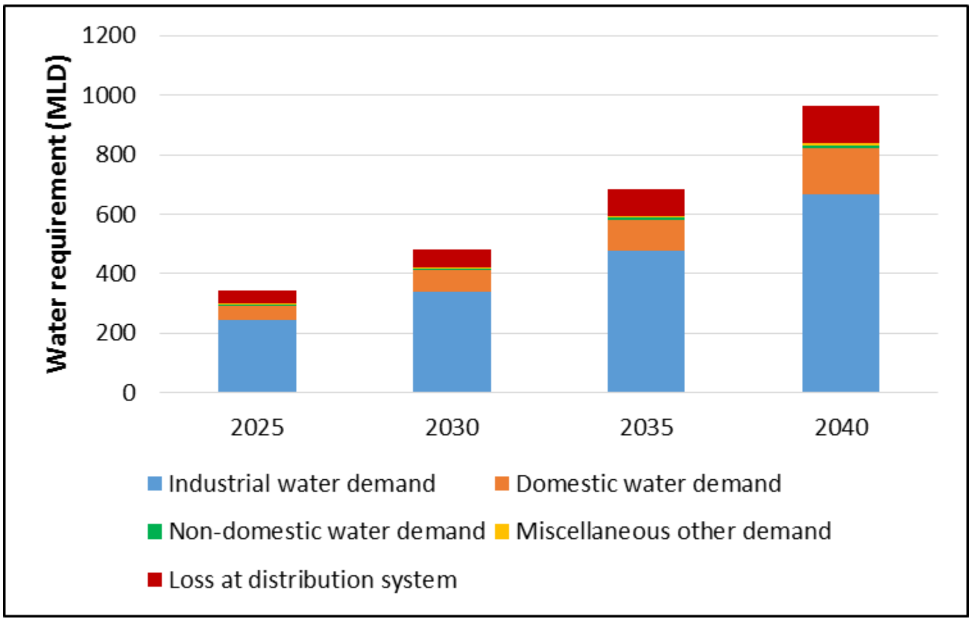


Figure 3.2: Estimated water demand for BSMSN

3.5 Water Requirement at Priority Area

Zone 2A, 2B, 3, 4 & 5 is considered as priority area which will be developed in Phase-1. The land area of these zones is around 2383acre and will be developed mainly as industrial area. Considering the factors as describe in sec. 7.3.1.2 the total water demand of these priority area is 106 MLD (without considering any loss).

3.5.1 Detail water requirement of Zone 2A

3.5.1.1 Land use of Zone 2A

Zone 2A comprises of an area of around 938.5 acre (379.9ha) and land allocation of these area has already done by BEZA. Many garments, textiles, food processing, LPG, pharmaceuticals industries will be developed in this area. Deducting the area allocated for transportation & communication and water body, the area for industrial and other usage are about 824 acre (337.5ha). The land use of zone 2A is given in **Table 3.12** and shown in **Figure 3.2**.

Table 3.12: Land use of Zone 2A

Type of land	Area (ha)	% of area
Administrative Zone	50.5	15%

Type of land	Area (ha)	% of area
Community Facility	7.9	2%
Green Buffer	0.1	0%
Residential Area	5.9	2%
Service Facility	14.8	4%
Training Center	4.8	1%
Battery Manufacturing	4.0	1%
Chemical Industry	0.8	0%
Food Manufacturing	52.5	16%
Leather Industry	19.5	6%
LPG	40.7	12%
Pharmaceuticals	4.1	1%
Steel Industry	8.1	2%
Textile	123.8	37%
	337.5	100%

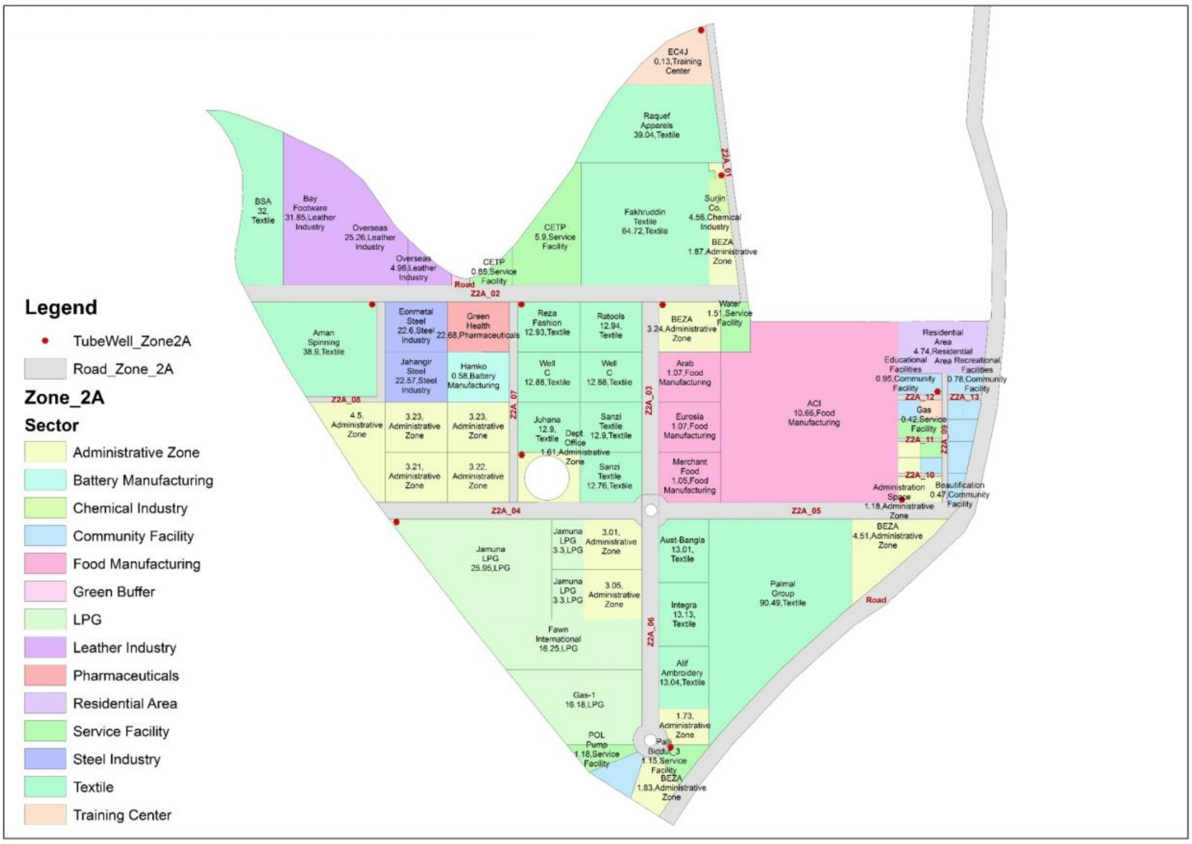


Figure 3.3: Land use of Zone 2A

3.5.1.2 Assumptions for water demand calculation

The assumptions for water demand calculation for Zone 2A area:

- Operating land area for industries and other usage is 60%.
- Loss along the raw water transmission main and distribution system is considered 15%

Moreover, data used in Feasibility Study for Mirsharai Economic Zone, July' 2014 has been considered as reference for demand calculation. Assumptions for demand estimation for industrial and other purposes are given in **Table 3.13** and **Table 3.14**.

Table 3.13: Industry wise daily water consumption

Type of Industry	Daily Water Consumption (m^3 / hectare)
Garment	399
Garment accessories	302
Integrated textile	1921
Motorbike assembly	70
Automobile assembly	56
Automobile parts	18
Other parts & machine	18
Chemical & other products	700
Food & beverage	33
Rental factory	397
Warehouse zone	20

Table 3.14: Daily Water Consumption of Various Land Use

Type of Land Use	Daily Water Consumption (m3 / hectare)
Commercial	200
Resident/ housing	100
Warehouse	50
Others (clinics & training, services)	100
Coal-fired power plants & jetty	20

3.5.1.3 Water demand

Considering the above factors the total water requirement of Zone 2A has been estimated about 50MLD without considering system loss.

3.6 Water Requirement at Zone of Influenced Area

The development of Bangabandhu Sheikh Mujib Shilpanagar will influence the surrounding area. These zone of influenced (ZoI) area comprises Mirsarai, Sitakunda and Sonagazi Upazilla with total area of about 209,384 acre (**Table 3.15**).

Table 3.15: Zone of Influence Area

District Name	Upazila Name	Area (Acre)
Chattogram	Mirsarai	114,238
	Sitakunda	33,732
Feni	Sonagazi	61,414
Total		**209,384**

3.6.1 Population in Zone of Influenced Area

The population caused by natural growth in the zone of influence and the migrated workers living singly or with family will make up the total population in the Zone of Influence area of Bangabandhu Sheikh Mujib Shilpanagar. The following assumptions have been considered while estimating the population in ZoI area:

- Annual growth (BBS, 2011) has been considered while calculating the natural growth of population;
- About 50% of the total employees will live in ZoI area ;
- About 30 % of these employees/ job holders live without families and 70% with their families;
- Average family size has been considered as 3.25.

Considering the above assumptions the local population and migrated population for employment generation will be 1.6 million and 1 million in the zone of influenced area in 2040. So the total population will be about 2.6 million in 2040. The population in different time horizon is given in **Table 3.16**.

Table 3.16: Population in zone of Influenced Area

Year	Number of Population		
	In-Migration	Local	Total
2025	595,838	838,117	1,433,955
2030	829,605	892,184	1,721,789
2035	1,177,534	950,347	2,127,881
2040	1,683,231	1,012,953	2,696,184

3.6.2 Water requirement in Zone of Influenced Area

For calculating the domestic and non-domestic water demand the considerations are as follows:

- Water demand for residents live in ZoI area is 120 lpcd;
- Water demand is 5% of domestic water demand for miscellaneous usage.

Accordingly water requirement for the ZoI area is estimated as given in **Table 3.17**. About 34MLD water will be requirement to fulfill the water demand in zone of influenced area in 2040.

Table 3.17: Population in zone of Influenced Area

Year	Water Demand (MLD)		
	Domestic	Misc.	Total
2025	172	9	181
2030	207	10	217
2035	255	13	268
2040	324	16	340

3.6.3 Source of water to meet the water requirement in ZoI area

The consultant team has identified the possible sources for supplying water in ZoI area, which is beyond the Terms of References of the Study. The identified sources are as follows:

- The main potential sources will be groundwater. But detail study is required to identify the safe yield from groundwater resources.
- Due to city development in ZoI area, the agricultural land will be reduced in future. The water that has been used earlier for irrigation is expected to be utilized for fulfilling the future water requirement.

4 Resource Assessment of Surface Water

One of the key components of this present study is to assess surface water resources availability that would provide continuous water supply throughout the year, meeting the water demand for industrial and other purposes in the project area. The year-round availability of surface water resources in the rivers and khals has been determined from historical discharge data.

Hydrodynamic modelling has been employed for this purpose. Two modules of DHI tool has been used for developing HD model: Rainfall-Runoff (MIKE11 RR) for hydrological modelling and one dimensional hydrodynamic (MIKE 11 HD) for hydraulic modelling. The detail description of the HD model has been described in **Annex-2**.

4.1 Climate Change Effects

According to the synthesis of the IPCC's *Fifth Assessment Report* (IPCC 2014), climate change will lead to two major changes in Bangladesh:

(i) Flooding of rivers/lakes, and/or droughts; and

(ii) Coastal erosion and/or sea level rise and other related effects.

4.1.1 Sea Level Rise (SLR)

The proposed BSMSN and its influenced areas are located besides the Bay-of-Bengal and under the influenced of sea level fluctuation and sea level rise due to climate change. According to IPCC's Working Group-1 report *the global sea level will be increased by about 30cm in 2055 and 63cm in 2090 under* Representation Concentration Pathway (RCP) 8.5 scenario, for high emission.

Table 4.1: Projected change in global mean sea level rise for the mid and late 21st century relative to the reference period of 1986-2005

Scenario (Representative Concentration Pathways RCP)	Emission Scenario	2100 CO_2 concentration (ppm)	Mean sea level rise (cm) Year 2055 (average of range)	Likely range of mean sea level rise (cm) Year 2046-2065	Mean sea level rise (cm) Year 2090 (average of range)	Likely range of mean sea level rise (cm) 2081-2100
RCP 2.6	**Low**	**421**	**24**	**(17-32)**	**40**	**(26-55)**
RCP 4.5	**Medium Low**	**538**	**26**	**(19-33)**	**47**	**(32-63)**
RCP 6.0	**Medium High**	**670**	**25**	**(18-32)**	**48**	**(33-63)**
RCP 8.5	**High**	**936**	**30**	**(22-38)**	**63**	**(45-82)**

[Source: IPCC working group 1 report, chapter 13, table 13.5]

The relative mean sea level rise for Bangladesh can be calculated considering local effect and land subsidence. Based on the global scenarios by Hinkel et al. 2014, the sea level rise in Bangladesh are slightly higher than the global average mean i.e. by 2050 sea level rise could be up to 4 cm higher than global mean and by the end of the century up to 10 cm. No detailed and fully reliable study on land subsidence is available for Bangladesh. Considering uncertainties, 8 cm land subsidence is considered. Thus the relative mean sea level rise will be then 50 cm by 2050.

4.1.2 Change in Rainfall

Many climate models show that due to climate change, the volume of rainfall would increase during the summer monsoon (May–October) and reduce during the dry period (December–March). Moreover, the frequency of short duration, high-intensity rainfall is expected to increase during the monsoon. From existing reports and data available in IWM, it is assumed that the monsoon rainfall will be increase by about 10% and dry season rainfall will decrease by 7% to 9% in this area.

4.1.3 Climate change near BSMSN

The river system around the BSMSN area is separated from sea by Musapur regulator on Little Feni River and Feni regulator on Feni River. Moreover, since the proposed economic zone area is planned to be protected by super dyke, sea level rise is not likely to any impact. Again, since the dry season flow of Feni River is mostly depended on base flow rather than rainfall runoff, the availability of flow is likely to be positively influenced if monsoon rainfall increases.

Therefore, it may be safely conclude that climate change is not likely to have any adverse impact on the hydraulic system of the area.

4.2 Application of Model

The calibrated BSMSN model has been developed to generate historical simulated water level and discharge data from February 1995 to December 2017. Surface water availability has been assessed in terms of dependable flow analysis for Ichakhali khal and Bamin Sundor khal based on the simulated discharge data as no observed data was available for these khals. Monthly and seasonal (dry & wet) flow duration curve of these khals has been developed.

Moreover, the rainfall runoff generated from the model has been used for assessing flow in Little Feni River, Bawa Chhara reservoir and Moro-Komoldoho reservoir as well.

4.2.1 Dependable flow analysis

The flow duration curve of a stream is a plot of discharge against the percent of time the flow was equalled or exceeded. The discharge at any percentage of probability represents the flow magnitude in an average year that can be expected to be equalled or exceeded. This type of analysis is very much suitable for evaluating dependable flows.

The *Weibull* flow-duration method has been used in this study for dependable flow analysis. In this method, the desired value (i.e. dependable flow) is obtained by ranking the daily flows in ascending order and assigning each with a non- exceedance probability of:

$$P = \frac{i}{N+1}$$

Where ***i*** is the rank number from 1 to N and N is the total number of ranked flow.

This method has been chosen due to its simplicity, non-subjectivity and easy adaptability to computers.

4.3 Resource Assessment of Feni River

4.3.1 Existing Features of Feni River

A surface water reservoir has been built-up by constructing Feni regulator at Sonapur to supply the irrigation water during dry season (December to April) in the Muhuri Irrigation Project (MIP). The scheme operation started in 1986-87. The Feni regulator comprises 40 bays, radial gates and flap gates. It is designed to discharge flood flows during wet season and to prevent sea water intrusion and to maintain appropriate water levels for irrigation in the reservoir during dry season. The reservoir formed consisting of three major rivers, namely, Feni-Muhuri-Selonia Rivers and its adjoining khals. The net irrigable area at the beginning of MIP was 23,067 ha. The effective storage of the reservoir depends on the combined upstream supply of water from Muhuri, Selonia and Feni River. The designed normal high pool elevation is 3.81 mPWD and normal low pool elevation is 2.59 mPWD. BWDB regularly monitor the river flows and water levels at the following locations:

- Muhuri River: Parshuram (Q & H),
- Selonia River: Malipur (H),
- Feni River: Kaliachari (Q & H), Dhumghat (H) and Sonapur (H);

Note: Q *means discharge (flow) and* H *means water level*

Dhumghat and Sonapur water levels used for monitoring reservoir levels is shown in **Figure 4.1**. The monitoring (measurement) locations are shown in **Figure 4.2** which also shows the Muhuri Irrigation Project area and proposed BSMSN area. The downstream part of Feni River (d/s of Feni regulator) flows through the BSMSN area. The freshwater at u/s of Feni regulator would be the one of major surface water source for industrial use by the BSMSN.

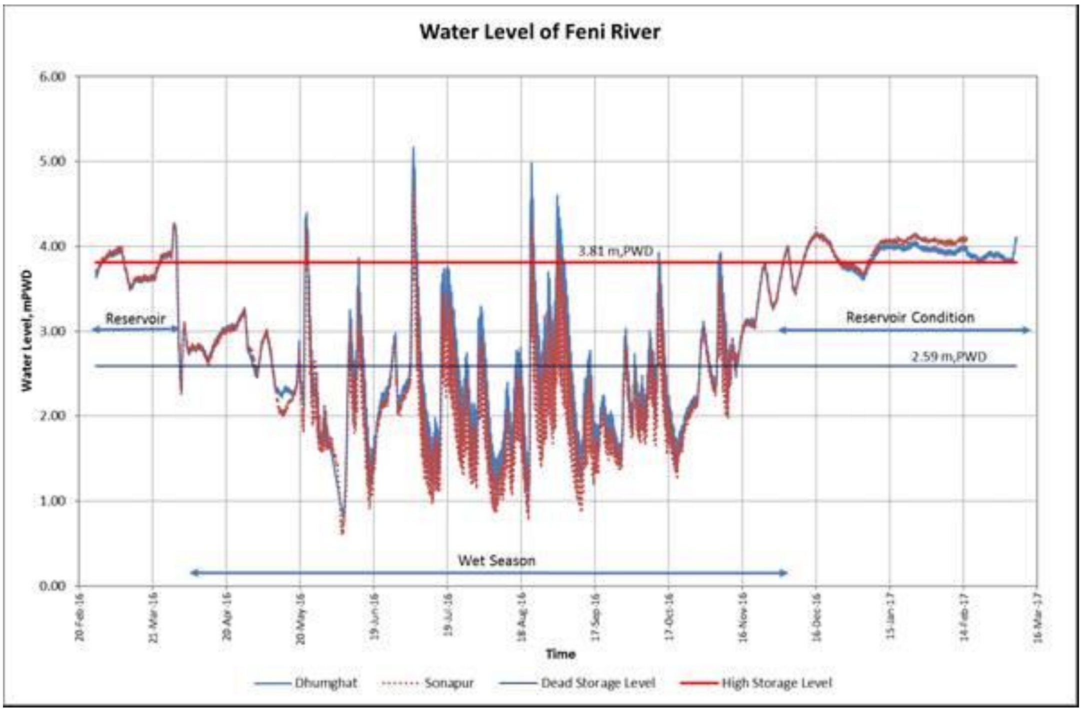


Figure 4.1: The monitoring water levels at Dhumghat and Sonapur for 2016-17 hydrological event

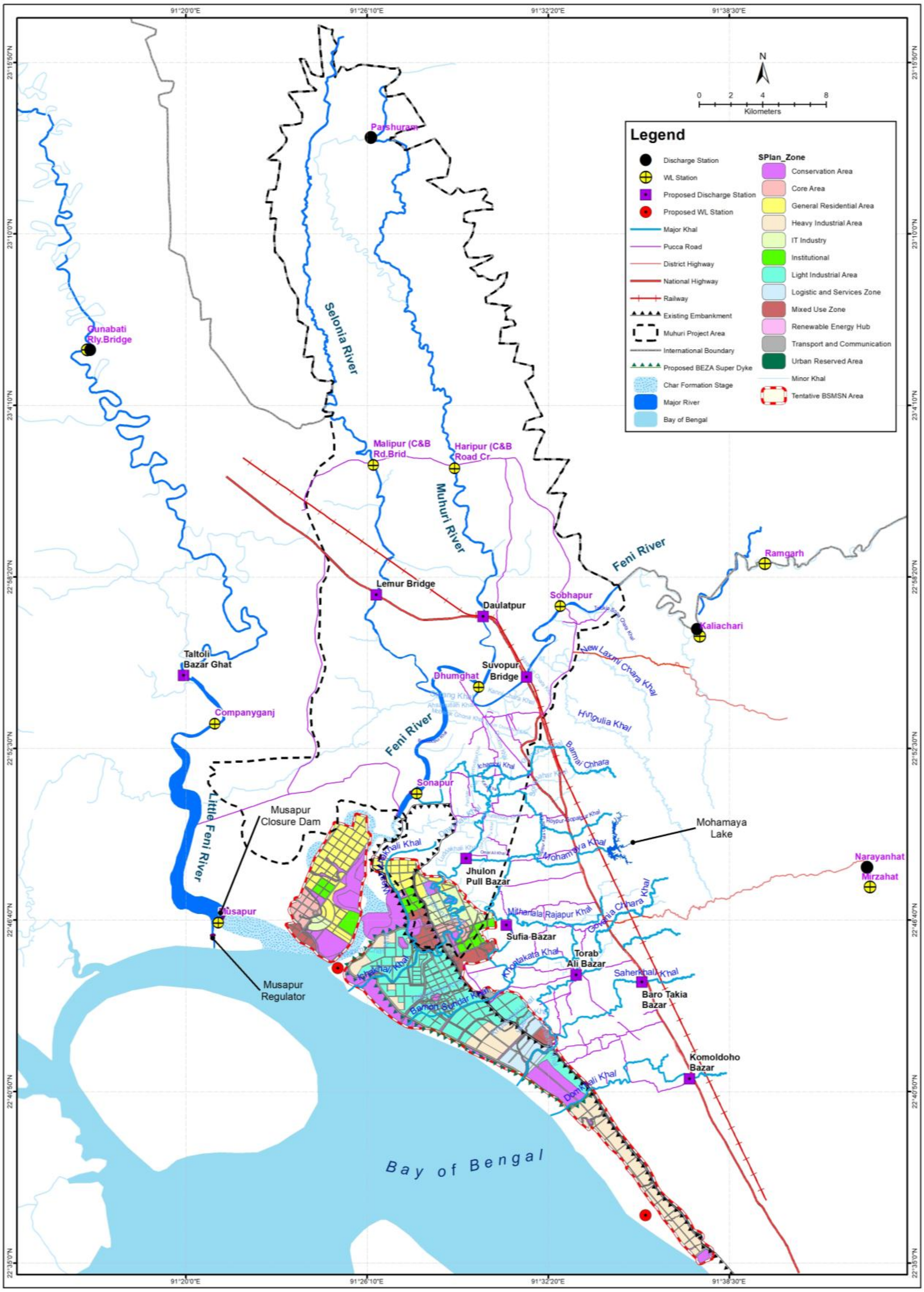


Figure 4.2: The monitoring gauging location map including MIP area and BSMSN area

Presently net irrigable area under MIP is reducing. It is learned that peoples/farmers/land owners are are no longer interested to grow paddy as the investment cost for producing rice is higher than that of produced rice. Labour cost is very high. Recently, a report on "water resources, crop water requirements, reservoir storage and water balance of MIP" has been published by the Irrigation Management Improvement Project (IMIP) under ADB funded in March 2016. In the study, an analysis of monthly field level crop water requirements has been made for average and dry years based on the existing cropping pattern and the two alternative future cropping scenarios. Monthly crop water requirements have been assessed by summing of crop evapotranspiration, land preparation requirements (for rice crops) and with irrigation efficiencies. The developed scenarios under present situation are for 9800 ha cropped area:

- Scenario-1a: Existing Condition – 100% Boro, Dry Year Rainfall and Stream flow
- Scenario-1b: Existing Condition – 100% Boro, Average Year Rainfall and Stream flow

The developed scenarios under future situation are for 17000 ha cropped area:

- Scenario-2a: Future Condition – 85% Boro, Dry Year Rainfall and Stream flow
- Scenario-2b: Future Condition – 85% Boro, Average Year Rainfall and Stream flow
- Scenario-3a: Future Condition – 60% Boro, Dry Year Rainfall and Stream flow
- Scenario-3b: Future Condition – 60% Boro, Average Year Rainfall and Stream flow

The round the year availability of water in Feni River have two parts: (i) wet season (from May to November) – when all 40 gates of Feni regulator at Sonapur have been opened and the system acts as natural flow in the rivers, (ii) dry season (from December to April) – when regulator gates are closed and the system acts as reservoir. There are plenty of perennial flow in the Feni-Muhuri-Selonia Rivers during wet season and at that time irrigation demand is also low. The dry season is considered as critical because very low perennial flow in the Feni-Muhuri-Selonia Rivers and at that time irrigation demand is also very high. As a result, in this study the availability of surface water resources in Feni River under reservoir condition (from December to April) has been assessed to maintain the continuous water supply throughout the year for fulfilling the industrial water demand at BSMSN.

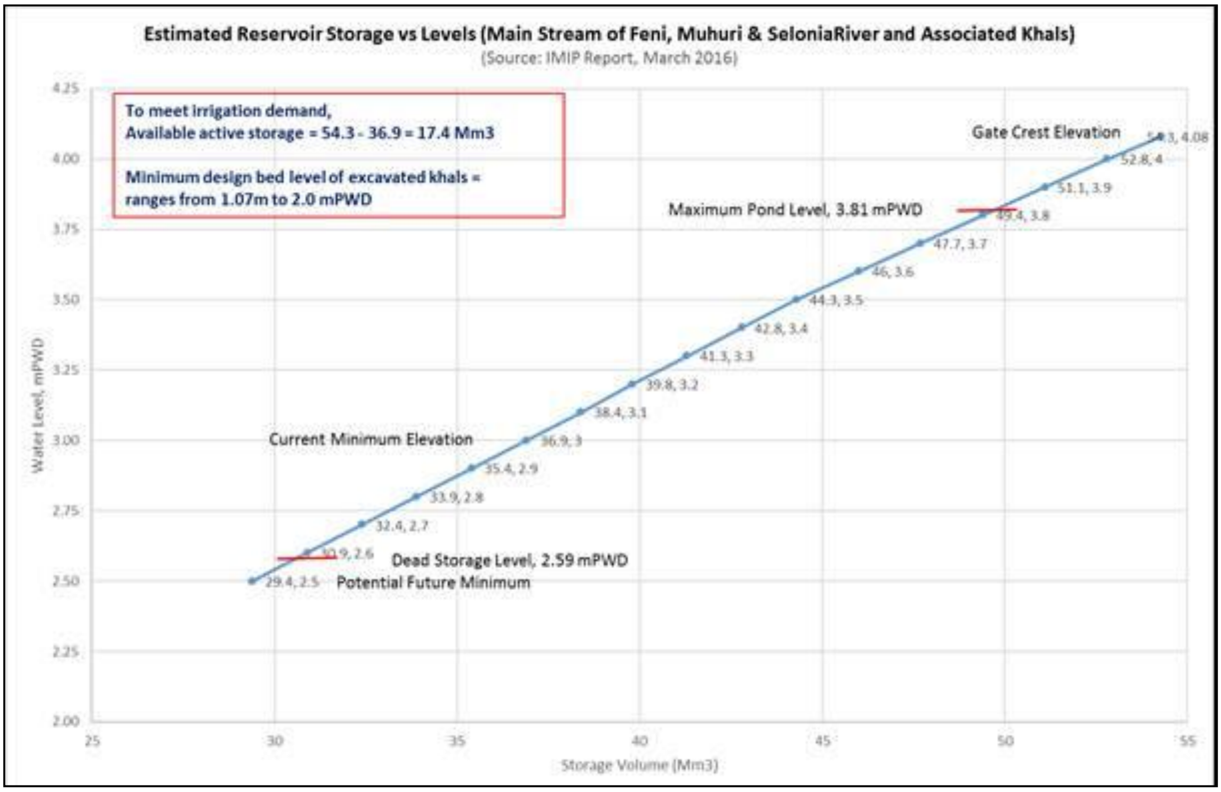
4.3.2 Capacity of Feni Reservoir Storage

Storage of irrigation water for MIP is provided by the Feni regulator which is located downstream of the confluence of the Feni, Muhuri and Selonia (known as Kalidas-Pahalia) Rivers. IMIP study in 2016 defined reservoir storage vs its level (see **Figure 4.3**) considering the mainstream of Feni-Muhuri-Selonia Rivers and associated khals. As on recommendation of this study all associated khals has been re-excavated to maintain the minimum water level at which water would flow in to the khals will be about 2.5 mPWD or possibly a little lower depending on the individual khal. The minimum design bed level of excavated khals ranges from 1.07 m to 2.0 m, PWD. Thus the active storage could be available to meet the irrigation demand. In this study, to define the storage of irrigation water following proposition have been made:

- The maximum reservoir water level of 4.08 mPWD corresponds to the crest level of the regulator gates instead of previously defined maximum pond level of 3.81 mPWD;
- The currently adopted minimum reservoir water level of 3.0 mPWD (instead of previously defined dead storage level of 2.59 mPWD) represents a conservatively high

estimate of the minimum water level required to allow water to enter the khals from which water is pumped for irrigation;

Thus, the available active storage, between these minimum and maximum reservoir levels, is 17.4 Mm^3 (54.3 – 36.9), which is regarded as storage estimated to meet the irrigation demand.



Estimated Reservoir Storage vs Levels (Main Stream of Feni, Muhuri & SeloniaRiver and Associated Khals)

(Source: IMIP Report, March 2016)

Figure 4.3: The estimated reservoir storage vs levels by IMIP, March 2016

4.3.3 Analysis of Dry Season Perennial Flow in Feni-Muhuri-Selonia River

Feni River flow data at Kaliachari (located adjacent Indian Border) has been measured by BWDB normally bi-weekly/fortnightly and are collected for a period of 1996 to 2019. However, the recorded data has many gaps, including a multi-year gap from 2006 to 2010. The average monthly discharge data (from December to April for all year collected data) has been analysed. The available records show some unusual variations and the estimates of average monthly discharge are of suspicious quality. In this regard, all dry season flow data has been plotted against water level and discarded some inconsistent data. Then a rating curve (water level vs discharge) has been generated and curve shows loop (twist) pattern due to backwater effect under the reservoir condition as shown in **Figure 4.4**. The generated rating curve indicates two hydrological events: (a) average year – lower part of the loop and (b) dry year – higher part of the loop.

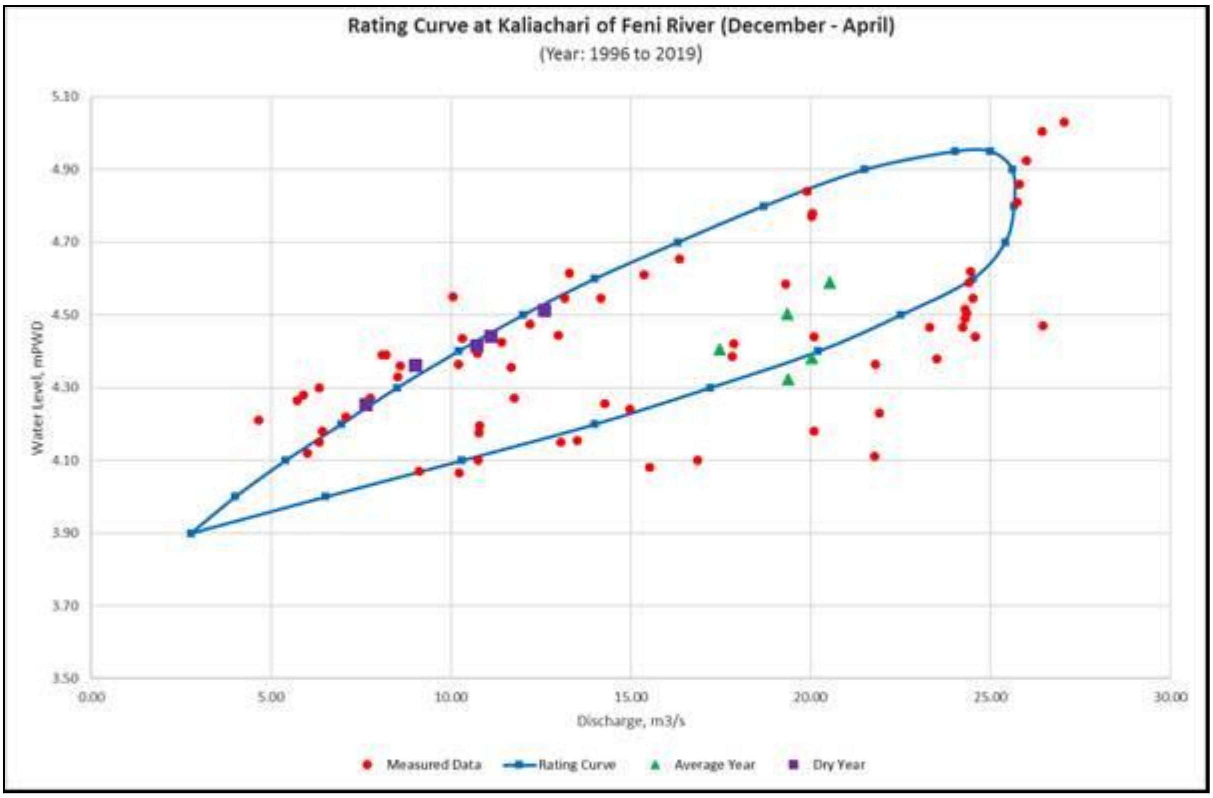


Figure 4.4: The generated rating curve at Kaliachari on Feni River

Similarly, Muhuri River flow data at Parshuram (located a short distance downstream from the Indian Border) has been measured by BWDB normally bi-weekly/fortnightly and are collected for a period of 1996 to 2019. Still the recorded data has many gaps. The average monthly discharge data (from December to April for all year collected data) has been analysed. The available records show some unusual variations and the estimates of average monthly discharge are of suspicious quality. In this regard, all dry season flow data has been plotted against water level and discarded some inconsistent data. Then a rating curve (water level vs discharge) has been generated and curve also shows loop (twist) pattern due to backwater effect under the reservoir condition as shown in **Figure 4.5**. Consistently, the generated rating curve indicates two hydrological events: (a) average year – lower part of the loop and (b) dry year – higher part of the loop.

In the same way, the model simulated Selonia River flow data at Upstream (located a short distance downstream from the Indian Border) has been analysed due to non-availability of measured data by BWDB. The average monthly discharge data (from December to April for a period of 1996 to 2018) has been analysed. Incidentally, all dry season flow data has been plotted against water level. Then a rating curve (water level vs discharge) has been generated and curve also shows loop (twist) pattern due to backwater effect under the reservoir condition as shown in **Figure 4.6**. Correspondingly, the generated rating curve indicates two hydrological events: (a) average year – lower part of the loop and (b) dry year – higher part of the loop.

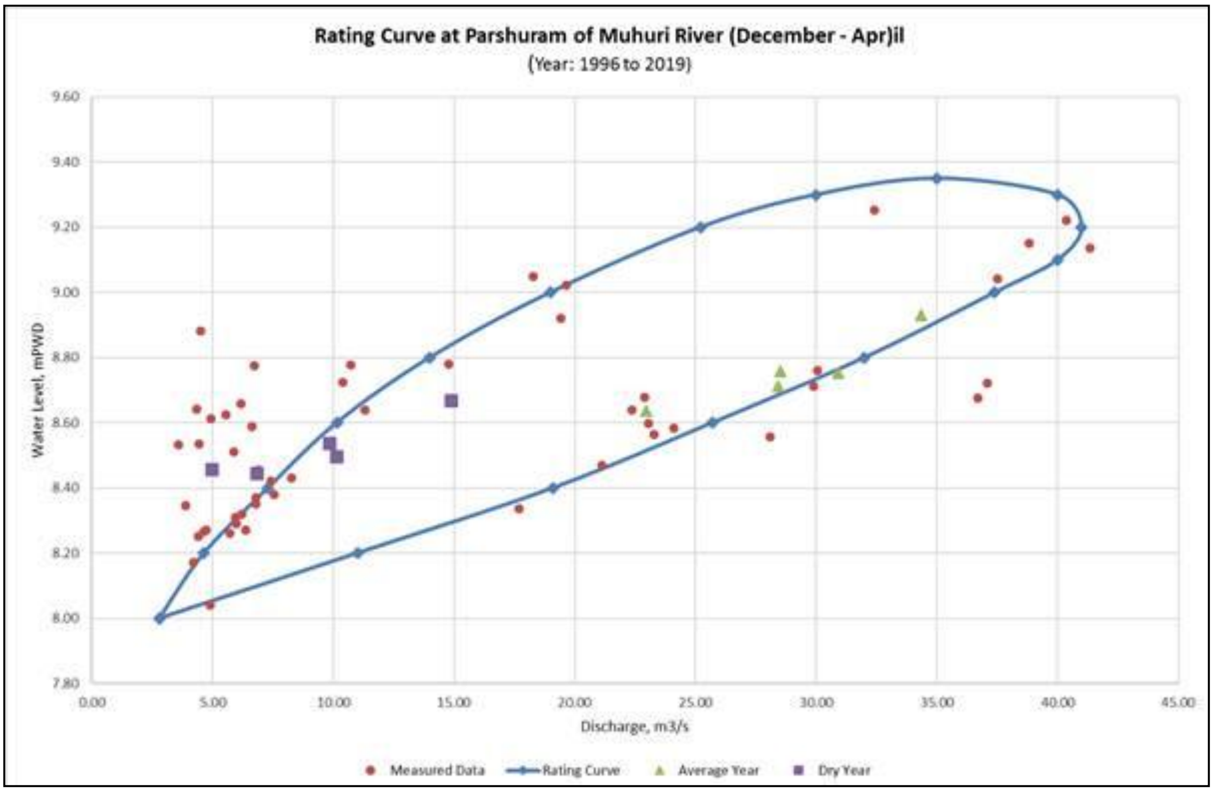


Figure 4.5: The generated rating curve at Parshuram on Muhuri River

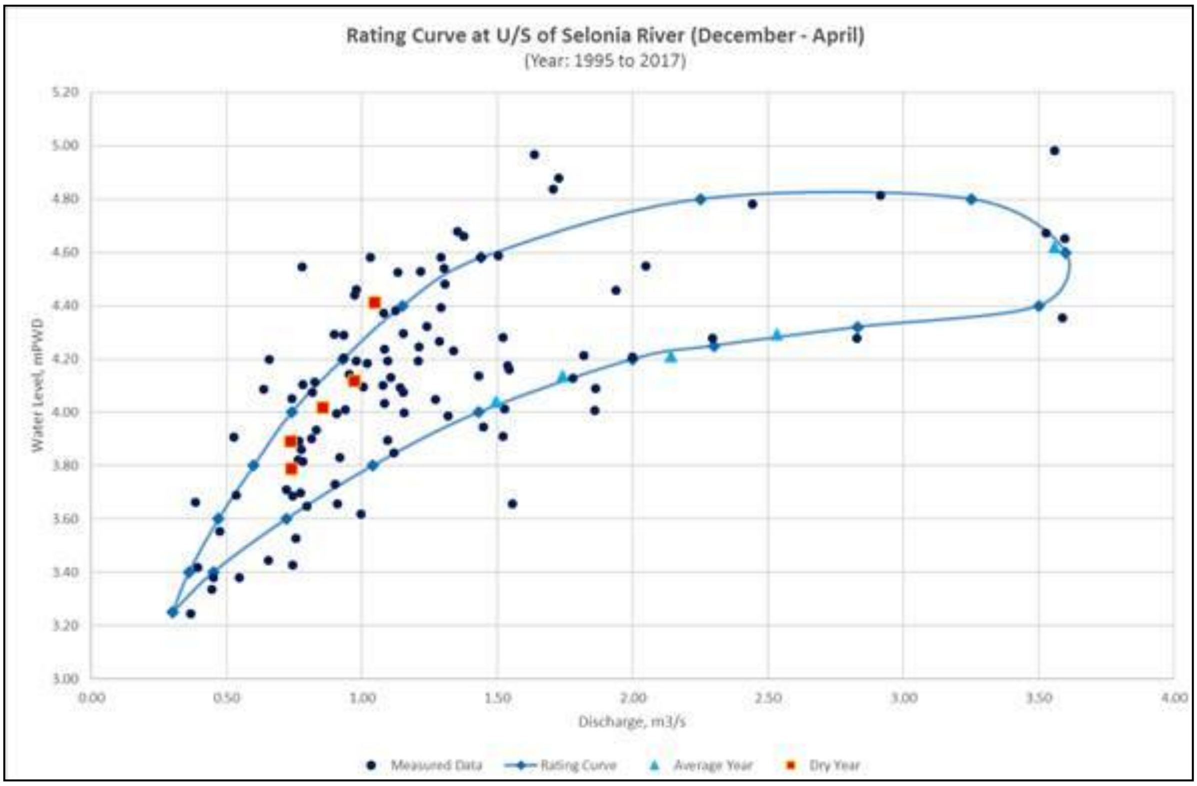


Figure 4.6: The generated rating curve at Upstream of Selonia River

The comparison of monthly (from December to April) rated discharge under two hydrological events for three perennial rivers are shown in **Figure 4.7** and **Figure 4.8**: (a) average year – frequency of occurrence is 2 to 3 years within 5 years, (b) dry year - frequency of occurrence is also 2 to 3 years within 5 years. Sometimes it (average & dry year) occurs in consecutive years and occasionally it occurs in alternative year.

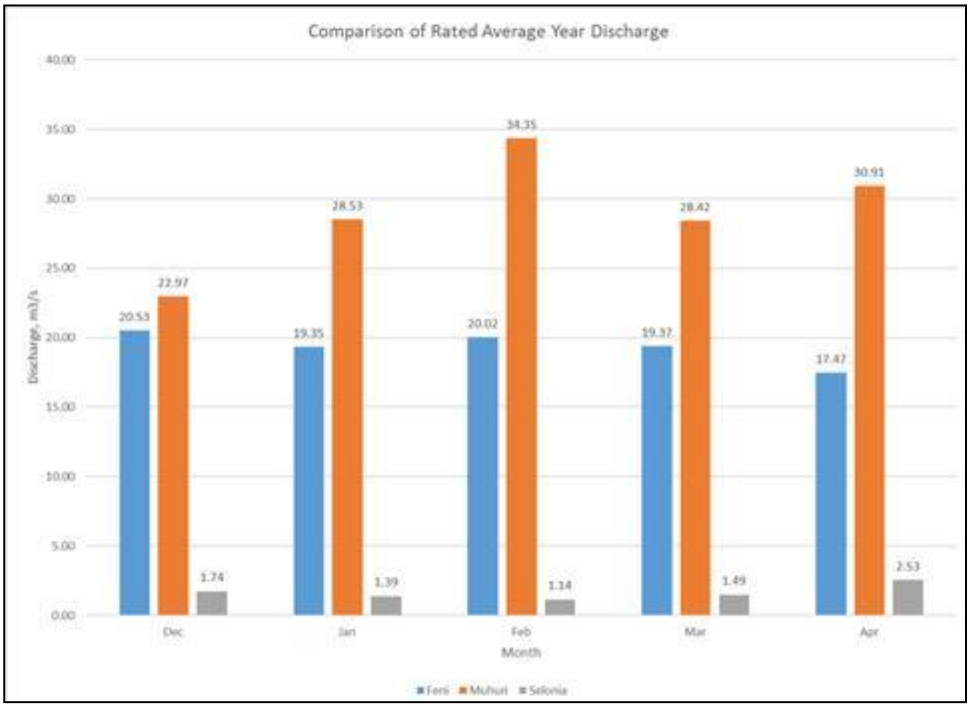


Figure 4.7: The comparison of rated average year discharge for Feni, Muhuri and Selonia Rivers

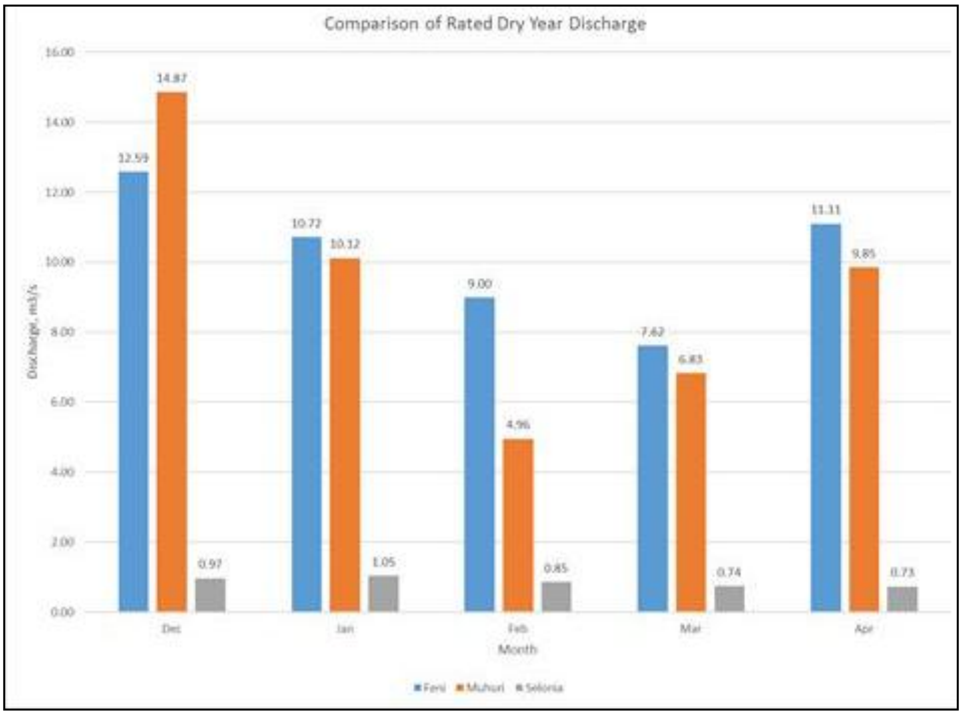


Figure 4.8: The comparison of rated dry year discharge for Feni, Muhuri and Selonia Rivers

The **Figure 4.9** shows that the generated dry year flow data in the Feni and Muhuri river catchment follow the line of perfection ranging the discharge from 5 m^3/s to 15 m^3/s. However, the generated average year discharge data in the Muhuri River catchment is higher than the Feni River catchment though the drainage catchment area of Feni River (128676 ha) is almost double than the Muhuri River drainage catchment (62420 ha).

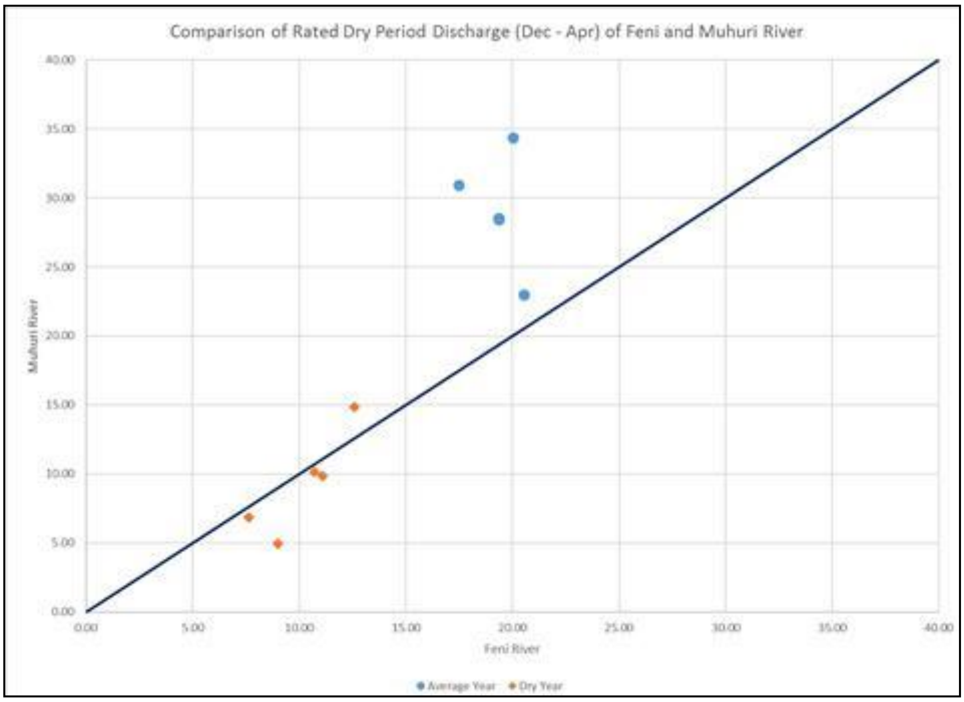


Figure 4.9: The comparison of rated dry period (Dec. – Apr.) flow data of Feni and Muhuri River

4.3.4 Surface Water Balance in Feni River under Reservoir Condition

A surface water balance in Feni River under Reservoir Condition has been assessed for above mentioned 3 scenarios shown in **Table 4.2, Table 4.3 & Table 4.4** respectively based on the following data analysis.

- Monthly field level crop water requirements (Mm^3) were undertaken for average and dry years for the existing cropping pattern and the two alternative future cropping scenarios [source: IMIP (March 2016)];
- Total reservoir monthly inflow (Mm^3) by summing up the rated perennial flow of the Feni, Muhuri and Selonia River;
- Anticipated monthly reservoir live storage is 17.4 Mm^3 (ref. **Figure 4.4**);
- Total monthly surface water excess (+ve) or deficit (-ve) by fulfilling the irrigation (crop water requirement) demand;
- Assessment of remaining reservoir storage if 100 MLD (3.0 Mm^3) is withdrawn for BSMSN industrial demand;

4.3.5 Key Findings of Feni River Surface Water Resource Analysis

- The calculated water balance (see **Table 4.2, Table 4.3 & Table 4.4**) shows that under average rainfall and streamflow conditions, surface water supply is adequate to meet estimated crop water requirements for MIP. There is excess inflow in the reservoir water. If 100 MLD (3.0 Mm3) is withdrawn for BSMSN industrial requirement there would be no impact on reservoir storage.
- The calculated water balance (see **Table 4.2, Table 4.3 & Table 4.4**) shows that under dry rainfall and streamflow conditions, surface water supply is inadequate to meet estimated crop water requirements for the month February (Scenario-1a) and for the month of February & March (Scenario 2a & 3a) respectively. The deficit of these month crop water requirement could be adjusted from the reservoir live storage. In this case, if 100 MLD

(3.0 Mm3) is withdrawn for BSMSN industrial requirement there would be little bit reduction on reservoir storage.

- Initial requirement of 100 MLD (3.0 Mm^3) for BSMSN industrial zone from surface water source (Feni River) could meet the whole year; In this connection, a Memorandum of Understanding (MoU) in between BWDB and BEZA is required for using the Feni River water under reservoir condition (December – April).

Table 4.2: Summary of Surface Water Balance under Reservoir Condition (December – April) for Existing Condition – 100% Boro

Scenario: 1a (Existing Condition - 100% Boro)	**Dry Year Stream Flow & Crop Water Demand**				
Cropped Area:	9800 ha				
	Dec	Jan	Feb	Mar	Apr
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	33.71	28.70	21.76	20.40	28.78
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	39.82	27.11	11.99	18.30	25.53
Reservoir Inflow (Mm3) - from Selonia River at U/S	2.60	2.80	2.07	1.97	1.90
Total Reservoir Inflow (Mm3)	**76.13**	**58.62**	**35.82**	**40.68**	**56.22**
Crop Water Demand (Mm3) *	23.20	29.6	40.6	35.5	20.1
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40
Total Surface Water Excess (+ve) or deficit (-ve) (Mm3)	52.93	29.02	-4.78	5.18	36.12
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	12.62	0.00	0.00
Excess Inflow (m3/s)	19.76	10.83	0.00	1.93	13.49
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	9.62	17.40	17.40

Scenario: 1b (Existing Condition - 100% Boro)	**Average Year Stream Flow & Crop Water Demand**				
Cropped Area:	9800 ha				
	Dec	Jan	Feb	Mar	Apr
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	54.99	51.82	48.43	51.89	45.28
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	61.52	76.42	83.09	76.12	80.13
Reservoir Inflow (Mm3) - from Selonia River at U/S	4.66	3.72	2.76	4.00	6.56
Total Reservoir Inflow (Mm3)	**121.18**	**131.96**	**134.29**	**132.01**	**131.97**
Crop Water Demand (Mm3) *	23.20	29.4	37.9	24.4	6.9
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40
Total Surface Water Excess (+ve) or deficit (-ve) (Mm3)	97.98	102.56	96.39	107.61	125.07
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	0.00	0.00	0.00
Excess Inflow (m3/s)	36.58	38.29	35.99	40.18	46.70
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	17.40	17.40	17.40

*Note: * & ** IMIP Report of MIP, March 2016*

Conversion factor: 100 MLD = 1.16 m3/s = 3.00 Mm3

Table 4.3: Summary of Surface Water Balance under Reservoir Condition (December – April) for Future Condition – 85% Boro

Scenario: 2a (Future Condition - 85% Boro)	**Dry Year Stream Flow & Crop Water Demand**					
Cropped Area:	17000 ha					
	Dec	Jan	Feb	Mar	Apr	
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	33.71	28.70	21.76	20.40	28.78	
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	39.82	27.11	11.99	18.30	25.53	
Reservoir Inflow (Mm3) - from Selonia River at U/S	2.60	2.80	2.07	1.97	1.90	
Total Reservoir Inflow (Mm3)	**76.13**	**58.62**	**35.82**	**40.68**	**56.22**	
Crop Water Demand (Mm3) *	22.10	33.4	46.1	42.4	23.7	
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40	
Total Surface Water Excess (+ve) or deficit (-ve) (Mm3)	54.03	25.22	-10.28	-1.72	32.52	
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	7.12	15.68	0.00	
Excess Inflow (m3/s)	20.17	9.41	0.00	0.00	12.14	
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	4.12	12.68	17.40	
Scenario: 2b (Future Condition - 85% Boro)	**Average Year Stream Flow & Crop Water Demand**					
Cropped Area:	17000 ha					
	Dec	Jan	Feb	Mar	Apr	
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	54.99	51.82	48.43	51.89	45.28	
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	61.52	76.42	83.09	76.12	80.13	
Reservoir Inflow (Mm3) - from Selonia River at U/S	4.66	3.72	2.76	4.00	6.56	
Total Reservoir Inflow (Mm3)	**121.18**	**131.96**	**134.29**	**132.01**	**131.97**	
Crop Water Demand (Mm3) *	22.10	33.2	42.8	29	7.6	
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40	
Total Surface Water Spill (+ve) or deficit (-ve) (Mm3)	99.08	98.76	91.49	103.01	124.37	
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	0.00	0.00	0.00	
Excess Inflow (m3/s)	36.99	36.87	34.16	38.46	46.43	
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	17.40	17.40	17.40	
*Note: * & ** IMIP Report of MIP, March 2016*						
Conversion factor:	*100*	*MLD =*	*1.16*	*m3/s =*	*3.00*	*Mm3*

Table 4.4: Summary of Surface Water Balance under Reservoir Condition (December – April) for Future Condition – 60% Boro

Scenario: 3a (Future Condition - 60% Boro)	**Dry Year Stream Flow & Crop Water Demand**					
Cropped Area:	17000 ha					
	Dec	Jan	Feb	Mar	Apr	
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	33.71	28.70	21.76	20.40	28.78	
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	39.82	27.11	11.99	18.30	25.53	
Reservoir Inflow (Mm3) - from Selonia River at U/S	2.60	2.80	2.07	1.97	1.90	
Total Reservoir Inflow (Mm3)	**76.13**	**58.62**	**35.82**	**40.68**	**56.22**	
Crop Water Demand (Mm3) *	20.40	29.3	40.7	42.7	20.6	
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40	
Total Surface Water Excess (+ve) or deficit (-ve) (Mm3)	55.73	29.32	-4.88	-2.02	35.62	
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	12.52	15.38	0.00	
Excess Inflow (m3/s)	20.81	10.95	0.00	0.00	13.30	
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	9.52	12.38	17.40	
Scenario: 3b (Future Condition - 60% Boro)	**Average Year Stream Flow & Crop Water Demand**					
Cropped Area:	17000 ha					
	Dec	Jan	Feb	Mar	Apr	
Reservoir Inflow (Mm3) - from Feni River at Kaliachari	54.99	51.82	48.43	51.89	45.28	
Reservoir Inflow (Mm3) - from Muhuri River at Parshuram	61.52	76.42	83.09	76.12	80.13	
Reservoir Inflow (Mm3) - from Selonia River at U/S	4.66	3.72	2.76	4.00	6.56	
Total Reservoir Inflow (Mm3)	**121.18**	**131.96**	**134.29**	**132.01**	**131.97**	
Crop Water Demand (Mm3) *	20.40	29	37.2	28.7	5.7	
Anticipated Reservoir Live Storage end of month (Mm3) **	17.40	17.40	17.40	17.40	17.40	
Total Surface Water Spill (+ve) or deficit (-ve) (Mm3)	100.78	102.96	97.09	103.31	126.27	
Change in Reservoir Storage end of month (Mm3)	0.00	0.00	0.00	0.00	0.00	
Excess Inflow (m3/s)	37.63	38.44	36.25	38.57	47.14	
Remaining Reservoir Storage, if 100 MLD withdrawn for MICITY (Mm3)	17.40	17.40	17.40	17.40	17.40	
*Note: * & ** IMIP Report of MIP, March 2016*						
Conversion factor:	*100*	*MLD =*	*1.16*	*m3/s =*	*3.00*	*Mm3*

4.3.6 Water quality of Feni River

Water quality samples has been collected in dry and wet season in Feni River at Azampur. The detail is described in Sec. 8.4.

4.4 Resource Assessment of Little Feni River

4.4.1 Existing Features of Little Feni River

A surface water reservoir has been built-up by constructing Musapur Regulator and dam closure at about 1 km north of Sanwip channel. The main purpose of the regulator is to protect the area from saline water intrusion, drainage control and facilitate small scale irrigation. The Musapur Regulator comprises 23 bays, radial gates and flap gates. The effective storage of the reservoir depends on the upstream supply of water from Karki which is originat in the hilly area of Tripura in India. BWDB regularly monitor the river water levels at the following locations:

- Companigonj
- Gunabati railway bridge

4.4.2 Capacity of Little Feni Reservoir Storage

From the bathymetry data collected under this study from Musapur regulator to 20km upstream of Little Feni River near Daganbhyiyan volume-elevation curve has been developed for Little Feni River as shows in **Figure 4.10**. The average bed level of this river is nearly -2.2mPWD and the bank level nearly 4.7mPWD. If we considered dead storage level at 2.0mPWD and maximum water level maintain in the reservoir in dry season at 4.0mPWD, the effective storage volume is about 20.14Mm^3.

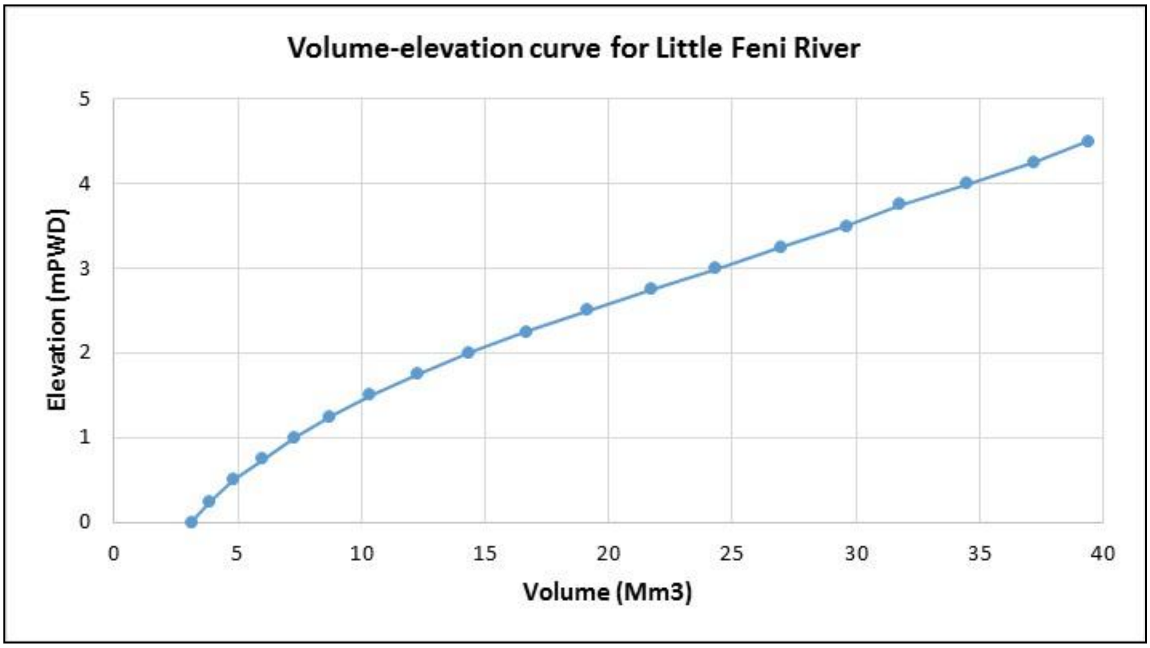


Figure 4.10: Volume-elevation curve for Little Feni River

4.4.3 Analysis of Dry Season Perennial Flow in Little Feni River

There is no discharge measuring station on Little Feni River. Therefore perennial flow of Little Feni River has been analyzed based on rainfall-runoff model developed under this study. The dry season runoff volume from December to April has been shown in **Figure 4.11**. It is observed that the minimum flow volume occur in dry season is about 0.82 Mm^3 and average flow volume is about 20.99Mm^3.

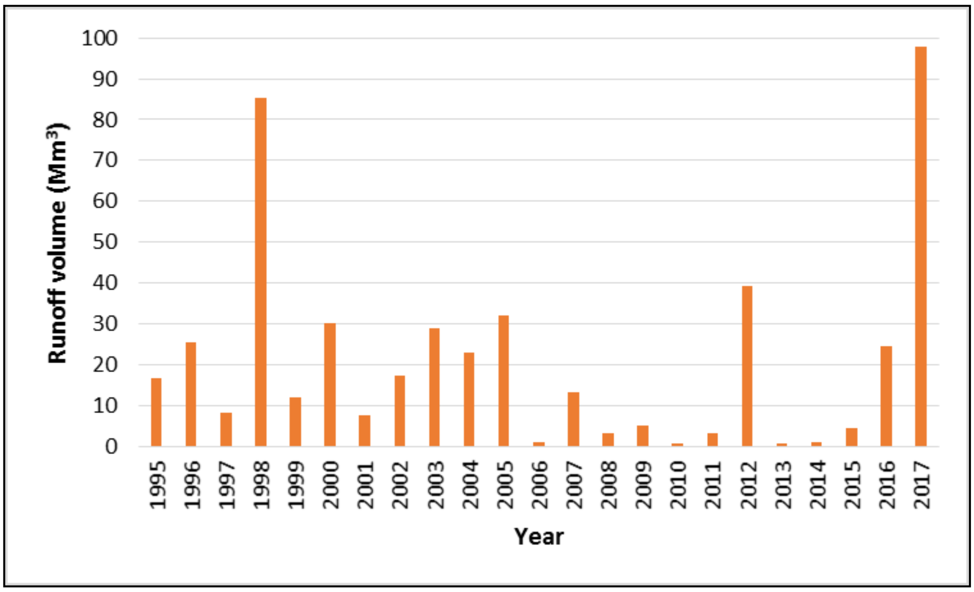


Figure 4.11: Dry season runoff volume of Little Feni River

4.4.4 Surface Water Balance in Little Feni River under Reservoir Condition

A surface water balance in Little Feni River under Reservoir Condition has been assessed for minimum flow and average as shown in **Table 4.5 & Table 4.6** respectively based on the following data analysis.

- Monthly field level crop water requirements (Mm^3) were undertaken based on existing cropping pattern of MIP project irrigation scheme;
- Total reservoir monthly inflow (Mm^3) by summing up the simulated runoff flow of the Little Feni River;
- Anticipated monthly reservoir live storage is 24.01 Mm^3 (ref. **Figure 4.10**);
- Total monthly surface water excess (+ve) or deficit (-ve) by fulfilling the irrigation (crop water requirement) demand;
- Assessment of remaining reservoir storage if 40 MLD (1.2 Mm^3) is withdrawn for BSMSN industrial demand;

4.4.5 Key Findings of Little Feni River Surface Water Resource Analysis

The calculated water balance (see **Table 4.5 & Table 4.6**) shows that under minimum and average runoff flow condition, there is excess water available after meeting some irrigation demand which can be supplied to BSMSN area. If 40 MLD (1.2 Mm3) is withdrawn for BSMSN area requirement there would be no impact on reservoir storage.

In this connection, a detail feasibility study and Memorandum of Understanding (MoU) in between BWDB and BEZA is required for using the Little Feni River water under reservoir condition (December – April).

Table 4.5: Summary of Little Feni River Water Balance under Reservoir Condition (December – April) for minimum flow condition

	Dec	Jan	Feb	Mar	Apr
Inflow (Mm^3)	0.38	0.17	0.12	0.09	0.06
Storage volume (Mm^3)	34.49	31.35	27.37	22.23	17.56
Irrigation demand (Mm^3)	2.32	2.96	4.06	3.55	2.01
Water requirement for 40MLD SWTP (Mm^3)	1.2	1.2	1.2	1.2	1.2
Total demand (Mm^3)	3.52	4.16	5.26	4.75	3.21
Excess storage (Mm^3)	31.35	27.37	22.23	17.56	14.41
Dead storage & environmental flow (Mm^3)	14.36	14.36	14.36	14.36	14.36
Change in storage ((Mm^3)	17.00	13.01	7.87	3.21	0.06

Table 4.6: Summary of Little Feni River Water Balance under Reservoir Condition (December – April) for average flow condition

	Dec	Jan	Feb	Mar	Apr
Inflow (Mm^3)	5.93	0.46	0.49	3.16	10.95
Storage volume (Mm^3)	34.49	34.49	30.79	26.02	24.44
Irrigation demand (Mm^3)	2.32	2.96	4.06	3.55	2.01

	Dec	Jan	Feb	Mar	Apr
Water requirement for 40MLD SWTP (Mm^3)	1.2	1.2	1.2	1.2	1.2
Total demand (Mm^3)	3.52	4.16	5.26	4.75	3.21
Excess storage (Mm^3)	36.90	30.79	26.02	24.44	32.17
Dead storage & environmental flow (Mm^3)	14.36	14.36	14.36	14.36	14.36
Change in storage ((Mm^3)	22.55	16.44	11.67	10.08	17.82

4.4.6 Water quality of Little Feni River

4.4.6.1 Water Sampling Program

Raw water samples of the Little Feni River has been collected during both dry and wet seasons. Two sampling campaigns have been conducted in October 2018 and January 2019. Water samples were near Musapur Bridge about 7kn upstream of Musapur regulator as shown in **Figure 4.12**.

Figure 4.12: Location of water quality the sampling site on Little Feni River

During the sampling campaign, a country boat was anchored parallel to the direction of current at the point of sample collection, and water samples were collected manually from a depth of about 0.30 m using a pre-washed container. The container was rinsed with the river water prior to the sample collection. The sampling campaign was carried out jointly by BUET and IWM. Collected water samples were transported to the Environmental Engineering Laboratory of the Department of Civil Engineering, BUET quickly for water quality parameters testing.

4.4.6.2 Testing at BUET Laboratory

As soon as the water samples reached BUET Laboratory, detailed laboratory analysis s were carried out to determine the water quality. The water quality parameters selected include

Color (true and apparent), Turbidity, Electrical Conductivity (EC), DO, TS,TDS, TSS, Iron, Ammonia, Total Coliform, Fecal Coliform (FC), COD, BOD5, and some heavy metal. The water quality parameters were measured following Standard Methods (APHA).

4.4.6.3 Characteristics of Raw Water Collected from the Sites

The results of laboratory analysis (at BUET) of raw water samples collected in dry and wet season from Musapur Bridge are presented in **Table 4.7**, along with Bangladesh Drinking Water Standard (GoB, 1997).

Table 4.7: Characteristics of raw water collected from Little Feni River

Sl. No.	Water Quality Parameter	Unit	Concentration Present		Bangladesh Drinking Water Standard
			Wet season	Dry season	
1	pH*	--	8.15	7.9	6.5-8.5
2	Color (True)	Pt.Co. Unit	**36**		15
3	Color (Apparent)	Pt.Co. Unit	**128**		15
4	Turbidity	NTU	**26.3**	**616**	10
5	Temperature*	°C	29.3	23.8	20-30
6	Electrical Conductivity (EC)*	mS/cm	0.197	30.5	-
7	Dissolved Oxygen (DO)*	mg/l	8.10	7.81	6
8	Total Solids (TS)	mg/l	991		-
9	Total Dissolved Solids (TDS)	mg/l	948	**22,068**	1000
10	Total Suspended Solids (TSS)	mg/l	**43**	**712**	10
11	Total Alkalinity	mg/l as $CaCO_3$	95	-	-
	Total Hardness	mg/l as $CaCO_3$		**3,750**	200-500
12	Total Iron (Fe)	mg/l	0.56	**6.8**	0.3-1.0
13	Total Ammonia (as NH_3-N)	mg/l	0.26		-
14	Nitrate (NO_3-N)	mg/l	0.80	0.1	10
15	Orthophosphate (PO_4^{3-})	mg/l	0.25	0.17	6
16	Biochemical Oxygen Demand (BOD_5)	mg/l	**6.4**	0.4	0.2
17	Chemical Oxygen Demand (COD)	mg/l	**70**	**60**	4
18	Lead (Pb)	mg/l	< 0.001	< 0.001	0.05
19	Cadmium (Cd)	mg/l	< 0.001	< 0.001	0.005
20	Chromium (Cr)	mg/l	**0.108**	< 0.001	0.05
21	Zinc (Zn)	mg/l	0.128	0.071	5
22	Mercury (Hg)	mg/l	< 0.001	< 0.001	0.001
23	Manganese (Mn)	mg/l		**0.12**	0.1
24	Sulfate (SO_4^{2-})	mg/l		**1,340**	400
25	Magnesium(Mg)	mg/l		**789.6**	30-35
26	Copper (Cu)	mg/l		0.006	1

Sl. No.	Water Quality Parameter	Unit	Concentration Present		Bangladesh Drinking Water Standard
			Wet season	Dry season	
27	Nickel (Ni)	mg/l		0.011	0.1
28	Total Organic Carbon (TOC)	mg/l		1.69	-
29	Chloride	mg/l		**12,275**	150-600
30	Total Coliform (TC)	cfu/100 ml	262		0
31	Fecal Coliform (FC)	cfu/100 ml	128		0

Table 4.7 shows that water quality of Little Feni River is within Bangladesh Drinking Water Standard for DO, Nitrate, Orthophosphate, Lead, Cadmium, Zinc, Mercury, Copper and Nickel concentrations. But water quality parameters like Color, Turbidity, TSS, TDS, Hardness, Iron, BOD, COD, Sulfate, Magnesium, Chloride concentrations exceed the Bangladesh Drinking Water Standard**.** It can be concluded, based on the test results, that to make the raw water suitable for drinking purpose, treatment of this water is necessary to remove the impurities.

4.5 Resource Assessment of Ichakhali Khal

Monthly and seasonal dependable flow based on model simulation data of Ichakhali khal is given in **Table 4.8**. Monthly flow duration curve for Ichakhali khal is given in **Figure 4.13**. It is observed that in wet season 80% & 50% dependable flow is about 0.7 m^3/s and 2.2 m^3/s respectively while in dry season 80% & 50% dependable flow is only about 0.7 m^3/s and 11.9 m^3/s respectively in Ichakhali khal. It is observed that is dry season the 50% dependable flow is more than monsoon flow. This is because, in dry season the gates of Feni regulator become closed and Ichakhali khal get water from this river. But in monsoon the gates are opened and the khal get very little water from Feni River. That's why in the months of monsoon the flow is not sufficient. Ichakhali khal is not a potential source of water for BSMSN area.

Table 4.8: Dependable flow for Ichakhali Khal

Period	Dependable flow (m^3/s)	
	80%	50%
Dry (Dec-Feb)	0.7	11.9
Wet (Jun-Oct)	0.7	2.2
Jan	12.0	19.8
Feb	7.2	14.2
Mar	4.9	10.5
Apr	5.1	11.5
May	0.1	0.3
Jun	0.4	2.5
Jul	1.1	3.8
Aug	0.0	17.7
Sep	0.9	2.1
Oct	0.5	1.3
Nov	0.2	0.5
Dec	3.3	13.5

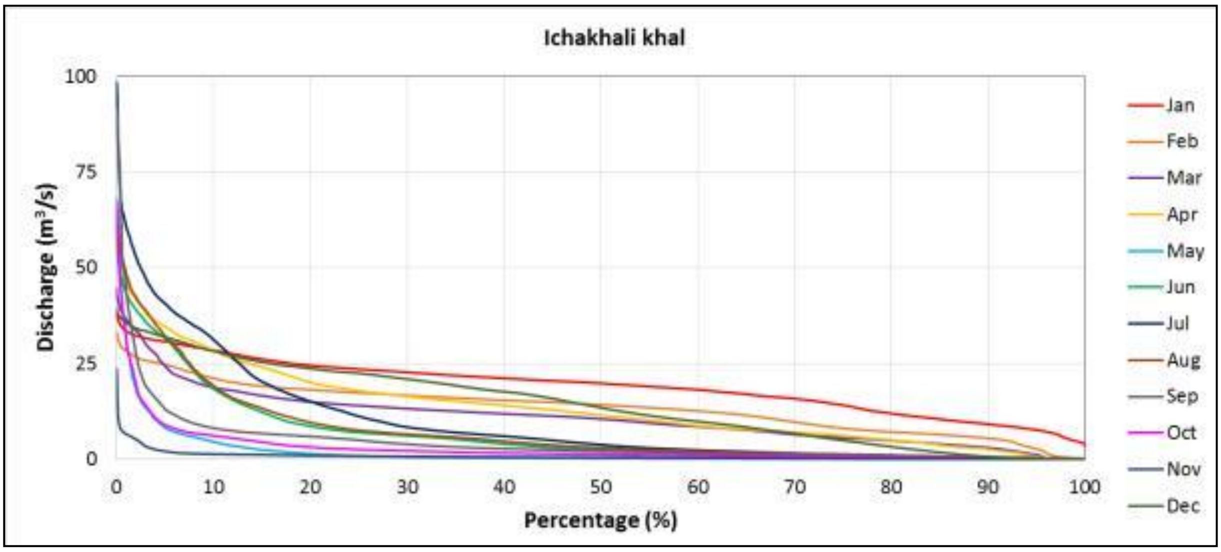


Figure 4.13: Flow duration curve for Ichakhali Khal

4.5.1 Water quality of Ichakhali Khal

Some water quality samples has been collected in Ichakhali Khal at Jhulonpul Bazar as it was initially selected as intake option. The detail is described in Sec. 8.4.

4.6 Resource Assessment of Bamon Sundor Khal

Monthly and seasonal dependable flow based on model simulation data of Bamon Sundor khal is given in **Table 4.9**. Monthly flow duration curve for Bamon Sundor khal is given in **Figure 4.14.** It is observed that in wet season 80% & 50% dependable flow is about 0.0 m^3/s and 14.2 m^3/s respectively while in dry season 80% & 50% dependable flow is only about 0.0 m^3/s and 2.3 m^3/s respectively in Bamon sundor khal. It is observed that is dry and wet season most of the time there is no water in the khal. In this regard Bamon sundor khal is not suitable to be considered as water source.

Table 4.9: Dependable flow for Bamon Sundor Khal

Period	Dependable flow (m^3/s)	
	80%	50%
Dry (Dec-Feb)	0.0	2.3
Wet (Jun-Oct)	0.0	14.2
Jan	0.0	3.3
Feb	0.0	1.3
Mar	0.0	0.6
Apr	0.0	0.7
May	0.0	0.8
Jun	0.0	15.3
Jul	1.9	20.0
Aug	0.0	17.7
Sep	0.0	13.9
Oct	0.0	9.4
Nov	0.0	2.9
Dec	0.0	2.2

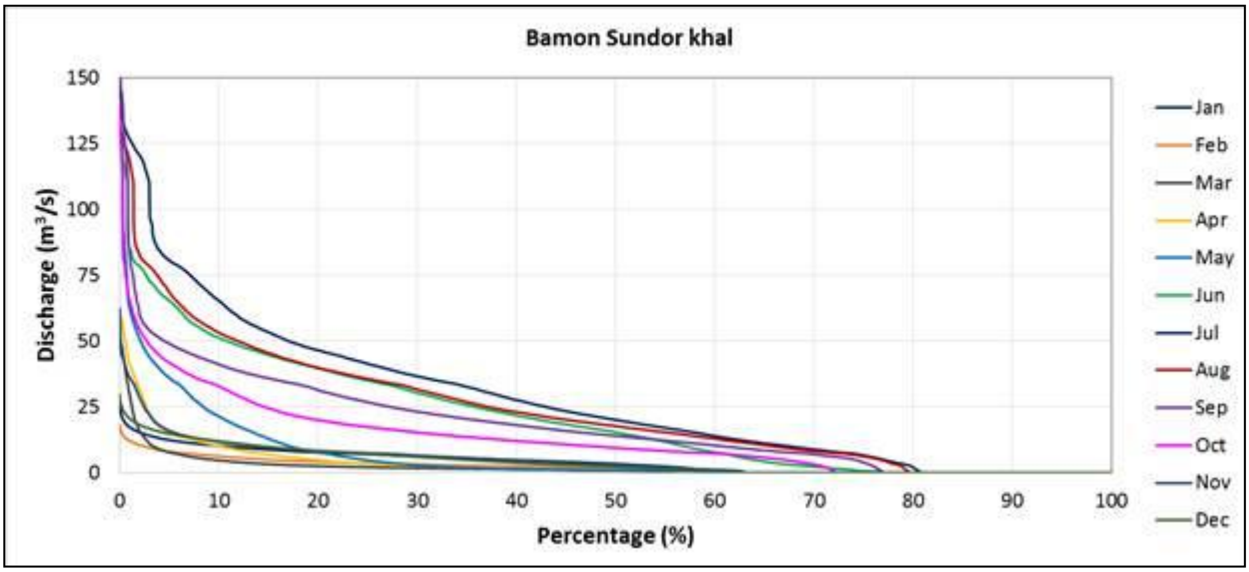


Figure 4.14: Flow duration curve for Bamon Sundor Khal

4.7 Resource Assessment of Mohamaya Reservoir

Mohamaya reservoir (**Figure 4.15**) was developed by BWDB under Mohamaya Chhara Irrigation (MCI) project in 2010 to supply water for irrigation in 1295ha area. The reservoir is about 12km away from BSMSN area. The reservoir area is about 1070ha and design lowest water level is 15.5mPWD. The water demand of the reservoir is given below:

Water demand for irrigation (for 2040):	5.92Mm^3
Water demand for Mirsharai Pourashava (for 2040):	0.23Mm^3
Total demand for irrigation and municipal supply:	6.15Mm^3
Net water available in the reservoir:	6.8 Mm^3

[Source: IWM, BETS, BCL, SARM, 2014]

After meeting water demand for irrigation and Mirsharai Pourashava municipal supply, about 0.65 Mm^3 water is available for other purposes. This indicate we can get 1.7MLD water for BSMSN area which is very negligible water compare to total water demand of the economic zone. So Mohamaya reservoir is not a potential water source for BSMSN project.

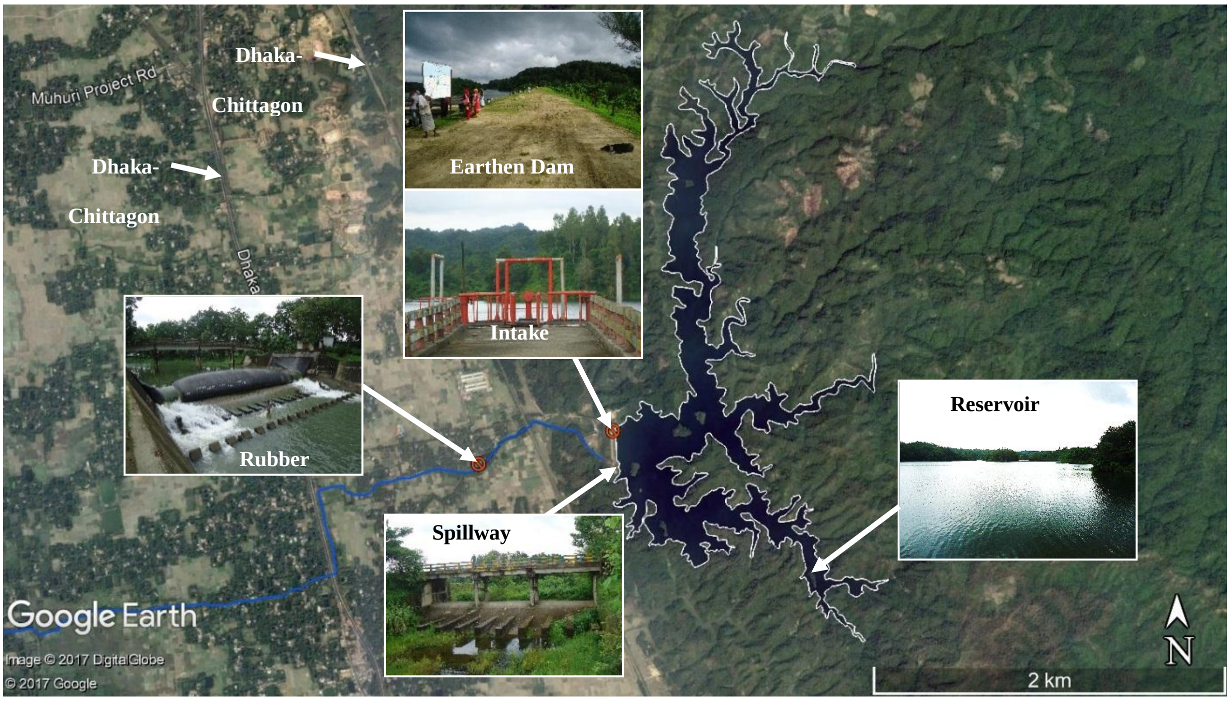


Figure 4.15: A glimpse of Mohamaya Chhara Irrigation Extension project

4.8 Resource Assessment of Bawa Chhara Reservoir

Local Government Engineering Department (LGED) implemented water conservation sub-project from 30 Dec 2007 to 31 July 2008 entitled as “Bawa Chhara Sub-project” located at the upstream of Domkhali khal. The sub-project is situated 7.5 km east of BSMSN (Zone 25) area. Gross area and net area of the project are 850ha and 700ha respectively. The land elevation varies from 3.95 mPWD to 11.75 mPWD within the sub-project. The Bawa Chhara originated from the hills on the eastern part of Wahedpur union and enters into the sub-project area. The reservoir water is used for irrigation of Boro and Robi crops. **Figure 4.16** shows the glimpse of the project area. Major physical components of the project are:

▪ Earthen Dam	(length 94m)
▪ Reservoir	(average length 250m, width 200m, depth 9m, max storage 450,000m^3, retention level 20 mPWD)
▪ WRS	(irrigation outlet with distribution box 1V-0.9mX0.9m)
▪ Syphon	(0.9mX0.9m)
▪ Check Structure-1	(3V-1.5mX1.2m, 50m upstream of the existing railway bridge)
▪ Check Structure-2	(4V-1.5mX1.2m, 20m upstream of the existing highway bridge)
▪ Check Structure-3	(5V-1.5mX1.2m, near Chhara)
▪ Spillway Structure	(length 9m, 3V-3.0mX2.0m)
▪ Khal re-excavation	(0.95 km of Bawa Chhara)

From the hydrological model it is estimated that the total runoff volume of the Domkhali catchment surrounding the Bawa chhara reservoir is 4.6Mm^3 (**Table 4.10)**. But the storage capacity Bawa chhara reservoir is about only 0.45Mm^3, i.e. about 1.0MLD water can be extracted from the reservoir. As the water is using for irrigation Bawa Chhara reservoir is not a potential source to supply water for BSMSN area.

Table 4.10: Average monthly runoff of Bawa Chhara catchment

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Runoff volume (Mm^3)	0.07	0.05	0.06	0.08	0.24	0.79	1.16	0.90	0.59	0.44	0.17	0.10

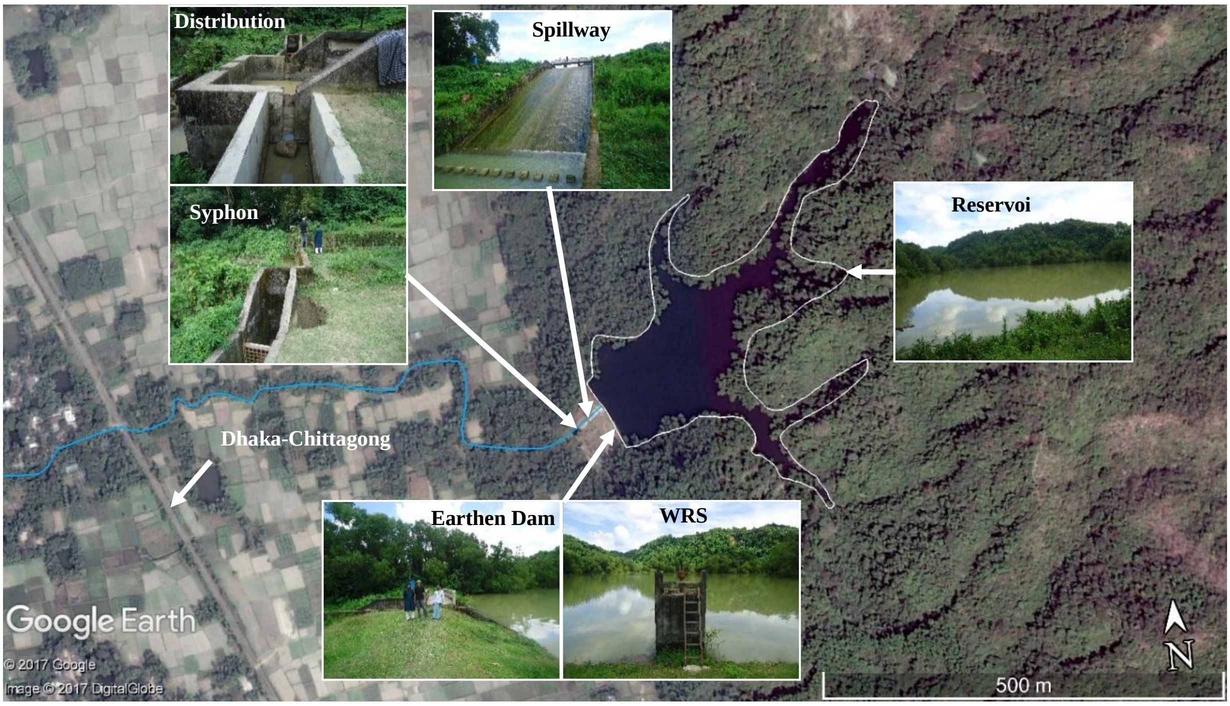


Figure 4.16: A glimpse of Bawa Chhara sub-project

4.9 Resource Assessment of Boro-Komoldoho Reservoir

Boro-Komoldoho water fall is about 7.5km east of BSMSN area. The source of water of the waterfall is perennial. The catchment area is approximately 3.15km^2. The Catchment area lies in the Bariadyala union of Sitakunda Upazilla and Wahedpur union of Mirsharai Upazilla.

From the hydrological model the runoff generated has been analyzed as shown in **Table 4.11**. It is estimated that the yearly average storage of the reservoir is about 6.2Mm^3. If the generated rainfall water is stored in a reservoir by constructing embankment and related other structures about 13.5 MLD water can be available for using. Comparing the total water demand and considering distance from the economic zone to the reservoir, it is not a potential source to supply water for BSMSN area.

Table 4.11: Average monthly runoff of Boro-Komoldoho catchment

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Runoff volume (Mm^3)	0.09	0.07	0.08	0.10	0.32	1.06	1.55	1.20	0.79	0.59	0.23	0.13

4.10 Resource Assessment of Sahasradhara Reservoir

Local Government Engineering Department (LGED) implemented water conservation sub-project entitled as “Sahasradhara Sub-project” near Sitakunda of Chittagong from 28 Feb 2006 to 05 June 2008. The sub-project is situated approximately 6.5 km east of BSMSN (Zone 25) area. The sub-project area stretches from the eastern foothill of Sitakunda towards the coastal embankment on the west. Gross area and net area of the project are 600ha and 528ha respectively. The sub-project area is mostly a high land and flood free. A short duration and shallow inundation has been reported due to heavy downpour in the sub-project area. The water is drained out in a short period of hours of time. The sub-project people suffer from the shortage of water for irrigation during dry season since the existing base flow in Sahasradhara is inadequate in compare to requirement. The sub-project concept developed by the beneficiaries is to conserve water in the upstream valley of hills from Sahasradhara chhara to an acceptable level during cessation of monsoon with the aim to provide irrigation water during dry season. Land level within the sub-project area is found to vary from 12.3 mPWD on the east to 3.1 mPWD on the west. **Figure 4.17** shows the glimpse of the project area. Major physical components of the project are:

▪ Earthen Dam	(length 55m)
▪ Reservoir	
▪ WRS	(1V-0.9mX0.9m)
▪ Check Structure-1	(3V-1.5mX1.5m)
▪ Check Structure-2	(3V-1.5mX1.5m)
▪ Check Structure-3	(3V-1.5mX1.5m)
▪ Spillway Structure	(3V-3.4mX2.0m)
▪ O&M shed	(12mX6m)
▪ Khal re-excavation	(5.6 km)

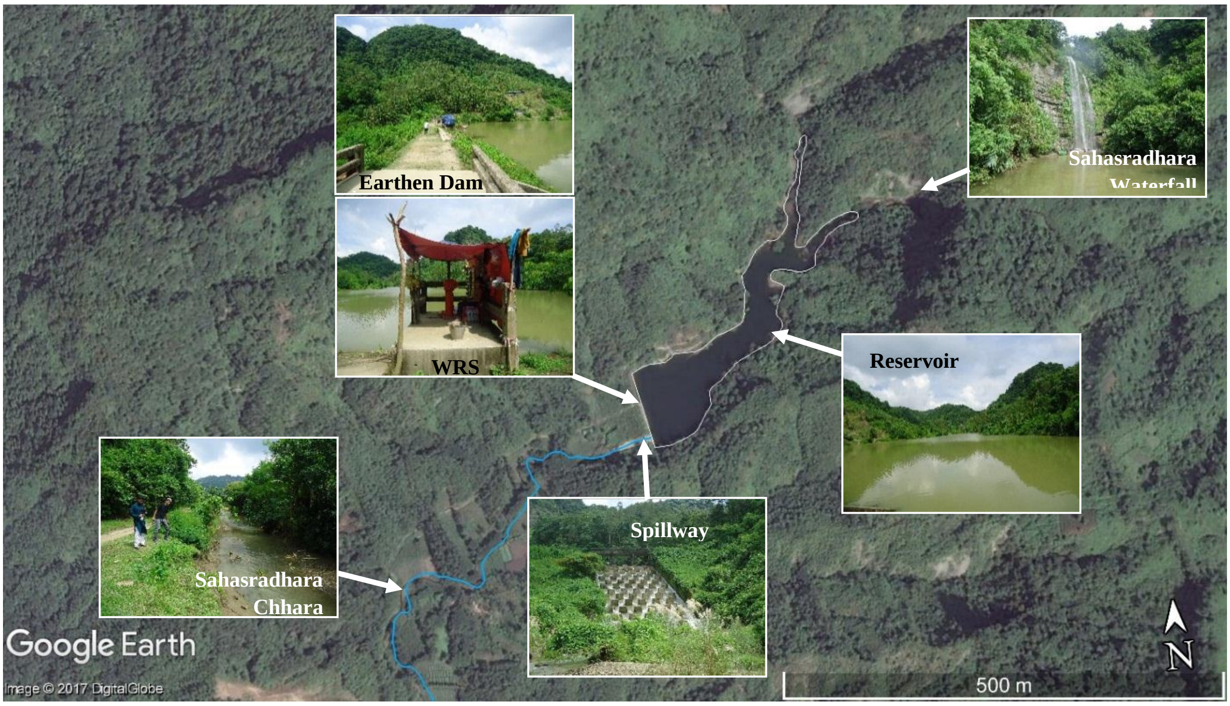


Figure 4.17: A glimpse of Sahasradhara sub-project

As the water available in Sahasradhara Reservoir is using as irrigation, it is not a potential source to supply water for BSMSN area.

4.11 Off-stream Reservoir (8nos.)

For BSMSN area, initially Off-channel reservoir was planned and designed as a water supply artificial lake built next to or near to Ichakhali Khal, Bamon Sundar Khal and Govania-Shaherkhali Khal. Finally, 4 off-channel reservoirs (**Figure 4.18**) have been planned and designed along the Ichakhali and West Ichakhali khal to conserve the surface water for recreation purposes and make the industrial zone as eco-friendly. Round-the-year surface water resource availability does not permit the off-channel reservoir along the Bamon Sundar Khal and Govania-Shaherkhali Khal. The planned Off-channel reservoir is relatively environment friendly without disturbing the main flow path of the khal.

4.11.1 Selection of suitable site for off-channel reservoir

Following criteria have been followed to select suitable site for off-channel reservoir:

- A thorough field investigation has been made by evaluating the surface water flow path in the BSMSN area including its perennial sources.
- Collected and assembled relevant information of topography, geology, meteorology and hydrology from different sources; on the basis of that
- 1 no. off-channel reservoir has been planned by cutting loops to straighten the flow path along the Ichakhali khal;
- Other 1 no. off-channel reservoir has also been planned along the Ichakhali khal considering the availability of flow including its seasonal variation;
- 2 nos. off-channel reservoir have been planned along the west Ichakhali khal by connecting this khal with Dawkhali khal, perennial source of water would be from Ichakhali khal;
- A wide and deep reservoir (around 6m depth) is preferred instead of shallow one considering the less evaporation loss and less possibility of weed growth;
- The geological formation of the reservoir banks, walls etc. have been planned to design to entail minimum leakage, minimum water losses through absorption and percolation;
- Intake channel have been planned to design by avoiding too much silt as much as possible.

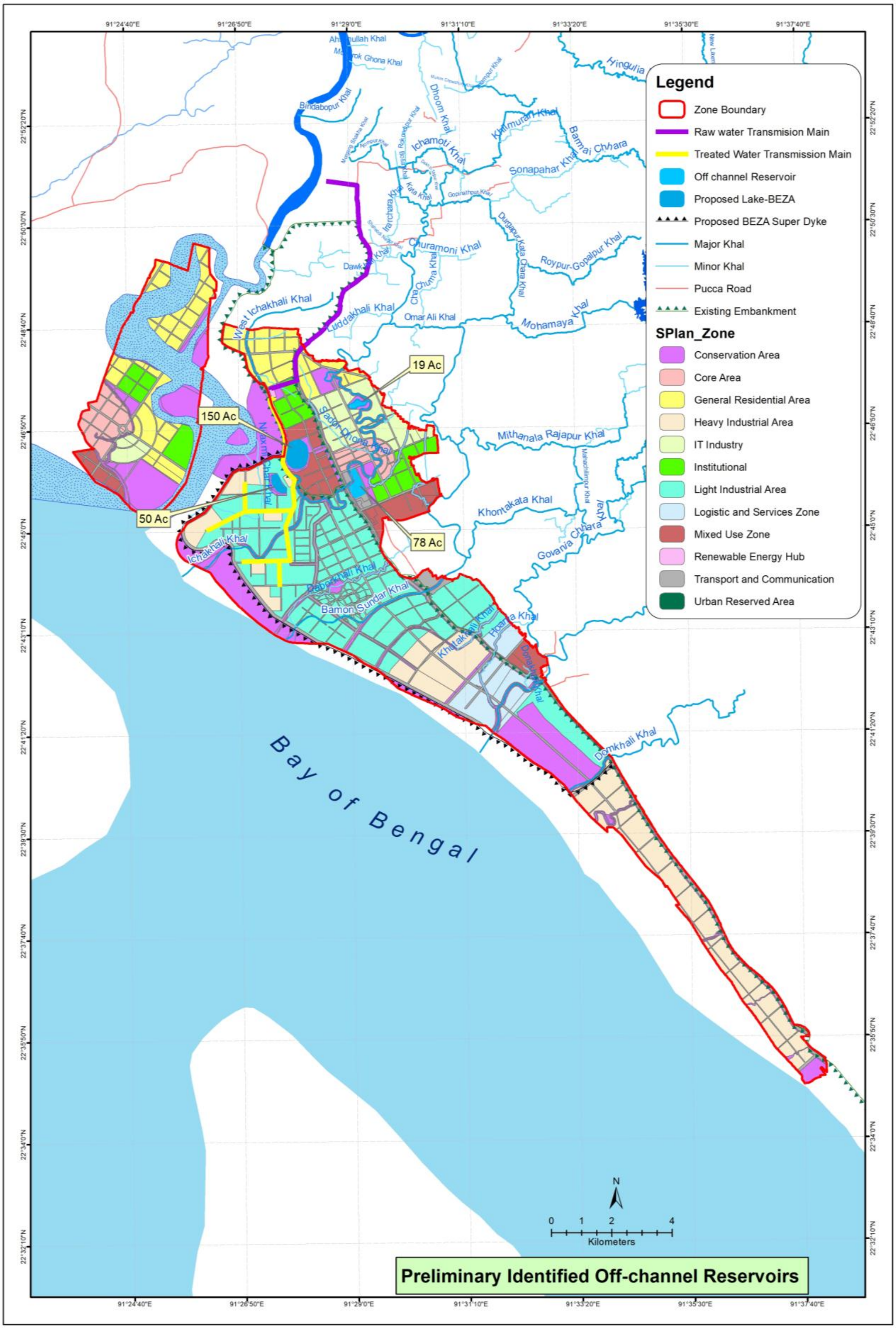


Figure 4.18: Identified off-channel reservoir

4.11.2 Planning concept of off-channel reservoir

Following steps have been followed in planning stage of off-channel reservoir:

- Straighten the flow path of Ichakhali khal by cutting loops;
- Extent (location, size, connectivity with intake and outlet etc.) of each proposed reservoir: The size could be rectangular, triangular, circular or any irregular shapes. The reservoir banks have been planned with a side slope 2:1 and a 3m berm to stabilize the 7m deep reservoir bank. The 4m wide motorway on the crest of dyke/embankment has been proposed with motor-bay at 4 locations of each side of the reservoir.

- Generated flood volume including time and duration of monsoon along the peripheral river:
  - The generated rainfall-runoff for 5-day 1 in 25-year frequency from Feni rainfall data (secondary source data, 1986 to 2009) have been analysed.
  - The calculated catchment flow discharge through Ichakhali khal at 9 vents regulator point is 31 m^3/s.
  - The existing khal system would be re-sectioned/re-excavated to accommodate the design rainfall-runoff (5-day 1 in 25-year) data and khal would be straightened, both bank would be protected with a 4m motorway.
  - The off-channel reservoir has been planned to fill-up by gravity flow during monsoon, post-monsoon season and Ichakhali water surface would be head up by closing the regulator to attain the full reservoir level during post-monsoon. In this connection, existing 9 vents regulator would be used for proposed off-channel reservoir along the Ichakhali khal.
  - A link channel would be developed by connecting West Ichakhali khal with Dawkhali khal to ensure the perennial flow from Ichakhali system. In this connection, existing 5 vents regulator on West Ichakhali khal would be used to head up water surface level for off-channel reservoir.
  - In addition, all major khals would be designed for accommodate the design flood and both banks will be protected with a 4m motorway on both banks.

- Fixation of elevation of the crest level (height) of the proposed reservoir dyke:
  - The crest level (height) of the proposed reservoir dyke have been fixed at +7.00 m,PWD considering the existing ground level would be developed up to +6.00 m,PWD.

- Fixation of bed elevation of the proposed reservoir:
  - The minimum bed level of the proposed reservoir has been fixed at -1.00 m,PWD to maintain the total active storage depth at least 5.5m excluding dead storage depth around 1.0m which may vary with reservoir size. The reservoir bed would be treated depending on the permeability test results of soil properties.

- Live storage capacity of the proposed reservoir:
  - Live storage capacity of each proposed off-channel reservoir has been analysed based on two criteria: (i) average potential evaporation rate at Chittagong hydro-meteorological station data – 6mm/day, (ii) deep percolation losses – 2mm/day (considering treated reservoir bed).

- Fixation of the invert level of inlet and outlet of each reservoir:
    - The invert level of inlet structure (regulator) has been fixed adjusting with the dead storage level of each proposed off-channel reservoir. The reservoir water (only active storage) would be pumped for Water Treatment Plant (WTP) and maximum total head, diameter of suction & distribution pipe for each reservoir has been calculated separately.

- Wave protection plan:
    - Wind generated wave is an important factor for evaporation loss from a wide water surface of off-channel reservoir. The greater the movement of air over the water surface, greater is the evaporation loss. Water hyacinth casing (2m wide) would be placed at a certain interval as an effective measure for checking evaporation loss. In addition, plants (small trees, shrubs or grass) would be grown around the rim of dyke/embankment in a row or rows to act as wind breaker. Plants to be arranged as conical formation with tallest one in the middle and smallest one at the end (shaped like a wave).

4.11.3 Typical plan of off-channel reservoir

Typical plan of off-channel reservoir with bank protection work is shown in **Figure 4.19**. The characteristics features of the proposed reservoir is:

- Reservoir banks (2:1 slope) would be protected by CC block at two stages and in between gabion box would be placed at 3m wide berm;
- Banks under water part (dead storage part) would be protected by geo-bag which would be connected with CC block by another 3m wide berm;
- Reservoir bed would be treated based on permeability test results of soil samples;
- 4m wide motor road on the crest of dyke has been proposed with a 4 motor-bay of each side for operation and maintenance of reservoir;
- Wave protection plan by 2m wide water hyacinth casing is shown in **Figure 4.20**. Water hyacinth could be arranged in tapering formation (as like as half sinusoidal curve) with a long stem colorful water lily;
- Each reservoir will provide individual archeological aesthetic outlook where peoples can spend their leisure time in the morning, afternoon and evening;

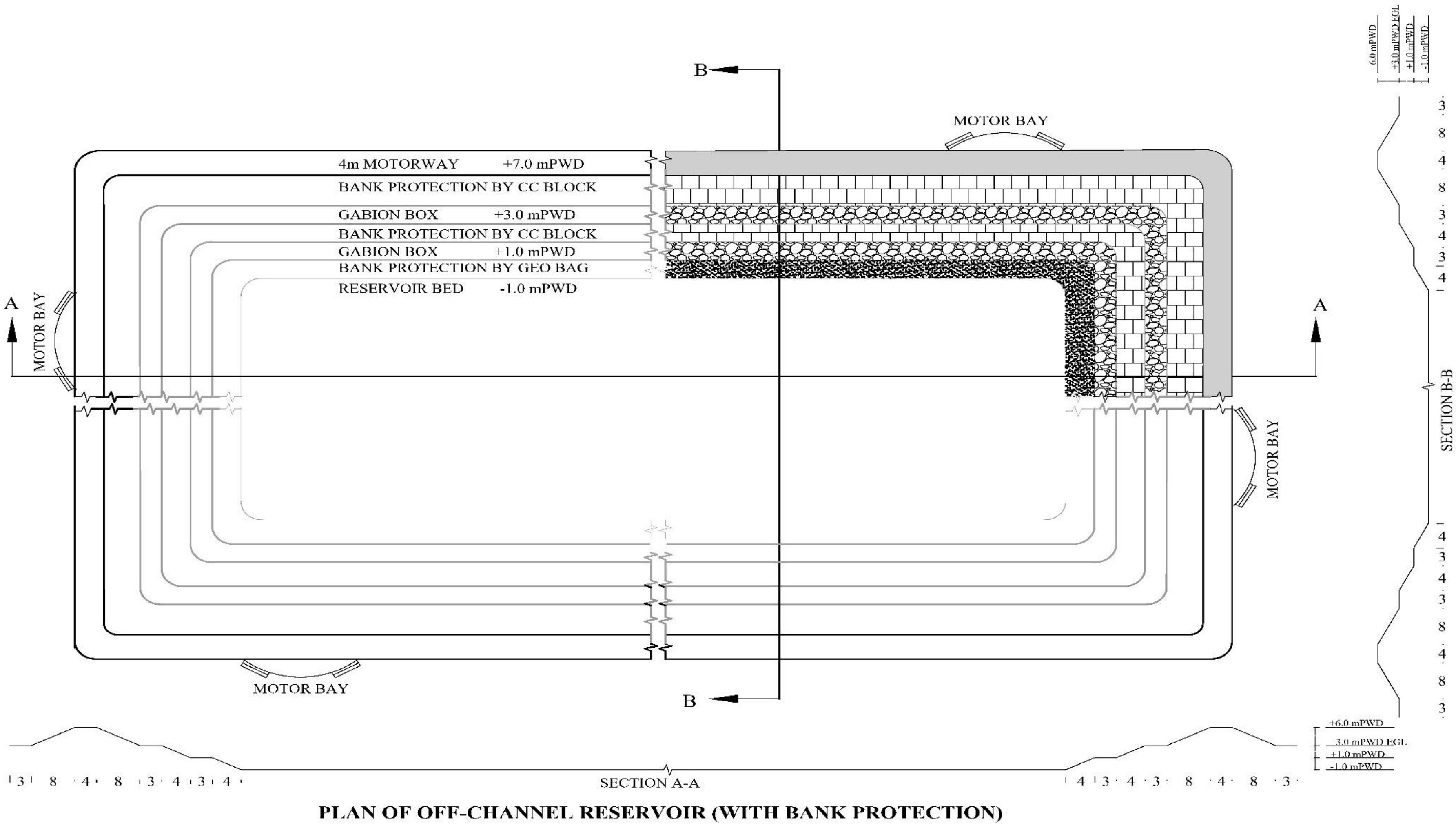


Figure 4.19: Typical plan of off-channel reservoir

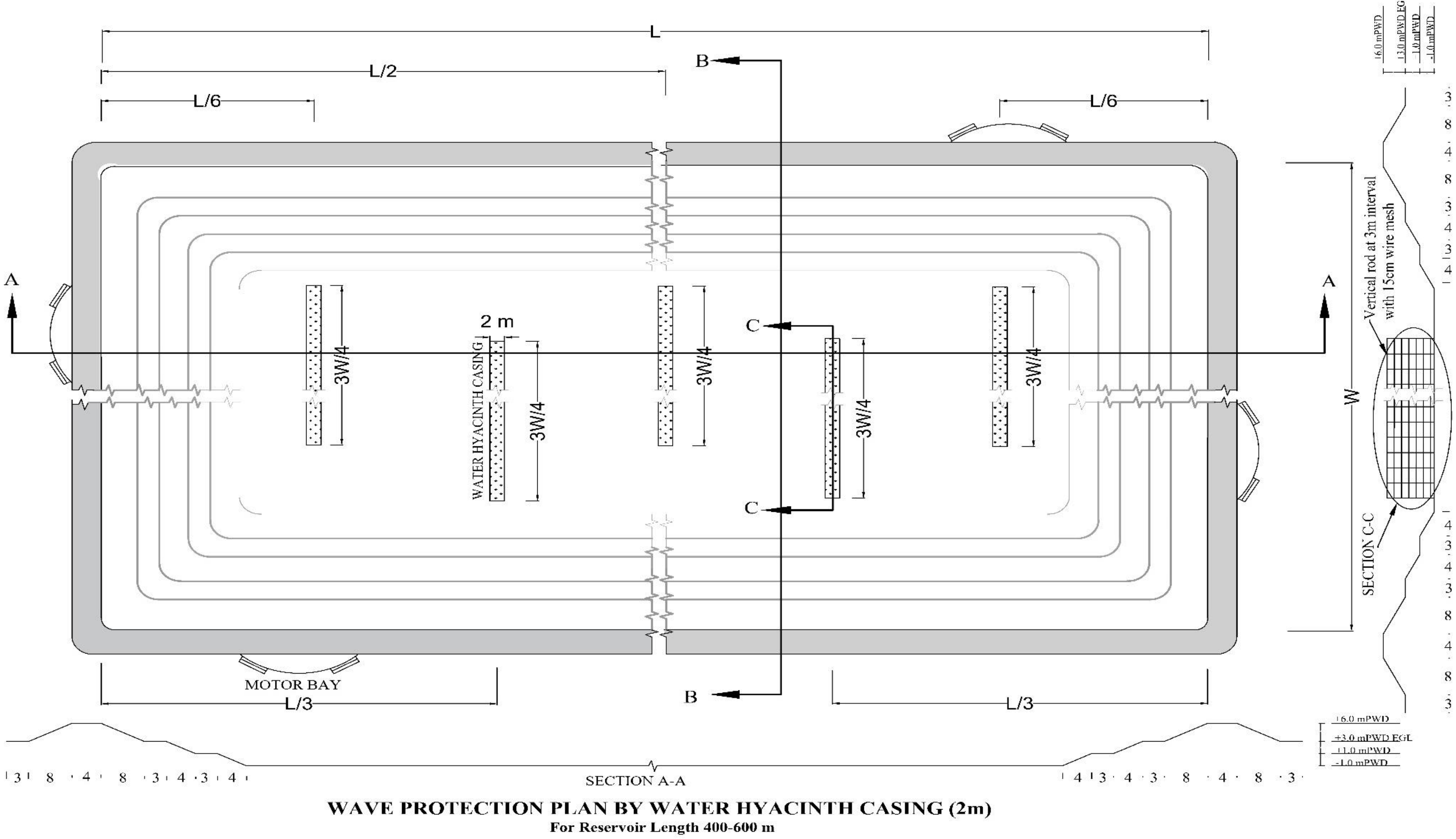


Figure 4.20: Typical wave protection plan by water hyacinth casing

4.11.4 Proposed Off-Channel Reservoirs

Finally, 4 off-channel reservoir as shown in **Figure 4.18** has been selected to restore the water body in the BSMSN area to make the industrial zone as eco-friendly recreation purposes. The area of the off-channel reservoirs are given in **Table 4.12**.

Table 4.12: Proposed off-channel reservoirs

Reservoir Zone	Off-channel Reservoir No.	Area in Acre
Ichakhali Khal	Off-res-1	19
	Off-res-2	78
West Ichakhali Khal	Off-res-3	150
	Off-res-4	50

5 Resource Assessment of Groundwater

Groundwater recharge and flow depends mostly on hydrogeological settings of that area. As such, hydrogeological investigation has been carried out for the lithology and stratigraphic classification to ascertain the aquifer depth location and extent in the study area. The water bearing formations in the study area are identified and explored as sedimentary aquifers based on the aquifer delination.

5.1 Hydrogeological Settings

The study area is located under Chittagong Coastal Plain (**Figure 5.1**). Eastern part of this project area is bounded by Sitakunda hilly range which is dipping in the eastern and steeper in the western flanks of the anticline and truncated abruptly by the alluvial plain of the Feni River. As the south western part is bounded by Bay of Bengal so the beach and dune sand deposit is the dominant feature of the area (Reimann 1993). So, the project area has direct influence on its hydrogeological settings by Little Feni River, Swandip channel and Bay of Bengal. Groundwater of this area lies on the valley alluvium deposits. Some channel deposit is also common on its hydrogeological settings. This region covers the piedmont deposits of Chittagong hill tracks and the Meghna estuarine floodplains (UNDP 1982).

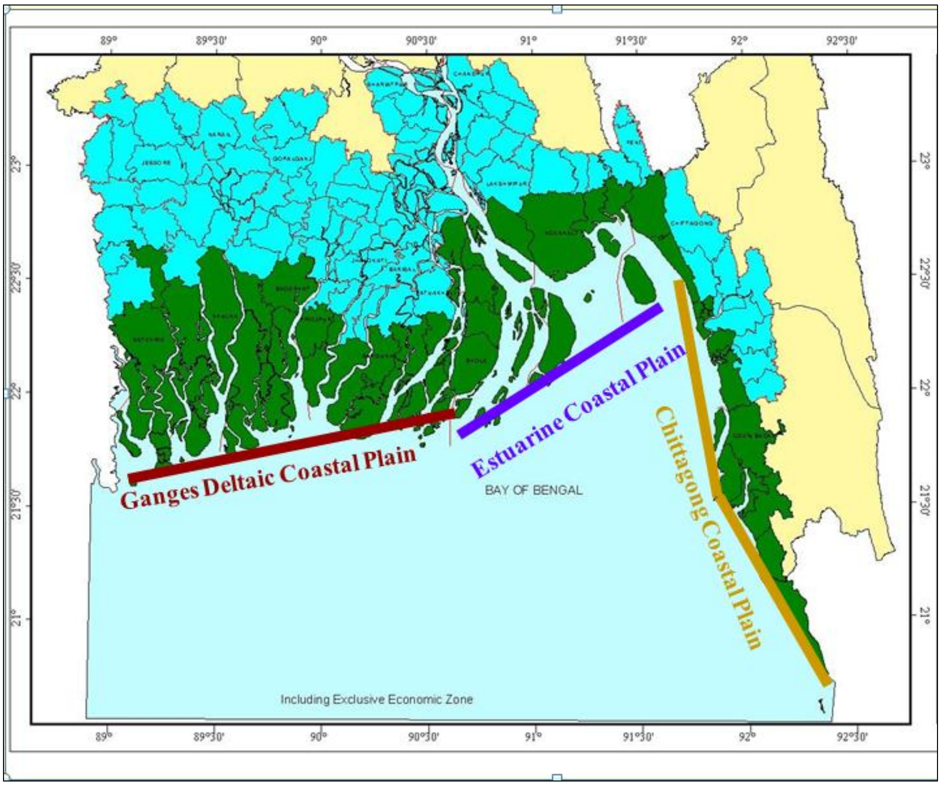


Figure 5.1: Three major units separating coastal area of Bangladesh

[Source: PDO-ICZMP]

Aquifers in the area are generally confined. At places, semi-confined conditions exist but leakage from the overlying water-bearing formations is negligible. As the study area comprises the floodplains of Chittagong coastal plain, groundwater quality is highly variable by intrusion of brackish and saline water. The ground water potentiality depends upon the development of the deeper aquifer, which is relatively unknown but there are indications that freshwater is being encountered in the deeper depth.

5.2 Hydrogeological Investigation

5.2.1 Surface Resistivity Survey

10 VES (Vertical Electrical Sounding) of Schlumberger configuration with 600 m spread were carried out at different sites of the study area (**Figure 5.2**).

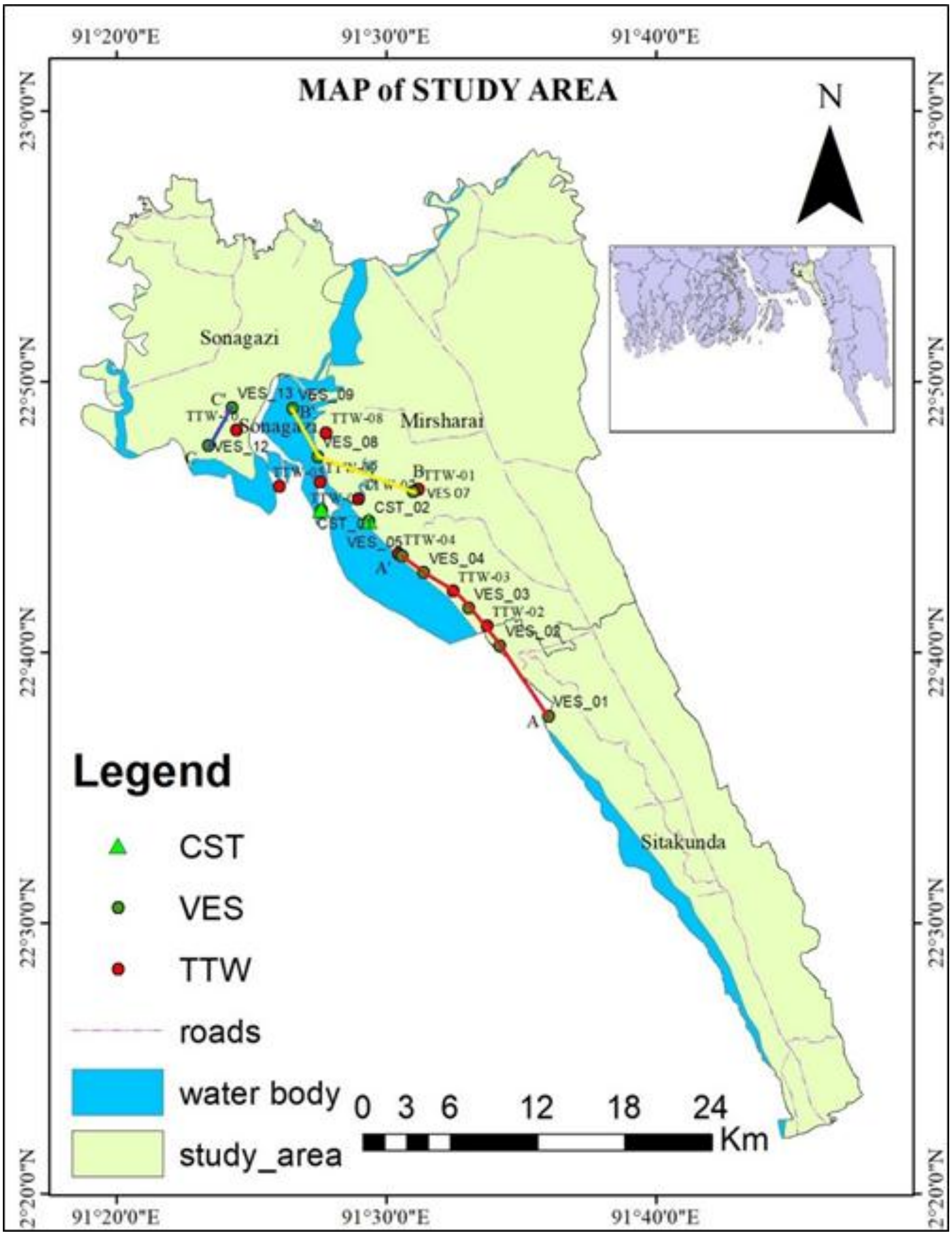


Figure 5.2: Map of the study area showing VES and CST locations and cross-sections

5.2.1.1 Geologic cross-sections of the study area

Geo-electric cross-sections have been made to delineate the aquifer system. Geo-lelectric cross section along line A-A` (**Figure 5.3**) is from south-east to north-west corner of the study area. Top layer is composed of silty clayey soil and the following layer is an Aquitard. At the south-eastern part of the study area aquitard is thick at the upper portion which is 140-150 m thick and the following layer is an aquifer. At the middle and south-eastern part of the cross section aquitard is interrupted by lens like sandy material. At the north-western part of the study area the aquitard is relatively thin and is followed by the deep aquifer. The shallower (about 50m) part of the aquifer of is brackish and the aquifer of deeper part is fresh. There is no continuation of clay layer (aquitard) separating the aquifer into isolated ones. Aquifers at different depth levels are hydraulically interconnected.

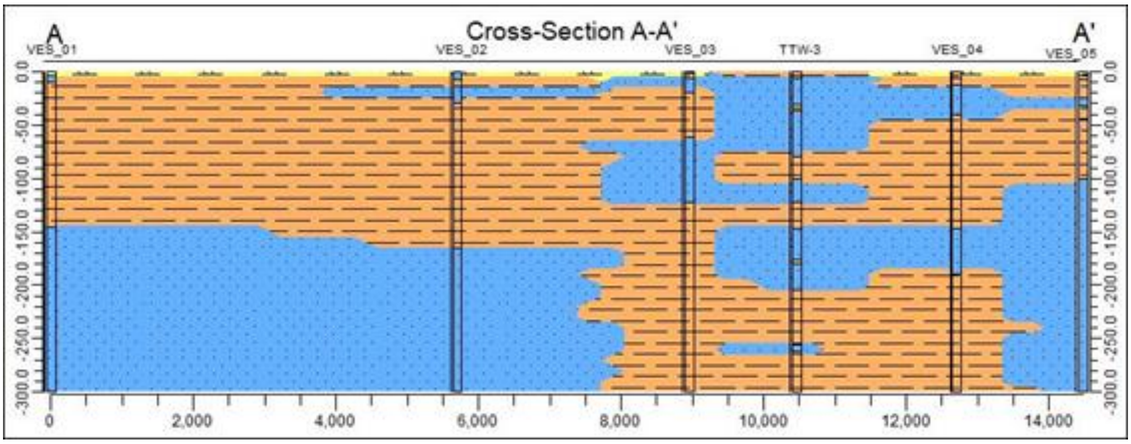


Figure 5.3: Geo-electric cross-section along line A-A` of the study area

Geolelectric cross section along line B-B` (**Figure 5.4**) is run from south-east to north-west (VES_07, VES_08 and VES_09) of the study area. Top soil is composed of clayey silt and the following layer is an Aquitard. In the left part of the cross section aquitard is not much thick and is followed by an aquifer. Below this aquifer a thick discontinuous aquitard is found at the middle part of the cross section. At the right part of the cross section at VES 9 a thick aquifer is identified below 50m. The aquifer at shallower depth (below 10m to 50m) is brackish while the deeper part is fresh. Below 150m no continuous clay layer is demarcated.

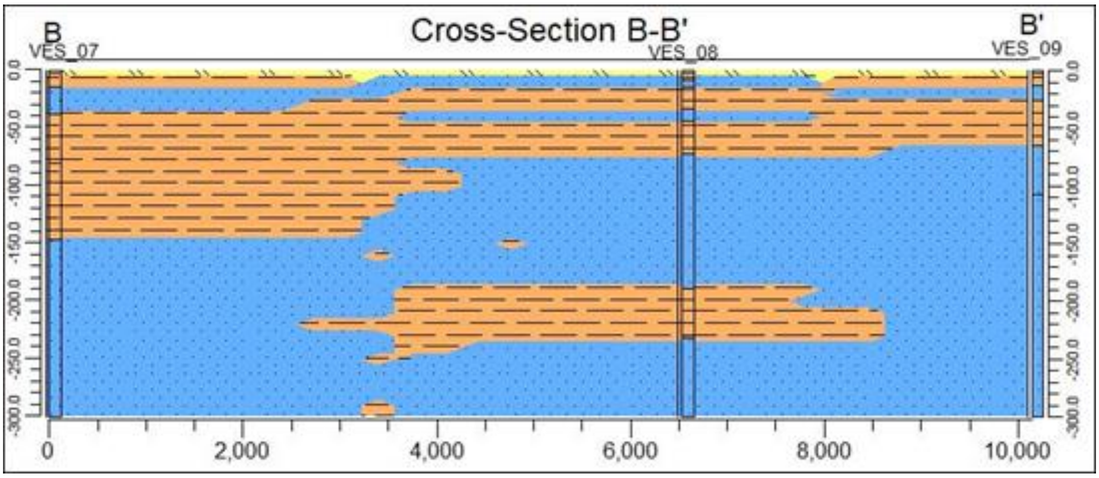


Figure 5.4: Geo-electric cross-section along line B-B` of the study area

Geo-electric cross section along line C-C` (**Figure 5.5**) is from southwest to northeast (VES_12, VES_13) corner of the study area. Surface layer is composed of silty clayey soil and is followed by a shallow (10m to 50m) brackish aquifer (low resistivity). A continuation of aquitard is found from southwest to northeast just below this shallow aquifer at depth around 50 m. This aquitard is not much thick at the shallower portion and is underlain by a deep aquifer.

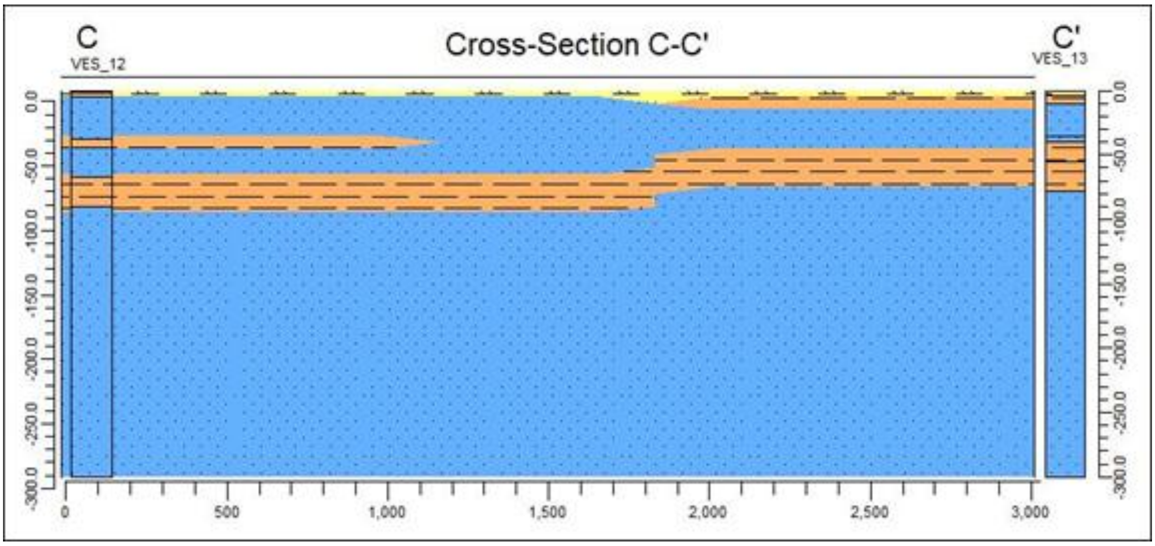


Figure 5.5: Geo-electric cross-section along line C-C` of the study area

5.2.1.2 Findings from Surface Resistivity Survey

Electrical resistivity sounding survey and existing bore hole data of the study area have been analyzed for the assessment of subsurface geological and hydrogeological conditions and ground water quality of the study area. Model parameters obtained through interpretation of the field sounding curves characterize the subsurface condition. The study area lies in the coastal area of Mirsharai Upazilla consists of shallow and deep aquifers.

The following conclusions are made considering the geology and hydrogeology of the area:

The top soil is composed by silty clay followed by a shallow aquifer showing resistivity range of 0.9 Ωm to 12 Ωm. Comparing with borelog data it is said that the shallow (10m to 121m) aquifer consists of very fine to fine sand is mainly brackish in nature.

The next geoelectric unit is aquitard which shows resistivity range of 1.24 Ωm to 17 Ωm and composed of clay or silty clay. Thickness of this unit varies from ~15m to ~100m and is highly variable.

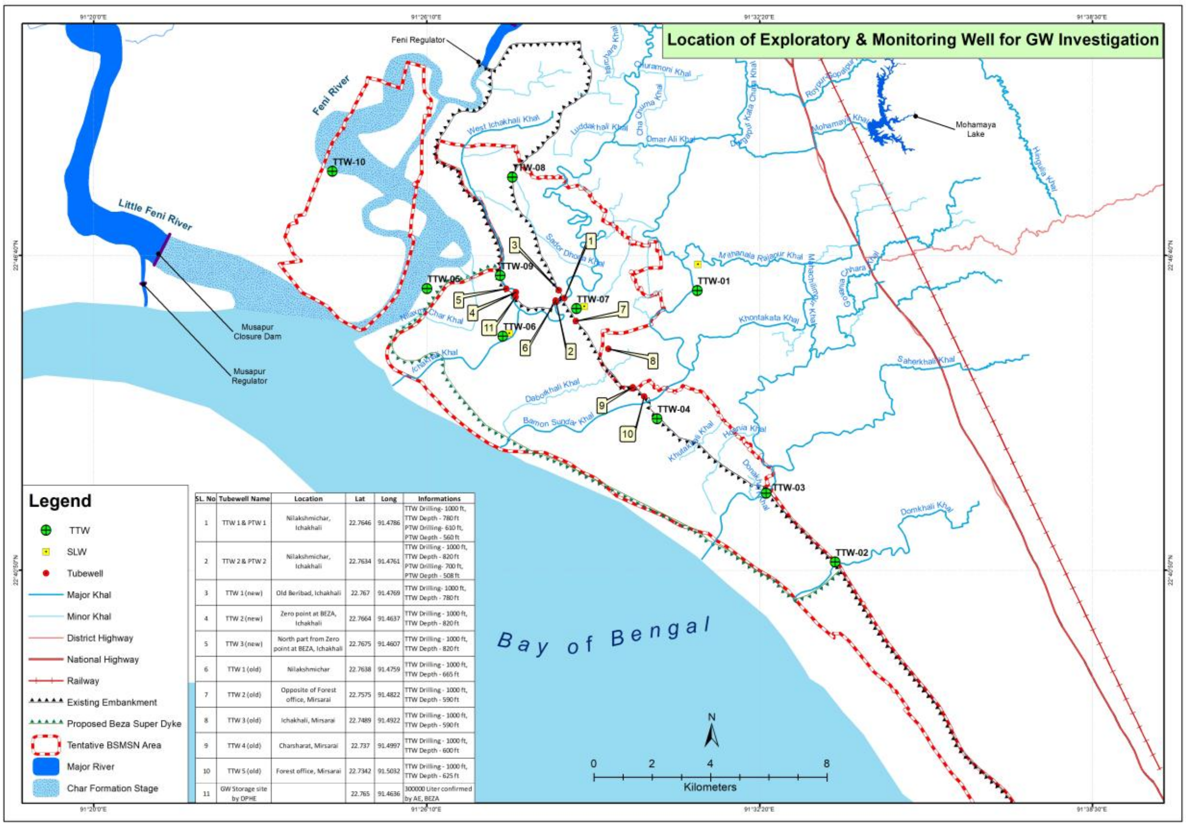
The deep aquifer shows resistivity value varying from 23 Ωm to 73 Ωm confirms the aquifer as fine to medium sand with fresh pore water. The depth to the deep aquifer varies from ~50m to ~150m and is increasing towards southeast.

It is observed that shallow or deep aquifers in the study area are interrupted by discontinuous clay deposition at multiple depth levels of different thickness.

Aquifers containing saline water show low resistivity value in the range of clay resistivity or even less and is difficult to identify lithology or pore water quality unless direct information about the texture of the formation or the water quality of the formation water is available.

5.2.2 Drilling and Installation of Test well

For further information about aquifer system of the project area 10 (Ten) exploratory drilling have been carried out in selected locations (**Figure 4.6**). The target drilling depth was about 300m comparing the secondary information and probable depth of the aquifer. Actual drilling depth and location obtained after field investigation, which is furnished in the **Table 5.1**.



SL. No	Tubewell Name	Location	Lat	Long	Informations
1	TTW 1 & PTW 1	Nilakshmichar, Ichakhali	22.7646	91.4786	TTW Drilling- 1000 ft, TTW Depth - 780 ft PTW Drilling- 610 ft, PTW Depth - 560 ft
2	TTW 2 & PTW 2	Nilakshmichar, Ichakhali	22.7634	91.4761	TTW Drilling - 1000 ft, TTW Depth - 820 ft PTW Drilling- 700 ft, PTW Depth - 508 ft
3	TTW 1 (new)	Old Beribad, Ichakhali	22.767	91.4769	TTW Drilling- 1000 ft, TTW Depth - 780 ft
4	TTW 2 (new)	Zero point at BEZA, Ichakhali	22.7664	91.4637	TTW Drilling - 1000 ft, TTW Depth - 820 ft
5	TTW 3 (new)	North part from Zero point at BEZA, Ichakhali	22.7675	91.4607	TTW Drilling - 1000 ft, TTW Depth - 820 ft
6	TTW 1 (old)	Nilakshmichar	22.7638	91.4759	TTW Drilling - 1000 ft, TTW Depth - 665 ft
7	TTW 2 (old)	Opposite of Forest office, Mirsarai	22.7575	91.4822	TTW Drilling - 1000 ft, TTW Depth - 590 ft
8	TTW 3 (old)	Ichakhali, Mirsarai	22.7489	91.4922	TTW Drilling - 1000 ft, TTW Depth - 590 ft
9	TTW 4 (old)	Charsharat, Mirsarai	22.737	91.4997	TTW Drilling - 1000 ft, TTW Depth - 600 ft
10	TTW 5 (old)	Forest office, Mirsarai	22.7342	91.5032	TTW Drilling - 1000 ft, TTW Depth - 625 ft
11	GW Storage site by DPHE		22.765	91.4636	300000 Liter confirmed by AE, BEZA

Figure 5.6: Locations of Exploratory and monitoring well locations for GW investigation

Direct circulation rotary method has used for exploratory drilling considering the sedimentary nature of the subsurface formation of the study area. Diameter of the borehole is 5 inch (127mm) up to the bottom of the borehole. In all exploratory wells 1.5inch (38.1mm) dia uPVC test wells have been installed. Drilling information such as: drilling time, lithology and cutting sediments characteristics has been recorded during drilling operation on approved form for further analysis.

5.2.3 Hydrostratigraphic Classification

For detail study of Hydrogeological parameter of the aquifer of the study area, 10 (Ten) exploratory wells have been installed on different locations. The study area is completely unknown in terms of aquifer properties to estimate the groundwater storage. To have borehole information and other aquifer properties of the subsurface, the study area is divided into four zones. These are:

- **Zone A**: The area consisting 3 exploratory well location (TTW-02, TTW-03, TTW-04)
- **Zone B**: The area consisting 3 exploratory well location (TTW-01, TTW-07, TTW-08)
- **Zone C**: The area consisting 3 exploratory well location (TTW-05, TTW-06, TTW-09)
- **Zone D**: The area consisting 1 exploratory well location (TTW-10)

Summary of the zones are given below on **(Table 5.1)** and map of the zones on study area given on **Figure 5.7**.

Table 5.1: Description of zones for ground water resource assessment

Zone	Well ID	Location		Depth (m)		Hydrostratigraphic unit	Aquifer Thickness (m)
		Lat	Long	From	To		
Zone A	**Test Well-02**	22.683	91.562	0	170.73	Aquiclude	
				170.73	**198.17**	**Aquifer**	**27.44**
				198.17	298.78	Aquiclude	
	Test Well-03	22.704	91.541	**6.1**	**60.98**	**Aquifer**	**54.88**
				60.98	79.27	Aquitard	
				79.27	100.61	Aquiclude	
				100.61	**121.95**	**Aquifer**	**21.34**
				121.95	146.34	Aquiclude	
				146.34	**176.83**	**Aquifer**	**30.49**
				176.83	179.88	Aquiclude	
				179.88	**204.27**	**Aquifer**	**24.39**
				204.27	295.73	Aquiclude	
	Test Well-04	22.727	91.507	0	24.39	Aquitard	
				24.39	**30.49**	**Aquifer**	**6.1**
				30.49	103.66	Aquitard	
				103.66	**109.76**	**Aquifer**	**6.1**
				109.76	115.85	Aquitard	
				115.85	**121.95**	**Aquifer**	**6.1**
				121.95	137.2	Aquiclude	
				137.2	**189.02**	**Aquifer**	**51.82**
				189.02	286.59	Aquiclude	
Zone B	**Test Well-07**	22.761	91.482	**6.1**	**36.59**	**Aquifer**	**30.49**
				36.59	146.34	Aquitard	
				146.34	**173.78**	**Aquifer**	**27.44**
				173.78	292.68	Aquitard	
	Test Well-08	22.801	91.462	0	30.49	Aquitard	
				30.49	**42.68**	**Aquifer**	**12.19**
				42.68	70.12	Aquitard	
				70.12	**109.76**	**Aquifer**	**39.64**
				109.76	121.95	Aquitard	
				121.95	**195.12**	**Aquifer**	**73.17**
				195.12	231.71	Aquitard	
				231.71	**256.1**	**Aquifer**	**24.39**
				256.1	304.88	Aquiclude	
	Test Well-01	22.766	91.519	**6.1**	**27.44**	**Aquifer**	**21.34**
				27.44	33.54	Aquitard	
				33.54	**60.98**	**Aquifer**	**27.44**
				60.98	70.12	Aquitard	
				70.12	109.76	Aquiclude	
				109.76	152.44	Aquitard	
				152.44	158.54	Aquiclude	
Zone C	**Test Well-05**	22.768	91.433	0	73.17	Aquitard	
				73.17	**79.27**	**Aquifer**	**6.1**
				79.27	94.51	Aquitard	
				94.51	**134.15**	**Aquifer**	**39.64**
				134.15	146.34	Aquiclude	
				146.34	**176.83**	**Aquifer**	**30.49**
				176.83	182.93	Aquiclude	

				182.93	**189.02**	**Aquifer**	**6.09**
				189.02	304.88	Aquiclude	
	Test Well-06	22.752	91.459	**9.15**	**21.34**	**Aquifer**	**12.19**
				21.34	79.27	Aquiclude	
				79.27	**91.25**	**Aquifer**	**11.98**
				91.25	106.71	Aquiclude	
				106.71	**149.39**	**Aquifer**	**42.68**
				149.39	170.73	Aquiclude	
				170.73	**207.32**	**Aquifer**	**36.59**
				207.32	304.88	Aquiclude	
	Test Well-09	22.771	91.458	3.05	6.1	Aquitard	
				6.1	**18.29**	**Aquifer**	**12.19**
				18.29	42.68	Aquitard	
				42.68	**54.88**	**Aquifer**	**12.2**
				54.88	121.95	Aquitard	
				121.95	**134.15**	**Aquifer**	**12.2**
				134.15	304.88	Aquitard	
Zone D	**Test Well-10**	22.803	91.407	**6.1**	**42.68**	**Aquifer**	**36.58**
				42.68	48.78	Aquiclude	
				48.78	**54.88**	**Aquifer**	**6.1**
				54.88	60.98	Aquiclude	
				60.98	**73.17**	**Aquifer**	**12.19**
				73.17	79.27	Aquiclude	
				79.27	**219.51**	**Aquifer**	**140.24**
				219.51	225.61	Aquiclude	
				225.61	**231.71**	**Aquifer**	**6.1**
				231.71	304.88	Aquitard	

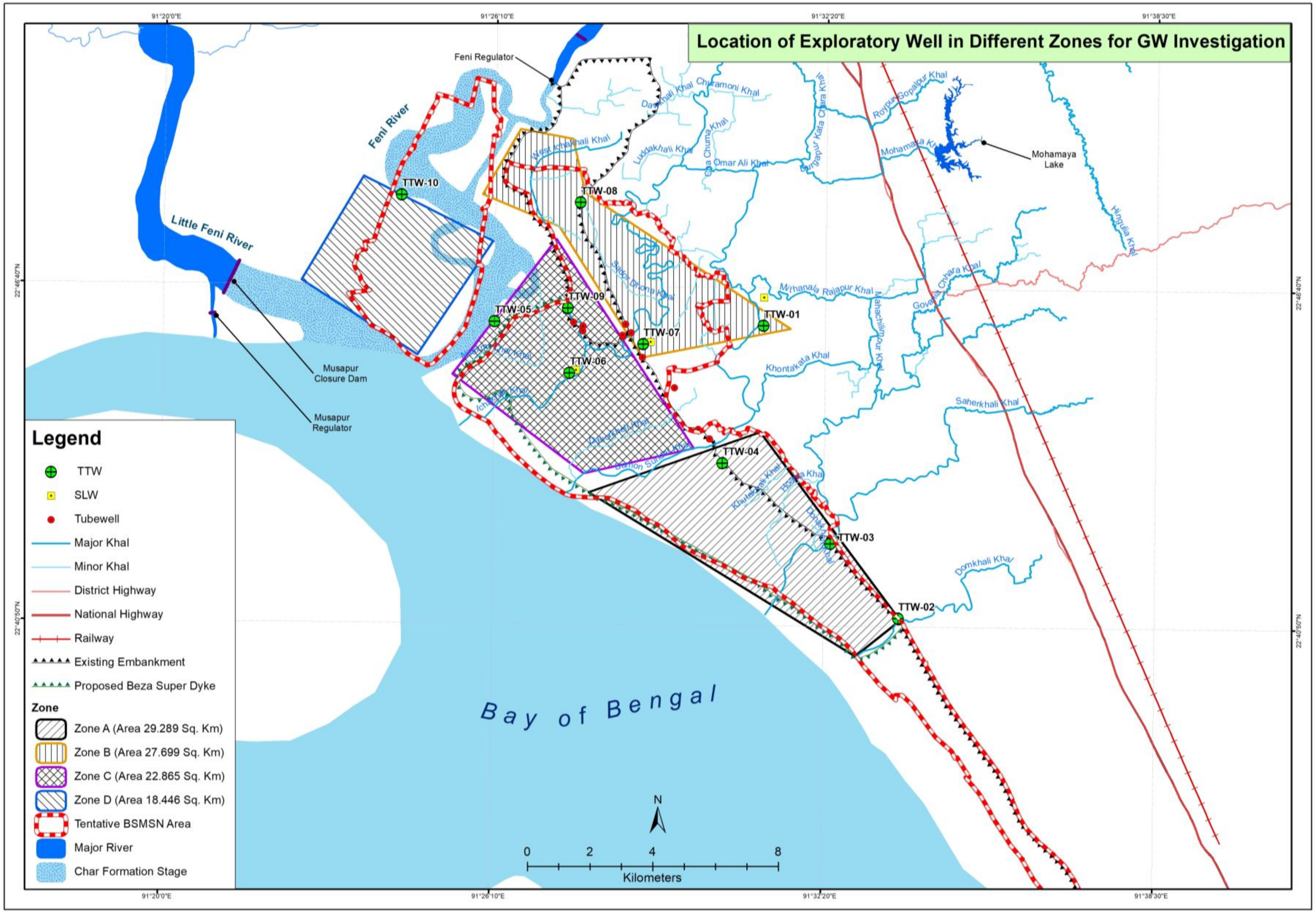
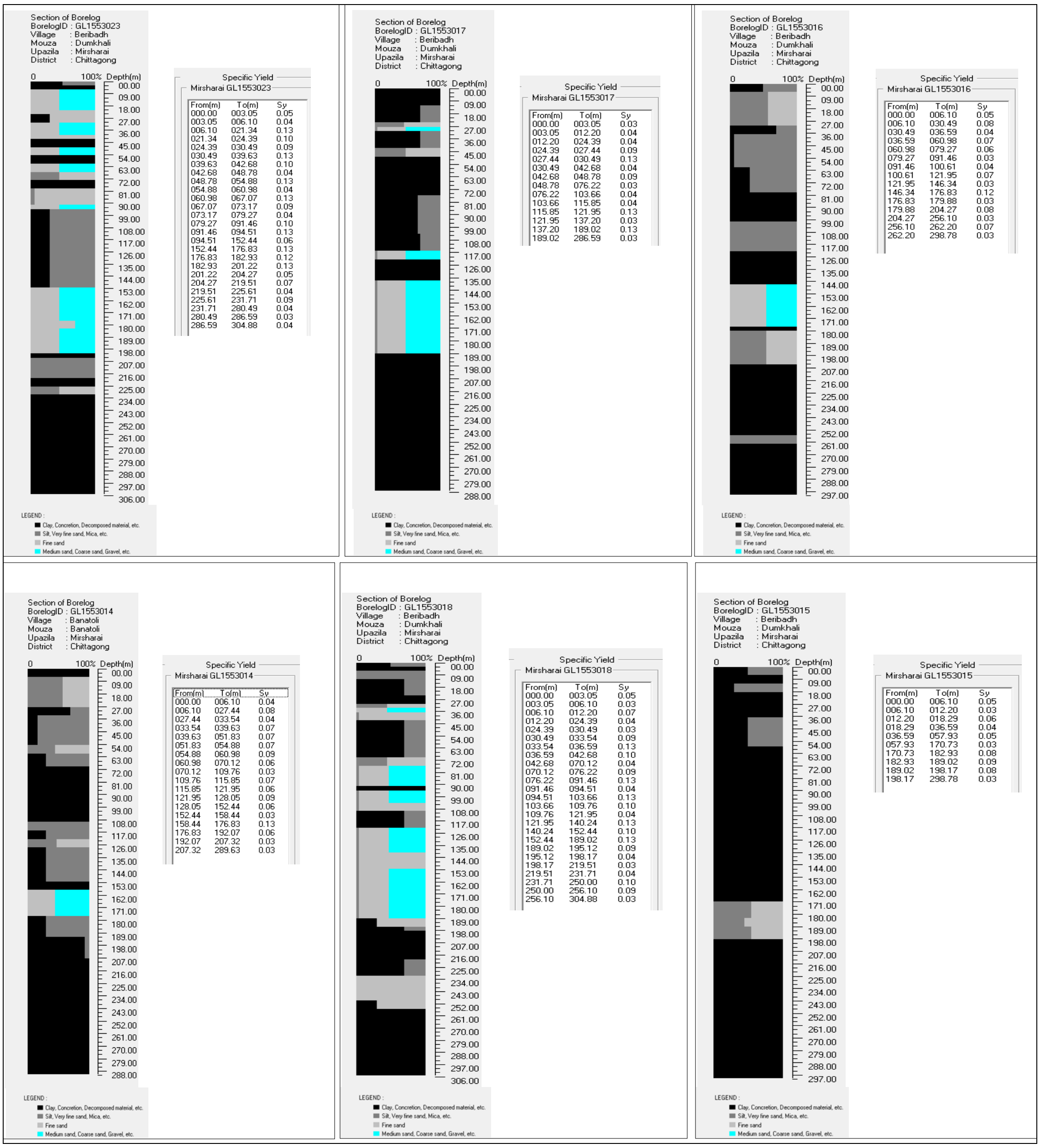


Figure 5.7: Different zones to estimate the total availability of groundwater

5.2.4 Aquifer System Delineation

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 collected sediment samples and the lithological information has been analyzed using customized computer software for constructing borelog probability **(Figure 5.8 to 5.12)** and hydrogeological cross section (**Figure 5.13 to 5.16**) and spatial distribution etc. Lithological characterization and aquifer storage volume has been estimated from such analyses. Formation permeability (K) and transmissibility (T) is determined from 10 nos. exploratory wells data.

Result of Test well-1 shows that there are three distinct aquifers; (i) 6.1 to 27.44 m (thickness 21.34m) comprising fine sand (ii) 33.54 to 60.98 m (thickness 27.44 m) comprising fine to very fine sand (iii) 158.54 to 176.83 m (thickness 18.29). The aquifer is found in a single layer at Test well-02, where it exits at 170.73 to 198.17 m (thickness 27.44m) but its grain size is coarser comparing to the Test well-01. At Test well-03 shows four aquifers with shallow one 6.1 to 60.98 m (thickness 54.88m), 2nd aquifer at 100.61 to 121.95 m (thickness 21.34m), 3rd aquifer at 146.34 to 176.83 m (thickness 30.49m) and last aquifer exits at 179.88 to 204.27 m (thickness 24.39m). Only the last aquifer is having good porous and permeable medium sand comparing to the other aquifer in shallower depth. Considering the thickness, sand quality and on field observation on water quality suggests that Test well-03 has some potentiality for good source. Test Well-4 is showing total four aquifers having three on the top (0-121.95 m). Considerable thickness found at 137.2 to 189.02m (thickness 51.82m). At Test well-05 where four aquifers are exits. But considerable thickness and grain size (i) 94.51 to 134.15 m (thickness 39.64m) and (ii) 146.34 to 176.83 m (thickness 30.49m). Two other pocket aquifers are also present around 73-79 m and 182-189m. Test Well-6 shows the aquifers at top most (i) 9.15-21.34m (thickness 12.19m), (ii) then 2nd aquifer lies in between 79.27 to 91.25m (thickness 11.98m) and (iii) 3rd one lies in between 106.71 to 149.39 m (thickness 42.68m) and (iv) fourth one lies between 170.73 to 207.32 (thickness 36.59). So, this area has that potentiality for good source. At Test well-07 has got only two water bearing sand layers (i) 6.1 to 36.59 m (thickness 30.49m) and (ii) 146.34 to 173.78 m (thickness 27.44m). At Test well-08 four individual aquifers found on different depth. (i) 30.49 to 42.68 m (thickness is 12.19m), (ii) 70.12 to 109.76 m (thickness is 39.64m), (iii) 121.95 to 195.12 m (thickness is 73.17m) and (iv) 231.71 to 256.1 m (thickness is 24.39m) these wells including TTW-06 and TTW-07 are suggested to have a closer look for good source. At TTW-09 there are three aquifers has been encountered like: (i) 6.1 to 18.29 m (thickness is 12.19m), (ii) 42.68 to 54.88 (thickness is 12.2m), (iii) 121.95 to 134.15 m (thickness is 12.2m). And final and far most from the economic zone area the Test well-10 has four water bearing layer on different depth. (i) 6.1 to 42.68 m (thickness is 36.58m), (ii) 48.78 to 54.88 m (thickness is 6.1m), (iii) 79.27 to 219.51 m (thickness is 140.24m) and (iv) 225.61 to 231.71 m (thickness is 6.1). At this location highest thickness has encountered which is 79.27 to 219.51 m (thickness is 140.24m). This area is in Feni sonagazi, so this area can be a good source. Detail is given below in **Table 5.2**.



Section of Borelog
BorelogID : GL1553023
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553023

From(m)	To(m)	Sy
000.00	003.05	0.05
003.05	006.10	0.04
006.10	021.34	0.13
021.34	024.39	0.10
024.39	030.49	0.09
030.49	039.63	0.13
039.63	042.68	0.10
042.68	048.78	0.04
048.78	054.88	0.13
054.88	060.98	0.04
060.98	067.07	0.13
067.07	073.17	0.09
073.17	079.27	0.04
079.27	091.46	0.10
091.46	094.51	0.13
094.51	152.44	0.06
152.44	176.83	0.13
176.83	182.93	0.12
182.93	201.22	0.13
201.22	204.27	0.05
204.27	219.51	0.07
219.51	225.61	0.04
225.61	231.71	0.09
231.71	280.49	0.04
280.49	286.59	0.03
286.59	304.88	0.04

Section of Borelog
BorelogID : GL1553017
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553017

From(m)	To(m)	Sy
000.00	003.05	0.03
003.05	012.20	0.04
012.20	024.39	0.04
024.39	027.44	0.09
027.44	030.49	0.13
030.49	042.68	0.04
042.68	048.78	0.09
048.78	076.22	0.03
076.22	103.66	0.04
103.66	115.85	0.04
115.85	121.95	0.13
121.95	137.20	0.03
137.20	189.02	0.13
189.02	286.59	0.03

Section of Borelog
BorelogID : GL1553016
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553016

From(m)	To(m)	Sy
000.00	006.10	0.05
006.10	030.49	0.08
030.49	036.59	0.04
036.59	060.98	0.07
060.98	079.27	0.06
079.27	091.46	0.03
091.46	100.61	0.04
100.61	121.95	0.07
121.95	146.34	0.03
146.34	176.83	0.12
176.83	179.88	0.03
179.88	204.27	0.08
204.27	256.10	0.03
256.10	262.20	0.07
262.20	298.78	0.03

Section of Borelog
BorelogID : GL1553014
Village : Banatoli
Mouza : Banatoli
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553014

From(m)	To(m)	Sy
000.00	006.10	0.04
006.10	027.44	0.08
027.44	033.54	0.04
033.54	039.63	0.07
039.63	051.83	0.07
051.83	054.88	0.07
054.88	060.98	0.09
060.98	070.12	0.06
070.12	109.76	0.03
109.76	115.85	0.07
115.85	121.95	0.06
121.95	128.05	0.09
128.05	152.44	0.06
152.44	158.44	0.03
158.44	176.83	0.13
176.83	192.07	0.06
192.07	207.32	0.03
207.32	289.63	0.03

Section of Borelog
BorelogID : GL1553018
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553018

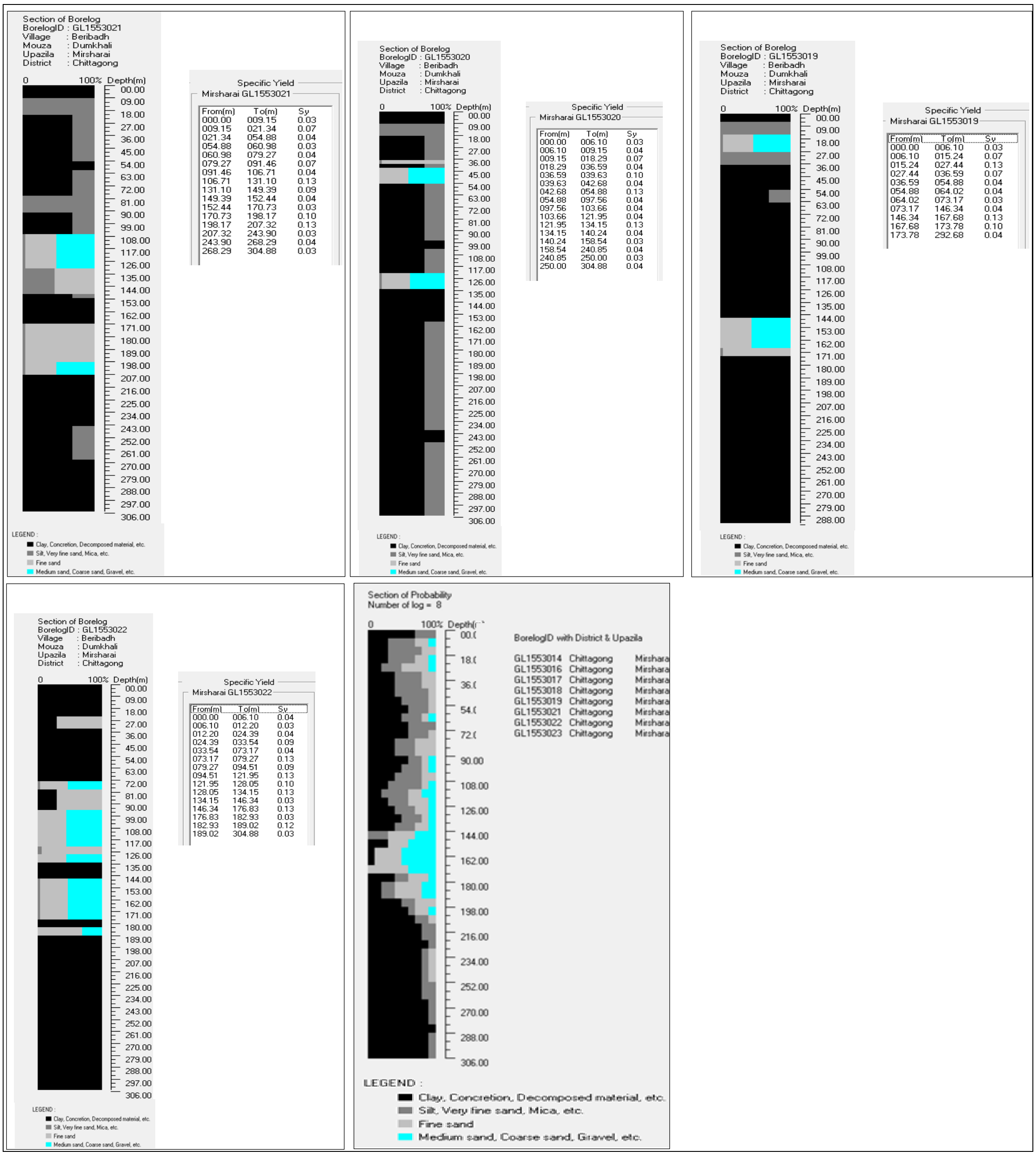
From(m)	To(m)	Sy
000.00	003.05	0.05
003.05	006.10	0.03
006.10	012.20	0.07
012.20	024.39	0.04
024.39	030.49	0.03
030.49	033.54	0.09
033.54	036.59	0.13
036.59	042.68	0.10
042.68	070.12	0.04
070.12	076.22	0.09
076.22	091.46	0.13
091.46	094.51	0.04
094.51	103.66	0.13
103.66	109.76	0.10
109.76	121.95	0.04
121.95	140.24	0.13
140.24	152.44	0.10
152.44	189.02	0.13
189.02	195.12	0.09
195.12	198.17	0.04
198.17	219.51	0.03
219.51	231.71	0.04
231.71	250.00	0.10
250.00	256.10	0.09
256.10	304.88	0.03

Section of Borelog
BorelogID : GL1553015
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553015

From(m)	To(m)	Sy
000.00	006.10	0.05
006.10	012.20	0.03
012.20	018.29	0.06
018.29	036.59	0.04
036.59	057.93	0.05
057.93	170.73	0.03
170.73	182.93	0.08
182.93	189.02	0.09
189.02	198.17	0.08
198.17	298.78	0.03

Figure 5.8: Borelog probability constructed from individual borelog section



Section of Borelog
BorelogID : GL1553021
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553021

From(m)	To(m)	Sy
000.00	009.15	0.03
009.15	021.34	0.07
021.34	054.88	0.04
054.88	060.98	0.03
060.98	079.27	0.04
079.27	091.46	0.07
091.46	106.71	0.04
106.71	131.10	0.13
131.10	149.39	0.09
149.39	152.44	0.04
152.44	170.73	0.03
170.73	198.17	0.10
198.17	207.32	0.13
207.32	243.90	0.03
243.90	268.29	0.04
268.29	304.88	0.03

Section of Borelog
BorelogID : GL1553020
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553020

From(m)	To(m)	Sy
000.00	006.10	0.03
006.10	009.15	0.04
009.15	018.29	0.07
018.29	036.59	0.04
036.59	039.63	0.10
039.63	042.68	0.04
042.68	054.88	0.13
054.88	097.56	0.04
097.56	103.66	0.04
103.66	121.95	0.04
121.95	134.15	0.13
134.15	140.24	0.04
140.24	158.54	0.03
158.54	240.85	0.04
240.85	250.00	0.03
250.00	304.88	0.04

Section of Borelog
BorelogID : GL1553019
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553019

From(m)	To(m)	Sy
000.00	006.10	0.03
006.10	015.24	0.07
015.24	027.44	0.13
027.44	036.59	0.07
036.59	054.88	0.04
054.88	064.02	0.04
064.02	073.17	0.03
073.17	146.34	0.04
146.34	167.68	0.13
167.68	173.78	0.10
173.78	292.68	0.04

Section of Borelog
BorelogID : GL1553022
Village : Beribadh
Mouza : Dumkhali
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553022

From(m)	To(m)	Sy
000.00	006.10	0.04
006.10	012.20	0.03
012.20	024.39	0.04
024.39	033.54	0.09
033.54	073.17	0.04
073.17	079.27	0.13
079.27	094.51	0.09
094.51	121.95	0.13
121.95	128.05	0.10
128.05	134.15	0.13
134.15	146.34	0.03
146.34	176.83	0.13
176.83	182.93	0.03
182.93	189.02	0.12
189.02	304.88	0.03

Section of Probability
Number of log = 8

BorelogID with District & Upazila

GL1553014	Chittagong	Mirshara
GL1553016	Chittagong	Mirshara
GL1553017	Chittagong	Mirshara
GL1553018	Chittagong	Mirshara
GL1553019	Chittagong	Mirshara
GL1553021	Chittagong	Mirshara
GL1553022	Chittagong	Mirshara
GL1553023	Chittagong	Mirshara

LEGEND :
■ Clay, Concretion, Decomposed material, etc.
■ Silt, Very fine sand, Mica, etc.
■ Fine sand
■ Medium sand, Coarse sand, Gravel, etc.

Figure 5.9: Borelog probability constructed from individual borelog section

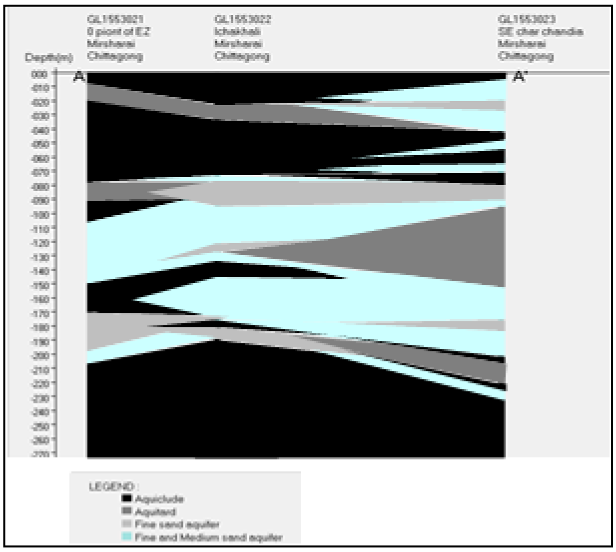


Figure 5.10: Hydrogeological cross section (A-A') for zone C

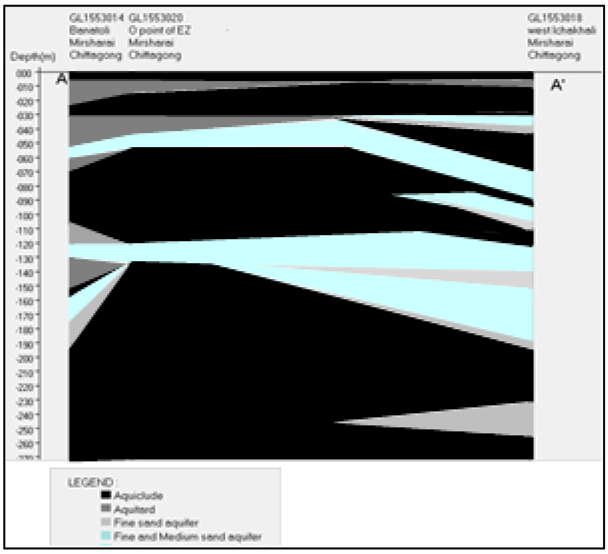


Figure 5.11: Hydrogeological cross section (A-A') for zone B

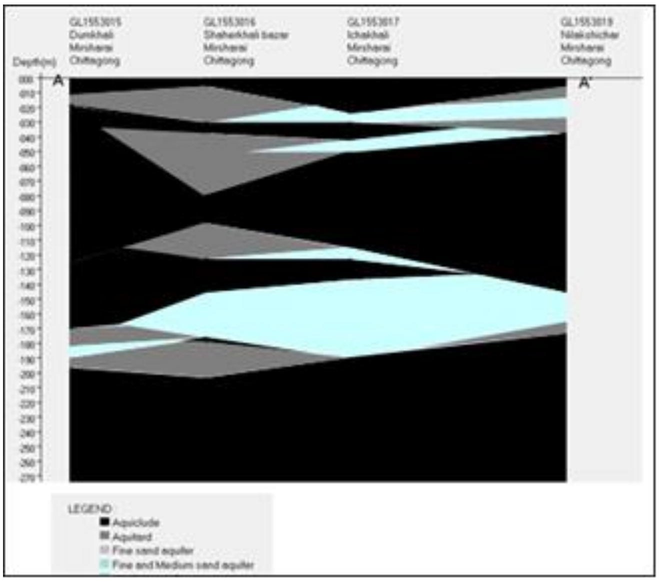


Figure 5.12: Hydrogeological cross section (A-A') for zone A

Hydrostratigraphic Columnar Section of Test Well (Zone- A)

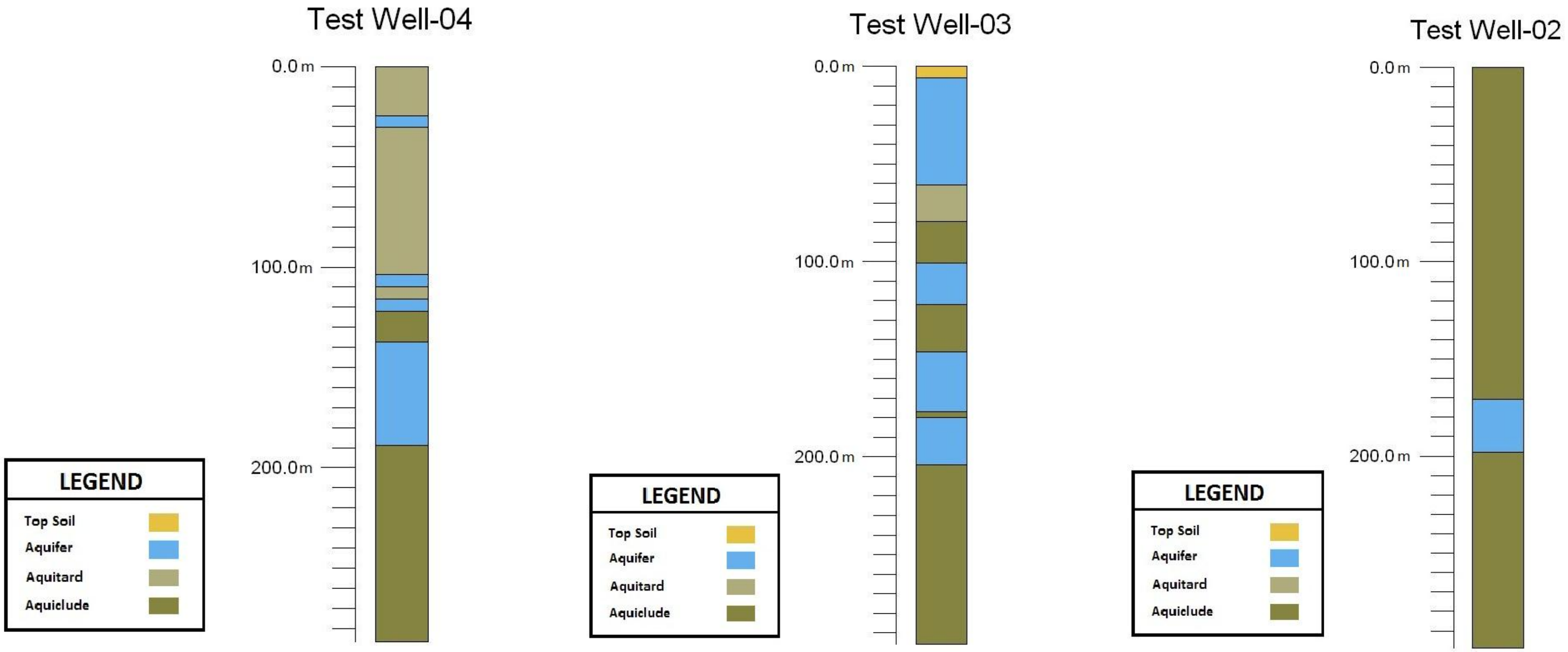


Figure 5.13: Hydrostratigraphic columnar section of the study area

Hydrostratigraphic Columnar Section of Test Well (Zone- B)

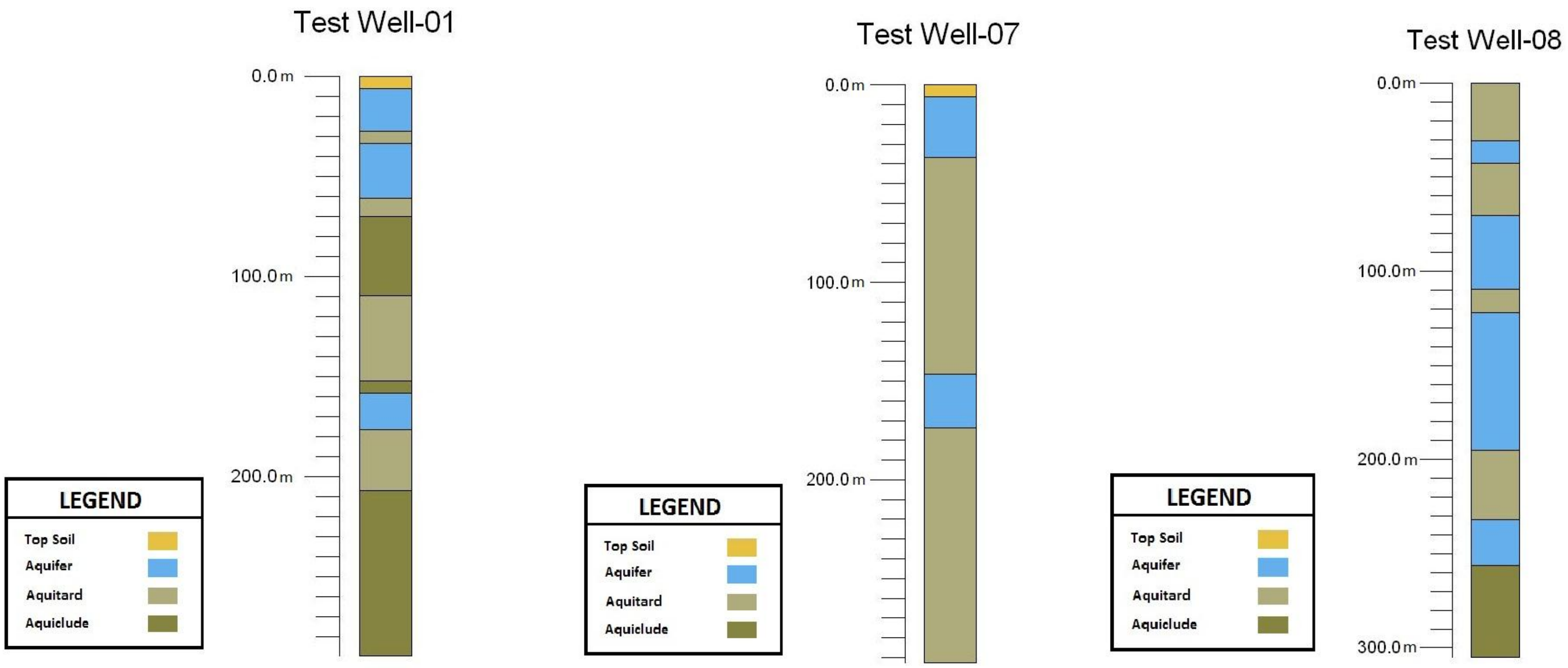


Figure 5.14: Hydrostratigraphic columnar section of the study area

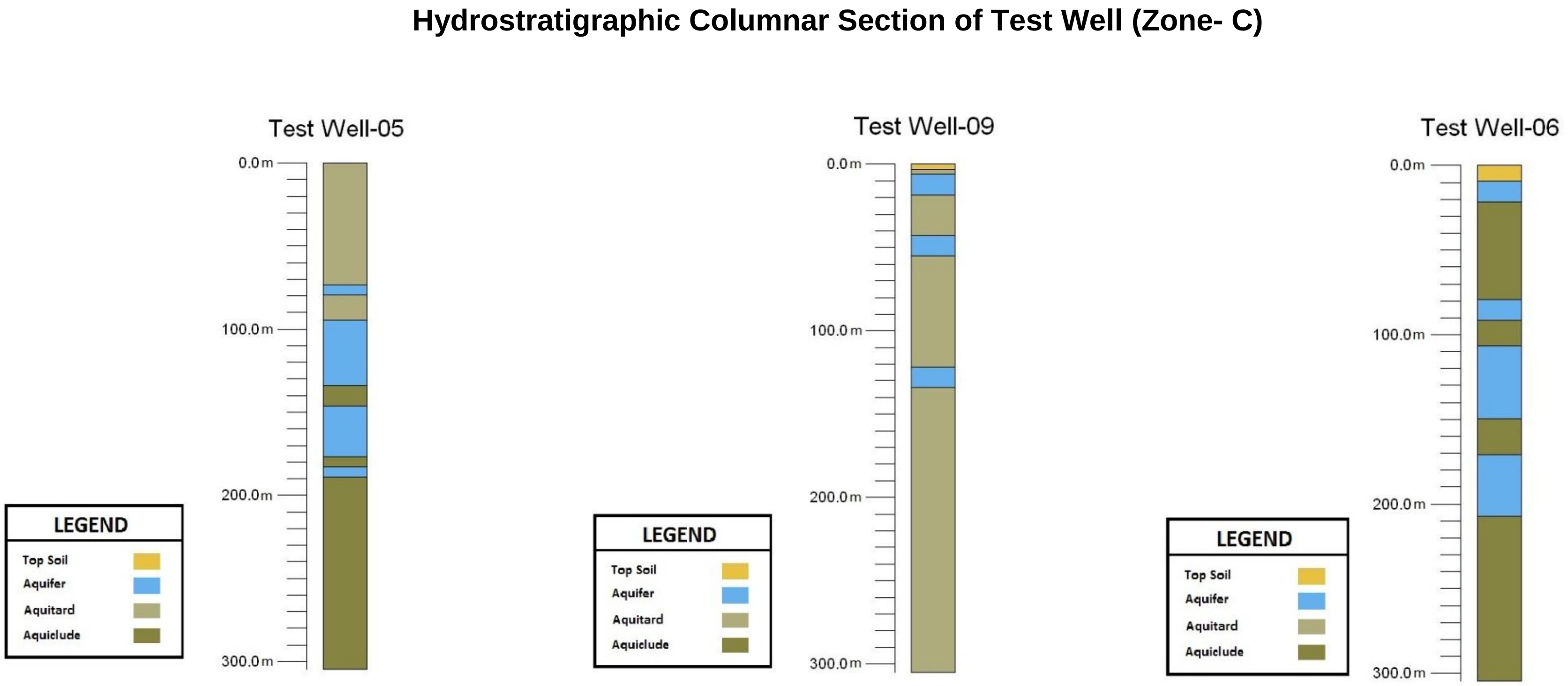


Figure 5.15: Hydrostratigraphic columnar section of the study area

Hydrostratigraphic Columnar Section of Test Well (Zone-D)

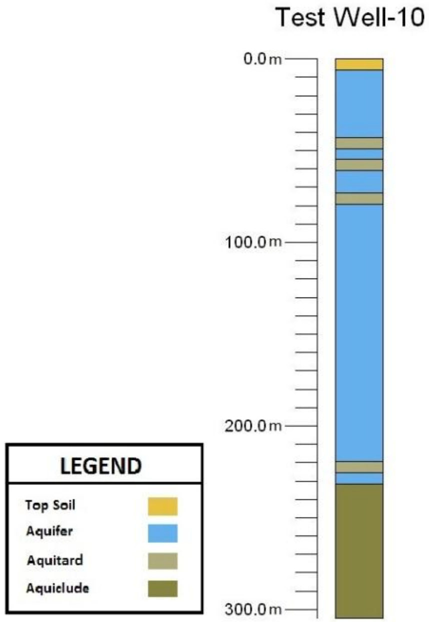


Figure 5.16: Hydrostratigraphic columnar section of the study area

5.3 Aquifer Properties Determination and Analysis

5.3.1 Production Well Construction

For groundwater situation analysis and aquifer properties determination, 1 (one) production well borehole, 8 (eight) observation well boreholes have been drilled and 2 (two) long term (72 hrs) aquifer test carried out. Soil samples were collected at every 1.52 m interval. Borelogs and production well design were prepared at site by Hydrogeologist of IWM and long term aquifer tests were carried out with the presence of respective officials of IWM and DPHE (in case of DPHE well).

5.3.1.1 Borelog Analysis and Interpretation

Depth storage relationship for the current study area has also been determined using the borelogs of exploratory wells and fed into a computer program developed by WARPO (Depth/Storage Model, Van Wonderen) for groundwater resource assessment. It may be mentioned that Depth-Storage Model has been extensively used for groundwater resources assessment under the National Water Management Plan (NWMP). During determination of the specific yield value of the granular formation of all exploratory well, borelog data has been analyzed using this customized programme and results are discussed below.

Granular Formation Evidenced in newly constructed PTW

PTW near CP More (**Figure 5.17**)at BSNSM shows that there are six distinct granular layer:

(i) 6.10 to 24.39 m (thickness 18.29m) comprising very fine to fine sand and fine to medium sand,

(ii) 39.63 to 51.83 m (thickness 12.20m) comprising very fine to fine sand and fine to medium sand little coarse sand,

(iii) 60.98 to 64.02 m (thickness 3.04) comprising of medium to coarse sand,.

(iv) 79.27 to 92.99 m (thickness 13.72m) comprising fine to medium sand,

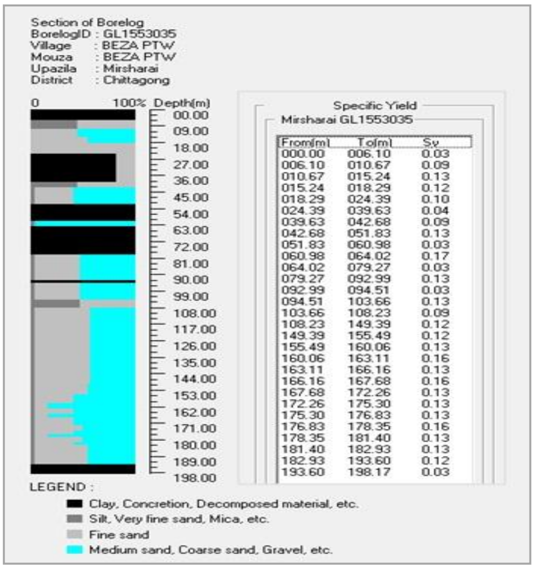
(v) 94.51 to 118.90 m (thickness 24.39 m) comprising very fine to fine and fine to medium sand and

(vi) 129.57 to 193.60 m (thickness 64.03m) comprising fine to medium sand, medium to fine sand, medium to fine sand little coarse sand, fine to medium sand little coarse sand and coarse to medium sand little fine sand and trace of mica.

Table 5.2: Aquifer thickness evidenced in borehole of PTW near CP More

Well ID	Depth (m)		Thickness (m)	Hydrostratigraphic Unit
	From	To		
BEZA-PTW (GL1553035)	0	6.1	6.10	Aquitard
	6.1	24.39	18.29	Aquifer
	24.39	39.63	15.24	Aquitard
	39.63	51.83	12.2	Aquifer
	51.83	60.98	9.15	Aquiclude
	60.98	64.02	3.04	Aquifer

Well ID	Depth (m)		Thickness (m)	Hydrostratigraphic Unit
	From	To		
	64.02	79.27	15.25	Aquiclude
	79.27	92.99	13.72	Aquifer
	92.99	94.51	1.52	Aquiclude
	94.51	118.9	24.39	Aquifer
	118.90	129.57	10.67	Aquitard
	129.57	193.60	64.03	Aquifer
	193.60	201.22	7.62	Aquiclude



Section of Borelog
BorelogID : GL1553035
Village : BEZA PTW
Mouza : BEZA PTW
Upazila : Mirsharai
District : Chittagong

Specific Yield
Mirsharai GL1553035

From(m)	To(m)	Sy
000.00	006.10	0.03
006.10	010.67	0.09
010.67	015.24	0.13
015.24	018.29	0.12
018.29	024.39	0.10
024.39	039.63	0.04
039.63	042.68	0.09
042.68	051.83	0.13
051.83	060.98	0.03
060.98	064.02	0.17
064.02	079.27	0.03
079.27	092.99	0.13
092.99	094.51	0.03
094.51	103.66	0.13
103.66	108.23	0.09
108.23	149.39	0.12
149.39	155.49	0.12
155.49	160.06	0.13
160.06	163.11	0.16
163.11	166.16	0.13
166.16	167.68	0.16
167.68	172.26	0.13
172.26	175.30	0.13
175.30	176.83	0.13
176.83	178.35	0.16
178.35	181.40	0.13
181.40	182.93	0.13
182.93	193.60	0.12
193.60	198.17	0.03

Figure 5.17: Columnar section of production well GL1553035

5.3.1.2 Geophysical Logging

Geophycial logging was carried out by RFL Plastics Limited at the newly constructed PTW near CP more. The cuttings were logged for lithology by geologist. The data analysis was concentrated on aquifer delineation and water quality determination from the conventional down-hole geophysical data.

Borehole: Newly constructed PTW near CP more, BSMSN area

Geophysical logging of the borehole was completed upto the depth of 202.12m and individual bed boundaries were identified to obtain the continuous lithology from surface up to borehole depth. Within the facities of the geophysical logger, a single log run has been done. Resistivity (SN, LN and SPR), Spontaneous Potential (SP) and natural Gamma logging has been carried out downhole automatically. The graphysical outputs were visualized on laptop computer monitor. The graphical presentation of geophisical log data is shown in **Figure 5.18**.

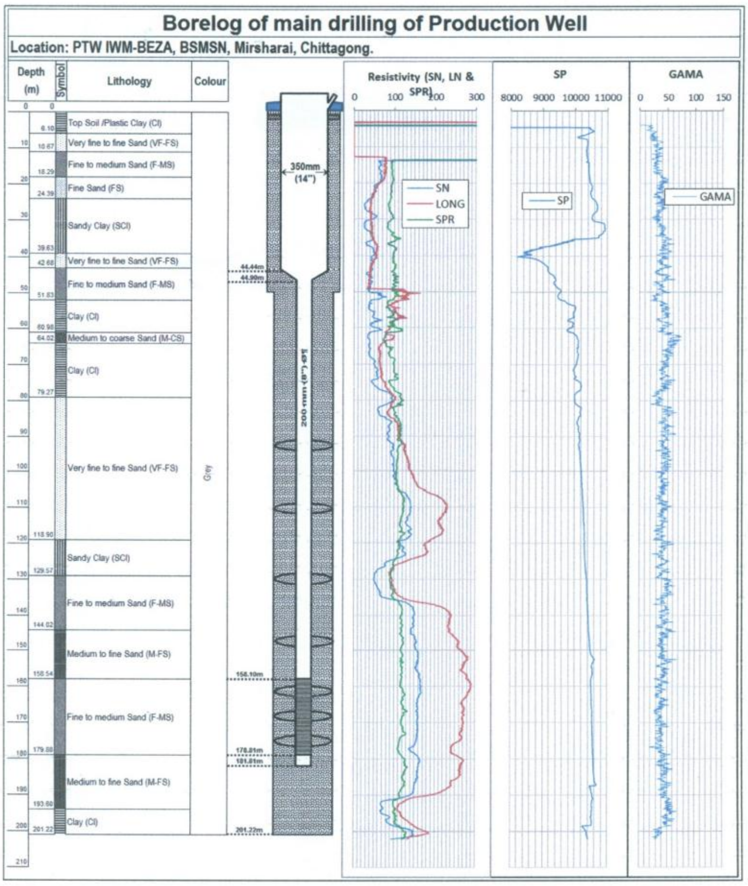
Interpretation of geophysical logging data:

The geophysical log shows mainly five distinct layer boundaries (**Table 5.3**). These layers are prominent mainly in the resistivity curves.

Table 5.3: The depth boundaries of different layers along with resistivity (LN) values

Layer #	Depth(m)	Resistivity (Ohm-m)	Lithology as indicated within logging depth boundaries	Formation boundaries	
				Depth (m)	Lithology
1	Upto 105	40-140	Alternation of finar lithology as sand-clay Inter layer	Upto 118.90	Inter layer of sand and clay,Sands are mainly fine to very fine
2	**105-124**	**140-230**	**Comparatively fine sand layer**	118.90-129.57	Sandy clay
3	124-136	90-140	Layer of silt/clay		
4	**136-190**	**140-290**	**Thick coarser sandy layer**	129.57-193.60	Fine and medium sand
5	Below 190	110-160	Silt/clay with finar sand	193.60-201.22	Clay

The resistivity curve indicates that the changes of lithology are also influenced by the electrical conductivity (EC) of formation water. The formation water against the sand layers (layer 2 and 4) indicate freshwater.The EC of groundwater at these sand layers is within 350 µS/cm.



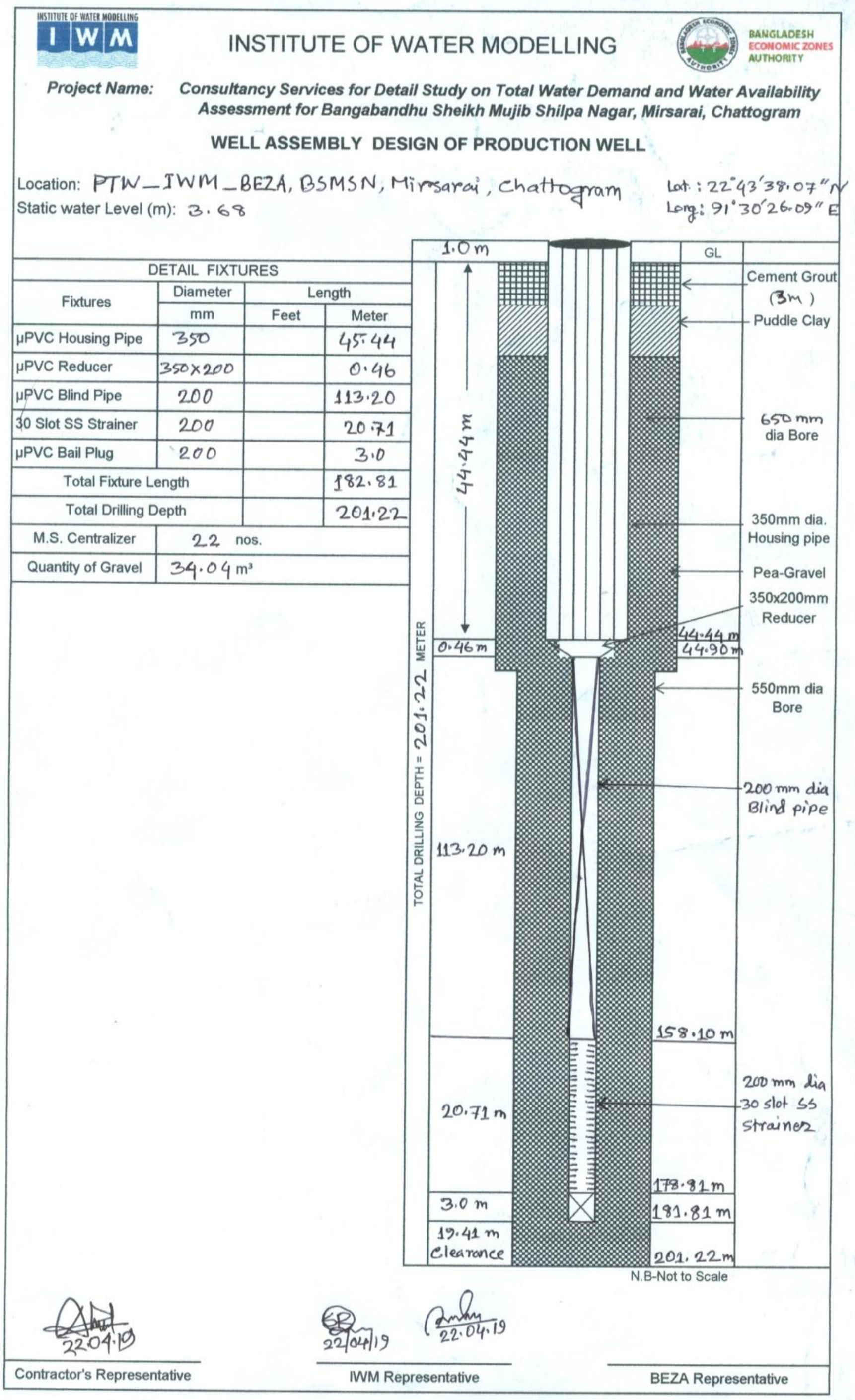
30.04.19
(আবদুন নূর)
সিনিয়র হাইড্রোজিওলজিস্ট
জনস্বাস্থ্য প্রকৌশল অধিদপ্তর
ভূঃ পাঃ তঃ ও উঃ বিভাগ, ঢাকা।

Figure 5.18: Combined Gamma, SP and Resistance logs of borehole at PTW near CP more

5.3.1.3 Production well design and installation

After completion of drilling up to required drilling depth, sieve analyses, geophysical logging and well assembly, design of newly constructed PTW was developed and approved by IWM after necessary verification and discussion. Production well was designed for obtaining 102m^3/h or 28.32 liter/sec discharge water.

Total fixture length of newly constructed PTW is 182.81 m. Well assembly design of newly constructed production well is shown in **Figure 5.19**.



INSTITUTE OF WATER MODELLING

Project Name: *Consultancy Services for Detail Study on Total Water Demand and Water Availability Assessment for Bangabandhu Sheikh Mujib Shilpa Nagar, Mirsarai, Chattogram*

WELL ASSEMBLY DESIGN OF PRODUCTION WELL

Location: PTW_IWM_BEZA, BSMSN, Mirsarai, Chattogram
Lat: 22°43′38.07″N
Static water Level (m): 3.68
Long: 91°30′26.09″E

DETAIL FIXTURES

Fixtures	Diameter	Length	
	mm	Feet	Meter
µPVC Housing Pipe	350		45.44
µPVC Reducer	350x200		0.46
µPVC Blind Pipe	200		113.20
30 Slot SS Strainer	200		20.71
µPVC Bail Plug	200		3.0
Total Fixture Length			182.81
Total Drilling Depth			201.22
M.S. Centralizer	22 nos.		
Quantity of Gravel	34.04 m³		

N.B-Not to Scale

22.04.19
Contractor's Representative

22/04/19
IWM Representative

22.04.19
BEZA Representative

Figure 5.19: Well assembly design of newly constructed PTW near CP More

After completion of fixture lowering, required quantity of gravel were sorted and shrouding of 34.04 m^3 of gravel was completed by the supervision of the consultant. After that the constructed well was washed for 10 hours at a constant discharge rate by air compressor with 200 psi pressure.

For well development dispersant agent Sodium Hexa-meta-phosphate (Calgon) was used for easy removing of clayey materials from the drilling fluid used and to destroy the iron bacteria developed during well construction. Dispersant agent- solution has been used before water jetting development start. Development by high velocity water jetting was carried using freshwater for 72 hours with 750 psi pressure horizontally from four opposite nozzles with 100m per second velocity.

5.3.1.4 Step Drawdown test and data analyses

The performance of installed production well was assessed by carrying out step drawdown test at four variable rates (0.75, 1.00, 1.25 and 1.50 cusec) of pumping for 2.0 hours at each stage at newly constructed PTW site on 19 May 2019. Data recoded during step drawdown test are presented in **Figure 5.20**. Result of analysis for installed production well is given in **Table 5.4**.

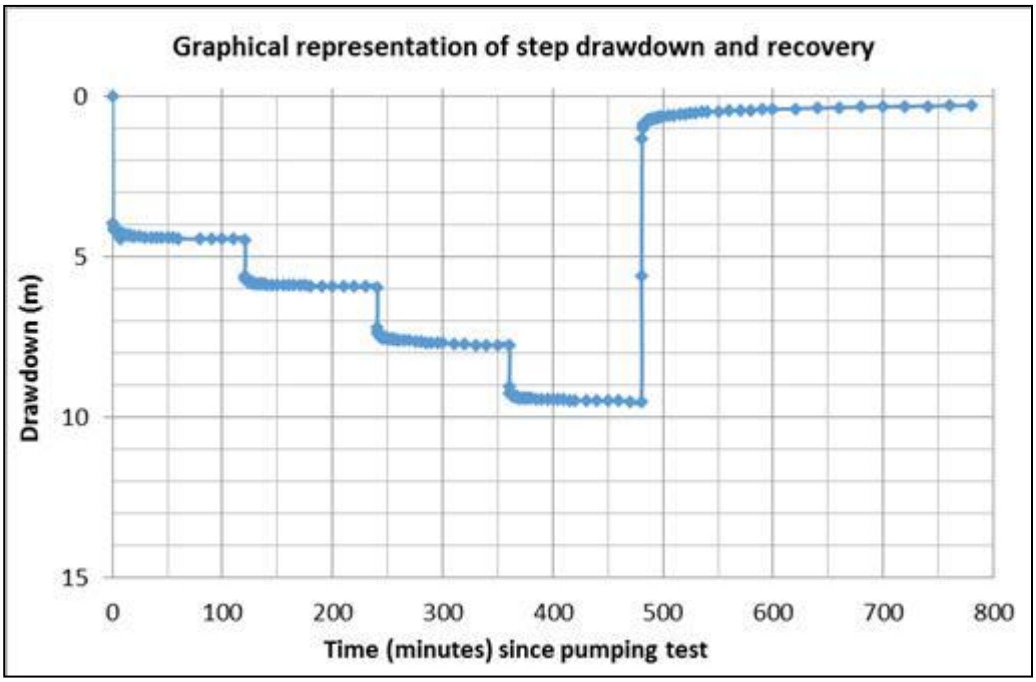


Figure 5.20: Graphical representation of step drawdown test and recovery data of PTW near CP More

The step drawdown tests were performed in the installed production tube well on 19 May 2019 to determine the well performance versus yield relationship.

Table 5.4: Step Drawdown Test result analysis of PTW near CP More

Steps	Manometer Reading (m)	Yield			SWL (m)	PWL (m)	Drawdown (m)	Sp. Capacity (L/Sec)/m)	Sp. Drawdown (min/m²)
		Cusec	L/Sec	m³/min					
1	0.203	0.75	21.24	1.27	4.71	9.16	4.45	4.77	3.50

Steps	Manometer Reading (m)	Yield			SWL (m)	PWL (m)	Drawdown (m)	Sp. Capacity (L/Sec)/m)	Sp. Drawdown (min/m²)
		Cusec	L/Sec	m³/min					
2	**0.330**	**1.00**	**28.32**	**1.70**		**10.64**	**5.93**	4.78	3.49
3	0.508	1.25	35.40	2.12		12.46	7.75	4.57	3.66
4	0.711	1.50	42.48	2.55		14.21	9.50	4.47	3.73

The plot of specific drawdown (Sw) versus discharge (Q) determines B & C values. Evaluation of C gives the well loss while B gives the aquifer loss and together is the total draw down. **Figure 5.21** is also prepared for calculating the well loss and aquifer loss of the PTW. The test results of installed PTW reveal that is 90.33% aquifer loss and 9.67 % well loss with 97.17 % recovery within five hours of time.

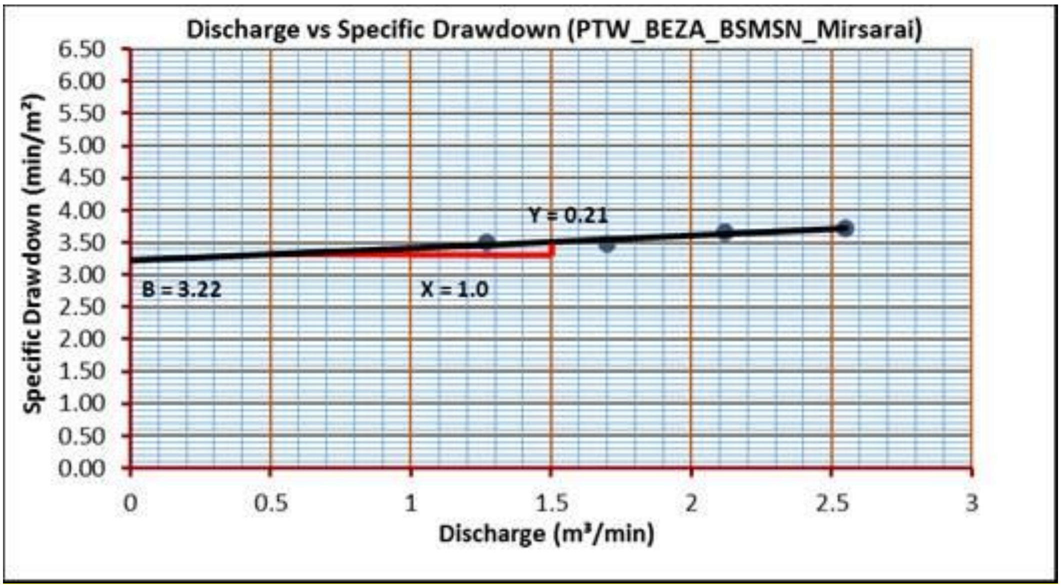


Figure 5.21: Graph for computing well loss and aquifer loss

Calculation of well loss and aquifer loss at installed PTW

From Figure 5.21,

Y = 0.21 min/m²

X = 1.00 m³/min

Co-efficient of well loss = C = Tan θ = Tan(Y/X) = 0.2027 min²/m⁵

Co-efficient of aquifer loss = B = 3.22 min/m³

Equation used are,

Drawdown or Total Loss, $S = BQ + CQ^2$

Well Loss, $CQ^2 = CQ^2/S \times 100\%$

Aquifer Loss, $BQ = BQ/S \times 100\%$

When, Discharge, Q = 28.32 liter/sec

= 1.70 m^3/min

$S = BQ + CQ^2$

= 5.47 m + 0.59 m

= 6.06 m

Well Loss, $CQ^2 = (CQ^2/S) \times 100$ %

= 9.67 %

Aquifer Loss, $BQ = (BQ/S) \times 100$ %

= 90.33 %

Specific Capacity, = Discharge/Drawdown (lt/sec)/m

= 4.78 (lt/sec)/m

5.3.1.5 Determination of Specific capacity

The specific capacity data was measured from water levels and pumping rate during the step drawdown test. The specific capacity is a measure of the capacity of a wells effectiveness per unit drawdown; i.e. Q/Sw. **Table 5.4** shows the step drawdown data with specific capacity. The specific capacity decreases with increase in Q and time, because the draw down continually increases with time as the cone of influence of the well expands.

The specific capacity analysis data shows that the installed production well is efficient enough for discharging 102 m^3/h or 28.32 lt/sec at a maximum drawdown of 5.93 m and the specific capacity is found 4.78 lt/sec/m which states that the effectiveness of the well is high and performed for a long time with its designed discharge.

By analyzing the drawdown data with IWM customized software, it is observed that well loss constant, C_w is 9.6677914E-08 and formation loss constant, C_f is 0.00221473. Consideration of the well loss of the tube well and observed drawdown indicates that the design of the well is adequate. It is also observed that slight increment of discharge results in large drawdown. Well loss of this production well calculated by IWM customized software is 9.65% (**Figure 5.22**) which is nearly same by manually calculated result.

A discharge drawdown curve is also given here in **Figure 5.23** which shows drawdown due to well loss, Drawdown due to formation loss and Total drawdown. For optimum design of the supply well, the well loss, also the formation loss of the screened aquifer should be considered. Maximum drawdown of the pumping well in steady condition and drawdown measured from the Discharge drawdown curve of step drawdown test are almost same which indicate that the design of the well is adequate.

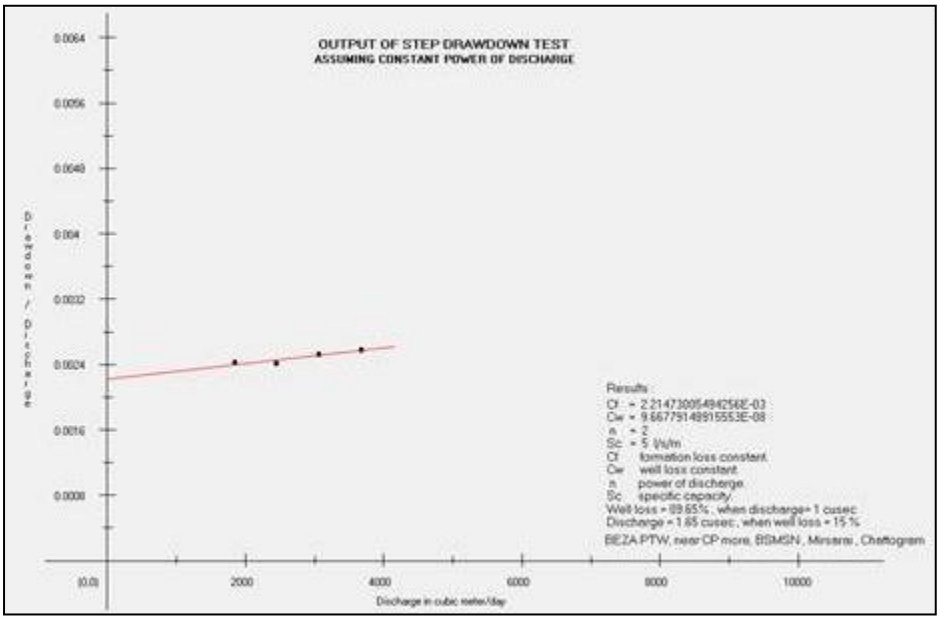


Figure 5.22: Step Drawdown test data analyzed by IWM customized software

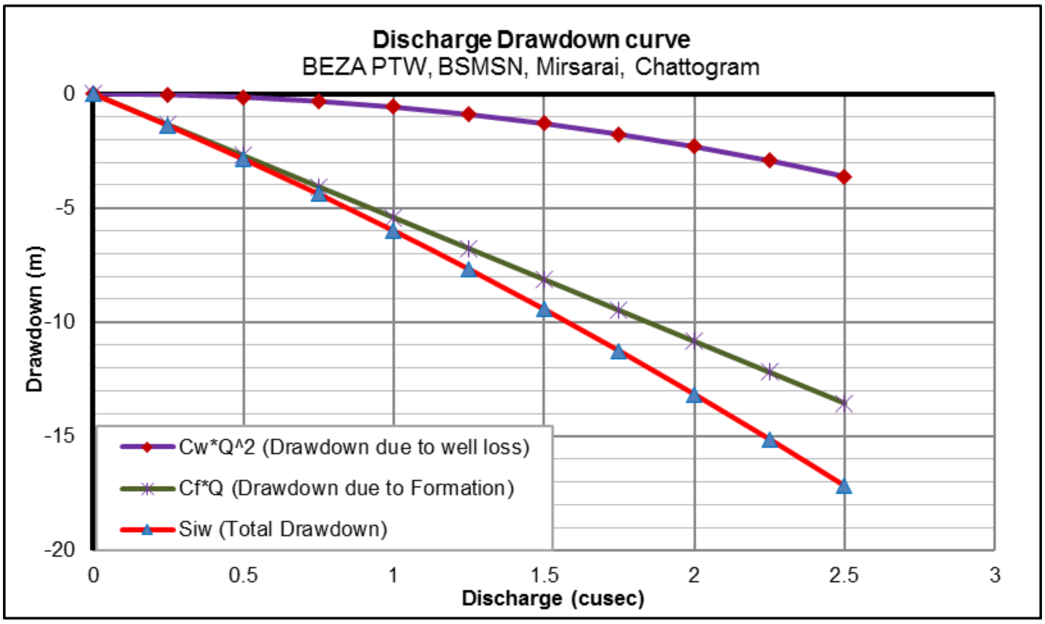


Figure 5.23: Relation between Discharge and Drawdown

5.3.2 Layout Design

For groundwater analysis, soil condition and aquifer properties, 8 (eight) observation well (**Figure 5.24 and Figure 5.25)** boreholes were drilled and 2 (two) long term (72 hrs) aquifer test were carried out in the project area. Soil samples were collected at every 1.52 m interval in the boreholes. Borelogs and production well design were prepared at site by Hydrogeologist of IWM.

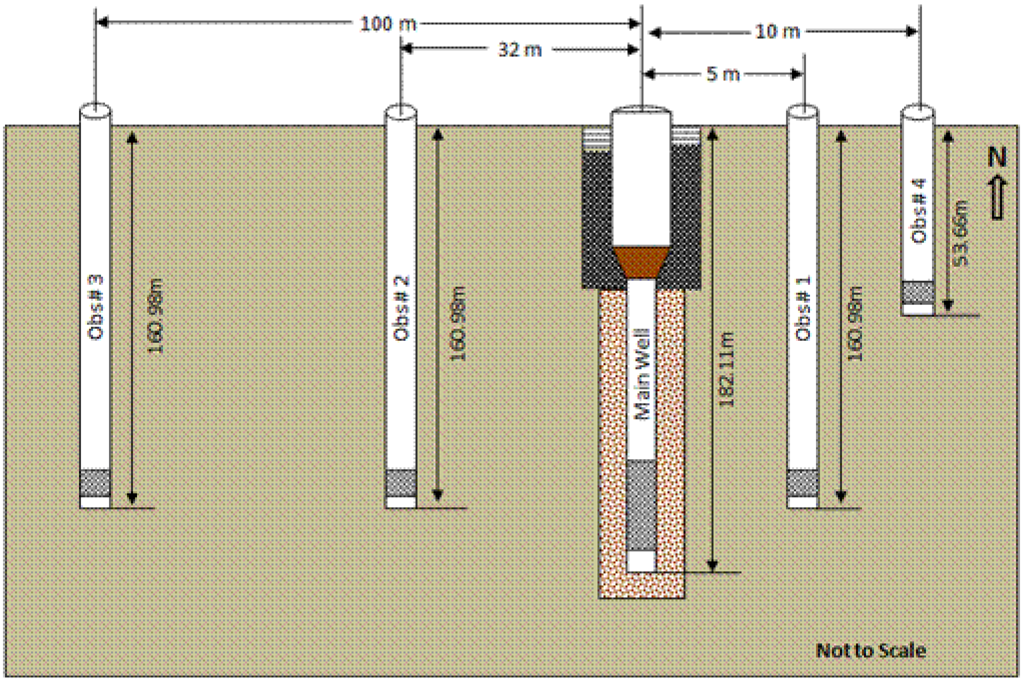


Figure 5.24: Layout plan of pumping well and observation well screens at DPHE PTW site

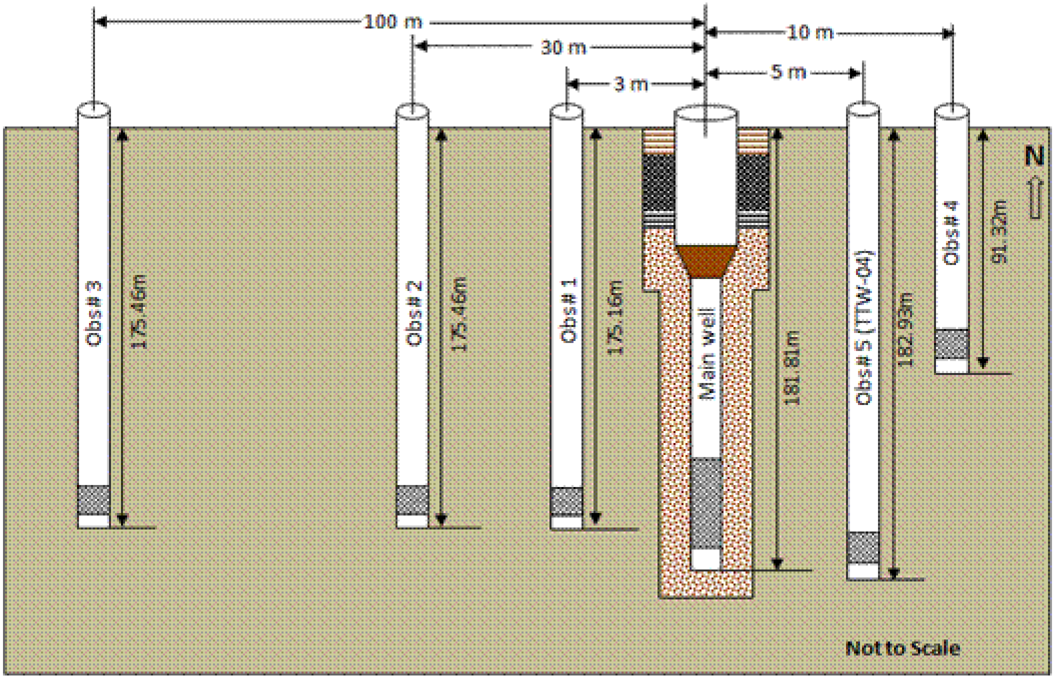


Figure 5.25: Layout plan of pumping well and observation well at PTW site near CP More

5.3.3 Long Term Aquifer Test

Aquifer test was conducted after completion of long-term aquifer test and analyses to determine the performance of the well and hydraulic parameters of the aquifer. From the aquifer test data, the principal factors of aquifer performance e.g. Transmissivity (T) and Storage coefficient (S) can be calculated.

Constant head pumping test at both newly constructed PTW and DPHE constructed PTW were carried out at the rate of 102 m^3/hr or 28.32 liter/sec of pumping for 72 hours. The static water level before the test, pumping rate, dynamic groundwater levels at various interval, water levels just after the pump was stopped (recovery data) were measured during the pumping. Water levels were measured both manually and by automatic data logger.

The long duration aquifer test was done 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. Time series water quality was monitored during the 72-hour test to determine if higher concentration of ions could be captured by the well during the test. Observation and interpretation of aquifer test data analyses by the IWM customized software is presented below.

The prime information about aquifer test at newly constructed PTW and DPHE constructed PTW is given in **Table 5.5**.

Table 5.5: Well information

Well information	Newly constructed PTW	DPHE constructed PTW
Production well depth	181.81 m	182.11 m
Aquifer thickness	64.03 m	54.88 m
Aquifer materials	Fine to medium little Coarse sand	Medium to fine sand and medium sand
Screen position of main well	158.10 to 178.81 m	148.58 to 179.07 m
Screen length	20.71 m	30 m
Screen diameter	200 mm	200 mm
Percent of aquifer thickness screened	32%	55%
Screen slot size	0.76 mm	0.76 mm
Open area of screen	22 %	22 %
Depth of observation well no.1	175.16 m	160.98 m
Depth of observation well no.2	175.46 m	160.98 m
Depth of observation well no.3	175.46 m	160.98 m
Depth of observation well no.4	91.32 m	53.66 m
Depth of observation well no.5	170 m	-
Distance of obs. well no. 1, 2, 3, 4 and 5 from pumping well.	3 m, 30 m, 100 m, 10 m and 5 m respectively.	5 m, 32 m, 100 m and 10 m respectively.

5.3.3.1 Response of Groundwater Level

Response in the Pumping Well

The water level in the pumping well declined abruptly during the first 36 hours (2040 minutes) of pumping, then stabilized at about 13.69 m in case of DPHE PTW (**Figure 5.26**). The water level in the pumping well declined abruptly during the first 24 hours (1440 minutes) and then stabilized at about 9.45 m in case of PTW near CP More (**Figure 5.27**). The pumping phase of the aquifer test was closed after 4320 minutes (72 hours), and recovery data was collected for 1440 minutes (24 hrs) after the end of the test.

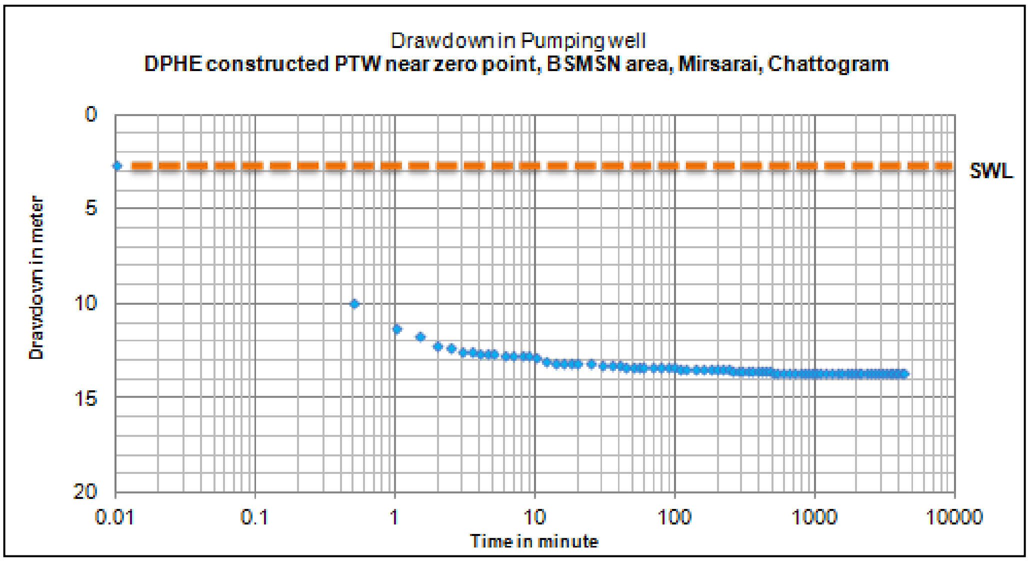


Figure 5.26: Drawdown in pumping well at DPHE constructed PTW

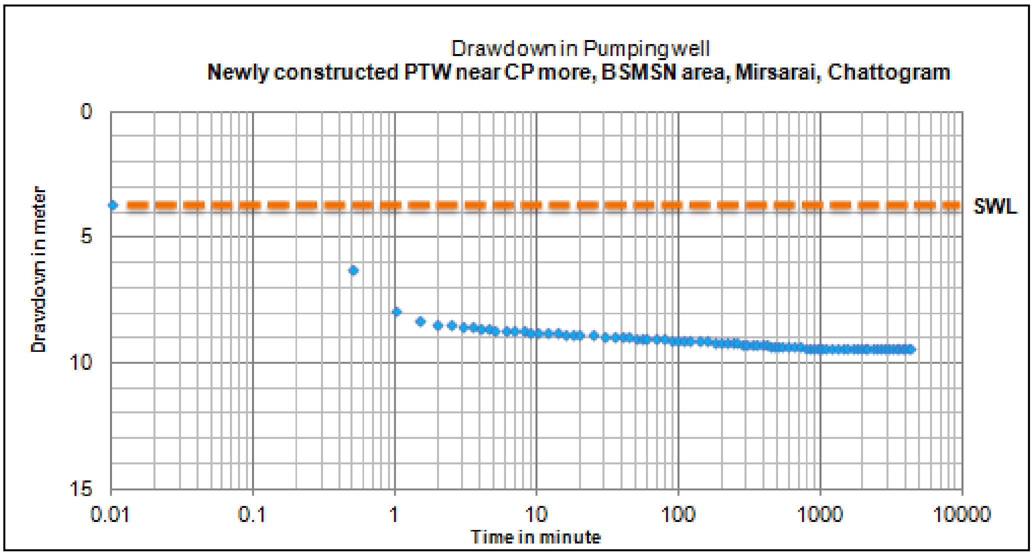


Figure 5.27: Drawdown in pumping well at newly constructed PTW

Response in Shallow Observation Wells

One observation well (Obs. Well - 04) was placed in shallow aquifer at both two sites. No water level changes in the wells were observed during pumping in the deep aquifer. This indicates that there exist a confining layer between the deep (pumped) aquifer and shallow depth layer and therefore not hydraulically connected.

Response in Deep Observation Wells

At DPHE PTW site, groundwater levels in the deep aquifer observation wells 1, 2 and 3 (5 m, 32 m and 100 m respectively from the pumping well) declined by about 2.32 m, 1.4 m and 1.01 m respectively in response to pumping.

At PTW near CP More, groundwater levels in the deep aquifer observation wells 1, 2 and 3 (3m, 30m and 100m respectively from pumping well) declined by about 1.62 m, 1.16m and 0.97 m respectively in response to pumping.

Water level in pumping well and observation wells rose rapidly at the end of the aquifer test during recovery, faster initially, but very slowly with time to reach pre-test water level.

5.3.4 Analysis of Aquifer Properties

The aquifer test data of both production wells were analyzed by IWM customized software using different methods, namely: Jacob's method, Walton's method, Chow's method and Theis's recovery method. Storage coefficient (S), Transmissivity (T), Hydraulic resistance (C), Leakage factor (L) and Permeability estimated from the analysis are given in **Table 5.6**.

Table 5.6: Summaries of aquifer properties from different methods

Method	Well Type	Transmissivity, T (m^2/day)	Storage Co-efficient, S /Specific Yield, Sy	Hydraulic Resistance, C (days)	Leakage Factor L (m)	Average Storage Co-efficient, S /Specific Yield, Sy	Average Transmissivity, T (m^2/day)	Permeability (K) (m/day) approx.
DPHE PTW (GA1553001)								
Theis Recovery	Main Well	1238	--	--	--	0.000175514	1282	23
Jacob	Obs#1	1320	0.00001553	--	--			
Theis Recovery	Obs#1	1211	--	--	--			
Jacob	Obs#2	1306	0.00021269	--	--			
Walton	Obs#2	1312	0.0001618	1951.22	1600			
Chow's	Obs#2	1313	0.00020508	--	--			
Theis Recovery	Obs#2	1218	--	--	--			
Jacob	Obs#3	1381	0.00028247	--	--			
Theis Recovery	Obs#3	1238	--	--	--			
BEZA PTW (GA1553002)								
Theis Recovery	Main Well	1325	--	--	--	0.0016872	1333	20
Jacob	Obs#1	1310	0.00461005	--	--			
Theis Recovery	Obs#1	1324	--	--	--			
Jacob	Obs#2	1357	0.00107563	--	--			
Theis Recovery	Obs#2	1376	--	--	--			
Walton	Obs#2	1324	0.0012507	1699.4	1500			
Chow's	Obs#2	1365	0.0010649	--	--			
Jacob	Obs#3	1375	0.00043717	--	--			
Theis Recovery	Obs#3	1290	--	--	--			
Jacob	Obs#5	1352	0.00168475	--	--			
Theis Recovery	Obs#5	1269	--	--	--			

5.3.4.1 Aquifer Properties

At DPHE PTW, average transmissivity is found to be around 1282 m^2/day and which indicates that the aquifer is suitable for groundwater development. The average storage coefficient is found to be around 0.000175514, which indicate that the aquifer is confined in nature.

At BEZA PTW, average transmissivity is found to be around 1333 m^2/day and which indicates that the aquifer is suitable for groundwater development. The average storage coefficient is found to be around 0.0016872 which indicates that the aquifer is semi confined in nature.

5.3.4.2 Area of Influence

The area of influence of pumping has been determined as observed in the well nos. 1, 2 and 3. The observed area of influence-at DPHE well and near CP More well is approximately 285 m (935 ft) (**Figure 5.28**) and 405 m (1328 ft) surrounding the pump (**Figure 5.29**) respectively.

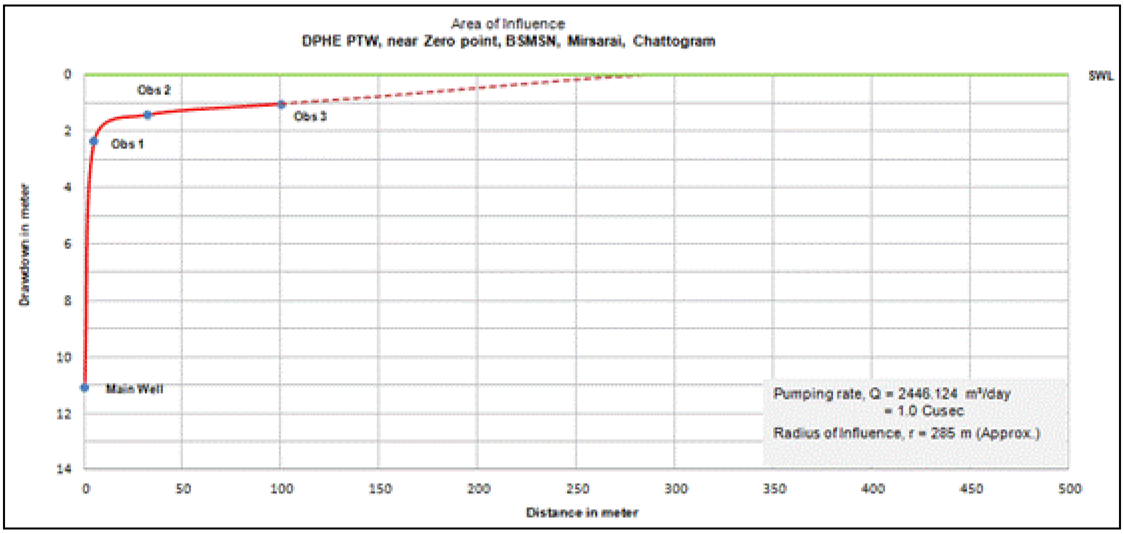


Figure 5.28: Area of influence due to pumping at DPHE PTW

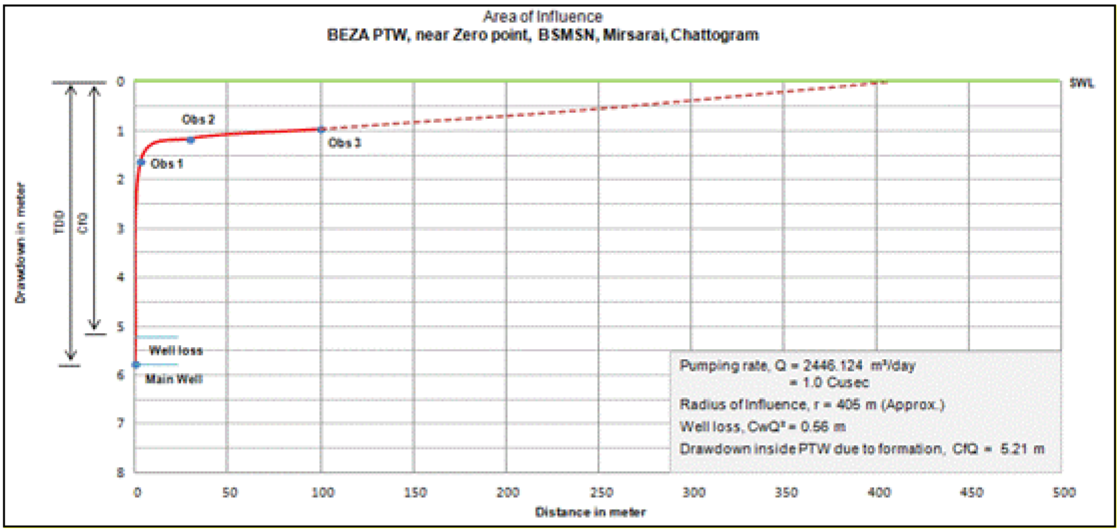


Figure 5.29: Area of influence due to pumping at BEZA PTW

5.3.5 Water Quality Survey

5.3.5.1 Exploratory Wells Water Quality Test

Groundwater sampling of eleven existing exploratory wells and two DPHE exploratory wells (**Figure 5.30**) both In-situ test and laboratory analysis were carried out to monitor water quality.

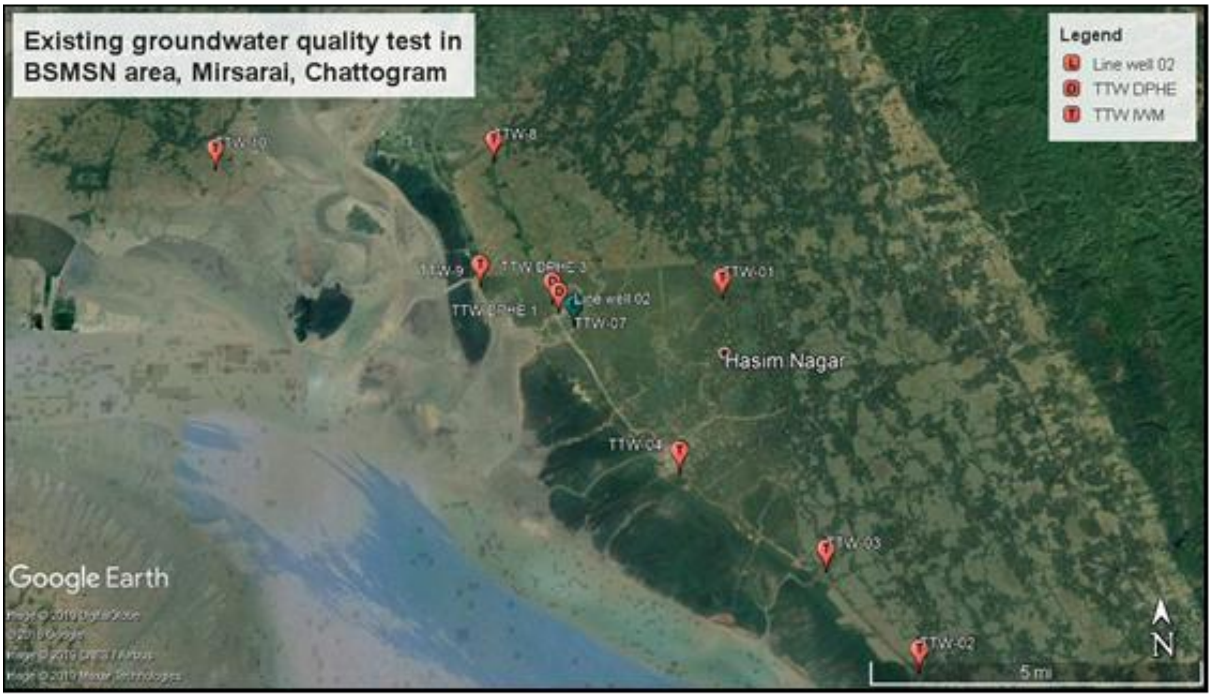


Figure 5.30: Location of existing groundwater quality monitoring wells

In situ Test Result Analysis

In situ water quality test was carried out during filed visit and the test results are given in **Table 5.7**. The following observations are found:

- Electrical conductivity (EC) at TTW-02, Line well - 2, TTW-08, TTW-09 and TTW-DPHE-01 wells show higher values than the allowable limit of Bangladesh standard.
- Total dissolve solids (TDS) at Line well - 2, TTW-08, TTW-09 and TTW-DPHE-01 wells show higher values than the allowable limit of Bangladesh standard.
- Concentration of Iron (Fe) was found higher than Bangladesh standard in all the wells except TTW-04 and TTW-10.
- Arsenic is found within allowable limit of Bangladesh standard except Line well-2.
- Manganese is found within allowable limit of Bangladesh standard except TTW-08 and Line well-2.
- Temperature and pH are found within allowable limit of Bangladesh standard.

Table 5.7: In-situ test results of different wells

Well ID	Location	Latitude (N)	Longitude (E)	Well Depth (m)	Fe (mg/l)	As (mg/l)	Mn (mg/l)	EC (µS/cm)	TDS (mg/l)	pH	Temp. (°C)
Bangladesh Standard					*0.3-1.0*	*0.05*	*0.10*	*600-1000*	**1000**	*6.5-8.5*	**20-30**
TTW-01	Banatoli	22.7669	91.5197	179.73	6.0	0.01	Nil	755.0	339.0	7.4	29.5
TTW-02	Dhumkhali	22.6829	91.5622	192.07	1.5	Nil	Nil	1590.0	732.0	7.53	29.4
TTW-03	Shaherkhali	22.7048	91.5416	176.78	2.5	Nil	Nil	892.0	404.0	7.76	29.2
TTW-04	Near CP Moor	23.7273	91.5073	182.93	0.5	Nil	Nil	702.0	307.0	8.11	28.3
TTW-07	South Ichakhali	22.7615	91.4823	170.08	1.5	Nil	Nil	642.0	281.0	7.84	30.0
TTW-08	Chunimidhir Tek	22.8019	91.4625	185.97	>7.0	0.01	0.40	3550.0	1566.0	7.06	29.8
TTW-09	NW Side of Cyclone Center, near zero point	22.7715	91.4589	134.19	3.5	Nil	Nil	2470.0	1127.0	7.48	30.2
TTW-10	**South Char Chandia, Sonagazi, Feni**	22.8014	91.3909	213.41	1.0	Nil	Nil	689	290	7.52	29.7
Line well -2	South Ichakhali	22.7614	91.4823	39.53	7.0	0.15	0.20	9590.0	4650.0	7.63	30.1
TTW-DPHE-01	Ichakhali	22.7646	91.4786	237.80	3.0	0.01	Nil	2350.0	1076.0	7.47	30.0
TTW-DPHE-03	Near PTW-03_DPHE	22.7672	91.4768	237.80	2.0	Nil	Nil	706.0	297.0	7.59	29.6

Laboratory Test Result Analysis

Great variation in water quality has been ~~is~~ observed in the analysis of periodic sampling (**Table 5.8**) collected from same depth, except well-2 (from the first sampling to the second one).

Summary comments on the water quality analysis:

Arsenic concentration:

- Concentration of arsenic of all the exploratory wells is within allowable limit of Bangladesh except Line Well-2 which is 0.17mg/l.
- In the 1st cycle (on June 2018) of sampling the concentrations are between 0.001 mg/l to 0.003 mg/l.
- In the 2nd cycle (on June 2019) the concentration varies between 0.004 mg/l to 0.018 mg/l.

Iron concentration:

Iron concentration data of 1st cycle of 8 (eight out of ten) exploratory wells were found within Bangladesh drinking water standard which ranges from 0.1mg/l to 0.85 mg/l except test wells TTW-07 and TTW-08.

Iron concentration data of 6 exploratory well in the 2nd cycle shows much higher concentration than the previous year, ranging between 2 mg/l to 19.60 mg/l. Iron concentration of TTW-08 was 8.4 mg/l in the previous year and present concentration is 19.60 mg/l). In case of TTW-01 Iron concentration was 0.85 mg/l but present year shows 9.00 mg/l. Other 4 exploratory wells (TTW-02, TTW-03, TTW-09 and TTW-10) show similar difference. The concentration of iron in 2 DPHE wells (TTW-DPHE-01 and TTW-DPHE-03) also show similar differences.

Manganese concentration:

Manganese concentration varied between 0.007 mg/l to 0.187 mg/l of 1st cycle (10 wells concentration are within Bangladesh drinking water standard) in 12 wells. The concentration in 10 wells (other three wells have no data) varied between 0.024 mg/l to 0.450 mg/l of 2nd cycle (4 wells concentration are within Bangladesh standard).

Chloride concentration:

Concentration of chloride were found within Bangladesh standard in all 12 wells (1 well no data) of 1st cycle. But 2nd cycle data shows that in TTW-08 and Line well-2 chloride concentration are higher than Bangladesh standard (other 8 wells are within Bangladesh drinking water standard).

Sodium concentration:

Concentration of sodium in 3 wells were higher than Bangladesh standard out of 10 wells in 2018, but only 1 well (TTW-10) contains allowable limit of sodium concentration in 2019. Since quality varies with time monitoring of groundwater quality need to be continued.

These variations might be due to accumulation of iron for about 1 year in unused wells.

Table 5.8: Periodic water quality laboratory analysis of different wells

Well ID	Location		Well Depth (m)	HCO_3 (mg/l)		Na (mg/l)		Cl (mg/l)		As (mg/l)		Fe (mg/l)		Mn (mg/l)	
				Previous	Current	Previous	Current	Previous	Current	Previous	Current	Previous	Current	Previous	Current
Bangladesh Standard for Drinking Water ECR97				--	--	**200**	**200**	**150-600**	**150-600**	**0.05**	**0.05**	**0.3-1.0**	**0.3-1.0**	**0.10**	**0.10**
WHO Guideline Value 2004				--	--	**200**	**200**	**250**	**251**	**0.01**	**0.01**	**0.30**	**1.30**	**0.40**	**0.40**
TTW-01	22.767	91.520	179.73	407.5	421.80	157	356.00	15	11	0.002	0.018	0.85	9.00	0.007	0.090
TTW-02	22.683	91.562	192.07	426	453.20	262	360.00	300	11	0.001	0.006	0.1	2.80	0.01	0.114
TTW-03	22.704	91.541	176.78	407.3	417.20	163	259.00	42	250	0.001	0.010	0.1	3.60	0.007	0.140
TTW-04	22.727	91.507	182.93	389	391.20	189	231.00	19	50	0.003	0.004	0.45	0.16	0.008	0.024
TTW-05	22.769	91.434	173.73	265.3		66.5		132.5		<MDL		0.35		0.013	
TTW-06	22.753	91.460	204.22	226.4		122		500		0.001		0.62		0.018	
TTW-07	22.761	91.482	170.08	290.5		51		25		0.001		**1.5**		0.015	
TTW-08	22.802	91.463	185.97	145	141.40	260	360.20	112.5	1200	0.002	0.015	**8.4**	19.60	0.187	0.450
TTW-09	22.771	91.459	134.19	254	237.00	142.2	337.40	570	430	0.001	0.007	0.9	4.80	0.036	0.170
TTW-10	22.804	91.407	195.12	231	308.00	**256**	78.40	95	66	0.001	0.006	0.1	2.00	0.02	0.045
Line well 2	22.761	91.482	39.53		141.4		1720		3500		0.17		7.5		0.228
TTW-DPHE-01	22.765	91.479	237.8		272.2		205	44	590	0.006	0.018	2.38	3.8	0.13	0.14
TTW-DPHE-03	22.767	91.477	237.8		269.3		290	47	55	0.002	0.004	1.79	1.8	0.08	0.041

5.3.5.2 Time Series Water Quality Test

5 (Five) groundwater samples were collected from both the pumping wells of DPHE constructed PTW and newly constructed PTW while aquifer tests were running, for time series analysis at site and in the laboratory.

In situ Time Series Water Quality Analysis

In situ quality test was done by using field kits after 1 hr, 5 hr, 24hr, 48hr and 72hr (before just end of the test) during aquifer test for both the production wells as shown in **Table 5.8**. Main objective of sampling and quality test is to detect the change of water quality with time. Time series quality test reflects changing water quality as water is drawn from distance by the pump.

Table 5.9: In-situ water quality test results during long term aquifer test

Well ID	**Date**	**Time**	**Parameter**						
			Fe (mg/l)	**Mn (mg/l)**	**As (mg/l)**	**pH**	**Temp. (^{0}C)**	**EC (µS/cm)**	**TDS (mg/l)**
Analytical method			***Field Kits***			***Multi-parameter***			
Bangladesh Standard			***0.3-1.0***	***0.1***	***0.05***	***6.5-8.5***	***20-30***	***600-1000***	***1000***
DPHE Constructed PTW	11.05.2019	1 hr	3.5	Nil	Nil	7.06	30.9	2360	1031
	11.05.2019	5 hr	3.5	Nil	Nil	7.66	30.4	2260	987
	12.05.2019	24 hr	3.5	Nil	Nil	6.88	30.8	2330	1058
	13.05.2019	48 hr	3.5	Nil	Nil	7.01	30.2	2310	1022
	14.05.2019	72 hr	3.5	Nil	Nil	7.01	30.5	2240	1014
Newly Constructed PTW	22.05.2019	1 hr	0.5	Nil	Nil	8.09	30.4	740	313
	22.05.2019	5 hr	0.5	Nil	Nil	8.3	30.6	741	314
	23.05.2019	24 hr	0.5	Nil	Nil	7.73	29.8	737	314
	24.05.2019	48 hr	0.5	Nil	Nil	7.84	29.3	735	311
	25.05.2019	72 hr	0.5	Nil	Nil	8.19	27.3	683	318

The following observations were made from the test results~~are~~:

- Iron concentration remained constant for 72 hours during running in both the wells. The iron concentrations were found 3.5 mg/l and 0.5 mg/l in DPHE constructed well and CP More well respectively.
- Manganese and Arsenic concentration were not found during pumping in both wells.
- Measured pH varied between 6.88 to 7.66 and 7.73 to 8.3 from 1st hr to 72th hr in DPHE constructed well and in CP More well respectively.
- Temperature were found almost constant during the 72 hours running period in both the wells.
- EC value was found higher and ranges from 2240 µs/cm to 2360 µs/cm and 683 µs/cm to 741 µs/cm in DPHE constructed well and the well near CP More respectively.
- TDS is slightly higher than Bangladesh standard found in DPHE well but within the standard range standard in CP More well.

From the water quality data and above observation, it can be inferred that these two aquifers in the vicinity of CP More and DPHE PTWs are not connected.

Time Series Water Quality Test at Laboratory

The major constituents (Na+, Cl- and HCO3-), minor constituents (Fe) and some trace elements (As and Mn) of collected water samples of DPHE constructed well and CP More well were tested in the laboratory by the standard methods. The results of the chemical analysis are interpreted to delineate spatial and vertical trends (**Table 5.10)**.

Table 5.10: Time series groundwater quality laboratory analysis result

Well ID	Date	Time	Parameter					
			HCO_3 (mg/l)	Na (mg/l)	Cl (mg/l)	Fe (mg/l)	As (mg/l)	Mn (mg/l)
Bangladesh Standard (ECR'97)			**–**	***200***	***150-600***	***0.3-1.0***	***0.05***	***0.1***
WHO Guideline Values, 2004			**–**	***200***	***250***	***0.3***	***0.01***	***0.4***
DPHE Constructed PTW	11.05.2019	1 hr	270.80	277	530	0.16	0.017	0.091
	14.05.2020	72 hr	398.40	163	490	0.60	0.011	0.081
Newly Constructed PTW	22.05.2019	1 hr	391.00	245	9	0.14	0.007	0.024
	25.05.2020	72 hr	378.60	258.30	10	0.15	0.007	0.010

Detail water quality analysis and interpretations are given below:

- It is observed that Bi-carbonate, Chloride, Iron, Arsenic and Manganese concentration in both the wells are within the allowable limit of Bangladesh except for sodium.
- Though field kit test (**Table 5.9**) shows Fe concentration as 3.5 mg/l in DPHE well, Laboratory test shows much lower concentration of 0.16 mg/l to 0.60 mg/l.

5.4 Groundwater Resource Assessment

Based on the available data groundwater resource volume of deep aquifer can be calculated by using Depth- Storage model. For Mirsharai area target rated drawdown is taken as 10m for estimating the available water resource. Using maximum lowered limit (10m) of groundwater level, depth-storage model is determined as shown in **Figure 5.31**.

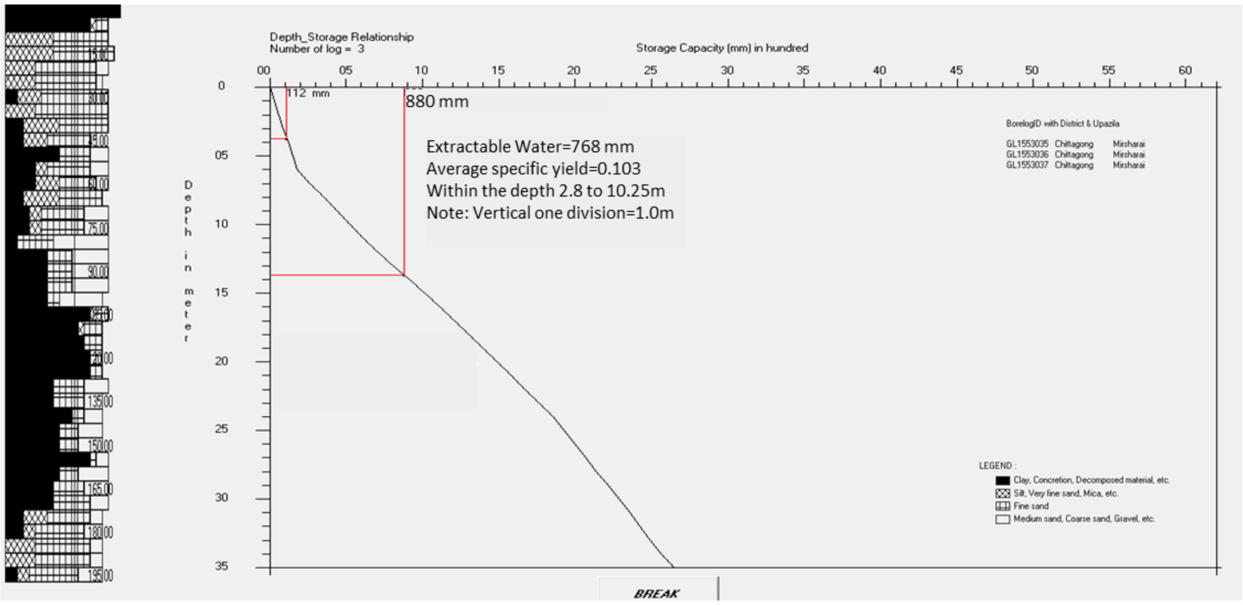


Figure 5.31: Depth-storage relationship of the study area

Storage of the aquifer system depends on 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 in the National Water Management Plan (NWMP).

Instead of groundwater table flactuation 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 considering 10m drawdown and 98.4 sq. km area using the following relationship.

Method1:

Total water resource=Extractable water depthX Area

Total storage water depth according to the depth-storage model is 880mm but extractable water depth is 768 mm. Considering 98.4 sq. km area of drainable area, the drainable storage volume is around 75 Mm^3 per year or 205 MLD. If the capacity of each pump is 1 cusec (28.414litre/sec) and the pumping period is 20 hours per day then total 100 nos. PTW can be installed in the BSMSN project area.

Method2:

Groundwater resource estimate is also compared with quantification based on specific yield of the soil material and rated drawdown. Considering lowering of groundwater level up to 10m depth drainable storage volume stands at 0.222 Mm^3 per day or 222 MLD (**Table 5.11**). If the capacity of each pump is 1 cusec (28.414 litre/sec) and the pumping period is 20 hours per day then total 109 nos. PTW can be installed in the BSMSN project area.

Table 5.11: Resource estimation considering rated drawdown 10.0 m and 28.414 litre/sec discharge at 20 hrs daily

Zone	Average Sp. Yield	Area of Zone (km^2)	Total storage Mm^3	Considering Aquifer Retention (Available) Mm^3	Total storage Mm^3/day	Total storage MLD	Number of the well
A	0.103	29.3	30.2	24.1	0.066	66	32
B	0.103	27.7	28.5	22.8	0.063	63	31
C	0.103	22.9	23.6	18.8	0.052	52	25
D	0.103	18.5	19.0	15.2	0.042	42	20
Total		**98.3**	**101.2**	**81.0**	**0.222**	**222**	**109**

Based on the above observation safe yield abstraction of 205 MLD water by installing 100 nos. PTW with capacity 1 cusec is recommended for the project area.

5.5 Concluding observations

After processing and evaluation of primary and secondary data including extensive field investigation, lithological characterization and necessary analyses following observation are furnished below;

- Salinity exist in shallow aquifer in most part of the project area. Therefore shallow aquifer (0-70m) need to be avoided for large quantity water supply.

- Average thickness of deeper aquifer varies between 120m to 205m;
- Water quality data of the existing wells were tested and found to differ in two cycle sampling and laboratory testing. This may be further verified.
- Time series water quality analysis during aquifer test for ~~of~~ 60, 300, 1440, 2880- and 4320-minutes elapsed time shows acceptable limit for potable water.
- Aquifer near CP More and DPHE PTW are not connected and therefore water from lower, upper or nearby aquifer is negligiable.
- Deep aquifer yield good quantity of water.
- Aquifer may be classified as semi confined to confined in nature.
- The discharges of the production well should not be more than 28.3 litre/sec (1 cusec).
- The area of influence is considered to be about 300m and distance from one well to another should not be less than 500 m.
- The aquifer is not suitable for large scale development due to possibility of saline water intrusion.
- Total volume of groundwater resource is estimated to be around 205 MLD based on 10m drawdown in the aquifer.
- Maximum 100 wells can be installed for 20 hours operation/ day, considering 1 cusec (28.3 litre/sec) capacity of each production well.

6 Desalination of sea water

6.1 Ocean current circulation pattern of Bay of Bengal

Semidiurnal fluctuations with two nearly equal high and low tides each day is observed in the Bay of Bengal. The upper layer circulation of the Bay of Bengal is subject to strong seasonal variability **(Figure 6.1)**. During the early northeast monsoon in November the large-scale flow pattern in the bay is cyclonic (clockwise circulation), and the western boundary current, the East Indian Coastal Current (EICC), flows southward from the Bengal Shelf north of 20øN to the east coast of Sri Lanka. In February the EICC reverses and flows northward along the Indian coast, reaching its maximum strength during the early southwest monsoon in April/May [Shetye et al., 1993]. In the interior of the Bay of Bengal the large-scale flow is anticyclonic (clockwise circulation) during this time. This variability is associated with the Indian monsoon: dry northeasterly winds coupled with cooling and evaporation in winter and southwesterly winds coupled with heating, precipitation, and an increased freshwater runoff into the northern bay in summer.

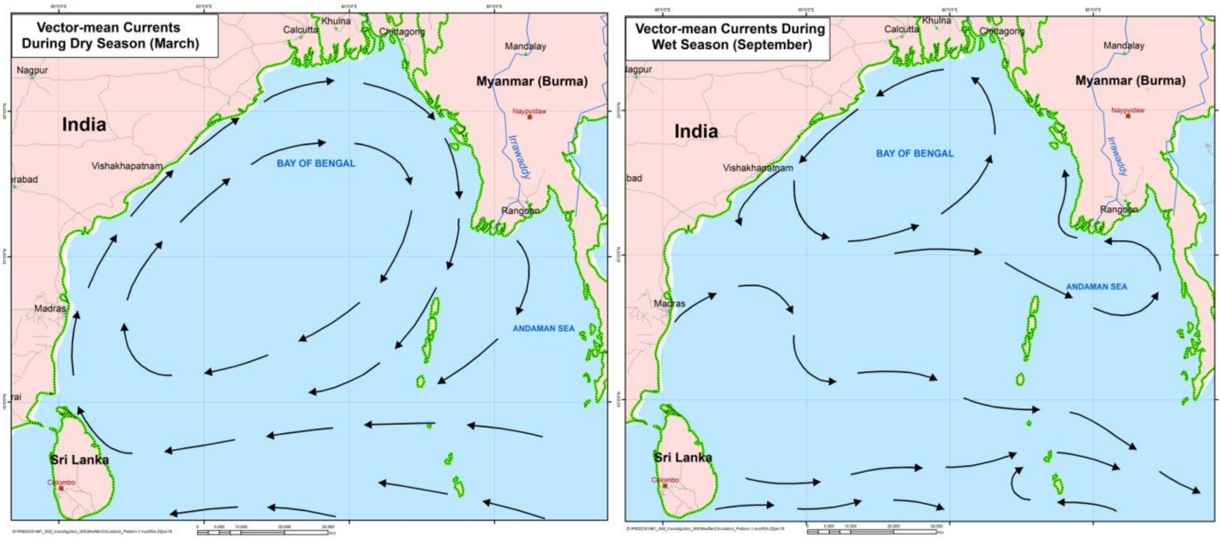


Figure 6.1: Typical large-scale ocean current circulation pattern in the Bay of Bengal in dry and wet season (Deutsches hydrographic Institute (1960))

6.2 Tide Fluctuation

To estimate the tidal range of the sea, two stations: one in the mouth of Feni River and another at Saidpur has been selected in the Sandwip channel. One pressure cell as well as staff gauges were installed at each location to observe the water level where applicable starting from 2nd week of February 2018. Manual gauge readings were taken by gauge readers at 30-minute interval during daytime only (where possible). Automatic data were recorded at 10-minute interval by pressure cell (continuously). The gauges have been connected from a Temporary Bench Mark (TBM) kept nearby, which was connected with the SoB Benchmark. A dedicated team was involved in monitoring tide gauge and downloading sensor data time to time. The water level data, collected upto May 2018 for Feni River mouth and July 2018 for Saidpur are presented in **Figure 6.2** and **Figure 6.3**. It is observed that the water level fluctuated between -2.6 to 3.2 mPWD at Feni River mouth and -3 to 3.75 mPWD at Saidpur in the Sandwip channel during February to May. The distance between these two stations is 25 km and water level difference is almost 0.5m.

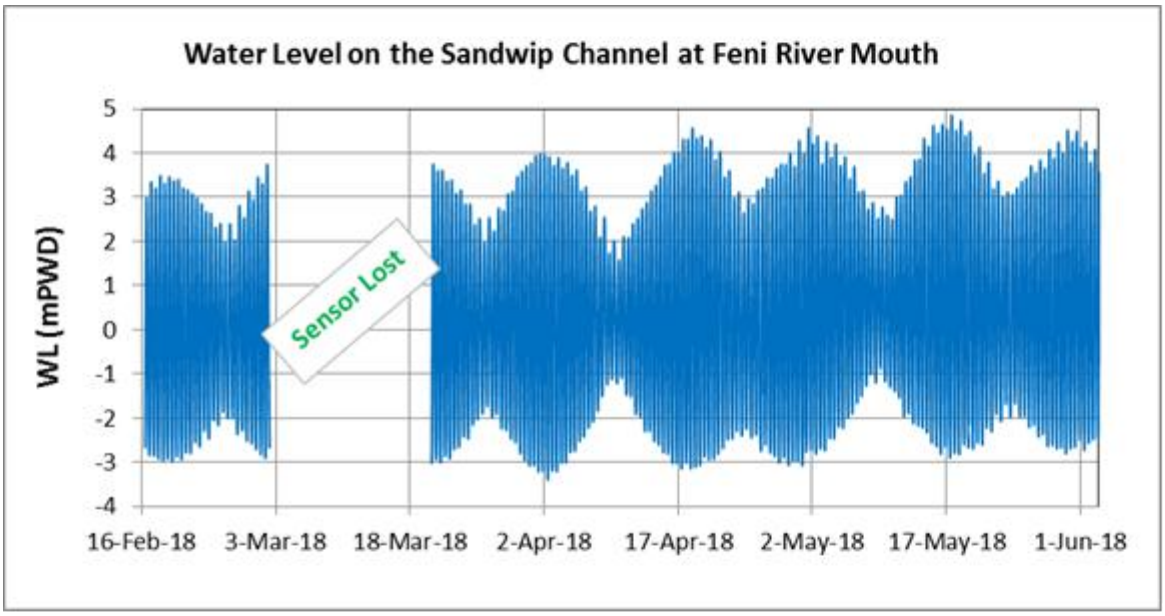


Figure 6.2: Water Level on the Sandwip channel at Feni river mouth

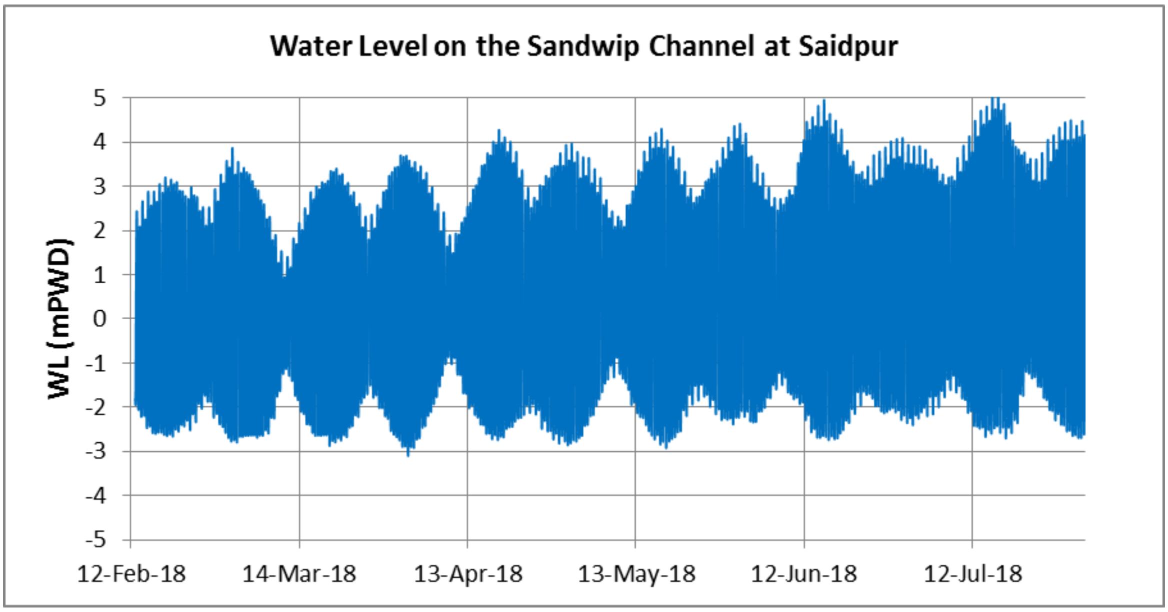


Figure 6.3: Water Level on the Sandwip channel at Saidpur

6.3 Water Quality of Sea Water

Chittagong Port in about 67km from the project area. Moreover, there are many ship breaking yard on the bank of Bay of Bengal near the project site. These cause marine pollution which propagate near the economic zone area with tidal wave. To assess the marine pollution marine and design of desalination plant water sample has been collected from the Sandwip channel at the downstream of Shaherkhali khal. The water sample has been tested in BUET laboratory and are shown in **Table 6.1**.

Table 6.1: Water quality data of Sandwip channel

Sl. No.	Parameter	Unit	Concentration
1	pH	--	7.90
2	Turbidity	NTU	616
3	Electrical Conductivity (EC)	mS/cm	30.5
4	Dissolved Oxygen (DO)	mg/l	7.81
5	Temperature	°C	23.8
6	Total Dissolved Solids (TDS)	mg/l	22,068
7	Total Suspended Solids	mg/l	712
8	Total Hardness	mg/l as $CaCO_3$	3,750
9	Chloride	mg/l	12,275
10	Manganese (Mn)	mg/l	0.12
11	Total Iron (Fe)	mg/l	6.80
12	Nitrate (NO_3-N)	mg/l	0.40
13	Orthophosphate (PO_4^{3-})	mg/l	0.17
14	Sulfate (SO_4^{2-})	mg/l	1,340
15	Biochemical Oxygen Demand (BOD_5)	mg/l	0.4
16	Chemical Oxygen Demand (COD)	mg/l	60
17	Magnesium(Mg)	mg/l	789.6
18	Lead (Pb)	mg/l	< 0.001
19	Cadmium (Cd)	mg/l	< 0.001
20	Chromium (Cr)	mg/l	< 0.001
21	Zinc (Zn)	mg/l	0.071
22	Mercury (Hg)	mg/l	< 0.001
23	Copper (Cu)	mg/l	0.006
24	Nickel (Ni)	mg/l	0.011
25	Total Organic Carbon (TOC)	mg/l	1.69

7 Rainwater harvesting

7.1 Introduction

Through Rainwater harvesting rainwater can be collected and store for reuse on-site, rather than allowing it to run off. The rainwater collected can be used for gardens, livestock, irrigation, domestic use with proper treatment, indoor heating for houses, etc. The harvested water can also be used as drinking water, longer-term storage, and for other purposes such as groundwater recharge.

7.2 Scope of Rainwater Harvesting in BSMSN Area

It reveals that the annual rainfall of the BSMAN area is 3300mm (sec. 1.4.1). About 90% of the total rainfall occur from May to October.

For rainwater harvesting the roof top area should be >300m^2. The Master plan has been conducted for an area of 27,014 acre excluding the area of water bodies and open space (**Table3.3**). Among this total area 20% area may be used as transportation and communication. It is found that the areas used for transportation and communication, transitional, port/logistic, open spaces and water body cannot be used for rainwater harvesting. The remaining area can be used for rainwater harvesting. If 50% of the plot area considered to be used for industrial and other purpose and 60% of rainfall from May to October can be collected, then annually about 65,487 million liters volume rainwater will be available for storage which is equivalent to about 179 MLD.

7.3 Rainwater Harvesting for Artificial Recharge

Excess groundwater abstraction could lead to either mining or saltwater intrusion. This threat is being cropped up because of imbalance in groundwater recharge and abstraction volume. Such situation should be avoided either by decreasing the dependency on groundwater or gradually increasing the groundwater storage volume by artificial recharge to aquifer systems. Recommendation has been given for measures for rainwater harvesting from the roof tops and open grounds for industrial, household and commercial use and for artificial recharge of groundwater aquifer.

Quantity of recharge depends on

- Characteristics of soils;
- Quantity of rainfall; and
- Rainfall pattern.

The available techniques are easy, cost-effective and sustainable in long term. Several methods of groundwater recharge like spreading, pit, induced recharge and injection well method are practiced. The area requirement of spreading method sometimes limits its use. Among them the recharge / injection wells can directly feed depleted aquifers with freshwater by gravity from ground surface. The recharge through this technique is fast and has no transit losses or evaporation losses. It may ensure timely disposal of the excess runoff as well as replenishment of aquifer. Except recharge pit, other structure of recharge well remains underground; there is hardly any loss of land. **Figure 7.1** shows the schematic diagram of artificial recharge of ground water aquifer.

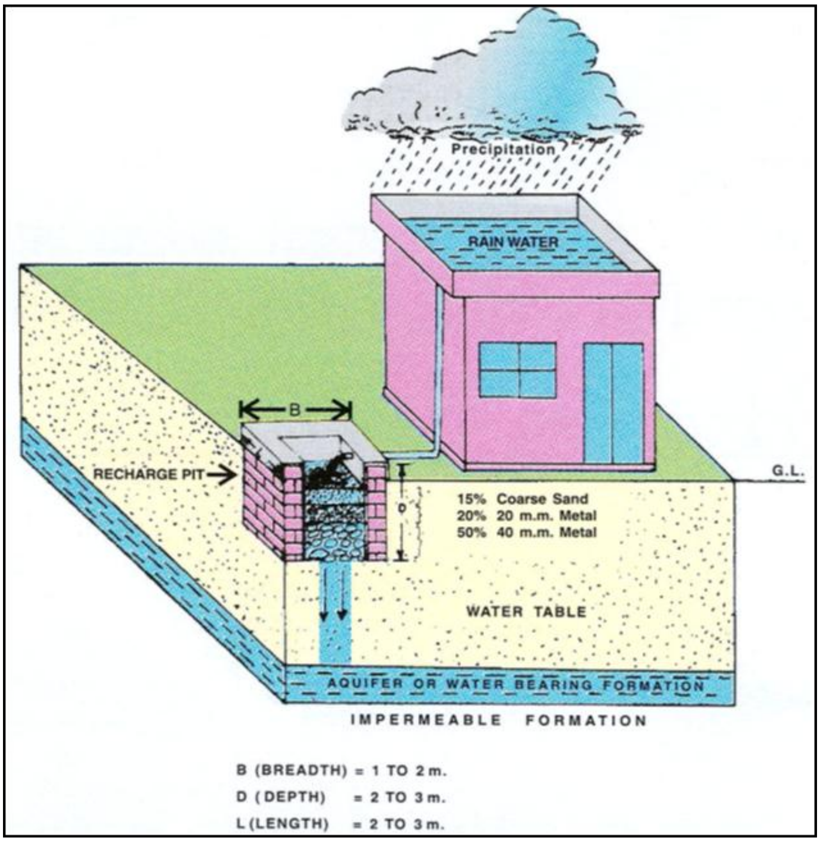


Figure 7.1: Schematic diagram showing artificial recharge of aquifer

7.3.1 Pipe Network for Rainwater Collection and Transmission to Recharge Pit

Pipe network should be designed for rainwater collection and transmission to recharge pit considering the existing outlet of drop pipe and rainwater. Drop pipe of enough diameter needs to be fixed at every existing rainwater draining outlet. The drop pipes should again be fixed with circular pipe for collection of rainwater, which should again be connected with a150mm delivery pipe for transmitting the water to recharge pit. Two gate valves need to be fixed with delivery pipe for flashing out initial rainwater to avoid harmful materials and to discharge water to recharge pit. Sufficient shower pipes are to be fixed with the delivery pipe horizontally above the recharge pit for uniform distribution of collected water on the filter bed of recharge pit. **Figure 7.2** shows a typical roof top rainwater collection network.

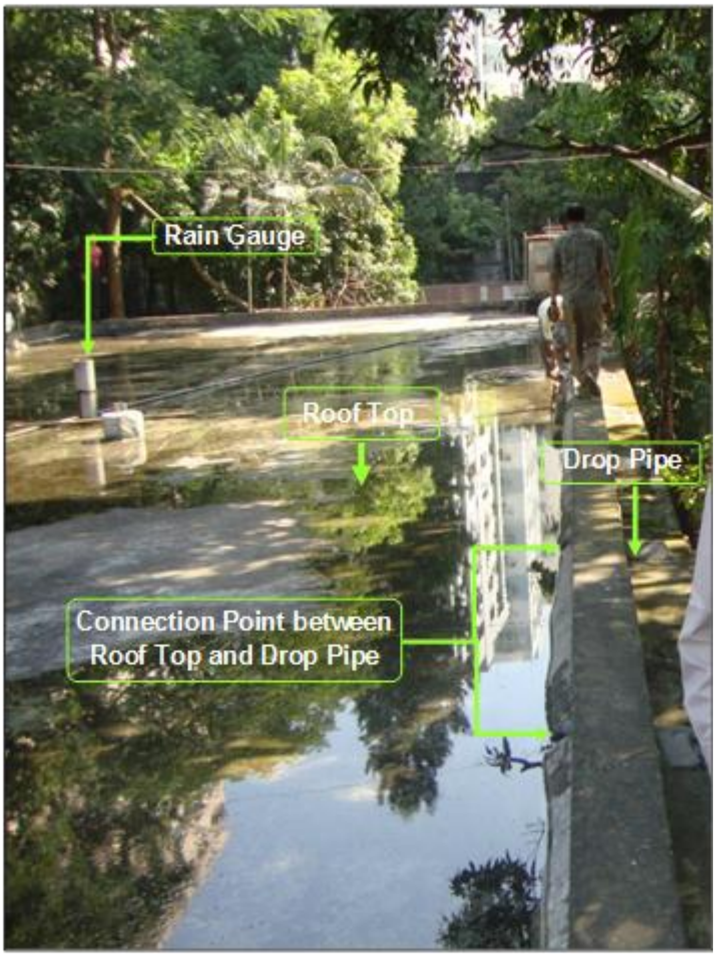
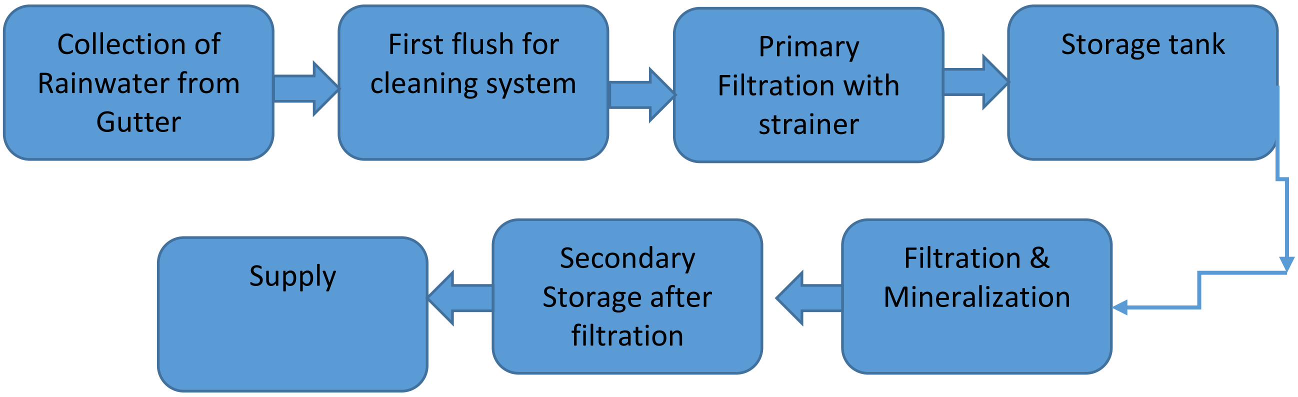


Figure 7.2: A typical Roof Top and collection network for Rainwater Harvesting

7.4 Rainwater Harvesting for Household Usage

Rainwater harvesting can be used to help solve water crisis problems. To this day, the concept of rainwater harvesting for house has been accepted all over the world. Rainwater from the house roof is collected through rainwater gutters and stored in a storage tank and can be used later after. Schematic diagram of arrangement system within tank is given in **Figure 7.3**. For using the water for drinking or industrial purpose need some treatment as follows.



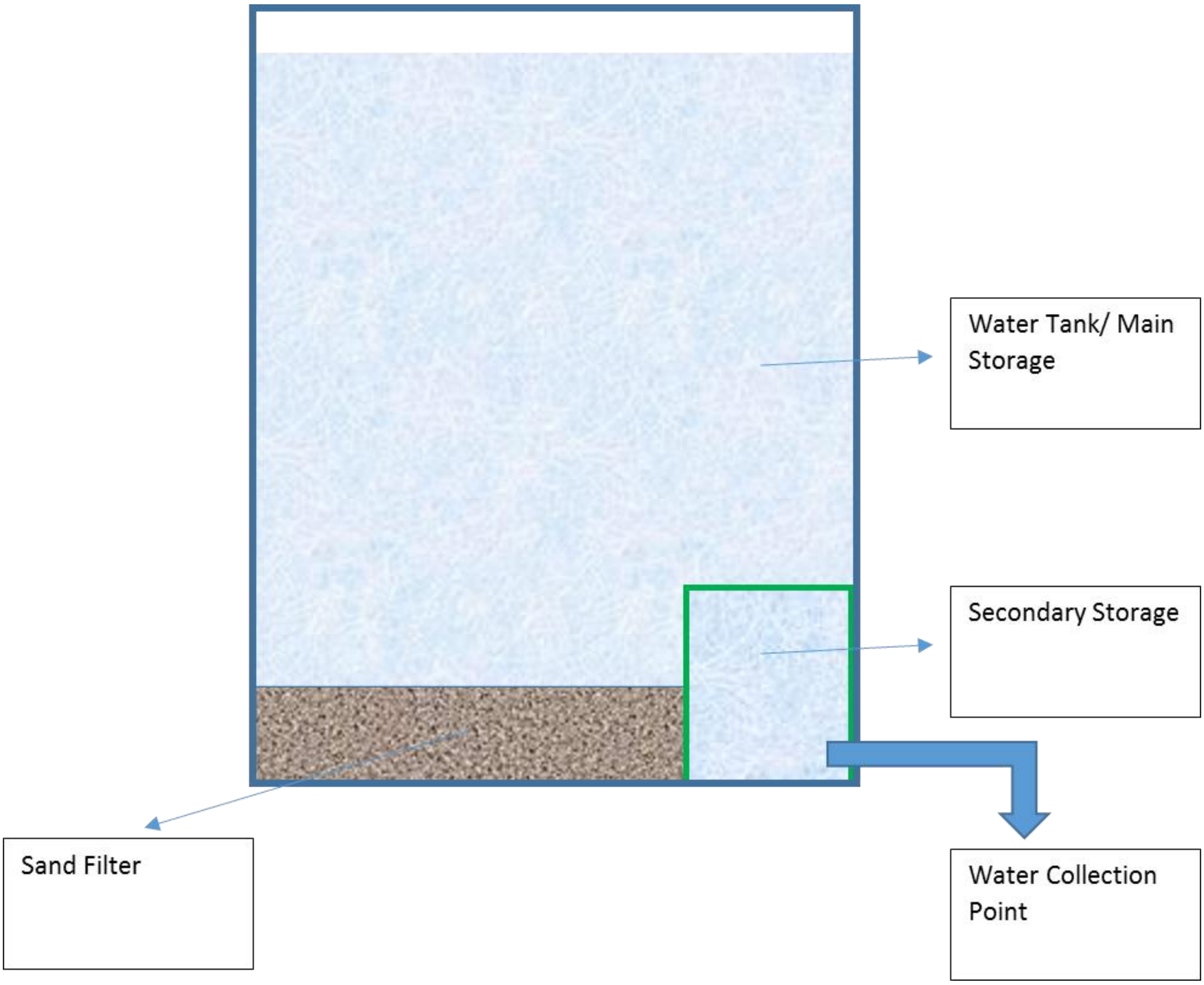


Figure 7.3: Schematic diagram of arrangement system within tank

8 Feni Surface Water treatment plant

8.1 Option Studies of Intake Selection for Surface Water Treatment Plant Considering Source of Feni River

8.1.1 General

Specific components that make up an intake facility are influenced by many factors, such as characteristics of the water source, required percent of intake flow and future capacity, water level variations, water quality variations, climate conditions, existing and potential pollution sources, protection of aquatic life, navigations hazards, foundation conditions, sediments at intake, bed loads and economic considerations.

More specifically the intake facility design should achieve the following:

- Reliability during water level fluctuations or channel instability
- Flexibility for water withdrawal at various depths, where desirable and feasible
- Protection against hydraulic surges, floods, floating debris, boats etc.
- Location to provide the best available water quality
- Prevention of entry of objects that might damage pumps and treatment facilities
- Adequate space for routine equipment cleaning and maintenance
- Facilities for removing pumps and other equipment for inspection and maintenance
- Minimize damage to aquatic life
- Adequate space and facilities for receiving, storing, containing, and feeding treatment chemicals

8.1.2 Intake Capacity

Unlike water system components such as pumping stations, basins, and filters, intake facilities are difficult to expand to provide additional future capacity. For this reason, long range water supply needs must be carefully considered during the intake design. In general, intake requirements to meet water needs for 40 to 50 years in the future (minimum) are considered. By considering future demand, the initial investment may be on the higher side but incremental costs of provisions for future demand will be relatively lower.

8.1.3 Intake Reliability

Reliability is essential, especially for waterworks that depend on a single intake facility. For larger systems, construction of duplicate intake structures is becoming increasingly common, including multiple inlet ports and screens, screen chambers, pump wet wells, and discharge conduits.

8.1.4 Considerations for Selecting Intake Location

Selecting the appropriate location for an intake facility must include an evaluation of the major factors presented in **Table 8.1.**

Table 8.1: Considerations for Selecting Intake Location

Criteria for Selecting Intake Location	Remarks
Water quality	Local surface drainage
	Wastewater discharge points

Criteria for Selecting Intake Location	Remarks
Stream flow condition	Stream currents
	Wind and wave impacts
	Water depth and variation
Water depth	Water depth and variation as available
	Adequate submergence over inlet ports
Silt, Sand	Location to minimize impact
Navigation	Uninterrupted navigation
Trash and debris	Provisions for unrestricted flow
W.S. elevation	Maximum practical hydraulic gradient
Treatment facility	Minimum conduit length to treatment plant
Cost	Lowest cost consistent with long-term performance and O&M

8.1.4.1 Water Quality Considerations

The preferred location for a shore intake system should provide deep water, a stable channel, and water of consistently high quality. The intake location should be upstream of local sources of pollution. Variation in water quality can result from the entrance of pollution from tributary streams upstream of the proposed intake location, and water quality near one bank may be inferior to the quality encountered midstream or at the opposite shore.

8.1.4.2 Flood Considerations

It is essential to protect intake structures against flood damage. The intake structure must be designed to prevent flotation and overturning. Flood stages at the intake site should be considered carefully, and a substantial margin of safety should be provided.

8.1.4.3 Sediment Considerations

Many rivers carry heavy loads of suspended silt at times, and heavy material move along the beds. The intake must be designed so that it will not be clogged by silt and bed load deposits. Silt, sand, and gravel can also cause abrasion of pumps and other mechanical equipment, leading to severe problems at the treatment plant. To prevent such deposits, adequate safety provision should be in place of intake.

8.1.5 Intake Options

Several reconnaissance visits were conducted to ascertain location of the intake sites at different points of the Feni River and its distributaries. The following locations were selected after visiting the entire area to gain first-hand information and knowledge:

- about 2.5 km upstream of the Feni regulator near confluence of the Azampur Khal and the Feni River at Azampur
- about 1 km downstream from Julanbazar near confluence of Omar Ali Khal and Ichakhali Khal

During the visits in-depth discussions were also held with the community to gather information viz. riverbank erosion, cost of land, and economic condition of the people and effects of land acquisition for proposed intake point. During discussion number of issues were identified that has been incorporated for successful outcomes of this project. Detailed overview of the possible intake locations are given in the following sections. The location of the possible intakes are shown in **Figure 8.1**.

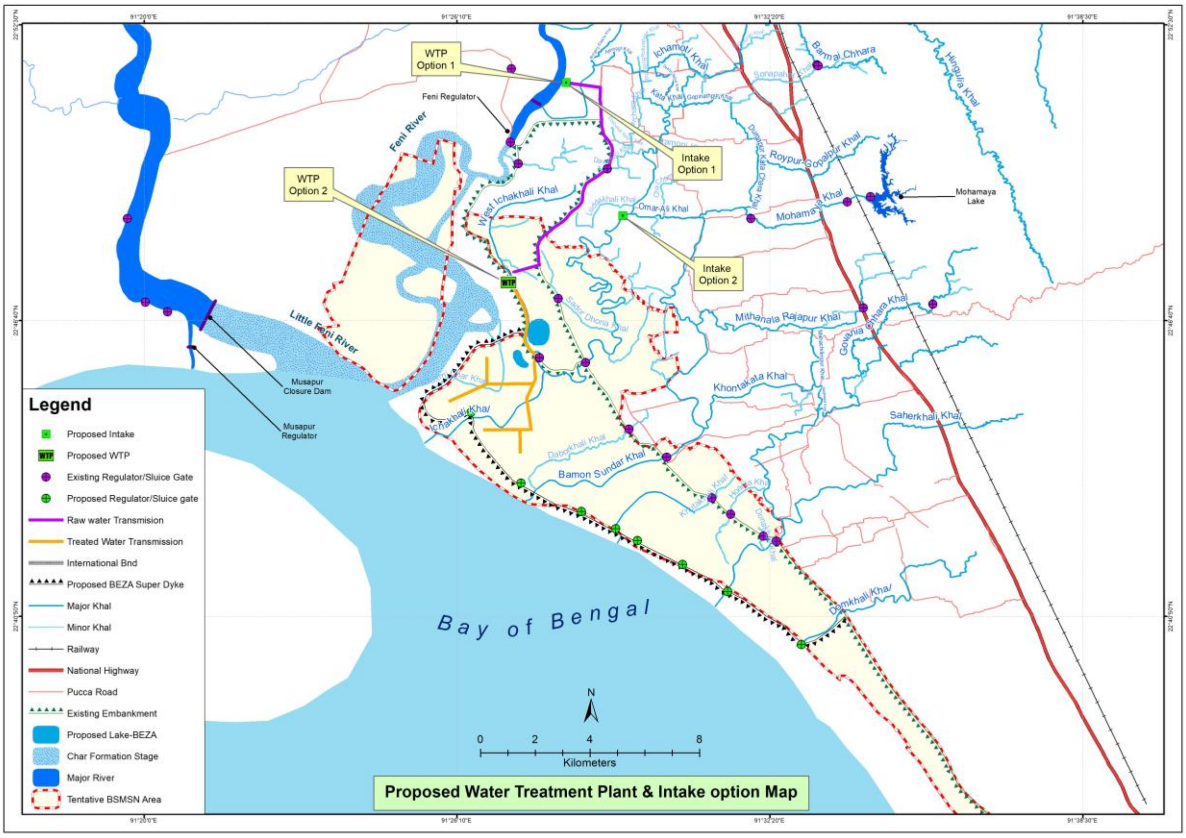


Figure 8.1: Proposed Intake and WTP Map Considering Source Feni River

Option 1: About 2.5 km upstream of the Feni regulator at Muhurighat near confluence of the Azampur Khal and the Feni River at Azampur Mouza of Osmanpur Union

During field visit, this proposed intake location was found reliable but it needs to be finalized after water quality analysis and morphological study. Discussions were made with the local people regarding availability of water throughout the year. The intake is located about 22.5 km away from the Mirsharai. If this location would find suitable through morphological study there may need primary sedimentation basin near the intake pumping station because of the higher sediment load in the Feni River. After that raw water will need to be transported by a closed conduit to the economic zone for treatment.

Option 2: about 1 km downstream from Julanbazar near confluence of Omar Ali Khal and Ichakhali Khal

The intake site is located at about 1 km downstream from Julanbazar near the confluence of Ichakhali and Omar Ali Khal. It is learnt from the discussion with the local people and the officials of Bangladesh Water Development Board that during wet season there is availability of water in the khal. Additional water comes from Mohamaya Lake to Omar Ali Khal. It may be noted here that if this intake point is selected, requirement of raw water for the Treatment Plant can be assured during wet season. Major disadvantage of this location is that low flow of water in the Khal can cause scar of water in dry season.

8.1.5.1 Comparison among Different Intake Options

Comparison among the two above mentioned alternatives are summarized in **Table 8.2**.

Table 8.2: Comparison of Different Intake Options

Intake Locations	Advantages	Disadvantages
Option 1 About 2.5 km upstream of the Feni regulator at Muhurighat near confluence of the Azampur Khal and the Feni River	• Riverbank is stable • Water quality is acceptable for treatment by conventional method • Available land for intake and treatment plant • Less social disturbance	• Far from the project area • may need primary sedimentation basin near the intake pumping station
Option 2 about 1 km downstream from Julanbazar near confluence of Omar Ali Khal and Ichakhali Khal	• Water quality is acceptable for treatment by conventional method • Available land for intake and treatment plant • Nearer to the economic zone, thus requirement of transmission pipe is less	• Scar of water during dry season • Possibility of poor water quality in future as located downstream • Higher social disturbance

8.1.5.2 Optimum Intake Location for Surface Water Treatment Plant

Considering the above mentioned facts and based on morphological study **Option 1** has been found to be the best. Though morphological study and historical analysis provides evidence about the suitability of this location but considering the unpredictable nature of the Feni River dredging arrangement will need to be kept assuring water availability at intake throughout the design life of the treatment plant.

8.1.6 Hydro-Morphological Analysis for Intake Option

One of the criteria for assessment of suitability of the proposed intake location is to check the stability of the left bank of the Feni River and availability of adequate water near the location. In this present case, both the criteria have been investigated from hydro-morphological viewpoint supported by analysis of secondary data. The following sections present the analysis of hydro-morphological data of the Feni River focusing the reach, which covers the proposed intake location and information. The selected intake location is about 2.5 km upstream of the Feni regulator near confluence of the Azampur Khal and the Feni River at Azampur.

Investigation of the hydro-morphology of the Feni River includes assessment of the bank and bed erosion situation, channel changing pattern, flow, water depth in the vicinity of the intake location.

8.1.6.1 Discharge Data Analysis

Historical observed discharge data up to December 2017 of Feni River at Kaliachari and Muhuri River at Parshuram has been collected from Bangladesh Water Development Board (BWDB). Records of maximum flow has been used for frequency analysis; results being used as boundary condition in the model to assess sustainability of the Intake structure. Minimum flow records has been used to assess the water availability at the intake locations. The intake location receives the combined flow of three river Feni, Muhuri and Selonia. The observed minimum combined discharge of Feni and Muhuri River is is around 8.84 m^3/s during April 2014, which is adequate to meet requirement of flow of 100 MLD at treatment plant.

To find a suitable surface water source from which water can extract throughout the year, IWM carried out discharge measurement per fourth nightly (**Table 8.3**) in wet and dry season.

Table 8.3: Primary discharge data of Feni, Muhuri and Selonia River

Date	Discharge (m^3/s)			
	Feni River at Suvopur Bridge	Muhuri River at Daulatpur	Selonia River at Highway Bazar (Lemua Bridge)	Total
30/03/2018 9:00	23.93	5.733	8.026	37.69
24/04/2018 12:28	62.052	3.467	12.297	77.82
20/05/2018 4:48	166.145	115.780	25.960	307.89
26/05/2018 10:00	46.55	29.640	13.037	89.23
09/06/2018 9:33	25.444	20.317	14.216	59.98
27/06/2018 10:07	172.985	134.841	24.271	332.10
10/07/2018 11:04	75.313	35.290	18.990	129.59
30/07/2018 11:15	146.5345	188.546	3.987	339.07
12/08/2018 10:00	71.63	41.941	17.318	130.89
31/08/2018 11:04	88.11	49.826	18.736	156.67
12/09/2018 11:15	85.22	49.834	18.424	153.48
28/09/2018 9:10	47.34	19.352	18.144	84.84
14/10/2018 9:20	73.72	32.672	24.092	130.48
30/10/2018 9:20	103.11	25.228	27.787	156.12

It is observed from the above primary data that the rivers Feni, Muhuri and Selonia have the required flow available during both dry and wet season. The minimum combined flow of these three rivers has been observed to be around 37.69 m^3/s. Therefore based on observed data the combined flow of Fein River can be reliable source of water.

8.1.6.2 Water Level Data Analysis

Historical water level data from 1987 to 2017 of Feni River at Sonapur (Feni regulator site) has been collected from BWDB. The proposed intake location is located at 4.5 km downstream from this water level measurement site. **Figure 8.2** shows the water level hydrograph of Feni River at regulator site during 2013-14. Maximum, minimum and average values of these water levels have been plotted in **Figure 8.3** and **Figure 8.4** to have an idea about the characteristics of flood intensity and dry flow of the Feni River. It is observed from the historical data that the lowest and highest water level is 0.6mPWD and 5.48mPWD in monsoon respectively. In dry season the lowest and highest water level is 1.1mPWD and 5.03mPWD respectively.

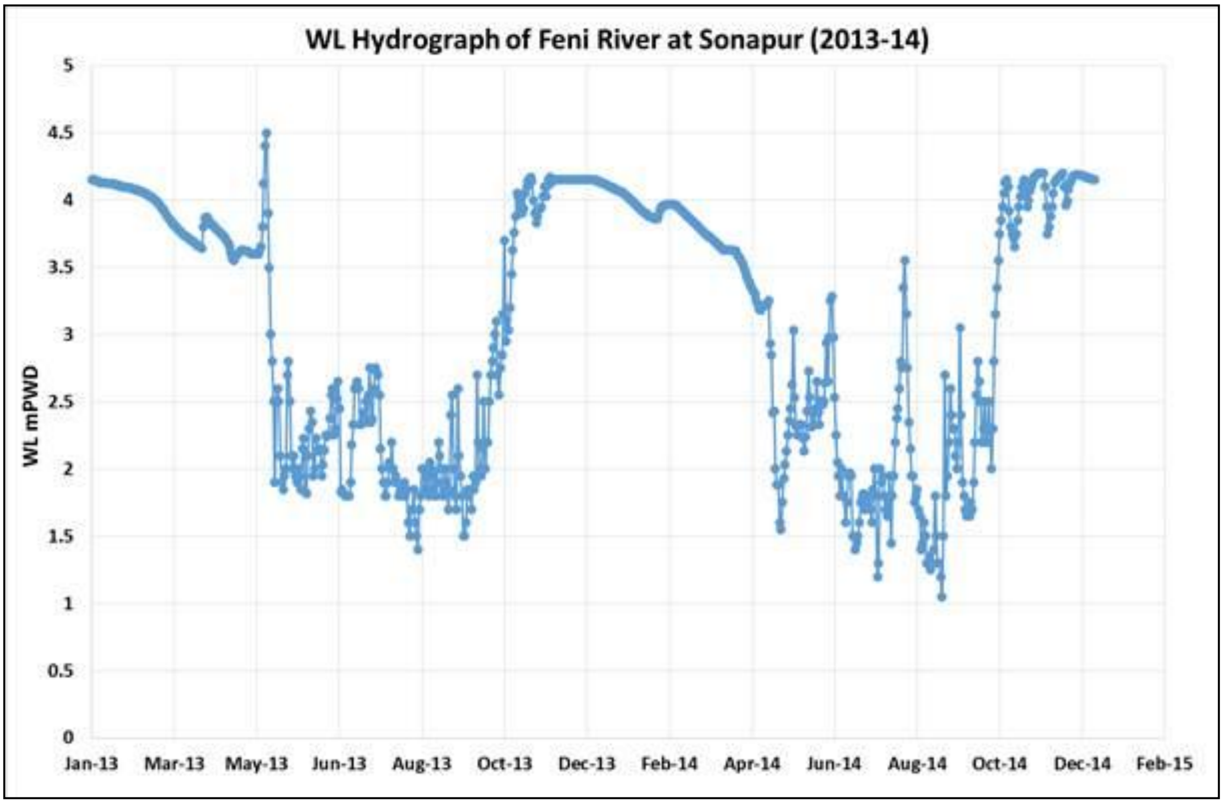


Figure 8.2: Water Level Hydrograph of Feni River at Sonapur

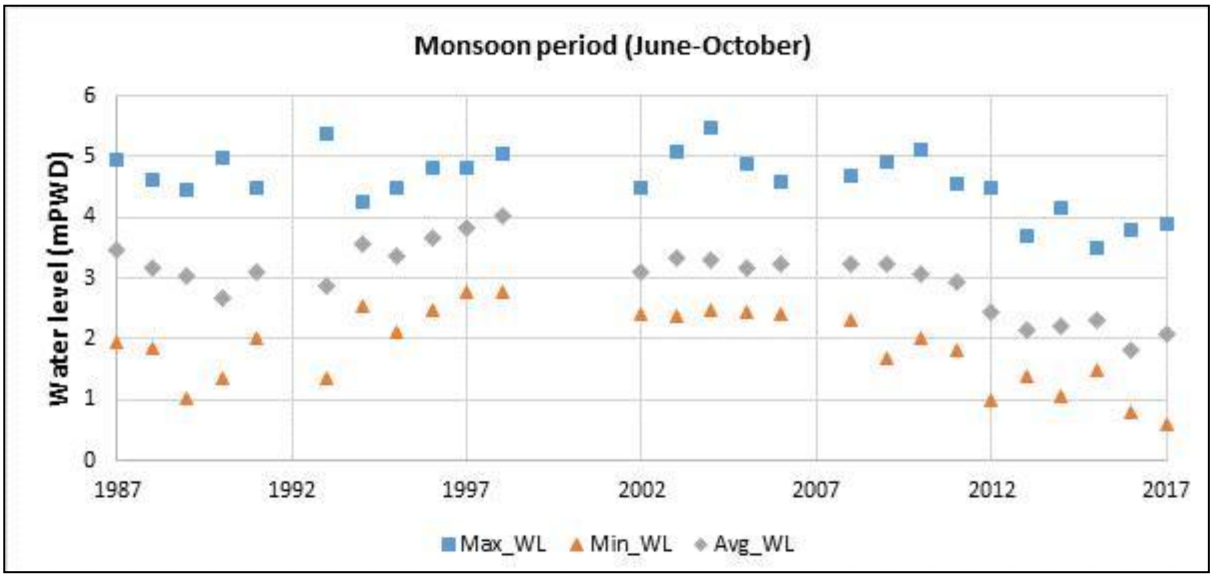


Figure 8.3: Maximum, average and minimum water level at Sonapur in monsson

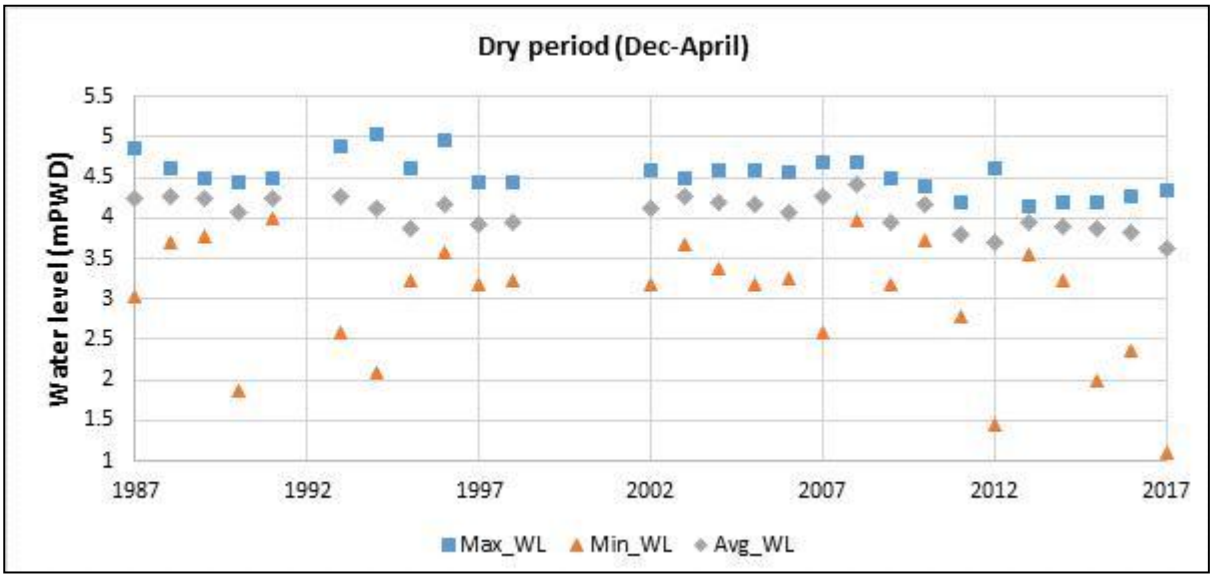
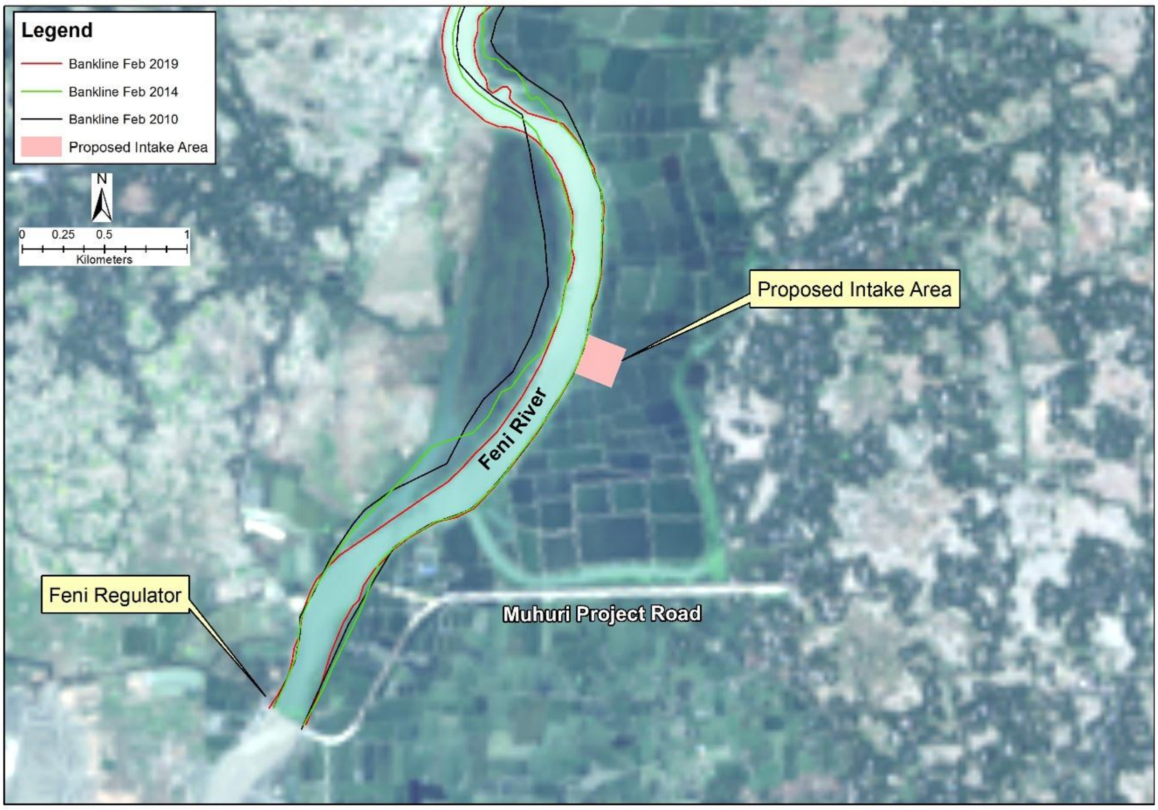


Figure 8.4: Maximum, average and minimum water level at Sonapur in dry season

8.1.6.3 Planform analysis

Satellite images from 2010 to 2019, covering the study area, have been collected from USGS website with resolution of 30 m. After superimposition of the digitized bank lines, it has been observed that left bank of Feni River is quite stable (**Figure 8.5**), though some bank line shifting is observed in the right side. The left bank is stable upto 3.3km from the Feni regulator. The observed left bank shifting is only 2m.



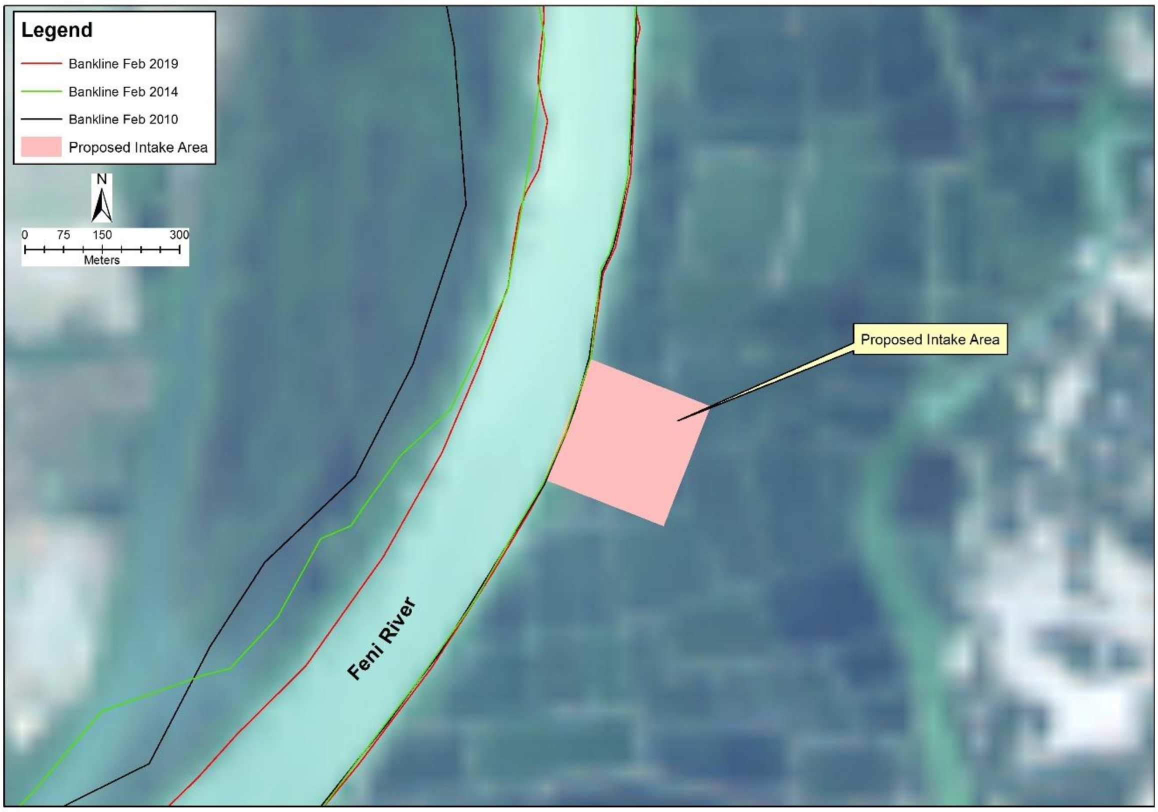


Figure 8.5: Bank lines of the Feni River during 2010-2019 near the proposed intake
(Zoomed view in bottom)

8.1.6.4 Bed Level

In order to see the bed scour and thalweg shifting, observed cross-sections for two different years 2006 and 2012 near the three intake location have been examined and plotted in **Figure 8.6.** The cross-section data of 2006 and 2012 have been collected from IWM database. **Figure 8.6** shows no significant thalweg shifting from 2006 to 2012. The proposed intake is located at the left bank of the river which shows very little changes. But bed erosion of about 1.5m has been found at the right side of the cross section. Bed erosion ensures water depth availability and from such consideration, the intake location shows potential.

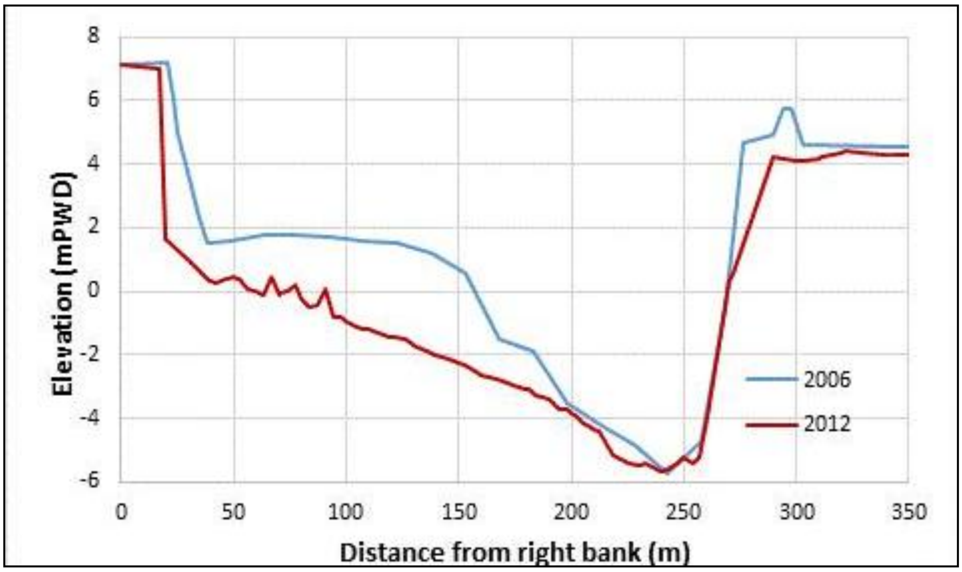


Figure 8.6: Cross-sections near proposed intake locations for different years

8.1.7 Selection of type of Intake

The intake structure is located and designed in a way to help in safely withdrawing raw water from the Feni River and to transfer it through a transmission system until it reaches treatment facilities. The water is expected to flow by gravity from the intake to the pump sumps from where it will be pumped to the water treatment plant. The raw water intake structure and various facilities to be provided have been designed to cater for the 100-year flood and dry season low levels in the Feni River watercourse.

The type of intakes to be envisaged for such flow to be withdrawn from a quite large and navigable watercourse shows three possible alternatives:

- Simple Submerged Intake
- Intake Tower
- Side Intake along the riverbank

The Consultant prefers the type of intake, as per recommendations from hydro-morphological study and taking into full considerations to the BEZA observations. Brief descriptions of the three possible intakes are given in the following.

8.1.7.1 Simple Submerged Intake

The simple submerged intake, located at the bottom of the watercourse, would consist of a simple concrete block of suitable size that supports the starting end of the withdrawal pipe. For safety and for more flexibility in operation, multiple pipes in parallel of identical size is envisaged for withdrawing the required flow. Each pipe will be sized to cater for 50% of the optimum flow at least.

The intake opening will be covered by a safety screen mesh to protect humans and to prevent entrees of fishes and debris into the conduit. The intake opening will be kept at not less than 1.00m below the lowest water level in the watercourse.

This type of intake is economically acceptable and can be envisaged in a place where it will not affect navigation. Nevertheless, it has the disadvantage to keep installations not easily accessible for cleaning and repairing all over the year. A typical arrangement of simple submerged intake is shown in **Figure 8.7.**

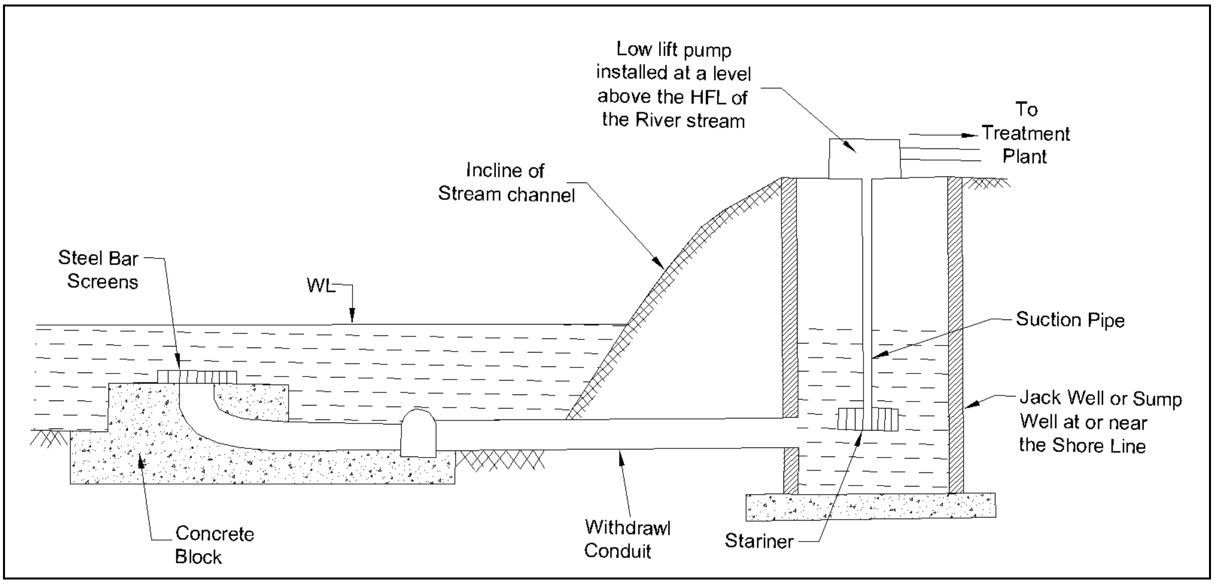


Figure 8.7: Simple Submerged Intake

8.1.7.2 Tower Intake

Tower intake (**Figure 8.8**) is generally used for large flow to be drawn from rivers and reservoirs having large change in water level, which is the case of the Feni River. Gate control openings or ports are provided at various elevations of the tower which generally consists of a reinforced concrete structure built in water. Ports which are always submerged do not show clogging problems by debris and any other floating matters as course screens are placed in front of the ports.

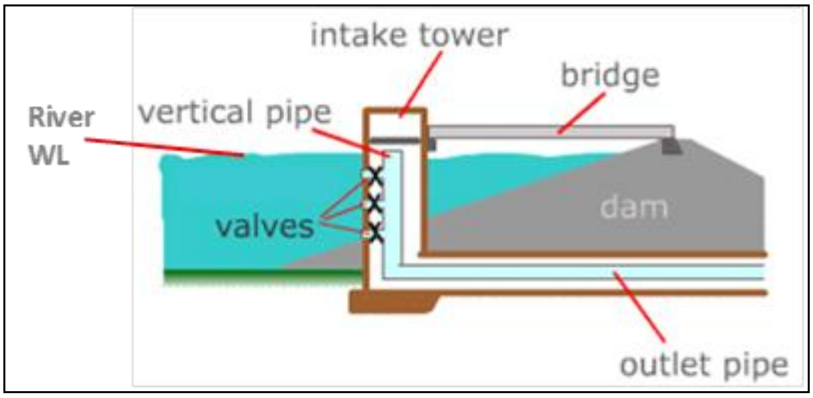


Figure 8.8: Typical Tower Intake

Two types of tower intake namely wet intake tower and dry intake tower is possible. Wet intake tower (**Figure 8.9**) would consist of a reinforced concrete circular structure filled with water up to the water level in the River. They have a concentric concrete shaft inside which is connected to the withdrawal pipes. The withdrawal pipes may lie over the bed of the River or may be provided in the form of tunnels to be built under the River bed. Openings are provided in both the outer and in the inner tower in order to receive the necessary flow. Wall gates are usually placed on inner tower openings for flow control.

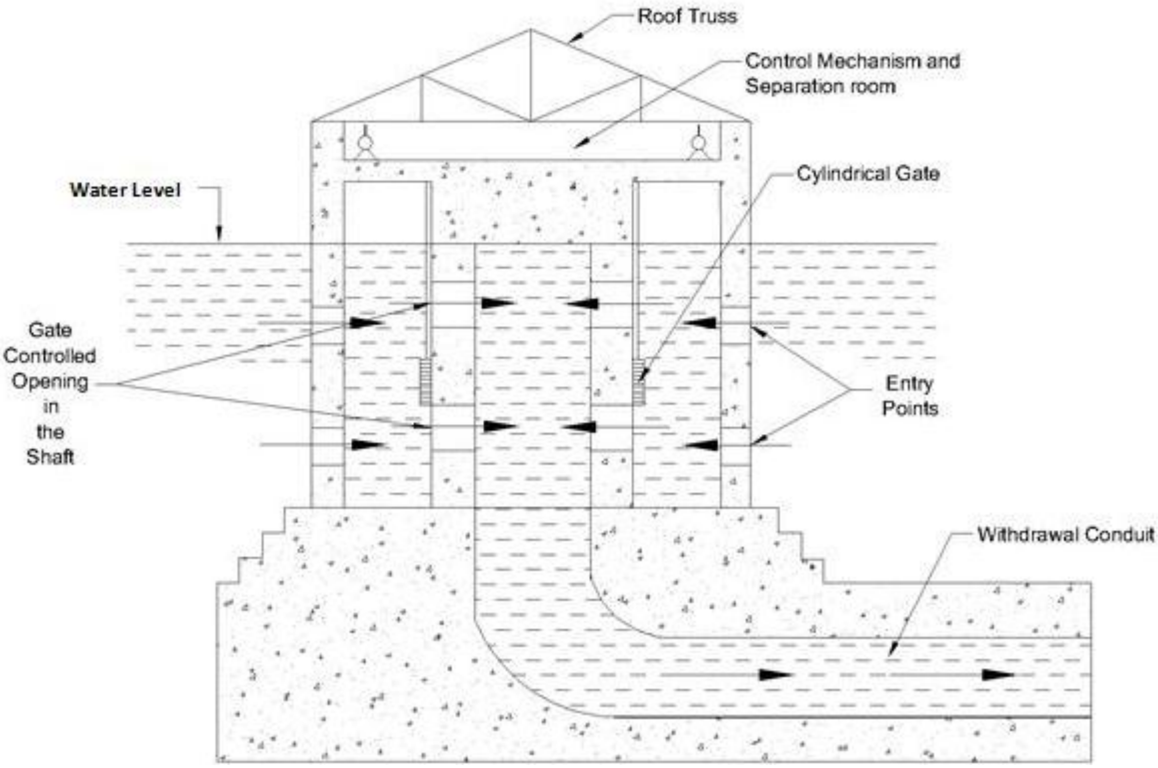


Figure 8.9: Components of Wet Intake Tower

In Dry intake tower water (**Figure 8.10**) water is directly drawn into the withdrawal conduit through openings or entry ports provided with wall gates.

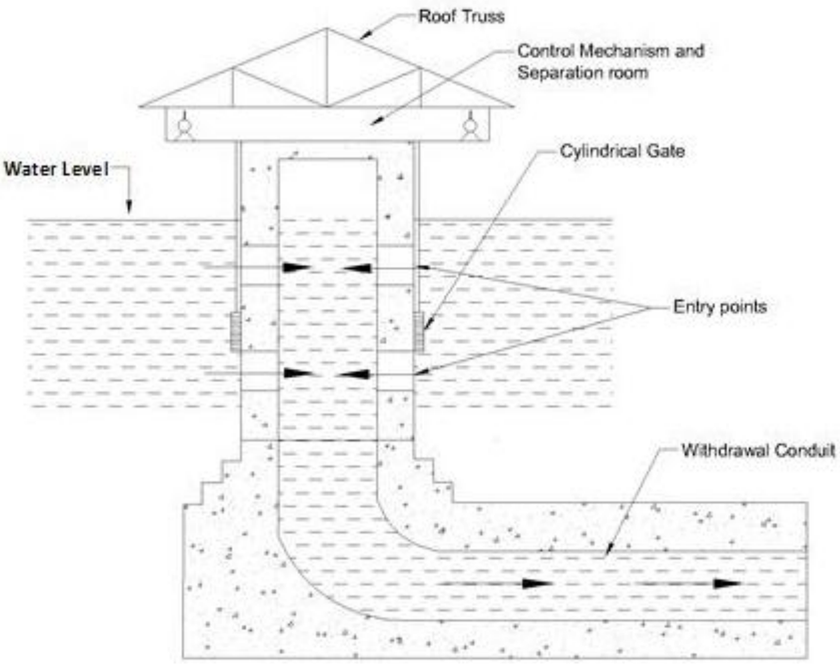


Figure 8.10: Components of Dry Intake Tower

The inside of the tower is expected to remain dry if gates are closed while the structure will be subjected to additional buoyant forces. Therefore, the reinforced concrete structure to be provided is supposed to be thicker and heavier than the structure of the wet intake tower. Gates are very useful since water can be withdrawn from any selected level of water in the River by opening the port at that level.

The intake tower solution is not recommended in watercourses used for navigation as it may constitute a threat for ships during limited visibility conditions such as darkness, bad weather etc.

8.1.7.3 Riverbank Intake

With such solution, a side intake (**Figure 8.11**) will be provided starting from the Riverbank. Flows will be admitted into horizontal intake pipes through protection mesh followed by coarse screens before reaching by gravity to settling basins or settling channels. Automatic fine screens will also be provided between the channels outlet and pumps sump.

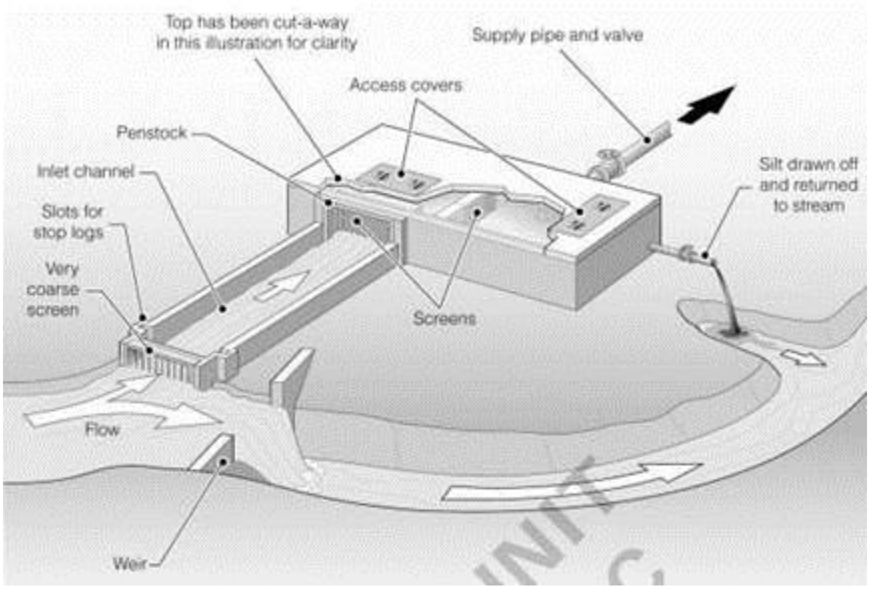


Figure 8.11: Typical Riverbank Intake

The side intake alternative has the advantage to be quite simple and requires little maintenance as compared to the two other preceding ones. However, important protection measures against erosion along the Riverbank where it will be installed should be provided. Moreover, results of morphologic study should also validate the location of the intake along the Riverbank for this kind of intake. Protection measures recommended by the morphology study should be adopted. It is worth noting that the intake bottom should always remain under the lowest water level and enough water depth should remain above the top of the intake in order to secure the flow of the required raw water quantities into the settling basins and pumps sump by gravity.

8.1.7.4 Comparison among Different Intake Types

A summarized comparison among the three above mentioned alternatives is given in **Table 8.4**.

Table 8.4: Advantages and Disadvantages of Different Options

Type of Intake	Advantages	Disadvantages
Submerged Intake	• Avoids large structure on the river/riverbank • Less capital investment and relatively lower	• Cleaning arrangements for the pipes will be necessary but with the provision of higher velocity this may be avoided.

Type of Intake	Advantages	Disadvantages
	maintenance cost • Also avoids navigation problems	
Tower Intake	• Less sediment deposition • Economy in pipe size	• Initial capital cost is very high • May create navigation problem • High operation and maintenance cost
Riverbank Intake	• Simple structure • Maintenance is relatively simple	• Large structure on Riverbank • Possible sedimentation/scouring

8.1.7.5 Optimum Intake Type for BEZA SWTP

Taking into consideration prevailing conditions in Osmanpur area, the Tower intake solution appears to be the most attractive not only in cost but also in control and maintenance. This recommendation is also based on the study conducted on analysis of historical satellite image consequences at the selected point.

For Feni River at Sonapur estimated historical lower water level is about 0.6 mPWD and highest water level is about 5.48 mPWD. Thus the intake pipes will be laid at -2.2 mPWD (2 m below the lowest water level).

Intake pipe edge can be found from the left bank at about 25m. So, from distance and water depth view point, Sonapur seems potential location for intake.

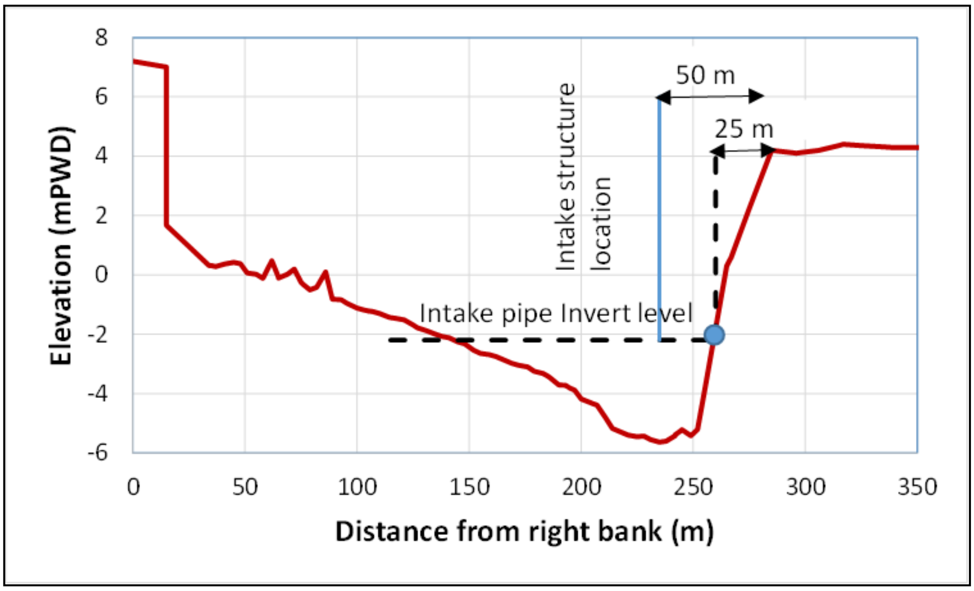


Figure 8.12: Cross-section along with intake pipe level

8.1.8 Uncertainties and Risks near Intake

The planform analysis for the past years shows that Feni River left bank is quite stable. But during major flood or due to strong earthquake the planform may changes.

As bed deposition-erosion observed at the right bank of the cross section near the intake, regular monitoring of bed aggression should be maintained.

The past year discharge shows decreasing tread though enough water is available in the Feni River and reservoir to ensure withdrawal water for the SWTP. Discharge data shows that the most critical month is February. In dry year there is possibility of zero flow in Feni River in February. But in that case water can be withdrawn from Feni reservoir without interrupting irrigation water demand.

At present that is no water diversion at upstream of Feni, Muhuri or Selonia river which feed water at the intake location. In future if there is any water diversion or major withdrawal, water availability may be at risk for the proposed SWTP. In that case Regional Corporation or treaty is essential to ensure flow in these rivers.

The monitoring of river function requires specialization, BEZA may borrow the services of BWDB under some long term contract.

8.2 Outline Design of Intake Structure and Raw Water Transmission Main

8.2.1 Introduction

It has been observed that water quality of river Feni will be treatable by chemical process of treatment. Based on this assumption and conceptual outline design of the water treatment plant and its related works have been prepared. As soon as the process selection is finalized the design will be reviewed and modified where necessary.

This section will address outline design of various components considering the intake location at Azampur Mouza of Osmanpur Union along the Feni River. It mainly includes the design of intake structure with intake pump station and raw water transmission main until treatment facilities. Various solutions/options have been analyzed, and conclusions with recommendations have been made as summarized in the **Table 8.5.**

Table 8.5: Overview of Technical Alternatives

Structure	Alternative Method	Recommendations
Intake	Intake at bottom	Alternative
	Intake Tower	Alternative
	Pumping from the River body	Recommended
	Gravity Intake channel	Alternative
	Gravity Intake pipes	Alternative
Intake Pump Station	Pump station at Azampur for Mirshari WTP will be of rectangular size pump house with a provision of high tension (HT) electric line, step down transformer and standby generator	Recommended
Raw Water Transmission System	Pipe in Trench	Recommended
	Ductile Iron	Recommended for Raw water transmission main
	Steel	Recommended for canal & road crossings

Structure	Alternative Method	Recommendations
Road Crossings	Pipe laying by tunnelling under the road surface	Recommended
	Pipe laying by open excavation	Alternative
Discharge Point at Arrival	To the selected injection points of the Misharai WTP	Recommended

The proposed system includes the following facilities:

a) The intake is designed for 105 MLD (for 100 MLD of treated water in two phases),

b) In Phase-1 size of the raw water transmission main would be for 52.5 MLD of water up to the WTP. Provision will be kept for raw water transmission main of Phase-2 of similar capacity.

8.2.2 Design Capacity

Selection of design criteria and flow rates should reflect the longer planning period, appropriate for major intake facilities. Hydraulic criteria to be evaluated are summarized in **Table 8.6**. The need of constructing an enlarged intake facility in advance should be carefully evaluated, for the likely capacity increase under future need. This would mean installing an oversized screen structure or intake channel to facilitate future expansion. Hydraulic analysis considered a hydraulic overload condition to provide a safety factor against loss of capacity due to channel deterioration over time or for emergency conditions.

Table 8.6: Hydraulic Criteria for Intake Design

Flow criteria	Capacity	Remarks
Design flow	Q	Treatment plant capacity
Minimum flow	0.1Q to 0.2Q	System-specific
Ultimate flow	2.0Q or higher	System-specific
Hydraulic overload	1.25Q to 1.5Q	To evaluate for all design conditions

The intake should be designed to meet maximum water required for the SWTP (in two phases) during its projected service life, and the intake capacity should be available during the period of minimum water level.

The design flow for intake at Azampur is 105 MLD, which include 5% of water loss at the treatment plant due to backwashing and removal of sludge. Raw water transmission main in Phase-1 has been designed for 52.5 MLD.

8.2.3 Constituting Elements

To transmit of surface water flow from the River Feni to water treatment plant located at Poshchim Ichakhali is consist of a single transmission system with the following elements:

- An Intake consists of 3 nos. of pipe, constructed to collect the required flow from the River to the intake pump station irrespective of the water level in the watercourse;

- Pumping facilities to secure the transmission of required flow to the water treatment plants site (**Figure 8.13** and **Figure 8.14**);
- Buried type transmission main through the selected route and discharge into water treatment plant;

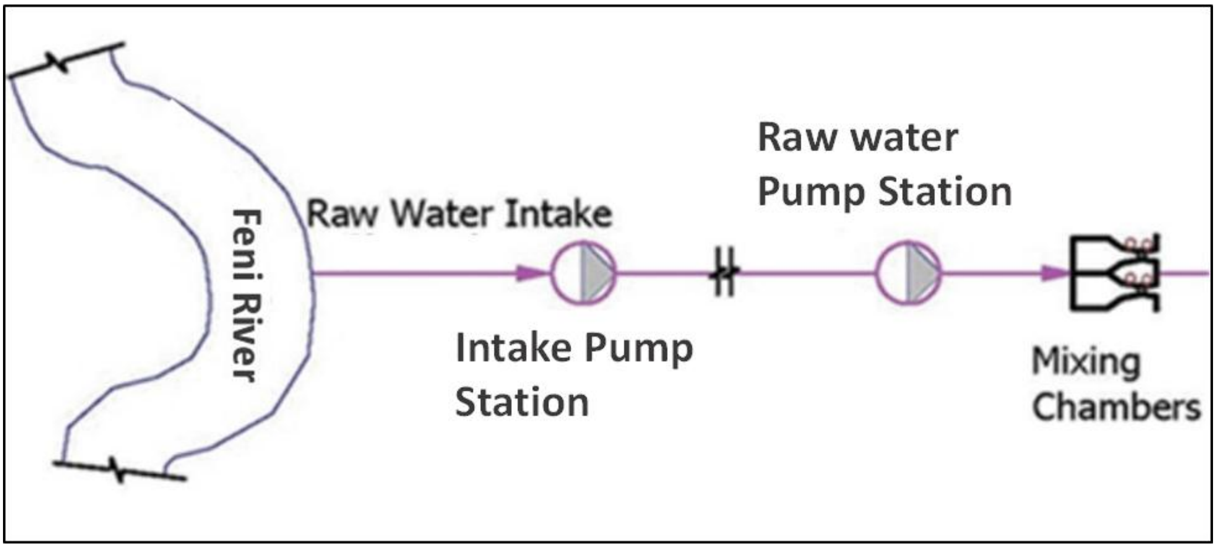


Figure 8.13: Process Diagram of Water Intake from River to Water Treatment Plant

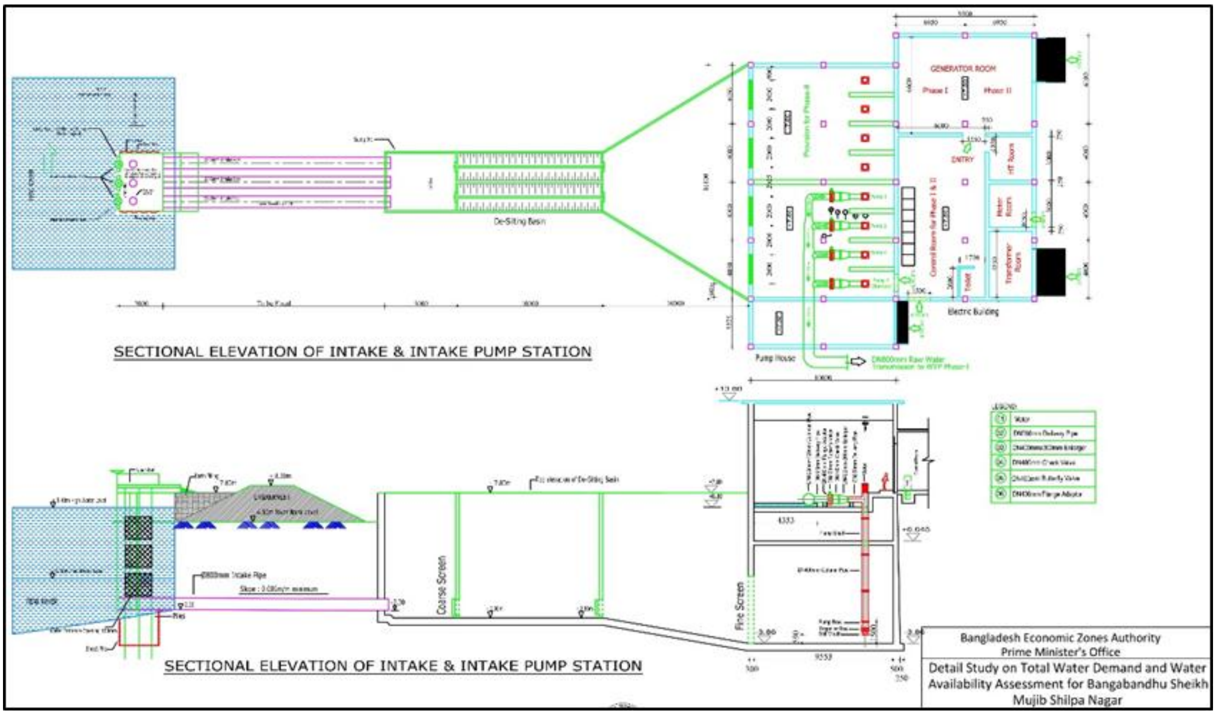


Figure 8.14: Layout of Intake Pumping Station

8.2.4 Riverbank Protection Works

Riverbank protection works in the form of revetment will be required along the stretch of 300m and 200m at both upstream & downstream of the intake and intake pumping station respectively.

8.2.4.1 Design Data

The design data of bank revetment for proposed site are given in below:

Table 8.7: Design Data for Bank Revetment (At Intake Point)

Sl. No.	Design Parameter	Value	Remarks
1	Design high water level (m PWD)	5.48	Observed highest water level (1986-2017)
2	Design lowest water level (m PWD)	0.6	Standard lowest water level (1986-2017)
3	Design velocity (m/sec)	0.6	Near bank maximum velocity
4	Existing bank level (m PWD)	4.5	Obtained from survey data
5	Present lowest bed level (m PWD)	-4.0	Near bank observed data

Table 8.8: The Other Parameters Used for Computation of Various Elements of Protection

Parameters	Value
Mass density of cc block (kg/m^3)	2,150
Mass density of water (kg/m^3)	1,000

8.2.4.2 Design Considerations

The following design considerations have been followed for detail design of various structural elements of bank protection works:

- **Design return period:** The return period for design of bank protection works has been used as 100 year.
- **Design discharge and water level:** Site specific annual maximum design discharge and annual maximum water level have been taken from mathematical model study result.
- **Design maximum velocity:** One of the most important design parameter for calculating the cover layer material size of bank protection works is depth average maximum velocity along the riverbank. The design velocity has been taken from model result.
- **Scour depth:** Structure induced depth of scour has been calculated using Lacey's formulae. The minimum bed level observed from the survey sections has also been taken into consideration in determining the design scour level.
- **Size of cover layer material**: The size of cover layer material has been calculated considering stability against velocity using widely used formula proposed by Pilarczyk.
- **Size of launching apron:** The length and thickness of launching apron have been based on design scour depth, apron setting level and concept of T.S.N. Rao as provided in BWDB's Design Manual. The placed apron is considered to be launch at 1:2 slopes.
- **Type of filter material:** Geo-textile has been used over sand filter.

- **Bedding layer:** A khoa bedding layer has been provided in between armor layer and geo-textile. The main functions of this layer are to prevent damages of geo-textile during placement of blocks, to prevent flapping of geo-textile which may cause loss of base material and also to prevent damage by ultra-violet light.

8.2.5 Design of Bank Protection Works

As per the requirements of Mirsharai WTP, the bank protection works have been considered as 300m upper stream and 200m downstream from the location of proposed intake at Azampur on the left bank of Feni River, taking the centerline of the channel as the baseline. The raw water pipes are designed with a desalting basing and desalting basing water will enter into the sump of the intake pump station. The bottom of the sump will be at least 2.0 m below the minimum water level of the river.

8.2.5.1 Slope protection

The proposed design top level of bank protection is at 7.8 mPWD, and it is 3.0m wide at the top. The embankment will be constructed with sandy soil and the soil imported from available source. And the design slope of the water facing side and the back side is 1:3 and 1:2 respectively. The protection structure of the water facing side is specified in sequence as follows: sandy soil slope, geotextile row, thick clay layer and brick lattice beam grass turf. The compactions of the embankment shall be no less than 92%.

The geotextile shall be provided with reinforced strips at certain spacing. Polypropylene woven fabric and polyester non-woven base fabric is supposed to be used. The upper end of geotextile shall be anchored within an anchoring trench and the anchoring trench shall be refilled with sand and then compacted. The clay layer could be clay from market or clay on site including natural clay, red clay, bentonite, loess or silty clay.

The lattice beam shall use the local clay brick laid with M7.5 cement mortar, which makes up the grid in 1m*1m. There should be 2m wide expansion joint at every 5m which is packed by tarred oakum. Settlement joint shall also be provided at places where soil property changes. Cross section of grid beam is in 24cm*24cm. The clay brick used here shall be of uniform texture and laid flat and stably and in staggering manner, using small stones to fill the gaps. The mortar for the masonry work shall be fully stuffed. The grid shall be refilled with planting soil and base fertilizer when the masonry work is finished. Grass shall be planted and curing shall be provided.

8.2.5.2 Foot Protection

The unit gabion is of 0.5(H)×2.0m(W)×2.0m(L), forming an integral gabion by connecting each other. And each unit shall be further divided into 4 parts in 0.5m×1m×1m. The steel wire is machine braided and is galfan (of 5% aluminum-zinc alloy and rare earth element) galvanized, and coated with plastic against corrosion. The gabion is throw-filled in two layers, the mesh whole size is of 60*80mm, packed with clay bricks inside. The diameter of the steel wire is of 2.0mm-4.0mm, with a tensile strength of no less than 380 MPa.

The geotextile shall be provided with reinforced strips at every certain spacing. Polypropylene woven fabric and polyester non-woven base fabric is supposed to be used. The geotextile shall be connected to the geotextile of the upper slope as an integral part. The top is anchored within an anchoring trench of 60cm wide or above and the bottom shall be pinned down by the gabion.

8.2.6 Design of Intake Structure

General Descriptions

The proposed piped intake consists of:

- A concrete intake structure in the river
- 3 pipes with diameter 1000 mm Glass fiber reinforced plastics (GRP) pipes transporting the raw water to the settling basin
- De-settling Basin

The piped intake avoids a large structure on the bank of the river (as in the case of the channel intake).

Design Considerations

The capacity of the intake will be 105 MLD with 3 pipes of 800 mm diameter; the velocity in the pipes at full capacity (0.61 m^3/s) will be 1.2 m/s. It is recommended that this minimum velocity is kept in order to avoid settlements in the pipes (sand should settle in the settling basin and not in the inlet pipe). The intake pipes can be constructed in seamless MS and buried in a trench and protected for outside damage e.g. ships at high water level) by concrete or a layer of soil and boulder.

Coarse screening

Three large safety screens with 5 cm mesh will be installed adjacent to the 3 inlet sluice gates, in order to prevent the intrusion in the system of large items floating or submerged. These screens may be checked on a regular basis and hand raked if needed. Bar screens shall be fabricated of stainless steel, with guides in stainless steel also.

Settling tank

Silt basins will be provided between the inlet pipes and the raw water pumping. They will be constituted of two rectangular shape adjacent tanks each connected to one of the three inlets Pipes. The tank will have 14m length and 5m width and its total height will be 9.0m. The tank bottom will be narrow for the collection of the deposited grits & other solid waste. It will have a “V” shape 0.80m deep trap ending with a collection trough where deposited grits and mud will be removed by pumping. Whatever will be the water level in the settling tanks, the average velocity of the flow should not be exceeding 0.15m/s.

The length of the tank, its depth, and the maximum expected average velocity of the raw water flow should always allow the retaining of 100 micron size solid particles and larger. Such a measure should be considered as enough to retain most of sand particles in the diverted raw water. Only colloid matters would remain, which are not considered as a threat for the transmission line operation at expected velocities. The settling tank bottom will be at -2.10 mPWD and the top of its wall will be fixed at +7.80 mPWD, i.e. at half meter vertical distance from the finished ground level. A protection guardrail should be installed on the settling tanks wall.

Two compartments will be provided at the tanks inlet and outlet. They will constitute a control box equipped with sluice gates. The outlet box will be constituted of two cells interconnected laterally with an opening equipped by a sluice gate which will remain closed during normal operation.

Mechanical screening

A battery of six fine screens in parallel will separate each de-settling basin from the pumping station sump, so a total of 6 rake automatic bar screens will be installed to provide fine screening (10 mm) of the inlet raw water. These self-cleansing screens shall be located at the inlet of each of the 6 pump sumps. At design flow these screens shall be capable of removing any additional detritus from the flow. The head loss through the screens should not, under normal operating conditions, lead to risk of cavitation in the pumps.

8.2.7 Design of Intake Pumping Station

8.2.7.1 General

The pump station consists of the following facilities:

- Pumps
- Control panels
- Electrical facilities
- The station compound furthermore includes the following facilities:
- Electrical sub-station and Transformers
- Standby generators
- Operators building with residence facilities
- Storage facility

8.2.7.2 Intake pumps

Detail consideration needs to be devoted to the intake pump design to serve various objectives, as follows-

- to prevent vortex formation
- to obtain uniform distribution of the inflow to all the operating pumps and to prevent starvation of any pump
- to maintain sufficient depth of water to avoid air entry during draw down

Civil structure of the intake pump station will be constructed for total capacity of 105 MLD. A total of 8 pumps (each of capacity 0.305 m^3/sec) will be installed for 105 MLD capacity intake. In the 1st phase 4 pumps will be installed and provision will be kept for installing 4 additional pumps under the 2nd phase of the project.

8.2.7.3 Choice and Design

Four (4) centrifugal vertical turbine mix flow pumps (including one for stand by and one for maintenance) have been considered. The capacity of each pump will be 0.305 m^3/s. To avoid mutual interference between two adjoining pumps by maintaining sufficient clearance of 2.0 m has been considered. To reduce the velocity gradually to about 0.25 m/s near the pump and to avoid sudden change in the direction of the flow tapered walls between the approach channels has been considered. Again to avoid dead spots bottom clearance of 0.25 m at the suction bell mouth has been considered also. A preferable slope of 10^0 is considered to avoid sudden drop between the approach channel and the sump. Adequate submergence of 2.0 m of the pump under the lowest water level has been considered in order to prevent entry of air during draw down and to satisfy NPSHr **(Figure 8.15).**

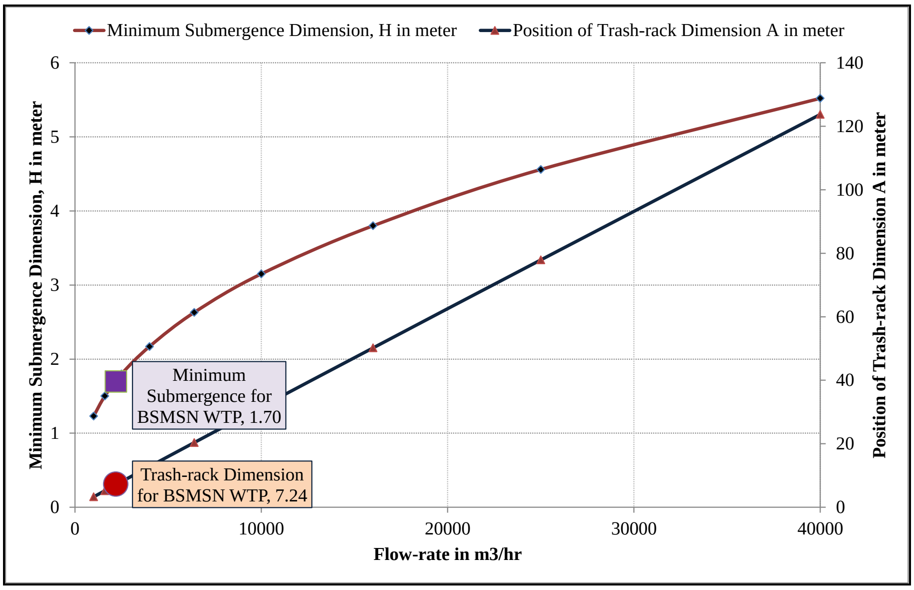


Figure 8.15: Determination of Minimum Submergence and the Position of Trash Rack According to CPHEEO, 1999.

Raw water from intake pumping station will enter into the treatment plant site through raw water transmission main having 800 mm diameter. Before entering into the pumping station an energy dissipation chamber will be constructed to reduce the velocity up to 0.6 m/s. A rectangular channel of about 25 m length will link the dissipater and the raw water pumping station. No additional screening is necessary for pump protection as a fine screening (10 mm) will be installed at the intake. The characteristic of the raw water pumping station are described in **Table 8.9** and **Table 8.10**.

Table 8.9: Characteristic of the Intake Pumping Station of Mirsharai WTP

Capacity of the pumping station	1.22 m^3/s
No. of on duty pumps	2
No. of Standby pumps	2
Capacity of each pump	0.305 m^3/s
Pump efficiency above	80 %

Table 8.10: Levels Used for the Design of Raw Water Intake

Maximum water level at intake pumping station	5.48 mPWD
Design low water level at intake pumping station	0.6 mPWD

Bottom level of the pump sump	-3.86 mPWD
Top level of pumping station	7.8 mPWD
Maximum estimated water level in intake pumping station	5.48 mPWD

8.2.7.4 Surge protection

Each row of four pumps will be interconnected to one of the transmission lines where an interconnection set of butterfly valves will be provided. Vertical type air vessel will be connected to the transmission line by a large size pipe at bottom. The top of the vessel will have a compression air chamber limited by a dipping/ventilation tube equipped with a shut off float valve for air admission and air escape. Such vessel is expected to secure three ways of operation:

- Compressed air vessel trapping air at top;
- Chimney to admit air with shut off valve float open;
- Air valve for air escape when all the water volume has been delivered to the piping system.
- The optimum flow per pump is estimated at 0.305m^3/s and the corresponding total dynamic head will be in the range of 25m. Nevertheless, final figure will be closely depending on:
  - The transmission line optimum size to be adopted;
  - The transmission pipe material; and
  - The position of the transmission line outlet as well as the water level of the discharge basin at the downstream end of the line.

8.2.7.5 Electromagnetic Flow Meters

In order to control flows transferred per each transmission pipe, 4 electromagnetic flow meters of DN400 mm shall be installed at the discharge of each pump.

This type of flow meters shall consist of a flanged flow tube and associated signal amplification and transmission equipment. The flow meter shall be sized so as to have a maximum range in excess of the design flow rate and an accuracy of 0.5% of span. The flow meter shall employ a pulsed DC excitation to ensure stable operation without the need for regular calibration. The flow convertor shall be housed in a separate enclosure mounted adjacent to the flow tube. The convertor shall provide the excitation for the flow tube and shall produce a 4-20 m. A analogue signal for connection to a chart recorder. The convertor shall also have a locally mounted digital display of actual flow rate and totalized quantity.

Flow meters shall be installed so that they are removable with the minimum of disturbance by disconnecting an adjacent flange adaptor or adjacent coupling. A suitable location should be proposed to insure flow meter accuracy and avoid non-linear flow turbulence resulting from valves or pipe elbows with minimum distance 10 m upstream and 5 m downstream.

8.2.7.6 Lifting Equipment

A double way 3 tons crane will secure installation of equipment and maintenance works as required. The crane and other auxiliary facilities shall be installed, for equipment heavier than 100 kg and requiring maintenance on a regular basis, like pumps and motors. It shall be arranged so as to be able to transport large items to an internal or external loading bay and lift it onto and off a lorry.

8.2.8 Electrical Installation

8.2.8.1 Power Requirements

A preliminary estimate has been made, based on the maximum power absorbed in steady state by units and the number of units running simultaneously:

Table 8.11: Power Requirements for Azampur Intake

Structural Elements	**Nominal Power Per Unit (KW)**	**No. of Installed Units**	**Total Installed Power (KW)**	**Number of Running Units**	**Absorbed Power Unit (KW)**	**Maximum Power Demand (KW)**
Intake Pumps at Azampur	130	4	520	2	104	208
Electro-magnetic flow meter-DN400mm	0.015	4	0.06	4	0.015	0.06
Lifting Equipment-3 ton bridge crane	2.0	1	2.0	1	2.0	2.0
Mechanical Screening-rack automatic bar screen	0.55	4	2.2	2	0.55	1.1
Mechanical sand removal-mobile bridge for raking & pumping	0.55	2	1.1	2	0.55	1.1
Provision for valves and actuators, ventilation, surge protection, switch boards, starters, variable speed drive, power factor correction capacity, alarm, lighting, general power, instrumentation and control	50	1	50	1	50	50
TOTAL			**575.36**			**262.26**

With P.F. 0.90 and a provision of 20 % as safety factor, it can be summarized as follows:

- Installed Load: 535.36 / 0.90 + 20 % = 714 kVA
- Application/Operation load: 246.26 / 0.90 + 20 % = 349 kVA

8.2.8.2 Power Consumption

Table 8.12: Power Consumption for Azampur Intake

Structural Elements	**Nominal Power Per Unit (KW)**	**No. of Installed Units**	**Number of Running Units**	**Absorbed Power Unit (KW)**	**Running Hours Per Day**	**Power Consumption (KWH) per Day**
Intake Pumps at Azampur	130	4	2	104	24	4992
Electro-magnetic flow meter-DN400mm	0.015	4	4	0.015	24	1.44
Lifting Equipment-3 ton bridge crane	2.0	1	1	2.0	0	0
Mechanical Screening-rack automatic bar screen	0.55	4	2	0.55	1.2	1.32
Mechanical sand removal-mobile bridge for raking & pumping	0.55	2	2	0.55	12	13.2
Provision for valves and actuators, ventilation, surge protection, switch boards, starters, variable speed drive, power factor correction capacity, alarm, lighting, general power, instrumentation and control	50	1	1	50	24	1200
TOTAL						**6207.96**

8.2.8.3 Power Distribution

As the usual and main source of energy, the electricity supply for the plant will be taken from Power Development Board (PDB) of Bangladesh. With an estimated installed load of about 714 kW and application / operation load of about 349 kW, an 11 KV/415 V substation will be provided with 350 KVA transformer. The 11 kV/ 415V sub stations will have H.T. switchgear equipped with P.T., P.C., Bus-bar, Vacuum Circuit Breaker, Meters, DC operating power supply, etc.

The power factor (P.F.) of electric motors for the intake pumps implements the quantified compensation with static power capacity to ensure a total minimum P.F of 0.95 at the switchboard bus-bar for the whole electrical system.

In general, the particular relevant applicable IEC, EN or ISO Standards will be used as well requirements of electricity utility company REB (Rural Electrification Board).

The following voltages will be used:

- 11 kV Network supply voltage from grid
- 415 V Generator network supply
- 415 V Supply voltage for pumps
- 3 x 400 / 230 V Power supply to small power consumptions
- 230VAC for lighting and plugs

- 110VAC for control power supply
- 24 V DC for control and signal voltage

The electricity power supply to the pumping station consists of two main systems:

- Electricity power supply through one voltage feeder with 11 kV cable from electricity utility company REB
- Electricity power supply from generators 415 kV with a capacity sufficient to power 2 duty pumps and necessary electrical equipment for operating the pump station.
- The main power including 11 kV medium voltage switchgear and low voltage switchgear 415V will be located inside the building. Transformers will be located outside buildings.
- Separate rooms for power distribution as:
- 11 KV switchgear from grid (Power generating station)
- 415 V switchgear from generator as well the generators (Power generating station)
- 11 KV medium voltage switchgears (Separate room in Pump room)
- 415 V variable frequency drive (Separate room in Pump room)
- 415/240 V low voltage switchgear (Separate room in Pump room)
- Outside building for transformers

Design parameters of transformers will be as per **Table 8.13**:

Table 8.13: Design Parameters of Transformers

Intake Pumping Station	Flow per each Pump	Initial Pump Head in mwc	Mechanical Power Requirement to Pump Efficiency Approximately: 80%	Power Factor Compensation to cos phi > 0.9	Safety Factor for Design of Transformers = 1.2;
Azampur intake to the Treatment Plant	1094 m3/h	26	96 KW	107 KVA	350 KVA

8.2.8.4 Standby Generators

Required Capacity

Stand-by generators for intake pumping station must allow the operation of the pumping station at full capacity excluding any degradation mode, with all plant options available when operating in generator mode. Based on the maximum power absorbed in steady state, minimum P.F. 0.95 and 20 % safety factor, required power capacity is 500 kVA.

Specifications

Proposed generators should be standard units, in this case 1 identical units of 500 kVA, to optimize standardization and redundancy.

The output voltage of the alternator powered by the generator will be 415 V to be connected to the Low-Tension distribution panel.

The generator room shall be sound proof shielded to reduce noise nuisance.

Energy Resource for Generator

Recommended option for back-up energy resource should be Diesel, as intake site is remote and not supplied from gas distribution network. Diesel fuel should be supplied by truck. An on-site fuel storage will be needed to secure not less than 6 hours operation during power failure (estimated capacity including 25% reserve: 2500 l), in addition to regular engine tanks.

It will be proposed to consider diesel power generators as base solution and to allow bidders to propose alternative gas or dual-fuel solutions, subject to their demonstration that their alternative solution is technically and economically preferable to the base one.

Control System

To ensure highest reliability during operation of the pump station in case of grid failure the emergency power generator system should allow continuous operation of all required equipment for the pump station process and required central facilities. For automatic control of feeder circuit breakers 415 V, a control system will manage the work to start up the entire pump station in case of grid failure and disconnection of the grid supply.

In case of a grid fault (no voltage, less voltage), the incoming circuit breaker for 11 kV grid supply will be switched off and the pump station will be shut down.

At the same time the generator system will be started automatically. Thereafter the control system will start the individual pumps in a sequence.

After the grid power is returned, detected by voltage measurement, the pumps will be switched off in a sequence and thereafter the emergency power system will be switched off and generators stopped.

Then feeder circuit breakers for 11 kV supply will be switched on automatically and the control system will again start the individual pumps in a sequence.

8.2.8.5 Power Supply System for Building Services and Control System

Power for the system of building services and control system as SCADA with Programmable Logic Controller (PLC) and redundant Uninterruptible Power Supply (UPS), one transformer with a capacity of 250kVA will be installed as well as a redundant similar transformer. The power shall be supplied through UPS having the function to supply continuously stable power even if the main normal power supply system has any failure. UPS shall be rated to supply the required load for 08 hours in case of a power outage. A redundant power system is essential because a failure in the supply of the control system will cause a complete shut-down of the entire pumping station.

8.2.8.6 Control and Monitoring

The pump house shall be provided with one set of Remote Control Unit (RTU) which includes a Programmable Logic Controller (PLC) in order to collect and store technical parameters of the intake pumping station, inlet works including settling channels.

Parameters concerned include operational signals of pumps and motors, control of processing equipment and delivered signals. All information will be sent to central control room at the pumping station building and to treatment facilities through wireless data transmission.

Flow Measuring

Each outlet on the main transmission line will be equipped with ultrasonic flow measuring device, sending signal to PLC.

Pressure Measuring

- Each outlet from the pump is equipped with a pressure sensor
- Transmission pipe is equipped with a pressure sensor.

Level Sensor in Pump Sump

- Level sensors shall be installed at suitable levels in the pump sump.

Controls

- Low level in pump sump: Pump operations will be controlled by level meters in the pump sump. If the water level drops below a certain level, then the pumps will stop one by one, in order to match the out flow to the inflow. At rising levels the pumps will start one by one.
- Very Low level in pump sump: All pumps will stop if the water level drops below a certain minimum level, in order to avoid damage to the pumps.
- High pressure in transmission line: A pressure sensor will register if the pressure in the main line rises and a signal is sent to the PLC, which will stop a pump. If the high pressure continues further pumps will be stopped.
- Low pressure in transmission line: If the pressure in the main line falls, a signal is sent to the PLC to start a pump.
- Very low pressure in outlet pipe: If the pressure suddenly drops with all pumps running, then the pumps stop (there may be a leak on the line).

8.2.9 Raw Water Transmission Main

Raw water transmission in closed type conduits will necessitate a special attention for the flow velocity to be considered. Velocities should remain enough high all through the transmission line in order to avoid a possible settling of suspended matters carried out in the water although large size particles are supposedly removed after a retention time in settling tanks that can be provided to the upstream side of pumping facilities and immediately after the intake structure.

With the removal of suspended matter particles sizing 100 microns and above from the raw water in settling basins the remaining will mainly consist of colloidal matters that can be removed at the water treatment plant.

Using cleansing velocity limits for sand particles sizing less than 100 microns, the threshold of the minimum average velocity to be secured in the pipe will be in the range of 0.6 m/s and the maximum velocity should be within 1.5 m/s. Considering this velocity criteria raw water transmission pipe may vary in size from 700 mm diameter to 1100 mm. It is to be mentioned here that higher diameter of pipe may reduce the pumping cost but the capital cost for pipe material will be much higher and ultimately will increase the project cost a lot. Thus considering economic viability of the project it is wise to choose pipe of lesser diameter. Considering above the pipe size for raw water transmission has been chosen 800 mm. ductile iron pipes is recommended for raw water transmission main. The total length of transmission main is 9.564 km. (**Figure 8.17)**. The details of pipe material selection, criteria for installation of pipes and transient protection are discussed in Sec. 8.6.

8.2.9.1 Transient Condition-Water Hammer Protection

Pressure surge or water hammer is generally occurring in pressure lines when the flow suddenly varies. The usual causes of flow changes in pressure line are: valves operation (opening/closing of valves), the starting or the stopping of pumps and/or power failure which has the most devastating effects as all pumps in operation come to a sudden stop simultaneously. The risk applies to positive and negative pressures as well. For the later, the pipes risk to buckle or even to collapse completely.

Measures to reduce water hammer will be ensured by slowly opening and closing of all valves and the start-up or stopping of pumps is not done at once but rather in sequence. However, the most critical conditions, specifically when several pumps are operating in parallel, will be a sudden stop of all of them due to power failure.

In order to limit the magnitude of anticipated surge pressures, the following appurtenances in the intake pumping station may be provided:

- At least two by pass lines connected between intake pumping station to discharge header
- Check valves at each pump delivery
- Installation tees and air release valve in each pump delivery

In addition, following measures may need to be taken:

- Normal pump starting and stopping will need to be staggered by at least 10 minutes' intervals
- After a power failure, the starting of the first pump will need to be delayed by at least 15 minutes
- Air valves are to be added along the raw water transmission main generally at 600 m interval allowing air entry and exit in order to avoid negative pressure.

Recommendation

In order to have an additional safety factor in the raw water transmission system, surge vessel/pressure vessel of sufficient capacity may need to be provided in the pump station delivery pipe. The decision have to be finalized in detail design report.

8.3 Option Studies for SWTP Location and Transmission Route Alignment

8.3.1 Selection of Location for SWTP

8.3.1.1 General

Selection of potential site for a new water treatment plant must take into consideration a number of factors. Some of the principal ones are:

- Proximity of plant site to the intake and to customers being served
- Consideration of water transmission requirements to interconnect the plant to the intake and the water distribution system
- Proximity of plant site to sludge disposal location
- Environmental and land use concerns
- Subsurface and geotechnical considerations
- Land availability, cost, and zoning
- Compatibility with surrounding, existing and planned developments
- Potential for flooding and storm water handling requirements
- Availability of utilities (power, natural gas, sewer, telephone etc.)
- Site topography and accessibility
- Vulnerability to security risks and natural disasters

Water supply source, treatment, and treated water transmission facilities must function as a complete system to provide a safe, reliable source of drinking water to the water distribution system.

8.3.1.2 Options for SWTP Location

The locations of the treatment plant have been selected for all the intake options independently. The options of the locations of the treatment plant are mentioned below:

- Option 1: Water Treatment Plant Location about 2.5 km upstream of the Feni regulator near confluence of the Azampur Khal and the Feni River
- Option 2: Water Treatment Plant Location at Takerhat

Proposed WTP sites are shown in **Figure 8.1**.

After successive field visits and in-depth discussions with the local people, the following treatment plant options are preliminary selected. The options of location of water treatment plant are described below:

Option 1: Water Treatment Plant Location at about 2.5 km upstream of the Feni regulator near confluence of the Azampur Khal and the Feni River (22^0 51′ 14.4″, 91^0 28′ 10.4″)

The proposed site is located near the confluence of the Azampur Khal and the Feni River. Sufficient land for constructing intake and water treatment plant is available at this site. The length of transmission main from the treatment plant to BEZA project area is about 10 km.

Muhuri project road and Vanghani road (BWDB old embankment) can be used for laying transmission main. But, the road is not straight enough to select the route of transmission. The proposed location of the WTP is nearby depression area, which might be used as a storage reservoir for dry weather flow. However, the requirement of storage reservoir is depending on the morphological and other associated studies

Option 2: Water Treatment Plant at Takerhat (22^0 48′ 37.2″, 91^0 27′ 47.64″)

The proposed water treatment plant is located at Takerhat near Takerhat Cyclone Centre is a close vicinity of BEZA project area. Land elevation is comparatively high and relatively suitable for flood protection. Sufficient land is available at this site.

8.3.1.3 Comparison among Different Options

A summarized comparison between the above mentioned options is given in **Table 8.14**.

Table 8.14: Comparison between SWTP Locations

SWTP Location	Advantages	Disadvantages
Option 1: Water Treatment Plant Location at about 2.5 km upstream of the Feni regulator near confluence of the Azampur Khal and the Feni River	• Sufficient land for WTP site is available but need aquisition. • Proximity of plant site to the intake will be comparatively easier. • Proximity of plant site to sludge disposal location will also be comparatively easier. • Availability of utilities (power, telephone etc.). • Sufficient land for impounding reservoir is available	• Consideration of water transmission requirements to interconnect the plant to the intake and the water distribution system. • Environmental and land use concerns will be comparatively less. • Site topography is in depression area and not easily accessible. • May vulnerable to security risks and natural disasters • 8 km away from economic zone 2A & 2B and route cover zigzag roads. Difficult to construct transmission main along the zigzag roads. • O&M cost will be comparatively high.
Option 2: Water Treatment Plant at Takerhat	• Sufficient land for WTP site is available. • Land cost is comparatively low • Water transmission requirements to interconnect the plant to the intake and the water distribution system will be	• Acquisition of land for construction of WTP is required. • Proximity of plant site to sludge disposal location has to be determined consciously. • Vulnerable to security risks and natural disasters

SWTP Location	Advantages	Disadvantages
	easier. • Compatible with surrounding, existing and planned developments. • Better resistance for flooding and storm water handling requirements. • Availability of utilities (power, telephone etc.). • Site topography is plain and the route of proposed plant is easily accessible.	

A map showing the proposed treatment plant locations at the economic zone is given **Figure 8.16.**

8.3.1.4 Optimum Location for SWTP

Based on the above mentioned facts, **Option 2** i.e. SWTP at Takerhat is likely to be the most reliable and cost effective. But after discussion with BEZA officials and availability of acquisition land**,** BEZA proposed a new location for SWTP located (**22°47'31.64"N, 91°27'17.96"E**) at Poshchim Ichakhali Mouza which is 1.5 km radial distance toward southwest direction form **Option 2**. This new location is just east side of CDSP embankment.

Though the new location is far away from the locality but the site is close vicinity of BEZA project priority area and it will be free from social disturbance. Moreover, permanent residence will be arranged in the vicinity of treatment plant for the staffs who will be involved with the operation and maintenance. Thus possible negative issues like enjoying facilities, spending time with family will not be of much concern. However, the **new Option** proposed by BEZA may be taken into consideration subjected to the availability of land and other technicalities.

Two treatment plant at the selected location will be constructed in two phases with each 50MLD capacity. The proposed treatment plant location by BEZA is given in **Figure 8.16**.

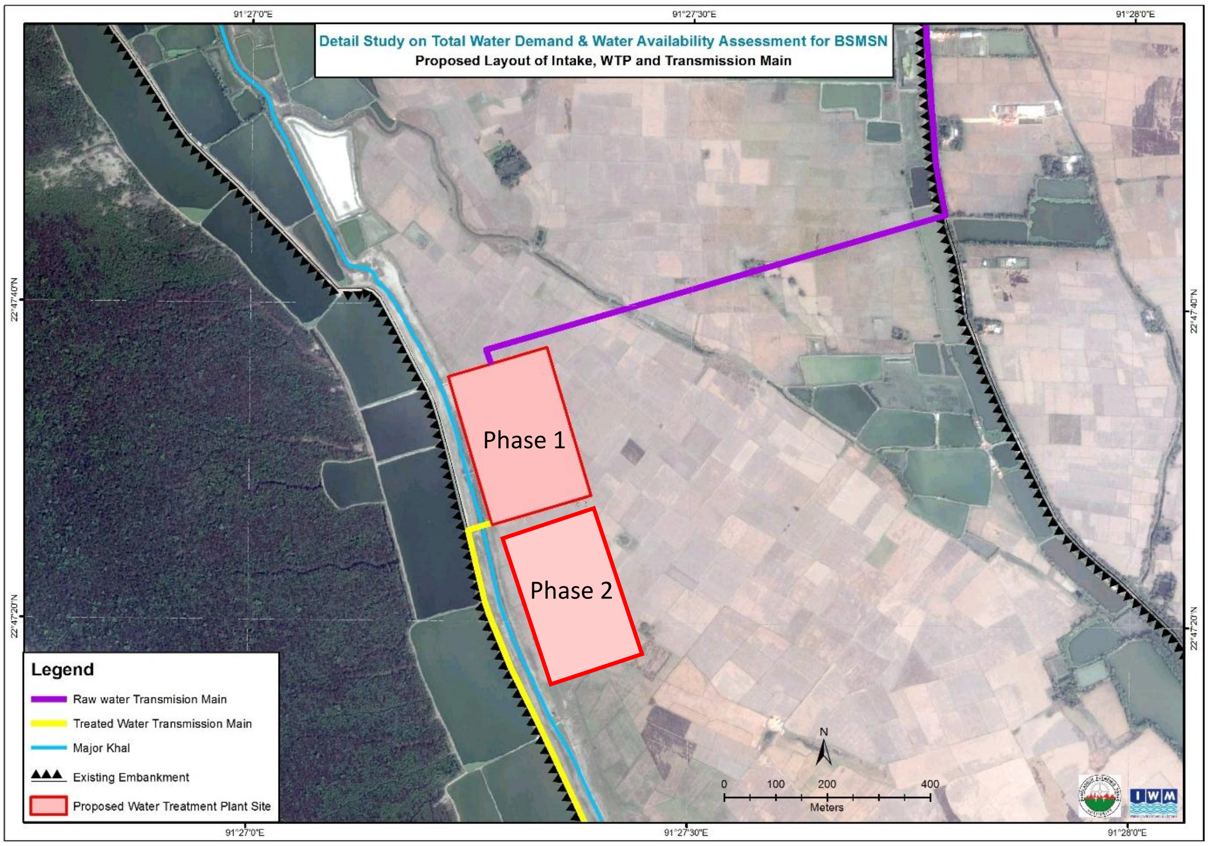


Figure 8.16: Map Showing the Proposed Treatment Plant Locations at Takerhat beside CDSP embankment

8.3.2 Selection of Water Transmission Main Alignment

Treated water from the WTP can be transported to the priority area along the existing CDSP embankment. After that the transmission main follow main road as per the master plan proposed (**Figure 8.17**).

8.3.3 Khal Crossing & Other Barriers

According to the field condition, the transmission main will cross khals and culverts. These crossings should be made by maintaining gentle slope and using small angled bents. Pipe jacking construction method is recommended for such crossings if necessary. Diameter of the jacking pipe should be sufficient so that the transmission main can pass through the jacking pipes smoothly.

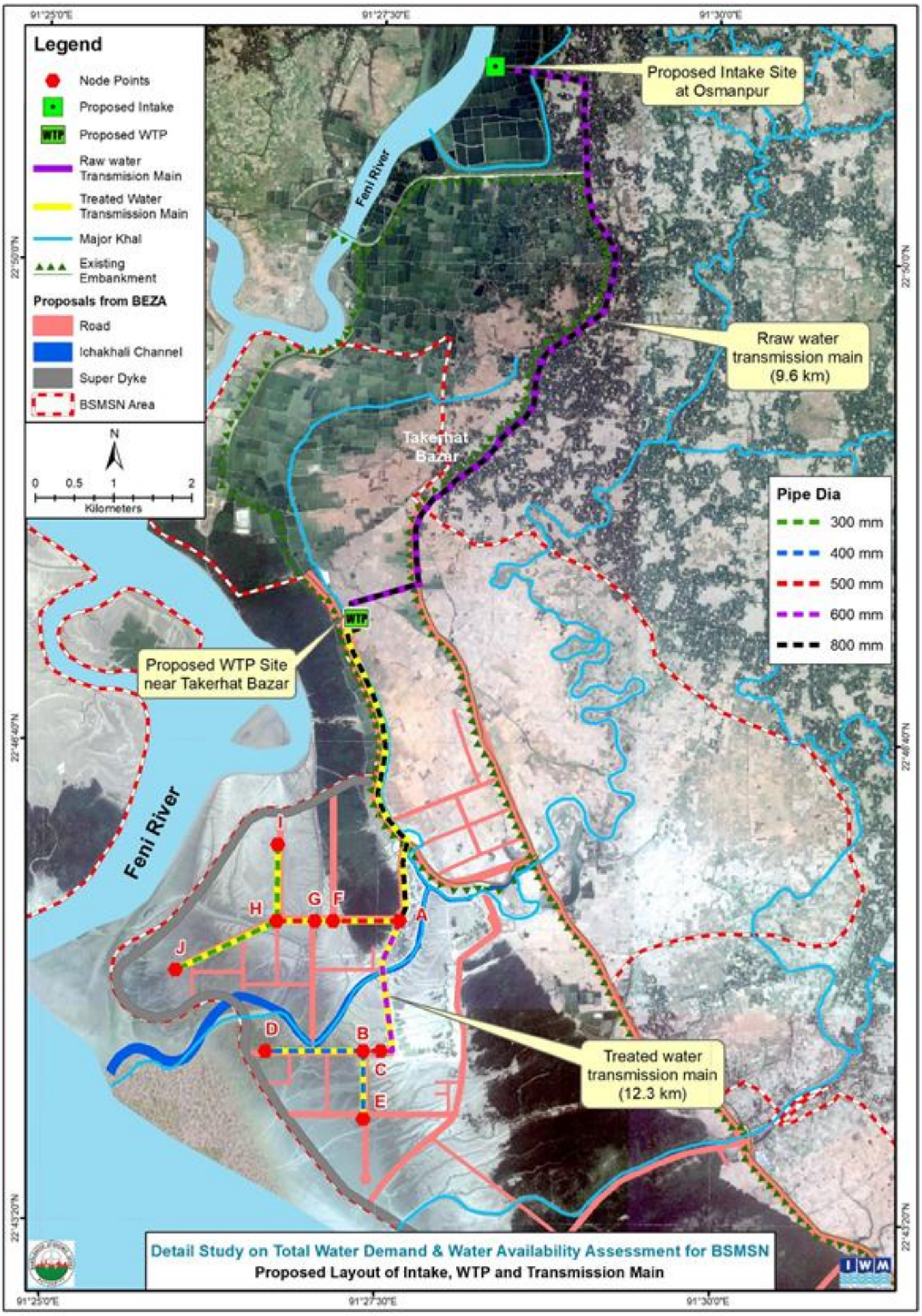


Figure 8.17: Selected Treated Water Transmission Main Route

8.4 Selection of Treatment Process for SWTP

8.4.1 Introduction

8.4.1.1 Background

Institute of Water Modelling (IWM) has engaged The Bureau of Research, Testing, and Consultation (BRTC) of Bangladesh University of Engineering and Technology (BUET) to carrying out a detailed study to select the treatment processes for the proposed water treatment plant.

8.4.1.2 Objective and Scope of treatment process selection

The main objective is to select the water treatment processes to supply water to the BSMSN area. The specific aims and scopes are:

- Finalize the proposed selected intake for the water treatment plant.
- Investigate the water quality of the raw water at the two locations identified as potential sources and select the most appropriate location for the treatment operation.
- Identify, develop, and carry out model studies to investigate various treatment processes.
- Select the required treatment processes to get the treatable water that would satisfy the drinking water standard in Bangladesh.
- Find the required chemical doses for the selected treatment processes to get the drinkable water from the treatment plant.

8.4.2 Outline of Methodology

For detail characterization of river water and carrying out of process studies, a water sampling program was chalked out, which involved collection of water samples from selected locations near the BSMSN (see Section 7.4 for details) during both dry season and wet season. Six sampling campaigns have been undertaken (from July 2018 to March 2019). For detail characterization, the collected water samples were analyzed for a wide range of parameters, including Temperature, pH, Color (true and apparent), Turbidity, Electrical Conductivity (EC), TDS, TSS, Iron, Ammonia, Total Coliform, Fecal Coliform (FC), Dissolved Oxygen (DO), COD, BOD_5, and Chlorophyll-a.

For selection of appropriate treatment processes for the proposed WTP, the raw water quality parameters were compared with Bangladesh drinking water standard, and the parameters which did not satisfy the standard were identified. Then a number of process studies were carried out to remove the identified pollutants from the water samples collected from the Feni River. Based on the target pollutants, different processes were studied to determine their effectiveness in removing the pollutants. The process studies included pre-chlorination, plain sedimentation, coagulation-flocculation-sedimentation, rapid sand filtration, and post-chlorination. Based on the results of the process studies, the chain of treatment processes has been selected and design parameters have been established. The characteristics of treated water achieved after employing the selected treatment processes were determined and compared with Bangladesh drinking water standard.

8.4.3 Water Sampling Program

To capture seasonal variation of water quality, raw water samples of the Feni River were collected during both dry and wet seasons. Six sampling campaigns have been conducted from July, 2018 to March, 2019. Water samples were collected from two locations during each sampling campaign: (a) proposed intake site in Feni River at Azampur, and (b) Ichakhali Khal at Jhulonpul Bazar. Although Azampur site was tentatively selected as the intake location by IWM, water samples were also collected from the additional location at Jhulonpul Bazar to compare the water quality of this location with the water collected from Azampur site. The sampling locations are shown in **Figure 8.18** and the details of the sampling campaigns are presented in **Table 8.15**.

Figure 8.18: Location of the sampling sites.

At each sampling site, the sampling location was about 100 – 150 ft from the Riverbank water line and water samples were collected manually from a depth of about 0.30 mm below the water surface to avoid the presence of floating impurities using a pre-washed container. The container was rinsed with the river water prior to the sample collection. Separate sampling bottles were used for collecting water samples for physical and chemical water quality analysis, bacteriological water quality analysis, metal concentration analysis (acidified sample using HNO_3 acid) for each location. The sampling campaign was carried out jointly by BUET and IWM.

Table 8.15: Time and location of the six sampling campaigns

Sampling Location	Azampur (Feni River)	Jhulonpul Bazar (Ichakhali Khal)
GPS Co-ordinates	22°51’27.50” N 91°28’11.10” E	22°48’45.56” N 91°29’31.55” E
Batch No.	**Time of Sample Collection**	
Batch 1	17/07/2018 - 18/07/2018 (wet season)	
Batch 2	01/09/2018 - 02/09/2018 (wet season)	
Batch 3	10/10/2018 - 11/10/2018 (wet season)	
Batch 4	28/01/2019 - 29/01/2019 (dry season)	

Sampling Location	Azampur (Feni River)	Jhulonpul Bazar (Ichakhali Khal)
Batch 5	25/02/2019 - 26/02/2019 (dry season)	
Batch 6	13/03/2019 – 14/03/2019 (dry season)	

During each sampling campaign, in-situ measurements were done for a number of water quality parameters (pH, Temperature, Turbidity, and DO). All collected water samples except those to be used for process studies were put into ice box and all the samples were transported to the Environmental Engineering Laboratory of the Department of Civil Engineering, BUET quickly for water quality parameters testing and batch experiments for treatment process selection.

8.4.4 Testing of Water Samples

8.4.4.1 In-situ Testing

A few water quality parameters were tested at the sampling site just after sample collection, because of possible changes of their values with passage of time. These parameters included pH, dissolved oxygen (DO), temperature and turbidity. A pH meter, a DO meter (fitted with a temperature probe), and a turbidimeter were used for these in-situ measurements.

8.4.4.2 Testing at BUET Laboratory

As soon as the water samples reached BUET Laboratory, detailed laboratory analysis of the six batches of collected water samples were carried out to determine the water quality and the extent of treatment required to make them potable. The water quality parameters selected include Color (true and apparent), Electrical Conductivity (EC), TDS, TSS, Iron, Ammonia, Total Coliform, Fecal Coliform (FC), COD, BOD5, and Chlorophyll-a. The water quality parameters were measured following Standard Methods (APHA).

8.4.5 Characteristics of Raw Water Collected from the Sites

The results of the in-situ testing and laboratory analysis (at BUET) of raw water samples collected in the wet season from the Azampur site are presented in **Table 8.16**, along with Bangladesh Drinking Water Standard (GoB, 1997). Similar results for the sample collected in the dry season from Azampur site are presented in **Table 8.17, Table 8.18** and **Table 8.19** present the raw water analysis data of the samples collected from Jhulonpul Bazar site in wet and dry season, respectively. In these Tables, the parameter values not satisfying the corresponding drinking water standards have been marked in "bold" font style.

Table 8.16: Characteristics of raw water collected in the first three batches from Feni River at Azampur location.

Sl. No.	**Water Quality Parameter**	**Unit**	**Concentration Present**			**Bangladesh Drinking Water Standard**
			Batch 1	**Batch 2**	**Batch 3**	
1	pH	-	7.35	7.62	7.18	6.5-8.5
2	Color (Apparent)	Pt-Co	**628**	**314**	**376**	15
3	Color (True)	Pt-Co	**176**	**147**	**147**	15
4	Turbidity	NTU	**218**	**69**	**72.4**	10

Sl. No.	Water Quality Parameter	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 1	Batch 2	Batch 3	
5	Total Dissolved Solids (TDS)	mg/L	78	88	118	1000
6	Iron (Fe)	mg/L	**3**	**3**	**1.52**	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	**8600**	**TNTC**	**TNTC**	0
8	Fecal Coliform (FC)	CFU/100 mL	**7000**	**TNTC**	**160**	0
9	Electrical Conductivity (EC) at 25°C	µS/cm	125	143	163	--
10	Dissolved Oxygen (DO)	mg/L	6.32	6.32	**5.44**	6
11	Ammonia (NH_3-N)	mg/L	0.4	0.45	0.26	--
12	Total Suspended Solids (TSS)	mg/L	**186**	**42**	**26**	10
13	Temperature	°C	**30.1**	29.6	28.9	20-30
14	Chemical Oxygen Demand (COD)	mg/L	**7**	**7**	**12**	4
15	Biochemical Oxygen Demand (BOD_5)	mg/L	**0.8**	**3**	**3.2**	0.2
16	Chlorophyll-a	µg/L	1.2	3.2	2	--

Table 8.17: Characteristics of raw water collected in the dry season (Batch 4, 5, and 6) from Feni River at Azampur location.

Sl. No.	Water Quality Parameter	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 4	Batch 5	Batch 6	
1	pH	-	7.19	7.42	7.59	6.5-8.5
2	Color (Apparent)	Pt-Co	**244**	**636**	**404**	15
3	Color (True)	Pt-Co	**176**	**280**	**224**	15
4	Turbidity	NTU	**46.2**	**80.2**	**55.8**	10
5	Total Dissolved Solids (TDS)	mg/L	119	160	132	1000
6	Iron (Fe)	mg/L	**1.04**	**1.6**	**2.0**	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	**38**	**380**	**1050**	0
8	Fecal Coliform (FC)	CFU/100 mL	**10**	**240**	**350**	0
9	Electrical Conductivity (EC) at 25°C	µS/cm	178	210	190	--
10	Dissolved Oxygen (DO)	mg/L	6.51	6.19	**5.48**	6
11	Ammonia (NH_3-N)	mg/L	0.41	0.53	0.38	--
12	Total Suspended Solids (TSS)	mg/L	**23**	**32**	**36**	10
13	Temperature	°C	21.2	22.8	26.1	20-30
14	Chemical Oxygen Demand (COD)	mg/L	2	**5**	**6**	4
15	Biochemical Oxygen Demand (BOD_5)	mg/L	**0.4**	**1**	**2.6**	0.2
16	Chlorophyll-a	µg/L	8.2	1.2	37.8	--

Table 8.18: Characteristics of raw water collected in the first three batches from Ichakhali Khal at Jhulanpul Bazar location.

Sl. No.	Water Quality Parameter	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 1	Batch 2	Batch 3	
1	pH	-	7.14	7.07	7.34	6.5-8.5
2	Color (Apparent)	Pt-Co	**1084**	**361**	**194**	15
3	Color (True)	Pt-Co	**130**	**201**	**33**	15
4	Turbidity	NTU	**190**	**152**	**78.3**	10
5	Total Dissolved Solids (TDS)	mg/L	75	71	133	1000
6	Iron (Fe)	mg/L	**3.2**	**4.8**	**2**	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	**26000**	**TNTC**	**TNTC**	0
8	Fecal Coliform (FC)	CFU/100 mL	**17400**	**TNTC**	**TNTC**	0
9	Electrical Conductivity (EC) at 25°C	µS/cm	113	136	247	--
10	Dissolved Oxygen (DO)	mg/L	**5.95**	**5.31**	**5.48**	6
11	Ammonia (NH_3-N)	mg/L	0.55	0.8	1.48	--
12	Total Suspended Solids (TSS)	mg/L	**153**	**119**	**97**	10
13	Temperature	°C	29.6	29.5	27.7	20-30
14	Chemical Oxygen Demand (COD)	mg/L	**10**	**11**	**13**	4
15	Biochemical Oxygen Demand (BOD_5)	mg/L	**2.8**	**2.8**	**3.6**	0.2
16	Chlorophyll-a	µg/L	3.7	5.1	0	--

Table 8.19: Characteristics of raw water collected in the dry season (Batch 4, 5, and 6) from Ichakhali Khal at Jhulonpul Bazar location.

Sl. No.	Water Quality Parameter	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 4	Batch 5	Batch 6	
1	pH	-	**--**	7.26	7.49	6.5-8.5
2	Color (Apparent)	Pt-Co	**--**	**150**	**197**	15
3	Color (True)	Pt-Co	**--**	**64**	**122**	15
4	Turbidity	NTU	**--**	**26.3**	**39.2**	10
5	Total Dissolved Solids (TDS)	mg/L	**--**	129	136	1000
6	Iron (Fe)	mg/L	**--**	0.70	**1.28**	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	**--**	**TNTC**	**TNTC**	0
8	Fecal Coliform (FC)	CFU/100 mL	**--**	**TNTC**	**TNTC**	0
9	Electrical Conductivity (EC) at 25°C	µS/cm	**--**	221	216	--
10	Dissolved Oxygen (DO)	mg/L	**--**	**4.44**	**4.18**	6
11	Ammonia (NH_3-N)	mg/L	**--**	0.38	0.35	--
12	Total Suspended Solids (TSS)	mg/L	**--**	**27**	**32**	10

Sl. No.	Water Quality Parameter	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 4	Batch 5	Batch 6	
13	Temperature	^oC	--	22.1	28.8	20-30
14	Chemical Oxygen Demand (COD)	mg/L	--	**7**	**5**	4
15	Biochemical Oxygen Demand (BOD_5)	mg/L	--	**1**	**1.6**	0.2
16	Chlorophyll-a	µg/L	--	0.9	6.8	--

Table 8.16 – 8.19 show that water quality at these two sites (Azampur and Jhulonpul Bazar) does not differ much. With some exception, for most of the samples, the apparent color, true color, turbidity, total suspended solids, iron, fecal coliform, total coliform, COD and BOD5 concentrations exceed the Bangladesh Drinking Water Standard. It can be concluded, based on the test results, that to make the raw water from the proposed intake site suitable for drinking purpose, treatment of this water is necessary for the removal of color (apparent and true), turbidity, total suspended solids, total coliform, fecal coliform, iron and organic matter (BOD and COD).

8.4.6 Treatment Process Studies

To remove the impurities identified above from the raw water of the Feni River at Azampur site, separate process studies have been conducted with the water sample collected during all six sampling campaigns. The results from the process studies are discussed in the following Section.

8.4.6.1 Imhoff Cone Test

Imhoff cone test was done to determine the concentration of settleable suspended solids present in the raw water sample collected from the Feni River at Azampur site. Required volume of raw water (1 Liter) was placed in an Imhoff cone and the water was stirred to have a uniform mixture. Then the settling of the suspended particles was observed from time to time. The results of the Imhoff cone test of the samples that are collected during all six batches are presented in **Table 8.20**.

It was observed that for samples collected in all six batches are very small. Though the volume of settled solids of the sample collected in batch 1 (July 2018 – wet season) is the highest, it was still very small (<0.2 ml) even after a very long detention time (over three hours). For all other batches the volume of settled solids are even smaller (<0.02 ml). It should be noted that the TSS concentrations of the water sample is the highest (186 mg/l) among all the six batches. TSS of the samples of Batch 2, Batch 3, Batch 4, Batch 5, and Batch 6 are smaller (<50 mg/L). The Imhoff cone test results clearly show that only plain sedimentation is not suitable for removal of suspended solids as well as turbidity from the raw water.

Table 8.20: Volume of settled solids in Imhoff cone tests carried out with samples collected from Feni River at Azampur site in different batches

	Batch 1 (Jul 2018)	**Batch 2 (Sep 2018)**	**Batch 3 (Oct 2018)**	**Batch 4 (Jan 2019)**	**Batch 5 (Feb 2019)**	**Batch 6 (Mar 2019)**
Turbidity (NTU)	218	69	72.4	46.2	80.2	55.8
TSS (mg/L)	186	42	26	23	32	36
Settling Time (hour)	**Volume of Settled Solids (ml)**					
0	0	0	0	0	0	0
0.5	<0.1	0	<0.01	0	0	0
1	<0.15	0	<0.01	0	0	0
2	<0.2	0	<0.02	0	0	0
3	<0.2	0	<0.02	0	0	~0.1

8.4.6.2 Pre-chlorination Test

Break point chlorination test was carried out with the raw water samples to estimate chlorine dose to be employed during “pre-chlorination”. Pre-chlorination test was carried out for all three sets of raw water samples collected so far. Bleaching powder was used as the source of chlorine and a contact time of 30 minutes was employed. After the completion of contact time, the residual chlorine was measured. The results from the batch chlorination test are presented in **Figure 8.19**. From the figure, break-point was identified, and pre-chlorination doses were selected for the different raw water samples (**Table 8.21**). The pre-chlorination dose for the raw water varies between 2 to 4.5 mg/L for the samples collected at various batches. Pre-chlorination dose is the highest (4.5 mg/L) for the Batch 5 sample collected in February 2019 and the lowest for the Batch 3 sample collected in October 2018. For the samples of Batch 2 and Batch 4, required dose is 4 mg/L, while required dose for Batch 1 and Batch 6 is 3 mg/L.

The pre-chlorination doses were applied to raw water samples during the subsequent process studies and tests (e.g., Jar tests). It should be noted that pre-chlorination of raw water is often carried out in surface water treatment plants (e.g., Saidabad Water Treatment Plant in Dhaka), not only to kill pathogens but also for prevention of algal growth and efficient removal of algae in the subsequent unit operations (e.g., coagulation-flocculation-sedimentation).

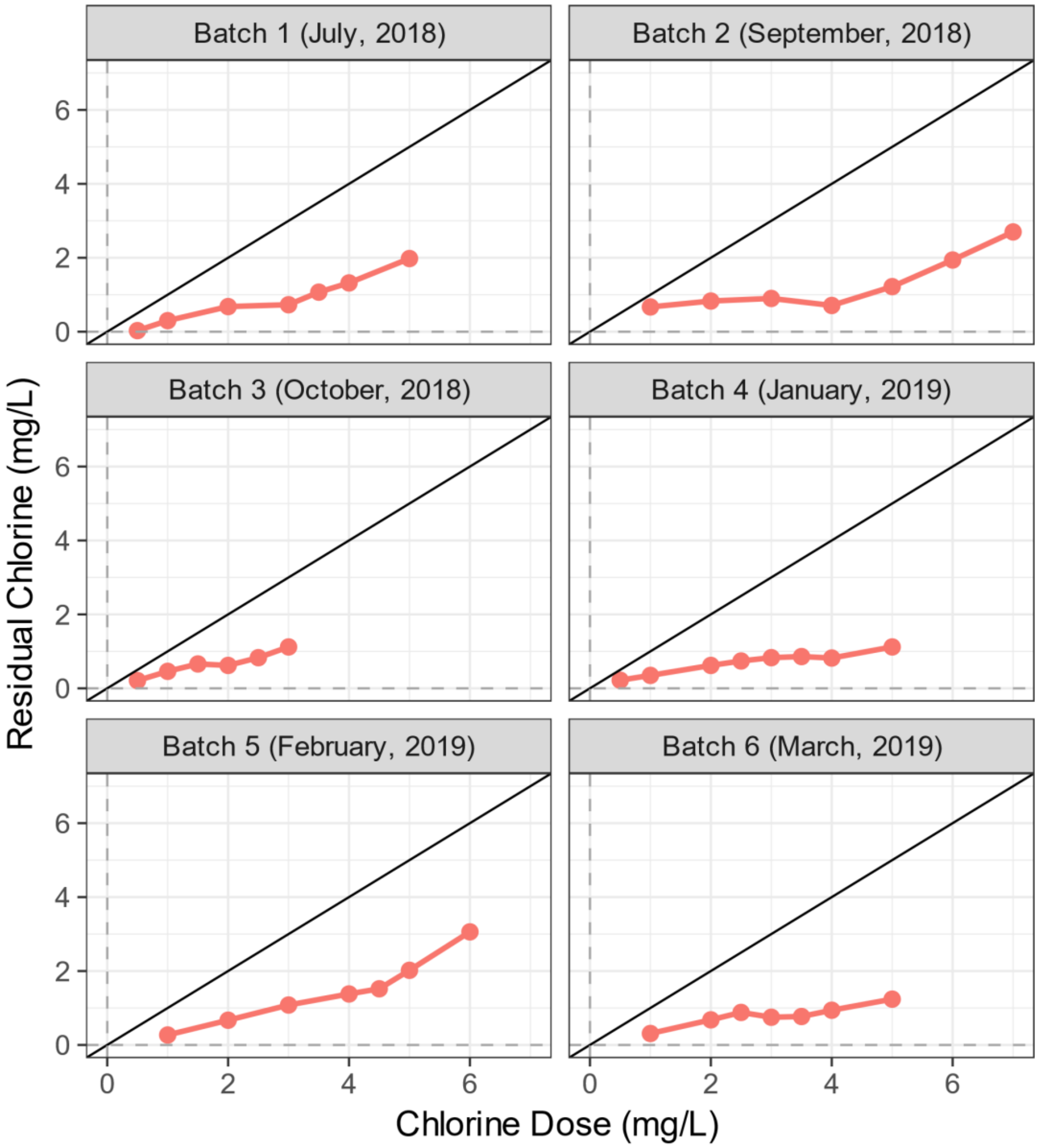


Figure 8.19: Break Point Chlorination Curve raw water sample from Feni River at Azampur site

Table 8.21: Chlorine Dose for the pre-chlorination of samples collected from Feni River at Azampur site in different batche.

Sampling Batch	Sampling Time	Chlorine Dose (mg/L)
Batch 1	July 2018	3.0
Batch 2	September 2018	4.0
Batch 3	October 2018	2.0
Batch 4	January 2019	4.0
Batch 5	February 2019	4.5
Batch 6	March 2019	3.0

8.4.6.3 Coagulation-Flocculation-Sedimentation Test (Jar Test)

Coagulation-flocculation-sedimentation test (Jar test) is widely used for determination of optimum coagulant dose for removal of turbidity and color of water. Alum (aluminum sulfate) is an easily available and cheaper coagulant. Hence, this chemical was used as the coagulant for the jar tests. Jar tests were carried out for all three sets of raw water sample collected from Feni River at Azampur site so far.

For each set, 500 mL water sample was taken in each of a series of 1000 mL beakers. Prior to jar test, pre-chlorination (with 30 minutes of contact time) of the raw water samples were carried out with chlorine dose determined in the earlier from pre-chlorination tests described in Section 8.4.6.2. Different alum doses, varying from 25 to 400 mg/L, were employed in the jar tests. After addition of the required volume of alum stock solutions in the beakers containing raw water samples (to attain desired alum dose), a rapid mixing (45 rpm) of one minute duration was applied to the contents of each beaker followed by a slow mixing (25 rpm) of 19 minutes. For the Batch 1 sample, the tests were performed with additional two different mixing time – 1 minute rapid mixing followed by a slow mixing of 9 and 14 minutes. For each different mixing time, after a settling time of 10 minutes, the residual turbidity and pH were measured. Changes in turbidity and pH during the Jar test with alum as the coagulant is presented in **Figure 8.20 and Figure 8.21**. Initial turbidity of the samples collected in the wet season (Batch 1, Batch 2, and Batch 3) were relatively higher with Batch 1 sample being the most turbid (**Table 8.22**). For Batch 1 sample collected in July 2018, the coagulation-flocculation-sedimentation process reduced the turbidity below 3 NTU with alum dose of 70mg/L if the mixing time was20 minutes. However, with alum dose 50 mg/l or higher the pH of water is decreased and falls below 6.5. For the samples collected in Batch 2, Batch 3, and Batch 4, the alum dose of 75 mg/L was also able to reduce the turbidity below 3 mg/L. However, for each of these three batch, the pH falls below 6.5 at this dose with mixing time of 20 minutes. For Batch 5 sample (in dry season), 75 mg/L of alum dose was also required to get the turbidity below 3 mg/L and the pH remained above 6.5. However, the samples collected in Batch 6 (in dry season), turbidity was less than 3 NTU even at 50 mg/L of alum dose with pH within 7.0 – 7.5.

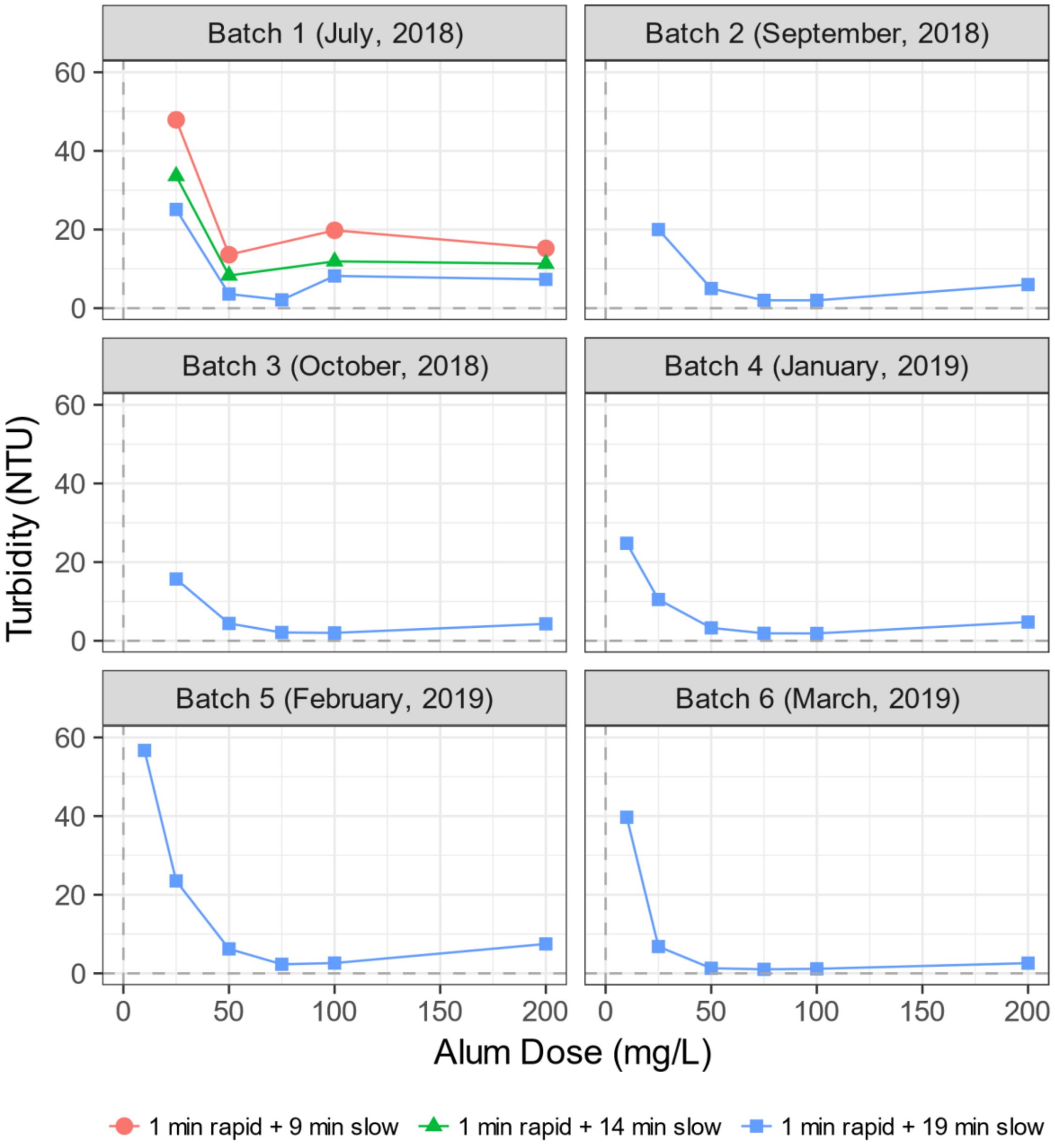


Figure 8.20: Variation of residual turbidity with alum dose for Feni River water sample collected from the Azampur site in all six batches

As the application of alum as coagulant resulted in significant drop in pH, Poly-Aluminium Chloride (PAC) was used as an alternative coagulant. **Figure 8.22** and **Figure 8.23** present the turbidity and pH of the treated water with varying PAC dose. For the samples collected in Batch 1, Batch 2, and Batch 3(wet season), turbidity was reduced below 3 mg/l with PAC dose of 25 mg/l (with 20-minute mixing time). Additionally, the pH value remained above 6.5 (Bangladesh standard for drinking water) for all these three batches, when PAC was used as the coagulant. At the same PAC dose (25 mg/L) and 20-minute mixing time, turbidity of the samples collected in Batch 4 and Batch 5 (dry season) reduced to less than 4 mg/L with pH > 6.5. However, 25 mg/L of PAC dose was able to reduce the turbidity below 3 mg/L with pH > 6.5 when mixing time is 20 minutes. True color of the water after coagulation-flocculation-sedimentation with PAC was below 5 mg/L for all the six batches

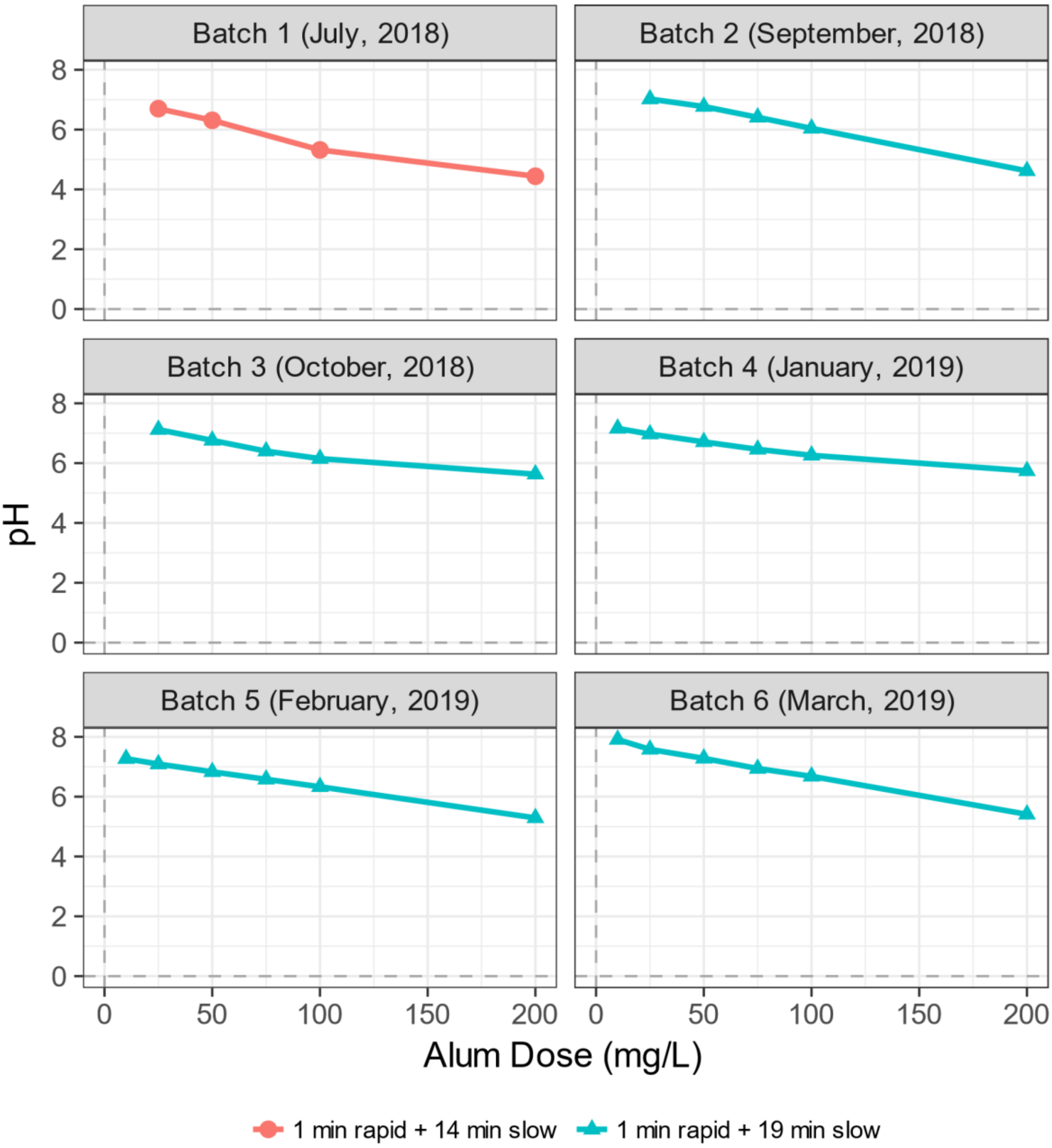


Figure 8.21: Variation of pH with alum dose for Feni River water sample collected from the Azampur site in all six batches

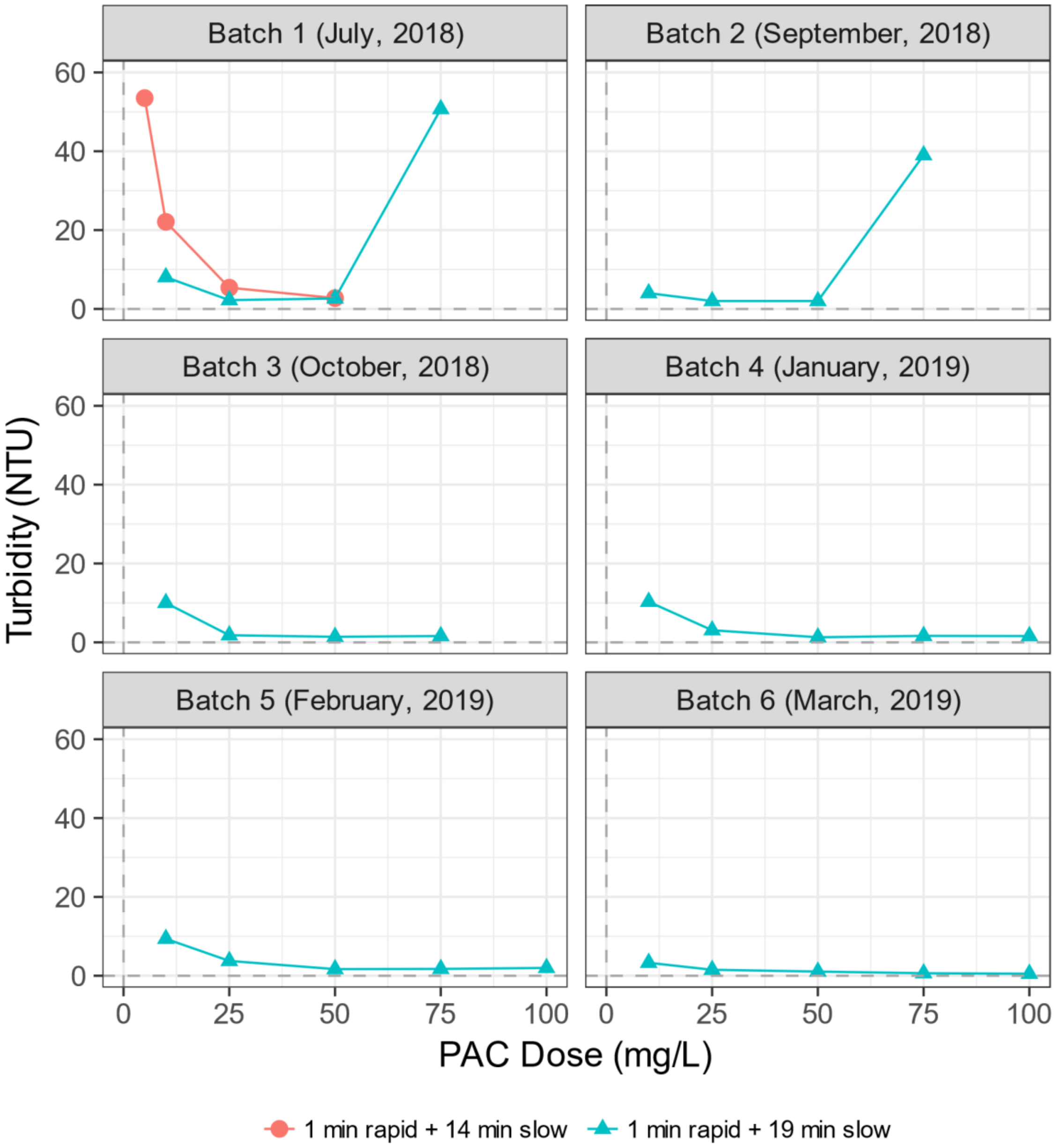


Figure 8.22: Variation of residual turbidity with PAC dose for Feni River water sample collected from the Azampur site in all six batches

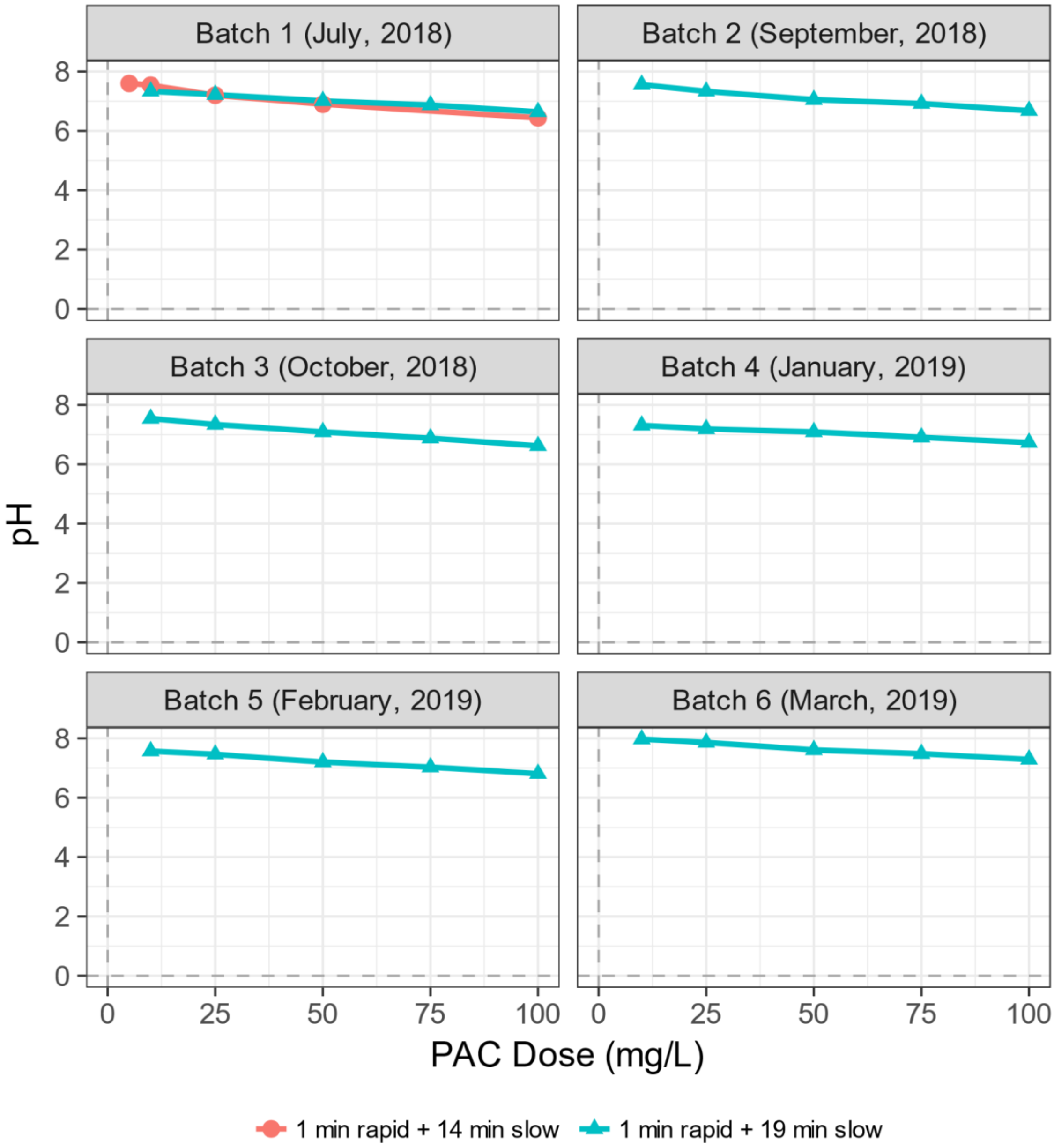


Figure 8.23: Variation of pH with PAC dose for Feni River water sample collected from the Azampur site in all six batches

Table 8.22: Summary of the water quality parameters after the coagulation-flocculation-sedimentation process with the optimum PAC dose for the samples collected from Feni River at Azampur site in different batches

Sampling Batch	PAC Dose (mg/L)	Turbidity (NTU)	pH	Apparent Color (Pt-Co)	True Color (Pt-Co)
Batch 1	25	2.23	7.22	12	2
Batch 2	25	2	7.33	12	2
Batch 3	25	1.8	7.34	10	3
Batch 4	25	3.07	7.19	15	3
Batch 5	25	3.76	7.46	22	4
Batch 6	25	1.51	7.86	10	2

8.4.6.4 Flocculent Settling Column Test

After the jar test, flocculent settling column test was carried out in a transparent column of 175 cm in height and 15 cm in diameter having four sampling ports for all three batches of samples collected till now. In each case, raw water samples were pre-chlorinated (with 30 minutes of contact time) with a chlorine dose determined from pre-chlorination. PAC was then added to the water samples and a rapid mixing was performed in a large bucket manually using a flat stick. Then the water was transferred in the settling column and the slow mixing for 30 minutes time was performed using a mechanical mixture (paddle type) fitted inside the column. For the samples collected in wet season (Batch 1, Batch 2, and Batch 3), 25 mg/l PAC dose was applied and for the samples collected in dry season (Batch 4, Batch 5, and Batch 6), 50 mg/l PAC dose was applied. Since the mixing in the column was less efficient than that in the Jar test, a PAC dose higher than the optimum dose determined through the jar tests (for the dry season samples Batch 4, 5, and 6) was applied. The mixing time was also longer in column tests than the jar test for the samples of all batches. Water samples were collected from the different sampling ports after 20 minutes, 40 minutes, 60 minutes, and 120 minutes of settling time after the completion of the slow mixing. The residual turbidity of the water samples collected from different ports was measured; the four ports located at 77 cm, 107 cm, 137 cm, and 167 cm below the highest water level in the column. The results of settling column experiment is presented in **Figure 8.24**.

Based on the settling column test, coagulation-flocculation-sedimentation process with PAC as the coagulant was effective in removing turbidity from the water collected from the Azampur site of Feni River. Turbidity was below 5 NTU when settling time is 60 minutes or longer for samples of all six batches with the applied PAC dose. However, light flocs settled satisfactorily in the column test may not be removed satisfactorily in the flocculation unit of the treatment plant because of water in motion. Hence coagulant aid may be necessary in actual plant operation.

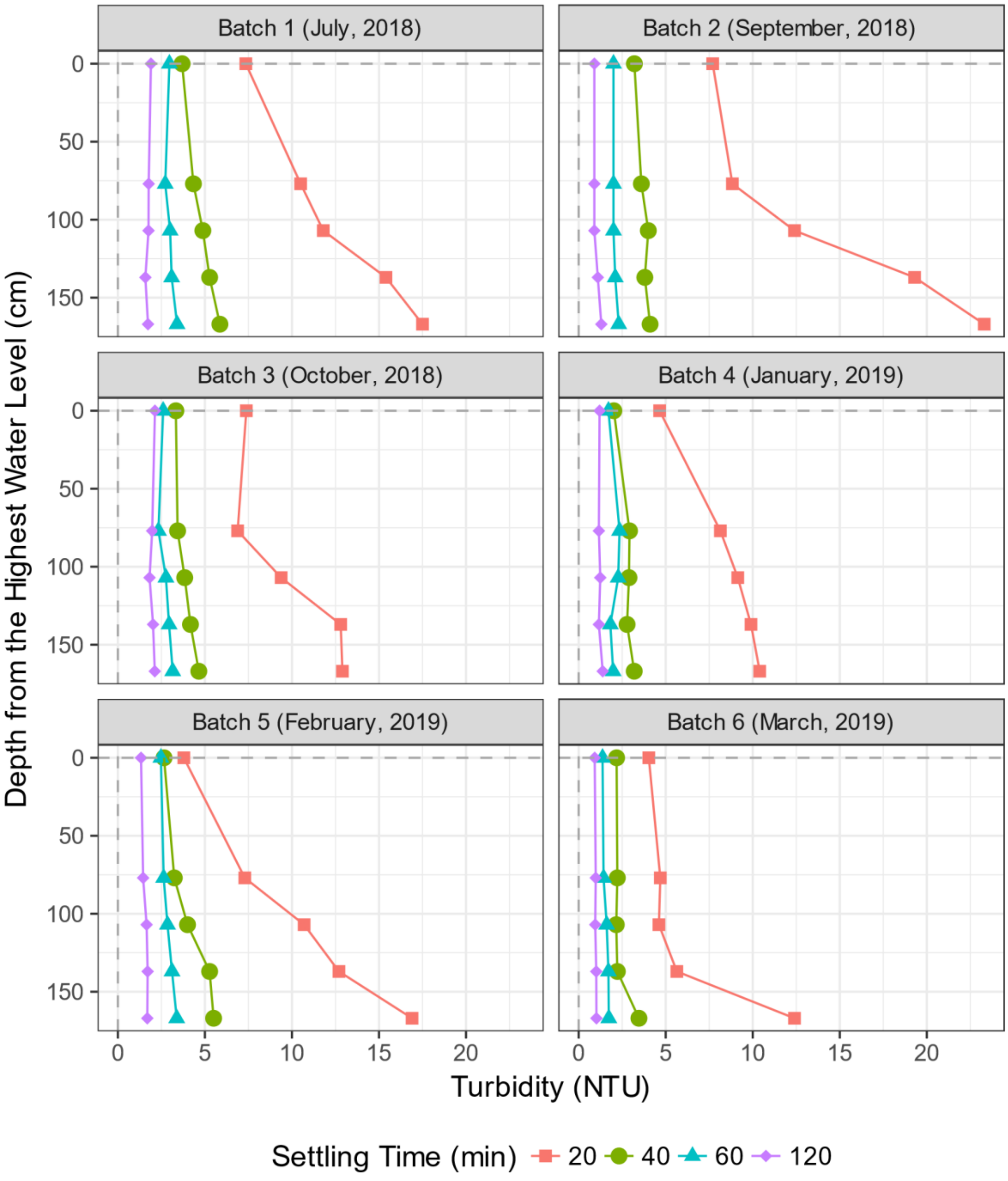


Figure 8.24: Variation of Residual Turbidity with settling time in column test for the water samples collected in different batches from the Feni River at Azampur site

8.4.6.5 Rapid Sand Filtration

A rapid sand filter (RSF) column was designed and constructed to treat the outflow of the flocculent settling column. The diameter and depth of the filter column were 147 mm and 1050mm, respectively. The filter column consisted of four different layers: the top two layers comprising of graded sand and the bottom two layers comprising of graded gravel material. The discharged water from the flocculent settling column (collected from Port-4) after 2 hours settling time was passed through the filter column and the outflow was collected to measure water quality parameters.

8.4.6.6 Post Chlorination

The out flow from the sand filter column was collected for all six batches of the samples. The chlorine concentration in the filtered water was above 0.2 mg/L for all six batches. Since the total chlorine of the filtered water discharged from the sand filter column was above 0.20 mg/L, the Bangladesh Drinking Water Standard for chlorine, post-chlorination was not required in any of the six sampling batches.

8.4.7 Characteristics of Treated Water Samples

As no post-chlorination was required, outflow from the RSF was considered as the treated water that would be supplied to the distribution network. **Table 8.23** shows characteristics of treated water of each of the three batches (Batch1, 2, &3) of water samples collected from Feni River at Azampur site during the wet season. All water quality parameters tested (including turbidity, TSS, TC, FC and Iron) satisfy the Bangladesh Drinking Water Standard, except COD and BOD5 which exceed the standard slightly for Batch 1 sample.

Table 8.23: Water quality analysis results of treated water samples for the first three batches of water samples collected from Feni River at Azampur site (July to October, 2018)

Sl. No.	Water Quality Parameters	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch1[a]	Batch2[b]	Batch3[c]	
1	pH	--	7.62	7.3	7.62	6.5-8.5
2	Color (Apparent)	Pt-Co	12.0	3	3	15
3	Color (True)	Pt-Co	2.0	2	1	15
4	Turbidity	NTU	0.50	0.32	0.64	10
5	Total Dissolved Solids (TDS)	mg/L	95.0	98	122	1000
6	Iron (Fe)	mg/L	<0.02	<0.02	<0.02	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	0	0	0	0
8	Fecal Coliform (FC)	CFU/100 mL	0	0	0	0
9	Electrical Conductivity (EC)	µS/cm	152	178	194	--
10	Nitrate (NO_3-N)	mg/L	0.6	0.7	0.8	10
11	Ammonia (NH_3-N)	mg/L	0.02	0.01	0.01	--
12	Chemical Oxygen Demand (COD)	mg/L	6	3	2	4
13	Biochemical Oxygen Demand (BOD_5)	mg/L	0.5	0.2	0.2	0.2
14	Total Chlorine (Cl_2)	mg/L	0.22	1.01	0.37	0.2
15	Aluminum (Al)	mg/L	0.008	0.006	0.003	0.2

Notes:

a = Treatment chain: Pre-chlorination (3.00 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

b = Treatment chain: Pre-chlorination (4.00 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

c = Treatment chain: Pre-chlorination (2.00 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

Table 8.24 shows characteristics of treated water of each of the three batches (Batch 4, 5, & 6) of water samples collected from Feni River at Azampur site during the dry season. All water quality parameters tested (including turbidity, TSS, TC, FC and Iron) satisfy the Bangladesh Drinking Water Standard, except COD and BOD5 which exceed the standard slightly for Batch 5 sample.

Table 8.24: Water quality analysis results of treated water samples collected in dry season (Batch 4, Batch 5, and Batch 6) from Feni River at Azampur site

Sl. No.	Water Quality Parameters	Unit	Concentration Present			Bangladesh Drinking Water Standard
			Batch 4[a]	Batch 5[b]	Batch 6[c]	
1	pH	--	7.06	7.28	7.45	6.5-8.5
2	Color (Apparent)	Pt-Co	5	4	2	15
3	Color (True)	Pt-Co	2	2	2	15
4	Turbidity	NTU	0.52	0.49	0.35	10
5	Total Dissolved Solids (TDS)	mg/L	132	157	131	1000
6	Iron (Fe)	mg/L	<0.02	<0.02	<0.02	0.3-1.0
7	Total Coliform (TC)	CFU/100 mL	0	0	0	0
8	Fecal Coliform (FC)	CFU/100 mL	0	0	0	0
9	Electrical Conductivity (EC)	µS/cm	226	259	237	--
10	Nitrate (NO_3-N)	mg/L	--	0.6	0.6	10
11	Ammonia (NH_3-N)	mg/L	0.01	0	0.01	--
12	Chemical Oxygen Demand (COD)	mg/L	3	6	3	4
13	Biochemical Oxygen Demand (BOD_5)	mg/L	0.2	0.4	0.2	0.2
14	Total Chlorine (Cl_2)	mg/L	1.2	1.5	0.84	0.2
15	Aluminum (Al)	mg/L	0.017	0.015	0.011	0.2

Notes:

a = Treatment chain: Pre-chlorination (4.00 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

b = Treatment chain: Pre-chlorination (4.50 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

c = Treatment chain: Pre-chlorination (3.00 mg/L) + Coagulation-Flocculation-Sedimentation (PAC 25 mg/L) + Rapid Sand Filtration

8.4.8 Selection of Treatment Processes

Based on the results of treatment process studies and treated water analysis, the unit operations and processes can be selected to produce drinking water of desired quality for the BSMSN from the raw water of the Feni River at or near Azampur site. Then the treatment process flow diagram can be constructed with the selected unit operations and processes.

As plain sedimentation was not effective in removing suspended solids from the raw water, pre-settling is not recommended for suspended solids reduction.

Coagulation-flocculation-sedimentation with PAC was found to be very effective in removing turbidity, suspended solids, and color from the raw water. Hence, rapid mixing chamber, flocculation unit and efficient clarifier must be provided in the treatment chain. A coagulant aid may be required to sustain the efficiency of the turbidity/suspended solids removal, in special cases.

The filtration of the outflow of flocculent settling column through normal filter column reduced the color substantially. If a rapid sand filter is installed after the coagulation-flocculation-clarification process, it will remove the suspended and floating flocs from the outflow of the clarifiers, thereby removing the suspended solids and turbidity further. Hence, provision of a rapid sand filtration unit will be beneficial for further improvement of water quality in terms of color, turbidity, and suspended solids.

Break Point Chlorination showed that low chlorine dose was required to make the water completely free from fecal and total coliforms. So, pre-chlorination is required to remove fecal/total coliforms from raw water, prevent growth of microorganisms in the raw water transmission pipeline, and prevent algal growth and improve efficiency of algae (if any) removal. From the model process studies, it is observed that the available residual chlorine after rapid sand filtration process will be satisfactory. The residual chlorine was above 0.2 mg/L for all the sampling batches. Hence, post-chlorination was not necessary prior to feeding the treated water into the water distribution network. However, in actual plant operation, the microbial quality may vary at different conditions, which may require a post-chlorination process for effective disinfection. The operator should monitor the microbial quality and residual chlorine in the treated water on a frequent basis to ensure effective disinfection.

It should be noted that iron and organic matter are also removed by different mechanisms when the raw water is passed through the unit operations and processes described above.

The proposed treatment process flow diagram is depicted in **Figure 8.25**. A suitable screen should also be installed in the intake structure to avoid the entry of objectionable suspended matters into the inlet pipes, and sufficient number of flushing outlets shall be provided in the raw water transmission line.

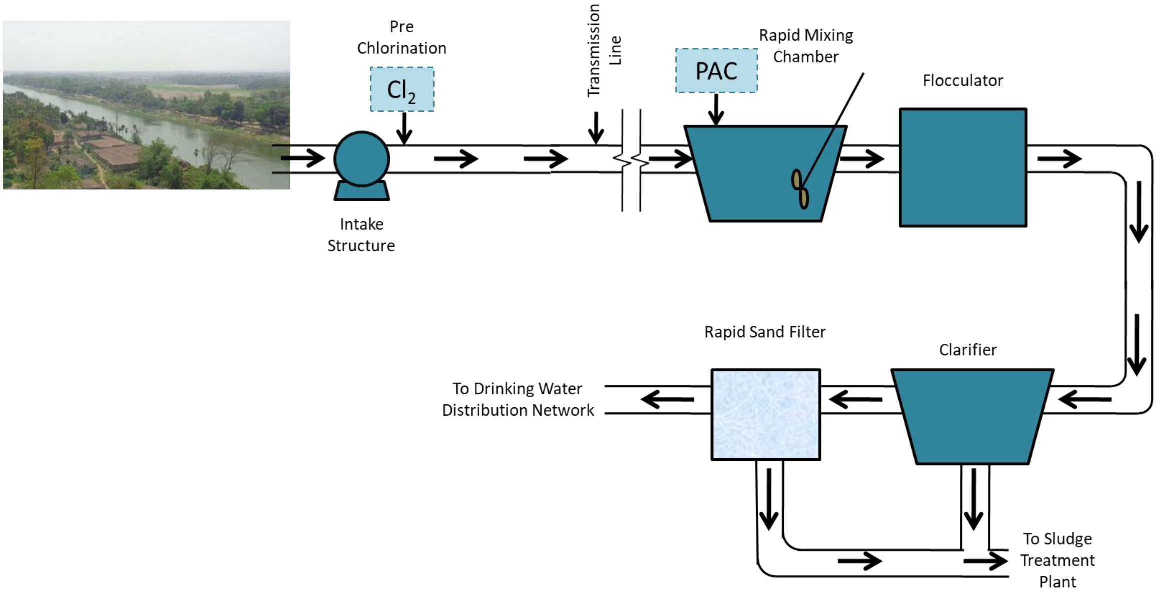


Figure 8.25: Treatment process flow diagram of the Water Treatment Plant for treating raw water from the Feni River to supply water to the BSMSN

8.4.9 Process Design Parameters

Based on the process studies carried out with the samples collected in the both the wet and dry season, the following design parameters can be recommended for the proposed Water Treatment Plant for the BSMSN.

For pre-chlorination, the break point dose is 3.0 – 4.5 mg/L for dry season and 2.0 – 4.0 mg/L for wet season.

The PAC dose requirement for coagulation-flocculation process is 25 mg/L all year round. The velocity gradient (G) for rapid mixing for the process studies (Jar Tests) performed was in the range of 35 s-1 to 48 s-1with mixing time of 1 minute. However, rapid mixing tanks operate best at G values from 700s-1 to 1000 s-1, with detention times of approximately 2 minutes (Peavy et al., 1986). Hence, this data can be used for design of the unit.

The favorable CAMP Number from the process studies is in the range 10000-20000 with detention time varying from 9 to 19 minutes, and G values in the range from 14 to 20 s-1. Values of the CAMP Number from 10000 to 100000 are commonly used with detention time ranging from 10 to 30 minutes, and reduction in G values by a factor of 2 from the intake end to the outflow end of the flocculator has been found to be effective (Peavy et al., 1986). The range of G values from 20 to 100 s-1 and the CAMP Number values from 20000 to 150000 have been found in practice to be the most effective for plants using mechanical flocculators (Schulz and Okun, 1984). Hence, the design G values may be in the range 10-30 s-1 and the CAMP Number in the range 10000-20000, with reduction of G values from the intake end to the out flow end of flocculator may be adopted for the proposed Water Treatment Plant for the BSMSN.

From the flocculent settling column tests, the minimum settling time has been determined as 40 minutes – 60 minutes. Practical limitations dictate longer detention time to be employed in the design of settling basins. The detention period should not be less than 2 hours in case of horizontal flow settling basins. Also, it should be noted that in transferring water from the flocculator basin to the clarifier, extreme care must be exercised to avoid turbulence that can break up the flocs.

A rapid sand filter column was designed and constructed at BUET to use it for process studies of the Feni river water. The features of the filter column are as follows:

Depth of filter material in the first layer (sand layer, FM=3.10), second layer (sand layer, FM=4.52), third layer (gravel layer, FM=6.07), and fourth layer (gravel layer, FM=7.70) is 30, 30, 30, and 15 cm, respectively.

8.4.10 Conclusions

From the above analysis, results and discussion, the following conclusions can be made:

(a) The Feni River at or near Azampur site is a good source of water for the proposed water treatment plant at the BSMSN.

(b) The turbidity, suspended solids, color, iron, fecal coliform and total coliform are to be removed from the raw water to make it suitable for drinking.

(c) Pre-settling of raw water is not required.

(d) Pre-chlorination of the raw water at the intake pumping station should be employed.

(e) Coagulation-flocculation-clarification using PAC is effective for removing turbidity and color from the raw water. Coagulant aid may be required in actual plant operation.

(f) Rapid sand filtration improves the water quality in terms of color and turbidity removal.

(g) Post-chlorination was not needed in the process studies. However, in the actual plant scenario post-chlorination may be required to ensure microbiological safety of the treated water at specific conditions.

(h) The process design parameters established through this study should be used for design of the proposed water treatment plant at the BSMSN.

The water quality of the Feni River should be protected against further pollution to preserve it as a good source of drinking water supply.

8.5 Outline Design of Surface Water Treatment Plant

8.5.1 Introduction

Upgraded and more environment friendly technologies are now available in the developed countries but in Bangladesh adaptation of such technologies will be very difficult in terms of operation and maintenance. In case of Mirsharai, conventional treatment plants has been proposed and accordingly outline design has been initiated. It will be advantageous for Mirsharai operation and maintenance problem can seek technical support from Chittagong one exiting water treatment plant as well as DWASA or other such organizations in case of emergency operation and maintenance problems.

In general, two common approaches for water treatment can be followed namely, natural process and chemical process. It may be mentioned here that natural process of treatment will increase both capital and O&M cost, therefore the project might not be financially viable. Considering the problem mentioned above chemical process of treatment has been selected. It is based on the result of the treatment process selection study previously completed and recommendations expressed at the end of this study.

It is recalled that the proposed treatment process includes:

- Raw water intake:
    - Coarse and fine screening
    - Collection raw water from the river by installing closed conduit and de-silting basin will be provided before pumping station
    - Intake pumping station;
- Water treatment plant:
    - Inlet pump station;
    - Pre-chlorination;
    - Coagulation (rapid mixing after addition of lime milk and Poly-Aluminium Chloride (PAC));
    - Flocculation;
    - Clarification (Sedimentation);

- Rapid filtration on sand filters;
- Final water chlorination for disinfection (post-chlorination);
- Water storage and distribution

The outline design is related to the water treatment plant. For intake structure design and screening treatment refer to the specific part of the outline design report for intake structures.

8.5.2 Water Treatment Layout

8.5.2.1 Design Parameters and Reference Design Criteria

Based on the results of treatment process studies and treated water analysis, the unit operations and processes can be selected to produce treated water of desired quality from the raw water of the Feni River.

Coagulation-flocculation-sedimentation with PAC was found to be very effective in removing turbidity, suspended solids, and color from the raw water. Hence, rapid mixing chamber, flocculation unit and settling tank must be provided in the treatment chain.

Laboratory tests have proved that filtration of effluent from flocculent settling column through normal filter column reduce the color substantially. If a rapid sand filter is installed after the coagulation-flocculation- sedimentation process, it will remove the suspended and floating flocs from the effluent, thereby removing the suspended solids and turbidity further. Hence, provision of a rapid sand filtration unit will be beneficial for further improvement of water quality in terms of color, turbidity, and suspended solids.

Pre-chlorination at the treatment plant over the break-point is required to prevent growth of algae, oxidize ammonia, organic matter, iron and manganese and remove the most part of microorganisms, including coliform, from water.

It is likely that the residual chlorine due to chlorination will not be present in sufficient concentration after rapid sand filtration. Hence post-chlorination will be required prior to feeding the treated water into the water distribution network.

The following criteria have been adopted in order to select the water treatment plant type and unit operations: raw water quality, type of community, water supply, operation and maintenance capacity, and level of industrial development.

8.5.2.2 General Layout

The treatment plant has been designed to be constructed into an integrated treatment unit up to filtration. The capacity of the plant will be 52.50 MLD (for 50 MLD of treated water) and the total plant capacity will be the same. Process diagram and general layout of the water treatment plant are shown in **Figure 8.26 and Figure 8.27** respectively.

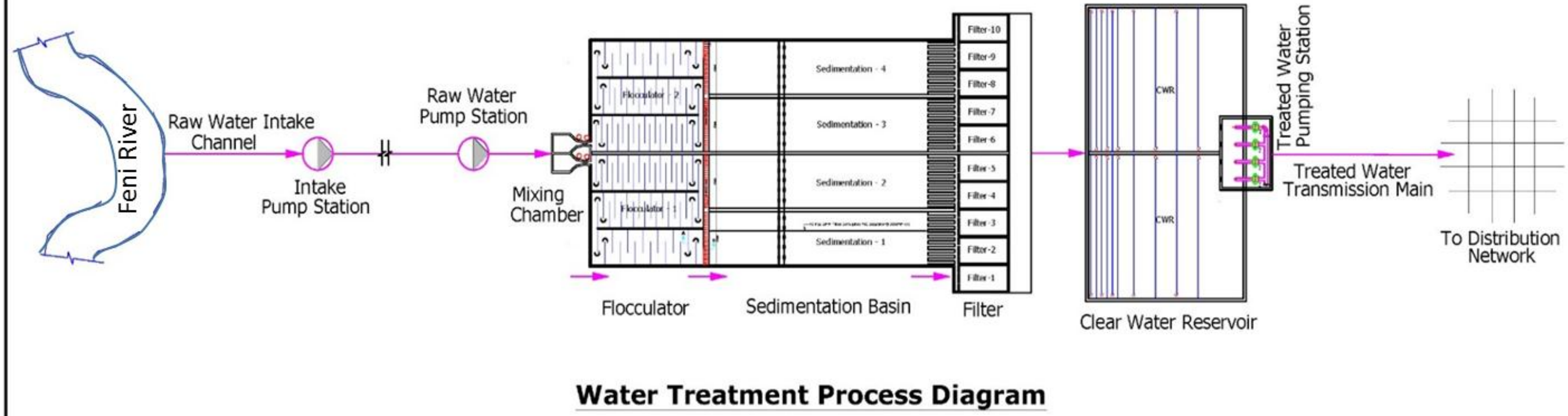


Figure 8.26: Process Diagram of Water Treatment Plant

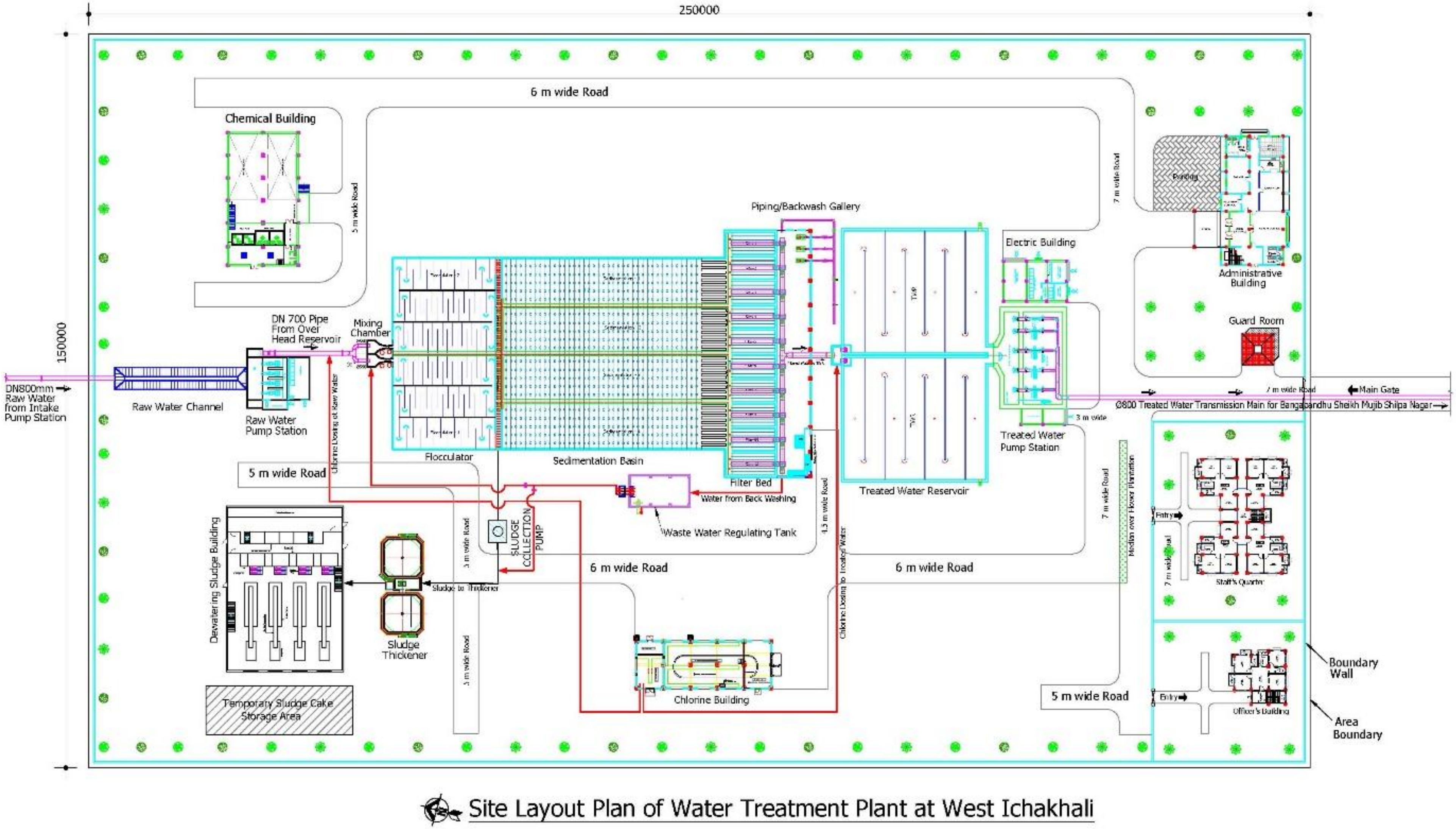


Figure 8.27: Layout of Water Treatment Plant at Poshchim Ichakhali

8.5.3 Design of Water Treatment Units

8.5.3.1 Inlet Pumping Station

Four (4) centrifugal pumps (including one for stand by and one for maintenance) have been considered. The capacity of each pump will be 0.305 m^3/s. To avoid mutual interference between two adjoining pumps by maintaining sufficient clearance of 3.0 m c/c of bowel has been considered. The adequate submergence is 2.0 m of the pump under the lowest water level in order to prevent entry of air during draw down and to satisfy NPSHr.

Raw water from intake pumping station will enter into the treatment plant site through raw water transmission main having 800 mm diameter. A rectangular pump sump with 15 minutes' water storage reservoir and the individual size of pumps will provide the sufficient head at the mixing chamber. The characteristic of the raw water pumping station is shown in **Table 8.25**.

Table 8.25: Characteristic of the Inlet Pumping Station inside the WTP Site

Capacity of the pumping station	0.61 m^3/s
No. of on duty pumps	2
No. of Standby pumps	2
Capacity of each pump	0.305 m^3/s
Pump efficiency above	80 %
Pump Capacity in KW	30 KW

The following levels which will be used are shown in **Table 8.26.**

Table 8.26: Levels Used for Raw Water Pumping Station inside the WTP Site

Maximum water level at raw water pumping station	4.5 mPWD
Minimum water level at raw water pumping station	0.6 mPWD
Bottom level of the pump sump	-1.4 mPWD

8.5.3.2 Pre-chlorination for Disinfection

Raw water can be disinfected by adding Cl_2 which is widely used. Also O_3, ClO_2 and UV ray are now being used as disinfection agent in developed countries but involve high cost and complex maintenance. Thus considering economic viability and easy availability in Bangladesh Cl_2 has been recommended as disinfection agent. Maximum 5 mg/l of Cl_2 is recommended for the disinfection process.

8.5.3.3 Coagulation (Rapid Mixing) and Dividing Chamber

Two rapid mixing and flow dividing chamber will be constructed for mixing and distributing the water into the two sets of flocculation basin. Each mixing & distribution chamber will distribute water into the two flocculation basins. The design sizes of mixing chamber have been considered from USDA, 1994 and lecture notes of conventional and advanced treatment methods of IHE-Delft (van Breemen, n.d.). Mixing and distribution chamber has been selected considering the following:

Table 8.27: Design of Mixing and Distribution Chamber

No. of mixing and dividing chambers	2
Total design Q	2 X 0.304 m^3/sec
Size of the Mixing and Dividing chamber	2 X (9m X 4m X 1.5m)
Velocity of the pipes connected to mixing and dividing chambers from raw water pumping station	1.55 m/s (500 mm dia. twin pipes)
Velocity of the channels connected to flocculator from mixing and dividing chamber	0.4 m/s

A very fine screening is necessary in order to avoid the clogging of filters by large size particles. For that purpose, it is proposed to set a battery of fine screens at the head of each mixing chamber. Mesh spacing will be 6 mm at most.

8.5.3.3.1 Plan and Section of Mixing Chamber

A sectional plan and elevation of mixing chamber is shown in **Figure 8.28.**

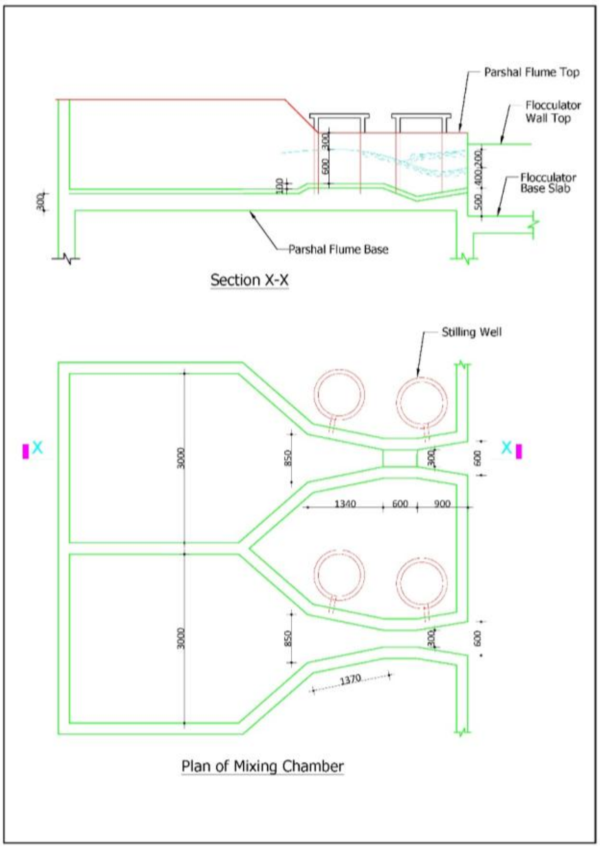


Figure 8.28: Plan and Section of Mixing Chamber

8.5.3.4 Flocculation Basin

Flocculation is the clarification process of gentle and continuous agitation, during which suspended particles in the water coalesce into larger masses so that they can be removed from the water in subsequent treatment processes, particularly by sedimentation. Flocculation follows directly after the rapid mixing process.

8.5.3.4.1 Objectives

- Providing suitable condition and time for formation of floc particles
- Keeping the water in a state of controlled agitation
- Formation of the moderately large dense and heavy flocs which will easily settle in the settling basin.

8.5.3.4.2 Choice

Selected flocculator type for this treatment is horizontal-flow baffled channel flocculator as capacity of the treatment plant is about 50 MLD. Baffled channel flocculator have been considered in order to maintain sufficient head losses in the channel for slow mixing due to the flow rates.

Again horizontal-flow flocculator with around-the-end baffles are preferable over vertical-flow flocculator with over-and-under baffles, because-

- Easier to drain and clean;
- Head loss which governs the degree of mixing can be changed more easily by installing additional baffles or removing portion of existing ones; and
- In vertical flow unit depth of the channel can be as high as 3 m. But the major problem is accumulation of settled material on the chamber floors and difficulty in removing it.

8.5.3.4.3 Design

The design sizes of flocculation basin and associate hydraulics have been considered mainly from the lecture notes of conventional and advanced treatment methods of IHE-Delft (van Breemen, n.d) and WASH, 1984. Flocculators of BSMSN drinking water treatment plant have been designed considering the following design parameters-

i. Number and Size

Two (2) independent flocculation basins have been considered for BSMSN WTP, which will encompass the sedimentation and filtration units, sharing a common side wall. Modified baffles and a sloped basin floor will be arranged in such way that the minimum water depth is at inlet and depth gradually increases to a maximum at outlet. Detail of the basins are given below-

- Size of each basin is 21 m x 18.9 m
- Each basin will comprise of three sub-chambers. Size of each chamber is 21m x 6.3m
- Number of baffles in each sub-chambers are designed as-

a) 1st sub-chamber: 20 nos. horizontal baffle@ 0.945 m c/c
b) 2nd sub-chamber: 18 nos. horizontal baffle@ 1.107 m c/c
c) 3rd sub-chamber: 14 nos. horizontal baffle@ 1.415 m c/c

- Depth of each sub-chamber is 1.0 m
- Wooden baffles are preferable

ii. Hydraulic Components

- Total flow is 0.608 m3/s (flow of each basin is 0.304 m3/s)

- Total detention time is 19.9 minutes (which is less than 21 minutes and the individual detention time of each sub-chamber will not exceed to more than 7.0 minutes)
- Total head loss (HL) is 0.307 m
- Permissible horizontal velocity through each sub-chambers are-
  a) 1st sub-chamber: 0.324 m/s
  b) 2nd sub-chamber: 0.287 m/s
  c) 3rd sub-chamber: 0.215 m/s
- Gt (velocity gradient x detention time) of each sub-chambers are
  a) 1st sub-chamber: 29160
  b) 2nd sub-chamber: 19770
  c) 3rd sub-chamber: 6165

8.5.3.4.4 Plan and Section of Flocculation Basin

A sectional plan and elevation of flocculation basin is shown in **Figure 8.29**.

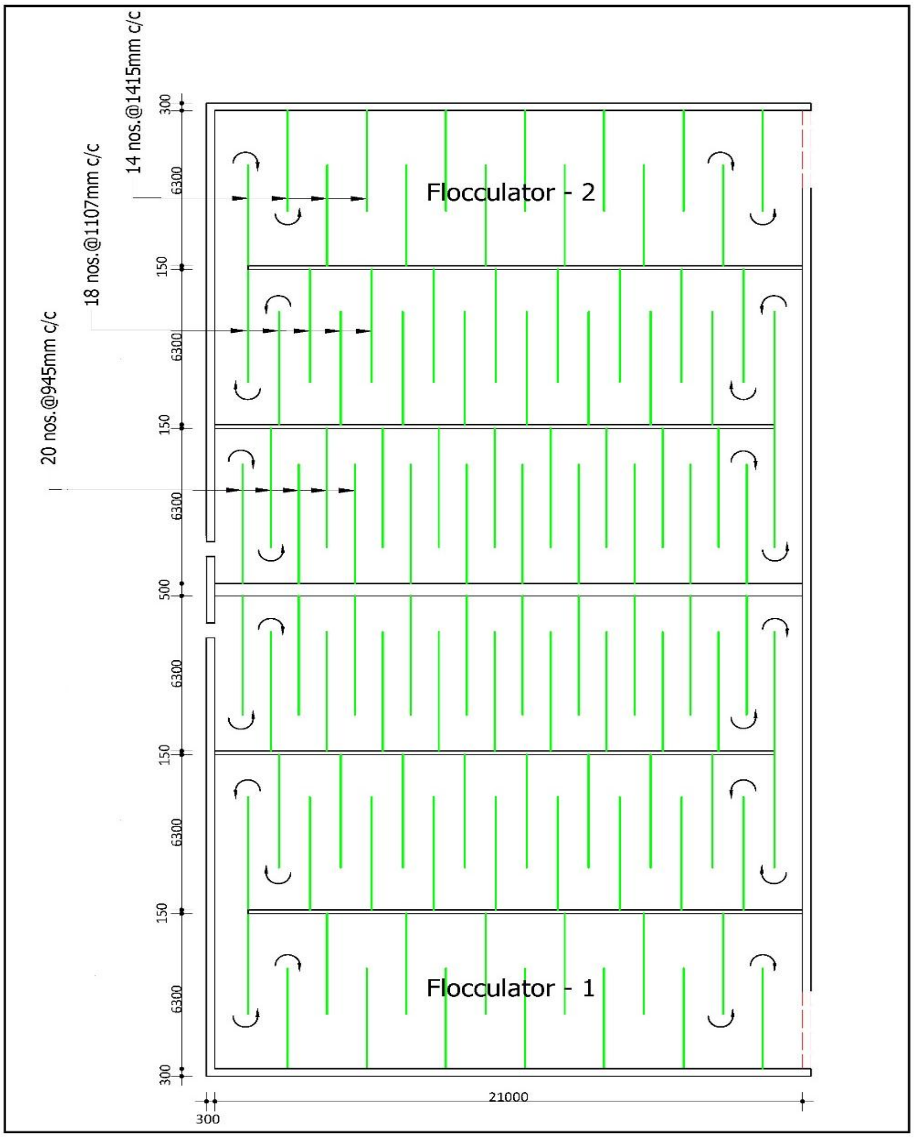


Figure 8.29: Plan of Flocculation Basin

8.5.3.5 Sedimentation Basin

The purpose of sedimentation basin is to accumulate impurities at pre-determined location. Sedimentation process contains (Blokland, n.d.) the followings,

- Impurities accumulate at pre-determined location (usually tank floor)
- Continuous or intermittent sludge removal is required to maintain settling zone

8.5.3.5.1 Choice

Tilted corrugated separator basins have been used for sedimentation for many years in different countries and will be in operation for years to come. Main advantage of tilted corrugated type basins is that settling depends on the settling area rather than detention time. For this tilted corrugated PVC separator sedimentation basin has been selected for Mirsharai.

Therefore, selected sedimentation basin type for this treatment is tilted corrugated PVC separator tank sedimentation.

Tilted corrugated PVC separator sedimentation basin is preferable due to following reasons,

- Not very sensitive for flow variation and some overloading
- Reliable and flexible
- Higher removal efficiency
- Not subjected to the scouring action of the flow through velocity
- Less short circuiting
- Lower losses at inlet and outlet
- Less power consumption for sludge collection

8.5.3.5.2 Design of Settling Zone

Sedimentation of BSMSN drinking water treatment plant has been designed considering the following design parameters-

i. Overflow Rates

Hydraulic overflow rate is the primary design parameter for sizing sedimentation basins. Acceptable overflow rates vary with the nature of the settling solids, water temperature, and hydraulic characteristics of the settling basin. It can be mentioned here that the higher rates are typical for warmer waters with heavier suspended solids. Rates higher than these may be applicable for warm waters greater than 20° C. Lower rates should be used for colder waters with lower turbidity or that are high in organic color or algae. Warm water temperature is considered as 25°C in most of the time and the corresponding kinematic and dynamic viscosities of water have determined as 8.96×10^{-7} m^2/s and 8.96×10^{-3} kg/m.s.

For Horizontal flow tank after coagulation with PAC and/or iron floc the range of surface loading and detention time varies from 25 to 75 $m^3/m^2/d$ (typical value: 30-40 $m^3/m^2/d$) and 2 to 8 hours (typically 2 to 2.5 hours) respectively. The space occupied by tilted plate settling tanks is thus a factor 20 smaller than is needed for horizontal flow tanks because of 20 times smaller surface overflow rates.

ii. Detention Time

Detention time (i.e., flow rate divided by tank volume) is usually not an important design parameter because settling depends on the settling area rather than detention time for tilted corrugated plate. It is likely that this detention requirement is a carryover from the days of manually cleaned basins designed to provide a sludge storage zone. According to the Huisman, 2004 (in Fig. 4.8), for rectangular sedimentation basin, SOR value varies from0.35x10^{-3} m/s to 0.46 x 10^{-3} m/s, the minimum detention time is required for 95% removal ratio is in the range of 4.8x10^{3} sec to 6.5x 10^{3} sec (1.33 hours to 1.80 hours) respectively. The detention time of this practice for tilted corrugated separator is considered as 1.472 hours for designing maximum flow and for the better efficiency against turbulence of flow, instability of flow, bottom scour and flocculation (TU-Delft, n.d), which is 2.20 times less than rectangular sedimentation basin.

iii. Number of Tanks

One important choice to be made is the number of basins. The minimum, and by far the least costly, plant would have only a single settling basin. However, that would make for poor operation, because tanks must periodically be taken out of service for maintenance. Two tanks would partially offset this problem, but unless plant flow can be reduced, the load on one tank could be excessive when the other is out of service. A minimum practical number of tanks would be three, allowing for a 50% increase on two tanks when one is out of service. If the design overflow rate is conservative, the three-tank approach is acceptable. The number of tanks may also depend on the maximum size tank that can accommodate the selected sludge removal equipment or on other factors, such as site constraints. Factors also to consider in selecting the number of tanks are their relationships to the flocculation basins and the filters.

In general, however, a minimum of four tanks is preferred (AWWA, 2005). Therefore, four (4) number of sedimentation tank has been considered in this project.

iv. Basin Dimensions

Rectangular basins are generally designed to be long and narrow, with length-to-width ratio of 3:1 to 5:1. This shape is least susceptible to short circuiting for the hydraulic condition in a basin when the actual flow time of water through the basin is less than the computed time. Short-circuiting is primarily caused by uneven flow distribution and density or wind currents that create zones of near-stagnant water in corners and other areas. The ratio of length to width is considered as 4.5:1 and dimension is 9.3 m x 41 m. The design depth of the basin is 2.4 m. 40 numbers of 5 mm RCC supported tilted PVC separator have been designed which will be spaced @ 1.0 m c/c.

8.5.3.5.3 Design of Inlet Zone

A basin's effectiveness at any overflow rate can be greatly changed by short circuiting. Short-circuiting reduces the actual area traversed by the flow, increasing the apparent overflow rate and reducing solids removal efficiency. The inlet zone has been designed (**Figure 8.30**) according to the guidelines provide by AWWA, 2005.

For long, narrow basins being fed directly from a flocculation basin, slots or a few individual inlets have to suffice. To obtain uniform flow distribution through wider basins, perforated base slab have been provided. For best results, flow from the flocculation basin should be in line with the basin axis. Following hydraulic principles to ensure equal flow distribution, head loss through the perforations should be 4 to 5 times the velocity head of the approaching flow. The velocity gradient G should be equal to or less than that in the last flocculation compartment to minimize floc breakup. The number of ports should be the maximum practical that will provide the required head loss. Port velocities typically must be about 0.21 to 0.30 m/s for sufficient head loss (AWWA, 2005; CPHEEO, 1999; WASH, 1984). Ports should be arranged to cover as much of the basin's cross section as possible without creating high velocities in the sludge collection zone that might cause scouring action. Thus the lowest port should be about 0.6 m above the basin floor. Port spacing is typically (25 to 61 cm) with a port diameter of 10 to 20 cm.

In this assignment the velocity through the holes is considered as 0.23 m/s. There are 100 numbers of holes in 4 rows having 150 mm of diameter and 0.375 m c/c is considered. The clearance of bottom holes from the settling basin floor is considered as 0.6 m.

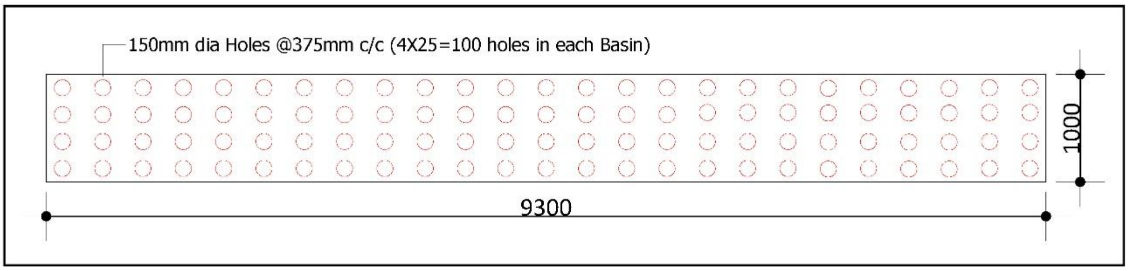


Figure 8.30: Sectional View of the Inlet Zone of Sedimentation Basin

8.5.3.5.4 Design of Outlet Zone

Outlet design is also critical in reducing short-circuiting and scouring of settled solids. Outlet designs have undergone a number of transformations. Basins were originally designed with end weirs. This type of outlet causes an increase in horizontal and vertical velocity as flow is forced up the end wall to the weir, and the increased velocities cause considerable floc carryover by scouring settled floc and removing floc that has not had time to settle.

Considered, 9 nos. of double weirs having 25 numbers of U-notch (size: 0.10 m of width and 25 mm of depth) in each for a single basin (**Figure 8.31**). The length of main weir is 5m.

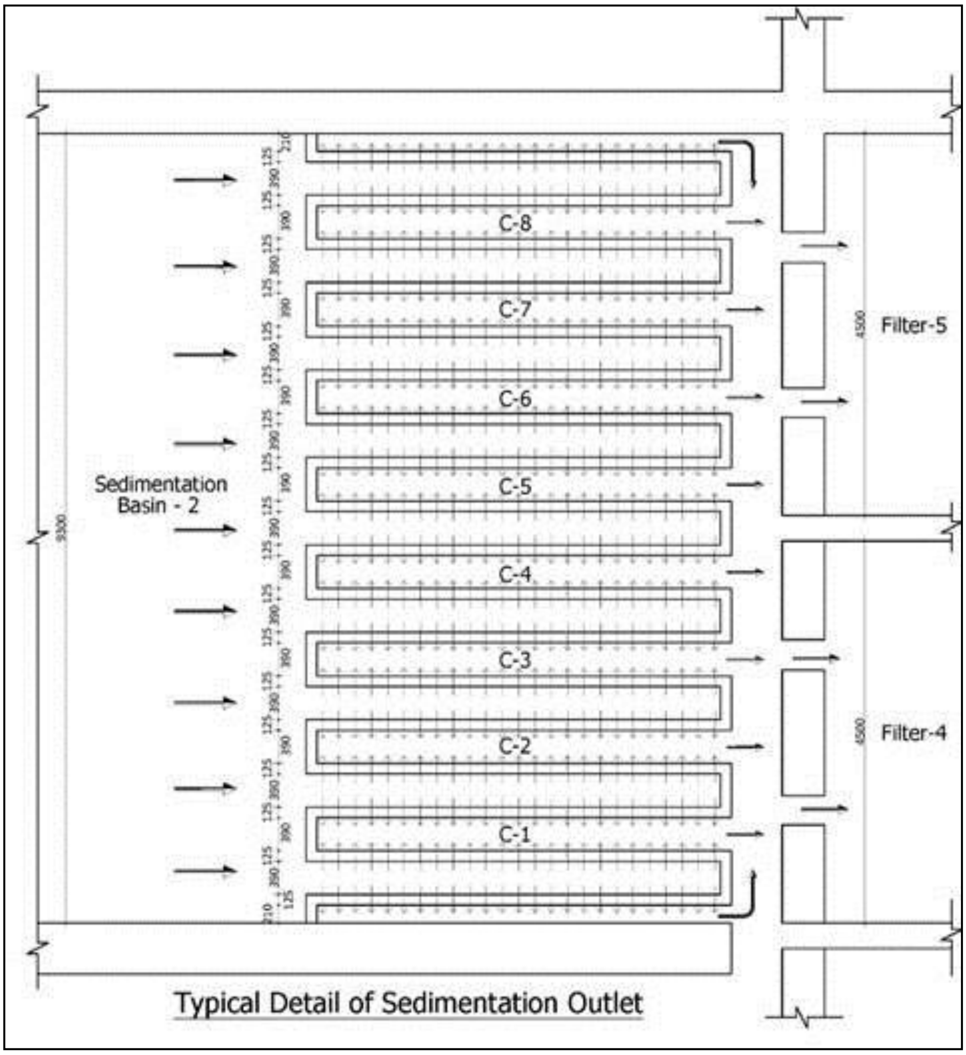


Figure 8.31: Typical Plan View of the Outlet Zone of Sedimentation Basin

8.5.3.5.5 Manual Solids Removal

Manual solids removal is recommended for the surface water treatment plant of BSMSN over mechanical solids removal. In such cases basins must be designed to store sludge for a reasonable time period of time. An extra depth of 1.2 to 1.5 m has been provided (AWWA, 2005). Basin floors have been assured sufficient slope to a drain and adequate pressurized water has been recommended to be available for flushing. Manually cleaned basins are suitable for use in developing countries because of their low labor rates.

8.5.3.5.6 Plan and Section of Sedimentation Basin

A sectional plan and elevation of Sedimentation basin is shown in **Figure 8.32.**

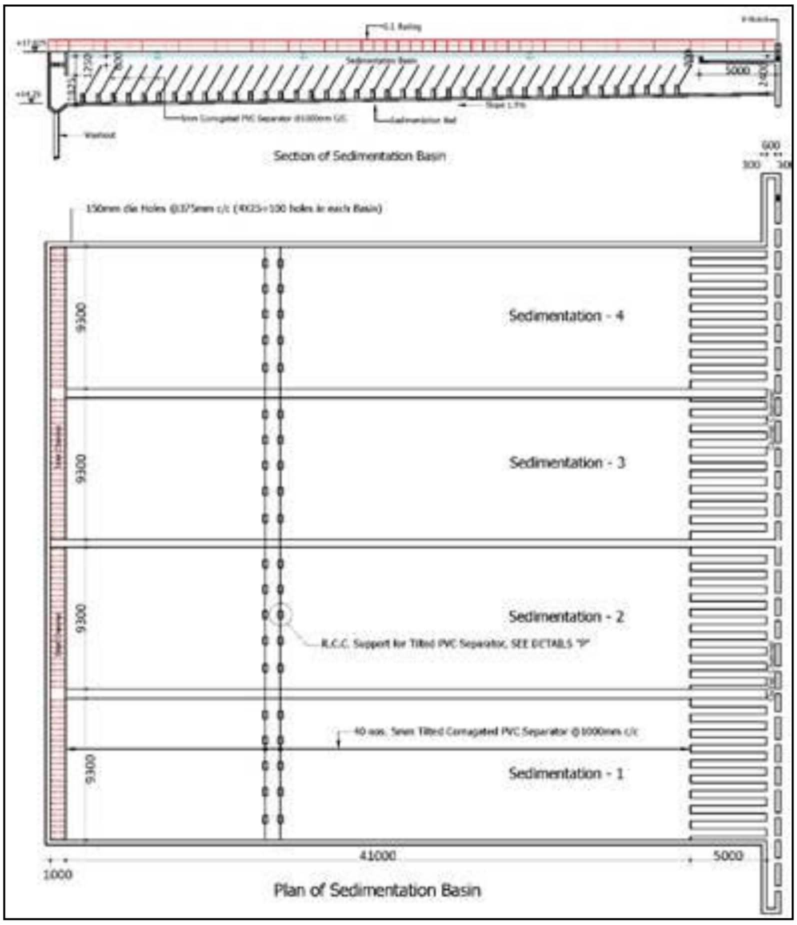


Figure 8.32: Plan and Sectional View of the Sedimentation Basin

8.5.3.5.7 Alternative option of Coagulation, Flocculation and sedimentation.

Clariflocculators/ Clarifiers can be another option including mixing and dividing chamber. Selected clarifier type for this treatment is a compact clarifier able to work at the same time as a flocculator and a settling tank, as sludge blanket clarifier or similar.

8.5.3.6 Filtration Chamber

Filtration is the purification process, whereby the water to be treated is passed through a porous substance. During this passage water quality improves by part removal of suspended and colloidal matter, by reduction of the number of the bacteria and other organism and by changes in its chemical constituents.

8.5.3.6.1 Choice of Filtration Type

During the process of filtration, the impurities are removed from the water, they accumulate on the grains and in the openings between the grains of the filter bed, in this way reducing the effective pore space by which the resistance against the flow of water increases and the filtration efficiency drops. After some time, this resistance becomes so high or the quality of the effluent so low, that cleaning the filter is necessary. With regard to the interval between cleanings and the way this cleaning is effected, two groups of filters may be distinguished, slow filters and rapid filters, which filters also differ greatly with respect to the filtration rate that is the capacity per unit area of filter bed surface.

In that case rapid filters have been chosen over the slow filters because of the following reasons.

- Very effective in removing turbidity / large particles (<0.1-1 NTU)
- High filter rate
- Small land requirements
- No limitation regarding initial turbidity level
- Cleaning time (backwashing) only takes several minutes

For rapid filter frequent cleaning is required (every 24 h-72h). In this case we recommend cleaning at the rate of 24 hours interval.

8.5.3.6.2 Design of Filtration Units

Filtration of BSMSN drinking water treatment plant has been designed considering the following design parameters-

i. Rate of Filtration

The rate of water flow through the filter is referred to as the hydraulic loading or the filtration rate. The filtration rate depends on the raw water quality and the type of filter media. The rate at which water passes through the granular filter media (the filtration rate) may vary widely, depending on the purpose for which the water is required. According to United States Environmental Protection Agency (EPA, 1995) for public water supply, 5 m/hour may be regarded as the standard rate and most authorities limit the maximum filtration rate to between 5 and 7.5 m/hour. For medium-sized sand (0.5mm ES), filtration rate may vary from 5 to 7.5 m/hour (AWWA, 2005; Page: 8.5). Normal practice for the filtration rate in India is considered in the range of 4.8 to 6 m/hour. According to Huisman (Huisman, 1985), commonly filtration rate can be considered as 5.4 m/hour (1.5 x 10^{-3} m/s) for 0.5 to 2mm sand. In this practice, filtration rate is considered as 5.4 m/hour (1.5 x 10^{-3} m/s) considering the guidelines mentioned above.

ii. Number and Capacity of Filter Units

The open down flow type of rapid filters essentially consists of a box, commonly made of reinforced concrete, rectangular in shape and varying in filter bed area between about 15 and 150 m^2. This box is filled with a 0.5 to 2 m deep layer of filtering material on top of which the raw water to be treated is present in a depth of 0.25 to 2 m. It is recommended that the minimum numbers of filter will be 4 that can be extending to infinitely as per requirement.

In this practice we considered 10 filter units (with 2 standby for filter backwashing) having filter bed are of 40.5 m^2 (4.5mx9.0m).

Filter Media

The most common filtering material in rapid gravity filters is sand. It has been the custom to designate sand for rapid gravity filters in terms of its effective size, uniformity coefficient and hydraulic size. Gravel is commonly used to support the filter media. Desirable characteristics for all filter media are as follows-

- Good hydraulic characteristics (permeable);
- Does not react with substances in the water (inert and easy to clean);
- Hard and durable;
- Free of impurities; and

- Insoluble in water.

iii. Selection of Filter Media

Criteria for selection of filter media are as follows-

a) Two factors are very important in making judgments about media selection:
    - The time required for turbidity to break through the filter bed; and
    - The time required for the filter to reach limiting head loss.

b) If the limiting head loss is frequently a problem and turbidity breakthrough rarely occurs, then a larger media size may be considered. If turbidity breakthrough is frequently a problem and limiting head loss is rarely encountered, then a smaller media size may be considered.

c) If both head loss and turbidity breakthrough are a problem, while the filter is operating within its rated capacity, a deeper filter bed with a larger sand size may be required. The optimum depth needed to obtain a given quality and length of run varies with the size of the sand. However, increasing the media depth is not always possible without modification of the filter.

d) Adequate clearance must be allowed between the top of the media and the weir cell of the wash water channel. Otherwise, filter media will be carried over into the wash water channel during backwash, when the bed expands.

e) Selection of an appropriate media for rapid gravity filtration depends on the
    - Source water quality
    - Filter design
    - Anticipated filtration rate

Generally, the more uniform the media the slower the head loss buildup. Media with uniformity coefficients of less than 1.5 are readily available. Media with uniformity coefficients of less than 1.3 are only available at a high cost.

More frequent backwashing will be required to keep the sand filter operating efficiently and therefore typically 0.8 to 1.0 mm of filter sand media has been considered (EPA, 1995). For higher filtration rate when the coarse medium is used, deeper sand beds are suggested. Normally 1.2m to 1.8m depth of filter media are considered (AWWA, 2005; CPHEEO, 1999). The selected filter media characteristics are given in **Table 8.28**.

Table 8.28: Selected Filter Media

Material	Size Range (mm)	Specific Gravity	Depth (m)
Medium Sand	0.8	2.6	1.15
Graded Gravel	2-84	2.6	1.0

iv. Filtration Efficiency

Rapid gravity filtration efficiency is roughly measured by overall plant reduction in turbidity. Although it should be noted that up to 90% of the reduction may take place in the pretreatment stages. Overall reductions of over 99.5% can be achieved under optimum conditions, while a poorly operated filter and inadequate pretreatment (coagulation. flocculation, and clarification) can result in turbidity removals of less than 50 per cent. The best way to assure high filtration efficiency is to select an outflow turbidity target and stay below the target value [such as 0.5 NTU (Nephelometric Turbidity Units)].

Because of the smaller media grain size, typically 0.8 to 1.0 mm, sand filters tend to clog with suspended matter and flock more quickly than dual-media filters. This means that more frequent backwashing will be required to keep the sand filter operating efficiently.

v. Filtration Control System

The filter control system regulates the flow rate through the filter by maintaining an adequate head above the media surface. This head (submergence) forces water through a gravity filter. The flow through a filter must be as stable as possible and any changes in flow rate, whenever operating conditions at the plant change should be controlled in order for the filter to yield the optimum outflow quality. The best control system therefore is one with simple, safe and reliable controllers that controls filtration without hunting.

An essential element in the control system for rapid gravity filtration is a slow start controller, which restricts the output from a filter for a period after backwashing while the filter is ripening. Rapid gravity filter control systems can be classified into three types

- Constant rate, with a controller;
- Constant rate, variable head type; and
- Declining rate (or variable flow rate)

In this practice we recommended constant rate control system with a controller. The constant rate type with a controller may be operated either on the Constant Level system or with Flow Measurement. With Constant Level control the inflow to the plant is distributed equally between the filters, each receiving a flow equal to the incoming flow rate divided by the number of operating filters. Each filter is equipped with a controller which detects the upstream level, which it keeps constant by adjusting the outflow controller. Because the upstream level is kept constant, the outflow is equal to the inflow and clogging is compensated for until it reaches a limit, which depends on the available head. When a filter is shut down for backwashing or maintenance, the inflow is automatically distributed over the filters that are still in service with the exception of filters using a surface flush of settled water. Equal distribution of inflow is achieved simply and reliably by static devices (orifice plates, weirs, etc.; here weirs have been considered). Use of this control system also eliminates the discrepancies between total filtered flow and incoming flow that can occur with control systems based on flow rate measurements.

Alternatively, in the Constant Rate control with flow measurement system each filter outlet has a flow meter linked to a controller which compares the metered flow from the filter to the flow rate set point and adjusts the outflow valve until they coincide. This system has no means of maintaining a specific water level above the filter media, so an additional central controller is needed. Normally the inflow rate to the filters is measured and the central controller adjusts the individual set-point rate of the filters accordingly. If the inflow rate increases, the level upstream of the filters rises and the central controller adjusts the set-point rate for the filters until the upstream level stabilizes and plant inflow and outflow are in balance. The central controller may alternatively adjust the individual set-point rate of the filters by reference to the water level in the Clearwater tank. Another central controller detects the water level in the inflow channel and adjusts the inflow control valve to provide the filters with a flow to correspond with their set point rate. The change in water level in the filters can be as much as 300 mm with this system.

8.5.3.6.3 Design of Backwashing Units

When during filtration the hydraulic resistance attains its maximum allowable value or the quality of the effluent drops below the set standards, cleaning of the filter is necessary to restore its capacity and/or to improve the quality of the filtered water. Today without exception mechanical cleaning is used, effected by reversing the direction of flow, admitting wash-water to the underside of the filter bed. At a rate many times larger than the filtration rate, this wash water flows upward, taking the impurities accumulated in the pores of the filter bed with it to above, where wash-water troughs and gutters are present to convey it to be a drain leading outside the filter. This backwashing process has two purposes such as-

- To dislodge impurities adhering to the filter grain surfaces by the shearing action of the rising wash-water stream, flowing at high rates past the stationary grains;
- To expand the filter bed, to increase the pore space allowing the liberated clogging to escape more easily with the wash-water.

i. Choice of Backwashing Source

Water needed for backwashing a filter may be supplied in different ways such as-

a) By the distribution system
b) By special wash water pumps connected to the clear well
c) By an elevated wash water reservoir/tank

Which solution is most attractive in a particular case depends primarily on the required backwash capacity compared to the production of the plant as a whole and on the minimum time interval between two successive cleanings in relation to the actual washing period.

Taking back wash water from the distribution system is bad practice unless the number of filtering units is large and the back-wash rate is low, as this will result in strong variations in system pressure.

For backwashing of filter by only water, a huge size of overhead tank will be required. So special wash water pumps connected to the clear well is selected for backwashing purpose of filters.

ii. Design of Backwashing Source

Design summary of filter backwashing source is given in **Table 8.29.**

Table 8.29: Design Summary of filter Backwashing Source

Item	Quantity
Capacity of backwashing pump	0.51 m^3/sec
Head of the pump	8.4 m from zero level

Item	Quantity
Number of pumps	2 (one in operation and one in standby)

iii. Rate of Backwashing

Wash rates are generally variable and depend on wash water temperature, filter media characteristics, and washing method. Water viscosity decreases with increasing temperature. Consequently, as wash water temperature rises, drag forces on media grains are reduced, and higher wash rates are required to achieve bed expansion. Each degree Celsius increase in water temperature requires roughly a 2% increase in wash rate to prevent a reduction in bed expansion. Filter wash systems should be designed for the warmest wash water temperature that will be encountered. Filter media characteristics also affect washing rate. A minimum rate of 37 m/h is recommended, with typical rates ranging from 37 m/h to 56 m/h. In current case 50 m/h or 14×10^{-3} m/s, backwashing rate is selected.

iv. Choice of Underdrain System

An underdrain system has two purposes: to collect water that passes through the filter media and to distribute wash water (and air, if used) uniformly across the filter bed. Support gravel is required when openings in the underdrain system are larger than the filter medium directly above it. Although the support gravel or other support method does not contribute to particulate matter removal, it aids in distributing wash water. For this reason, it should be considered part of the underdrain system. Uneven distribution of wash water can displace support gravel, eventually requiring removal of the filter media to be regarded or replaced. Four basic types of underdrain systems are common: pipe laterals, blocks, false bottom, and porous bottom.

In this practice we recommended pipe lateral types of underdrain systems for the backwashing of filters. Pipe, lateral underdrains were once popular because of their relatively low cost and adaptability for use in pressure filters. Problems with relatively high head loss and poor wash water distribution have to be overcome by ensuring sufficient pressure from wash water tank.

v. Design of Underdrain System

Pipe underdrain systems generally consist of a centrally located manifold pipe to which smaller, equally spaced laterals are attached. Lateral pipes usually have one row of 10 mm of diameter perforations on their bottom sides. Features of laterals design are as follows:

- Perforations: 10 mm Φ ((Referenced value: 6 to 19 mm; AWWA, 2005)
- Laterals: 75 mm
- Manifold: 800 mm
- Total area of orifices (surface area of bed): 0.003:1
- Cross-sectional area of lateral (total area of orifices served): 3:1 (Referenced value: 2 to 4:1; AWWA, 2005)
- Cross-sectional area of manifold (total area of laterals served): 2:1 (Referenced value: 1.5 to 3:1; AWWA, 2005)

Orifices are normally spaced at 16.2 cm c/c (referenced value: 8 to 30 cm; AWWA, 2005) and laterals are considered at the same spacing's as the orifices. 45 cm of support gravel is considered to cover a lateral network (CPHEEO, 1999). Mainly five graded layers are usually involved above the laterals with sizes varying from 2 to 32 mm. The bottom layer will be extended to 10 cm above the highest wash water outlet (AWWA, 2005). The designed underdrain system is shown in **Figure 8.33** and **Figure 8.34.**

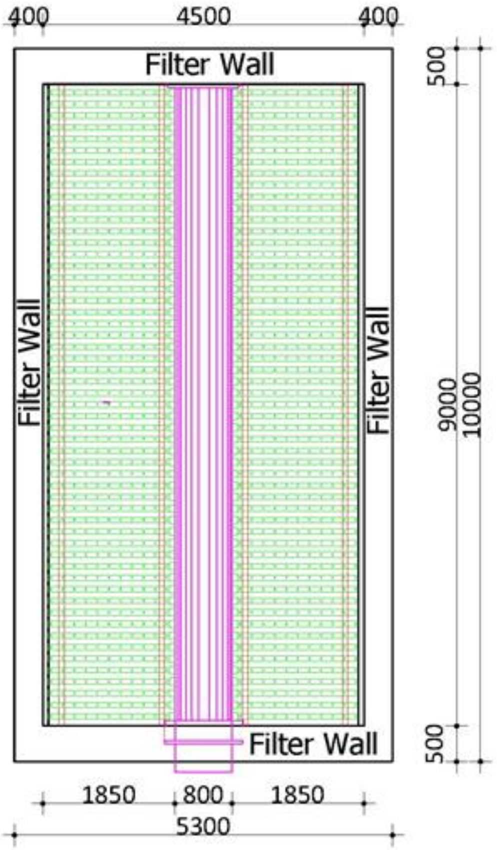


Figure 8.33: Typical Layout of Laterals and Manifold for One Filter

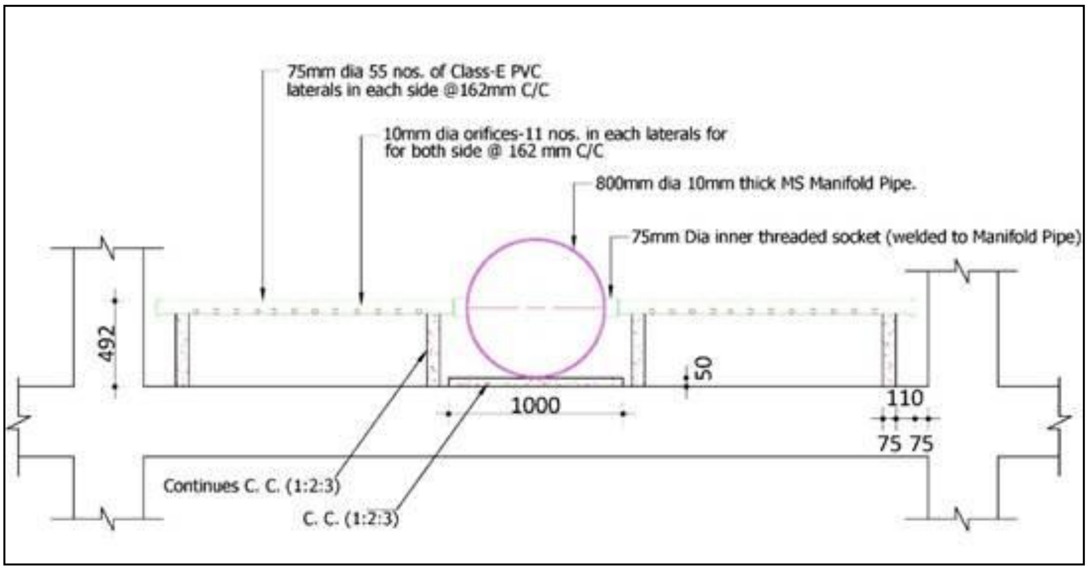


Figure 8.34: Typical Cross Section of Laterals and Manifold for One Filter

vi. Filter Gravel

Gravels placed between the sand and the underdrain system to prevent sand from entering the underdrain and to aid uniform distribution of wash water. The gravel should accomplish both purposes without being displaced by the rising wash water. Size of gravel varies from 45 to 84 mm at the bottom to 2 to 2.8 mm at the top with a certain depth. The faster the rate of application of water the larger the gravel size is required. European-type deep-bed filters use relatively coarse and uniformly graded media.

The depth will vary according to the type of filter bottom and strainer system used, except in the case of porous bottom where no gravel is required. For perforated pipe under drain system of BSMSN WTP, gravel has been selected as 2 mm of minimum size, 16 mm maximum size above the laterals which may extend to 84mm at the bottom and the total depth is considered as 1.0 m. The layers of filter gravel are shown in **Figure 8.35**.

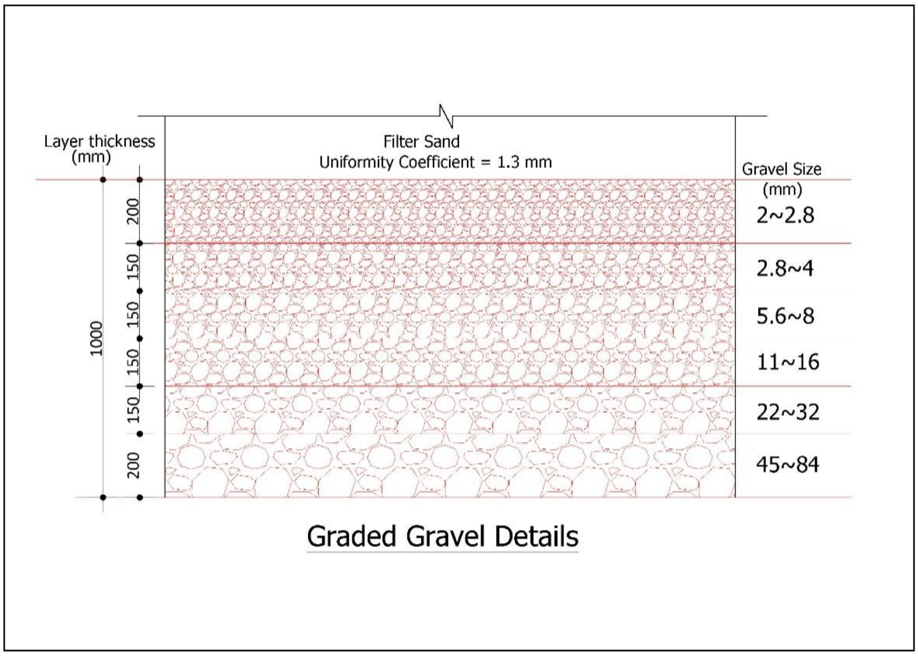


Figure 8.35: Typical Cross Section of the Gravel Layers

vii. Wash Water Gutters

Material used for wash water gutters include concrete, asbestos cement, plastic, cast iron and steel. According to Huisman (Huisman, 1985), horizontal travel distance (or maximum permissible length of horizontal travel) is considered as 0.75m to about 2.5m. While the horizontal travel of dirty water over the surface of the filter is kept between 0.6 to 1.0 m before reaching the gutter, there are successful units with troughs eliminated and having only main gutters where the dirty water travel has been as high as 3 m (CPHEEO, 1999). It is uneconomical to place to place wash water gutters against the side walls of the filter. The upper edge of the wash water gutter should be placed sufficiently near to the surface of the sand so that a large quantity of dirty water is not left in the filter after the completion of washing. At the same time, the top of the wash water gutter should be placed sufficiently high above the surface of the sand so that sand will not have washed into the gutter (from minimum 20% expansion to about 50% expansion of sand bed; Huisman, 1985; AWWA, 2005). The edge of the trough should be slightly above the highest elevation of the sand as expanded in washing. Where this height cannot be determined by test, a convenient is to place the edge of the gutter as far above the undisturbed sad surface as the wash water rises in one minute. The gutter should be large enough to carry all the water delivered to it with at least 50 mm between the surface of the water flowing in the gutter and the upper edge of the gutter. Any submergence of the gutter will reduce the efficacy of the wash. The gutter may be made with the same cross section throughout its length or it might be constructed with varying cross section increasing in size towards the outlet end. The bottom of the gutter should clear the top of the expanded sand by 50 mm or more (Huisman, 1985). During back washing, the wash-water together with the dislodged impurities from the filter bed is carried away with a system of troughs and galleys at a distance of 0.75m to 0.9m above the filter bed (AWWA, 2005). The wash water gutters with sand bed are shown in **Figure 8.36**.

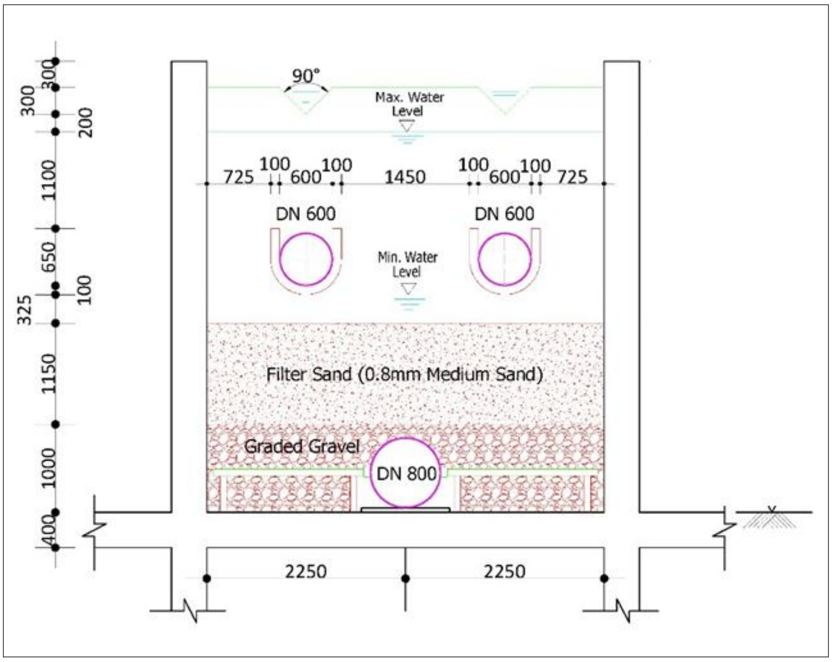


Figure 8.36: Typical Cross Section of a Filter with Wash Water Gutter with Manifold System

Numbers, size and filtration rate

Clarified water flows by gravity to the filter influent header channel. The filters have been designed as constant rate, variable head, and inlet flow splitting rapid sand filters. A total 10 filters have been chosen. The size of each filter is 9 m x 4.5 m. Filtration rate is 5.24 $m^3/m^2/h$ when the total flow is dispatched between the 10 filters of filter battery. The flow into individual filters will always be equal and will be controlled by filter inlet weirs built across the filter inlet channel. The quantity of water being filtered is constant, except for small increase or decrease that occurs each time filters are taken out of service for backwashing and returned service again. When one filter is having backwashing, the filtration rate of the 9 working filters rises up to 5.8 $m^3/m^2/h$, which remains acceptable for a short lap of time.

Backwashing facilities include backwash water pumps.

Backwash water pumps

The design includes:

- Construction of backwash facilities including 3 (two for operation and one standby for filter battery) backwash pumps, including control panel, pipes and accessories.
- Installation of access gate and ladders – installation of appropriate and standalone lifting equipment to ease O&M.
- Flexible hose pipe including water supply to be installed for the maintenance.
- Protection – Automation – Controls:
  - Automation – controls: Manual – Semi-automatic – Automatic as per backwash process.
  - Manual change-over with the spare pump, pumps equipped with timer for alarm for manual change- over.
  - Pumps protected by LSL in the back water tank.

Alternative of Filter Battery and Backwashing Facilities:

An alternative of filter battery with filter Nozzles arrangement can also be used and backwashing facilities include air blowers and backwash water pumps to reduce the backwashing time.

8.5.3.6.4 Influent & Effluent Lines and Controls

The filter box is finally provided with a number of influent and effluent lines, equipped with valves and with controllers to keep water levels and the filtration rate constant. For clarity in Design, all these lines have been considered separately; although in practice they are combined and concentrated as much as possible to reduce the cost of construction and operation.

8.5.3.6.5 Filter Units and Level of Corridor

A rapid filtration plant always consists of a number of filtering units, mostly between 4 and 40 (here 10). These units are commonly situated on one or on both sides (here one sided) of a two level corridor, while a central building houses special equipment such as –

- Pumps
- Compressors
- Tanks for back-washing with water and/or air
- Heating and ventilation equipment for air-conditioning
- Storeroom
- Laboratory
- Offices

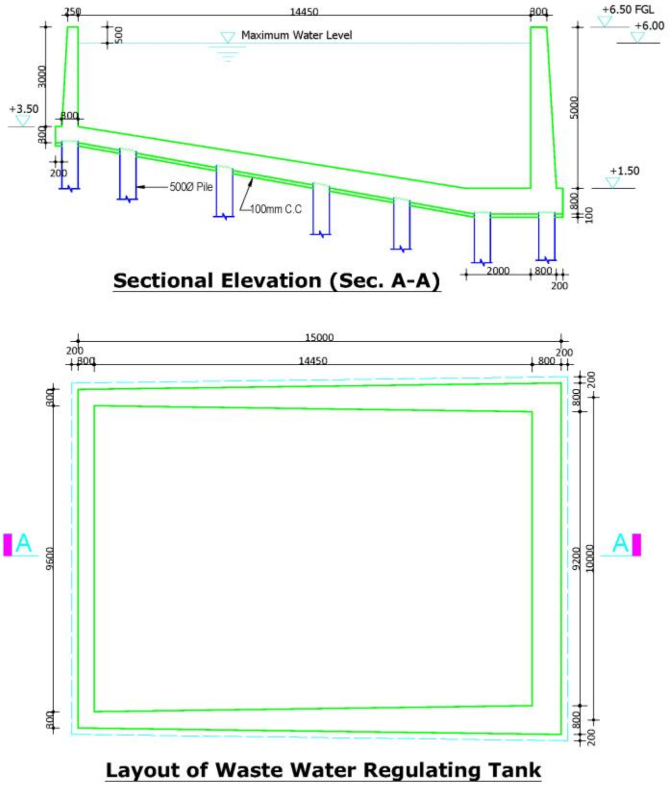
8.5.3.6.6 Back-Wash Recycling Facilities

Back-wash water will be recycled in order to save water resource. Indeed, total backwash water volume is about 2% (1000 m^3) of total flow for on backwash per day.

- Construction of one backwash recycling tank of 15mx10m of size (storage capacity is considered for three filter battery), including pipe and accessories and overflow.
- Construction of pumping facilities for one backwash recycling tank, each including 1+1 (one on duty & one standby) back wash recycling water pumps and control panel, pipes and accessories & metering facilities.

- Installation of access gate and ladders – installation of appropriate and stand-alone lifting equipment to ease O&M.
- Flexible hose pipe including water supply to be installed for the maintenance.

The plan and section of back wash recycling tank is shown in **Figure 8.37.**



Sectional Elevation (Sec. A-A)

Layout of Waste Water Regulating Tank

Figure 8.37: Plan and Section of Wash Water Regulating Tank

8.5.3.7 Treated Water Reservoir

The highest water level at treated water reservoir is 7.6 mPWD and the depth of water is 4 m. The bottom elevation of the reservoir is 3.6 mPWD.

A chlorine zone has been established in the treated water reservoir and sized for a 30 minutes contact time. From the chlorine contact zone, the water flows over a weir into the second section of treated water reservoir from which the treated water pumps will take suction. Typical water works practice is to design the treated water reservoir on the basis of percentage of maximum capacity of the treatment plant. The storage is usually 5-10% of the plant rated capacity.

Following consideration have been made for selection of size:

- Provide chlorine contact basin for post chlorination;
- Act as a buffer between raw water pumping rate and high lift pump rate into the transmission main, so that the treatment plant can be operated at a constant rate.

The capacity of the reservoir has been considered for about 2 hour's production of the treatment plant (4,500 m3). Hence total volume is 5600m^{3,} including contact tanks volume

(1100 m^3), which represent 11.20% of the plant capacity. The size of the contact tanks and the reservoir is 50m x 29m x 5m including the free board. The reservoir will be divided equally in two (02) parts (2,250 m^3 each) for maintenance purposes. The reduced level (R.L) of the top slab of the reservoir will be 7.6+ 0.7= 8.3 mPWD to avoid contamination from the surface. Similarly, access manhole and air vents will be raised to sufficient level to prevent flood water intrusion.

A part of the treated water reservoir has been proposed as treated water pump sump whose bottom will be at 1.8 mPWD. A plan of clear water reservoir is shown in **Figure 8.38.**

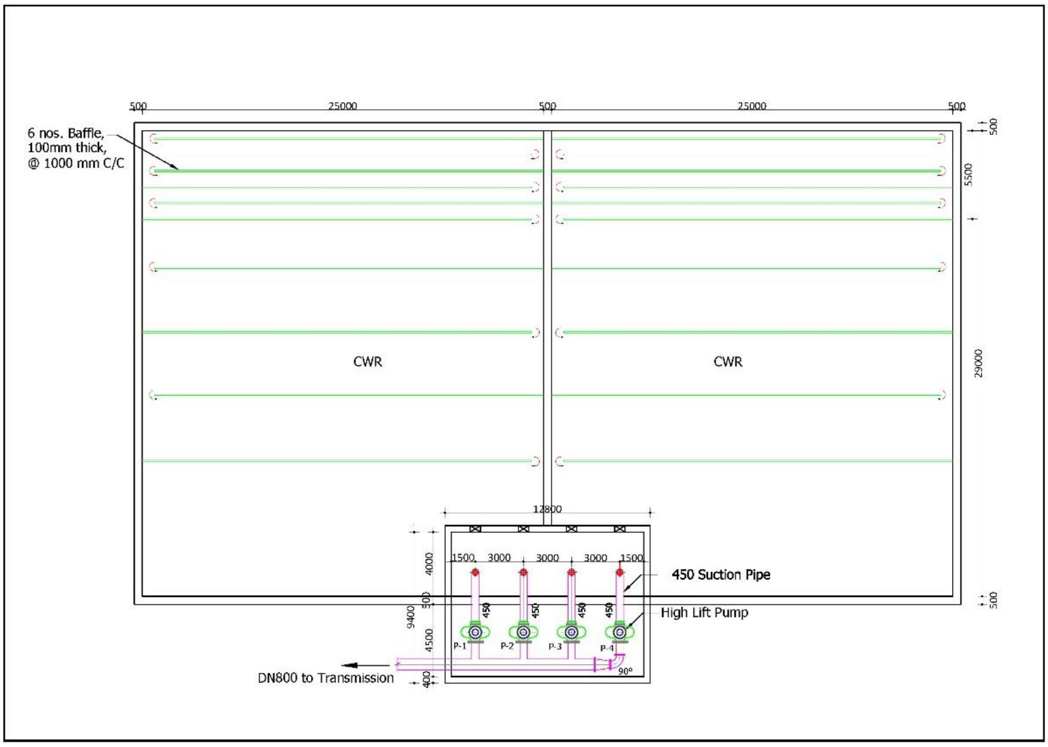


Figure 8.38: Plan of Clear Water Reservoir

8.5.3.8 Treated Water Pumping Station

For transmission of the water produced in the plant to a high lift pumping station will be necessary. The pumping station will be placed near the treated water reservoir. The characteristic of the treated water pumping station are as follows:

Table 8.30: Characteristic of the Treated Water Pumping Station of WTP Site

Items	Considered Values
Capacity of the pumping station	0.58 m^3/s
No. of on duty pumps	2
No. of standby pumps	2
Capacity of each pump	0.29 m^3/s
Pump efficiency above	80 %
Bottom level of the pump sump	1.8 mPWD
Design head of pump	50 m
Design KW of pump	200 KW

Pumping station delivery head is 50 m to ensure a 1.5 bar pressure in the secondary transmission main (which will ensure at least 1.0 bar pressure at each node of main distribution system). The diameter of individual column pipes of each pump and the common transmission main are considered as 400mm and 800mm respectively. The transmission main length from the treatment plant to proposed priority zone is about 12.3 km.

8.5.3.8.1 Pump Suction Arrangement

All the pumps will discharge to a pipe header located in the pump house opposite to the reservoir end. An overhead bridge crane will be provided to aid in the maintenance equipment within the pump house.

8.5.3.8.2 Surge

In order to limit the magnitude of anticipated surge pressures, the following appurtenances in the treated water pumping station will be provided.

- At least two by pass line will be connected between reservoir to discharge header;
- Check valves at each pump delivery will be provided as anti-vacuum devices to allow introduction of treated water from the reservoir, through the by-pass here-above mentioned;
- Installation tees and air release valve will be installed in each pump delivery;
- Flow discharge device with quick opening to evacuate flow in case of overpressure risk;
- Normal pump slating and stopping will need to be staggered by at least 10 minutes intervals;
- After a power failure, the slating of the first pump will need to be delayed by at least 15 minutes.

8.5.4 Sludge Treatment Process Selection

8.5.4.1 Sludge balance

8.5.4.1.1 Sources of water

Whatever the sludge treatment process is, the sizing is based on the determination of the quantity of sludge to be treated. When a drinking water treatment plant is fed from a river, the quantity of sludge is variable according to the season, due to the variations of raw water quality. Peak sludge production is generally observed during the rainy season, as a consequence of soil erosion, or during algae bloom period.

Sludge dewatering infrastructures have to be designed to comply with all the possibilities regarding sludge quantity. Sizing key data are the maximum mass of sludge to be treated per week (peak quantity) and the average quantity to be treated per day.

The values of these two parameters have been estimated considering the sources of raw water 50,000 m3/day from Feni River throughout the year.

8.5.4.1.2 Sludge Balance for Feni River water

The quantity of sludge resulting from the treatment of Feni river water has been evaluated from the results of the water quality study realized during wet and dry season. This study is based on 3 samplings collected in July, August and September 2018. This evaluation is presented in **Table 8.31**.

Table 8.31: Estimation of sludge quantity resulting from BSMSN WTP

Date of sampling	TSS	PAC required dose	Estimated dry solids associated with SS content	Estimated dry solids associated with chemicals	Estimated total dry solids	Estimated total dry solids for 50,000 m^3/day
	mg/l	mg/l	mg/l	mg/l	mg/l	t/day
17/07/2018	186	25	186	5.85	191.9	9.6
01/09/2018	42	25	42	5.85	47.9	2.4
10/10/2018	26	25	26	5.85	31.9	1.6
28/01/2019	23	25	23	5.85	28.9	1.4
25/02/2019	32	25	32	5.85	37.9	1.9
13/03/2019	36	25	36	5.85	41.9	2.1
Average	**57.5**	**25**	**57.5**	**5.85**	**63.35**	**3.2**

Note: 1 mg of alum results in 0.234 mg of chemical sludge consisting in $Al(OH)_3$ *precipitate as per the following relation:*

$$Al_2(SO_4)_3, 18\ H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 18\ H_20 + 6\ CO_2 + 3\ CaSO_4$$

According to these data:

- The average sludge production will reach 3.2 t/day in wet season;
- We assume that the peak sludge production could reach during wet season three times as much as the average quantity, therefore 9.6 t/day;

We also assume that sludge quantity is maximum during wet season, so that the sludge treatment work should be sized according to the above average and peak quantities

8.5.4.2 Sludge Treatment Line

8.5.4.2.1 Sludge Characteristics

The quality of sludge depends both on the raw water quality and the water treatment process.

Generally, drinking water sludge contain 4 mains components: silts, organic matter, hydroxide precipitate and carbon activated particles. Silts and organic matter are present in raw water, in the form of suspended solids or dissolved matter (organic matter only). Hydroxide precipitate comes from the application of coagulant to enhance settlement. Carbon activated is added in settlement tanks to remove pesticides as well as other dissolved organic components.

In BSMSN WTP, the sludge contains all these components except carbon activated particles as carbon is not used in the treatment process.

According to the above calculation, the proportion of hydroxide in sludge could be 25%.

8.5.4.3 Treated sludge possible destinations

It appears that there is no regulation and no case of sludge re-use in Bangladesh.

Several possibilities regarding sludge final destination can be proposed:

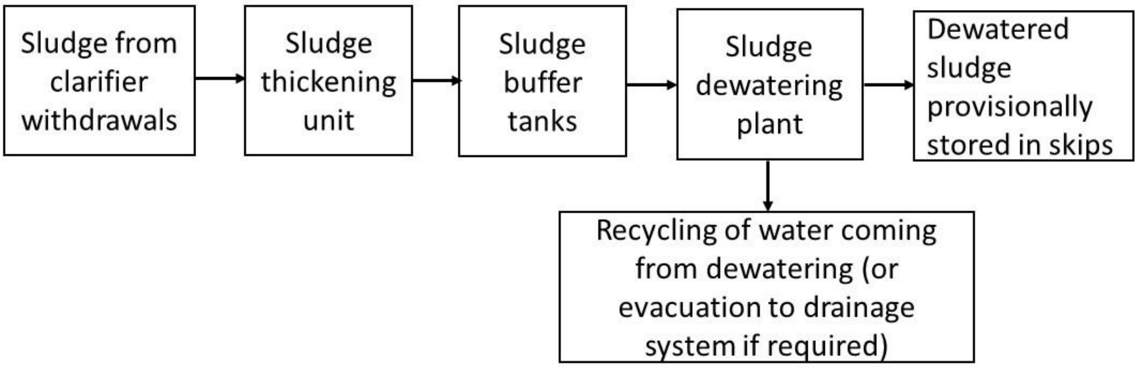
- Use of sludge as land-filling material;
- Use of sludge as filling material for public works (road, pipe laying) provided that sludge contents in organic matter are acceptable;
- Use of sludge as material for brick manufacturing by incorporating sludge in clay;
- Use of sludge as material for agricultural soil improvement, providing that lime is added and aluminium concentration is acceptable (aluminium is toxic for humans and plants);
- Evacuation of sludge to dumping site.

The final destination or reuse of the dewatered sludge will be determined by BEZA according to local possibilities

8.5.4.4 Sludge treatment general recommendations

Due to drinking water sludge characteristics, the treatment will include 2 steps: thickening and dewatering.

As thickening will be operated continuously 7days/ week and dewatering only 6days/week, it is recommended to add buffer tanks between the thickening and the dewatering steps. These tanks will also support the homogenizing of the sludge coming from the Water Treatment Plants. The general arrangement of sludge treatment will be as shown in the following diagram.



8.5.4.5 Comparison of sludge treatment solutions and recommendations

8.5.4.5.1 Possible technologies

Technologies used for drinking water sludge thickening are the following ones:

- Static thickening;
- Lamellar;
- Floating thickening.

Static thickening

Static thickening is the simplest technology. It allows theoretically obtaining sludge with a dryness rate in the range of 1% (10 g/m^3) and 10% (100 g/m^3) according to sludge characteristic, with an average value of 3%. In Saidabad, a dryness rate of 2% at least could likely be obtained, possibly with addition of polymer.

Lamellar thickening

Lamellar thickening results in sludge concentration higher than the one obtained from Static thickening. Dryness rate is in the range of 5% to 20% according to sludge characteristics. In BSMSN WTP, a dryness rate of about 10% could likely be obtained, possibly with addition of polymer.

These performances are made possible by use of lamella which increases the settling area for the same global size of the thickener. Hence lamellar thickeners are more compact than static ones.

Floating thickening

This thickening treatment consists in pressurizing sludge by mean of injection of pressurized air at a pressure in the range of 3 bars to 6 bars. Contact between air and sludge takes place in a metallic air saturating tank.

In a second time, pressurized sludge is expended and sent into a flotation unit where floating sludge is extracted by mean of a surface scraper.

Two types of floating thickening are used:

- Thickening with direct sludge pressurization (direct thickening) as described below;
- Thickening with pressurization of clear water instead of sludge, followed by expansion and injection of water in sludge before floating step (indirect pressurization).

Floating thickening is compact and floated sludge has a high rate of concentration (about 40 to 60g/l). On the other hand, floating operation is a bit delicate and this type of floating does not allow storing sludge in the thickener. Floating thickeners are more compact than static ones.

Recommendation

Due to robustness and simplicity of operation, static thickening have been recommended. It will be necessary to use it in combination with an addition of polymer, in order to obtain the sludge concentration required for dewatering treatment (at least 20 g/l). Polymer injection rate will have to be determined by the bidder according to its experience for such a process. It is usually in the range of 0.5 ppm to 5 ppm. In case of overflow recycling, polymer will have to be compatible with drinking water quality requirements.

8.5.4.5.2 Size calculation for static thickening solution

The calculation in relation with the sizing of thickeners is presented in **Table 8.32**.

Table 8.32: Sizing of thickeners

Total Sludge Flow	Maximum Load	Velocity	Number of unit	Minimum area per thickener	Theoretical thickener diameter	Proposed thickener diameter	Proposed thickener volume	Mass load	Maximum thickened sludge discharge	Recycled water flow
m^3/h	TDS/day	m/h	u	m^2	m	m	m^3	kg/m^2.day	m^3/h	m^3/h
65.63	3.2	0.7	2	47	7.7	8	201	31.8	6.6	59.1

In this table:

- Sludge flow is calculated on the basis of 3% of the water flow admitted into the clarifiers;
- Maximum load is the peak load in the strongest conditions (refer to the **Table 8.33**: Provisional sludge production of BSMSN WTP);
- Peripheral height of fluids (sludge and supernatant) is fixed to 4 m.

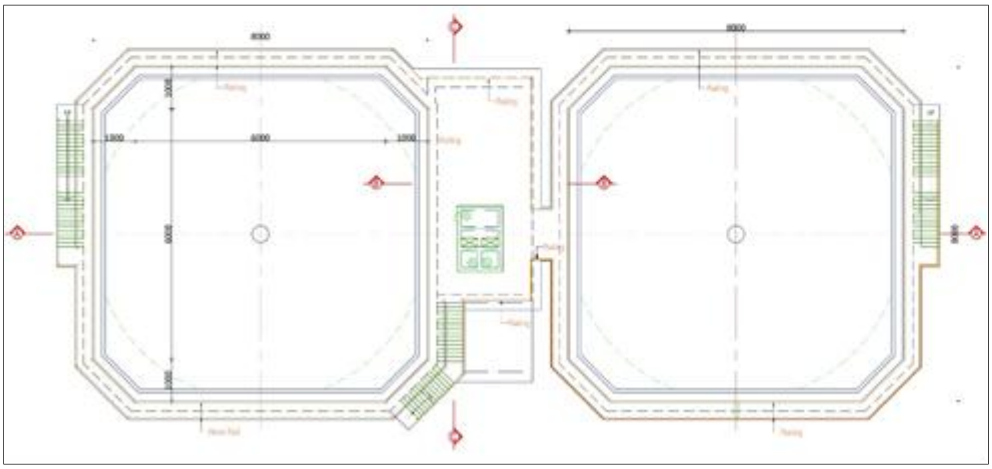


Figure 8.39: Plan of Sludge Thickener

Thickening needs addition of specific polymer to obtain dry solid at required concentration of at least 20 g/l. The provisional polymer consumption is calculated and given in **Table 8.33**.

Table 8.33: Polymer consumption for thickening

Polymer injection rate (kg/m^3)	Total sludge flow (m^3/day)	Polymer consumption (kg/day)	Polymer storage requirement	
			Storage autonomy (month)	Storage capacity (ton)
0.003	1575	4.725	12	1.7

8.5.4.5.3 Sludge buffer tanks

One buffer tank will be constructed under the dewatering building in order to:

- Homogenize sludge from various thickeners;
- Store sludge during filter stop periods (for example during night or holidays);
- Control the functioning of the dewatering plant.

Buffer tanks will be equipped with stirrers and pumps. Stirrers will aim at sludge homogenization and settling prevention. Pumps will discharge sludge to preparation tanks.

The total capacity of the tanks must allow storing the daily peak production. **Table 8.34** shows the sizing of the tanks.

Table 8.34: Sizing of the sludge buffer tanks

Designation	Unit	Value
Sludge peak production	T DS/day	9.6
Storage autonomy	Day	1
Sludge concentration	g/l	20
Total storage capacity	m^3	480
Number of tank	u	1
Volume per tank	m^3	480

8.5.4.5.4 Supernatant recycling

Sludge thickening results in water losses (supernatant) representing about 3% of the raw water flow admitted in the water treatment line (about 1418 m^3/day)

As the suspended solid concentration of supernatant is generally small, it can be mixed with raw water and recycled in the water treatment line. This arrangement avoids rejecting water outside the plant and allows saving water.

However, recycling is not desirable in the following cases:

- Bad quality of raw water;
- High concentration of suspended solids in the supernatant (due to thickener dysfunction)

To cope with such events, the project will include facilities for the evacuation of supernatant to the west Ichakhali khal.

These facilities include:

- A 60 m^3/h pumping station located in the WTP site;
- A 150 mm diameter and 250 m long pipe.

8.5.4.6 Dewatering plan

8.5.4.6.1 Possible technologies

Two compact technologies are now currently used for drinking water sludge dewatering: centrifugation and filter-press technology. With these technologies, sludge concentrations in the range of 18% to more than 30% are attained, provided that sludge is previously thickened.

Centrifugation

Centrifugation achieves water-solid separation by settlement and consolidation of solids under the influence of strong centrifugal forces generated by high speed rotating machines. Provided prior sludge flocculation by means of polyelectrolyte, centrifugation is able to produce a sludge cake with a solid concentration of about 20%. This concentration can be increased up to 30% by use of quick lime.

Filter-press technology

Filter press technology is a water-solid separation process using the principle of pressure drive, provided by a slurry pump. Filter press is system working with fixed volume and in batches: the operation has to be stopped to discharge the filter cake before the next batch can be started. The major components of filter press are the skeleton and the filter pack. The skeleton holds the filter pack together while pressure is being developed inside the filter chamber. The filter pack can only hold a specific volume of solids.

Belt filter

Belt filter technology is a water–solid separation process consisting in pressing sludge between a belt and successive rollers. Sludge is mixed with cold lime before dewatering treatment. Obtained levels of dryness are lower than levels obtained with other solutions.

Table 8.35 shows the range of final dryness rate for each technology to reach at reagent demand.

Table 8.35: Existing compact dewatering technologies

Technology	Reagent	Range of dryness rate for hydroxide sludge
Centrifugation with	With addition of polymer (4 to 8 kg/t dry solids)	15 to 20%
Centrifugation with high	With addition of polymer (7 to 12 kg/t dry solids)	20% to 25%
Filter press	With addition of lime (30% to 50% of the dry solid mass) Addition of polymer is possible but leads to reduce dry solid rate (about 20%) and to augment pressing time (4 hr. or more instead of 3 hr.)	30% to 35%
Belt filter	With addition of lime (20% to 40% of the dry solid mass)	20% to 25%

Dryness rates mentioned above are provisional estimations which will have to be confirmed by the bidder on the basis of effective sludge characteristics.

Among these 4 solutions, we propose to dismiss normal centrifuge solution as well as belt filter solution for the following reasons: dryness rate obtained from normal centrifuge solution is too low. Filter belt unitary capacity is relatively weak and would involve numerous filters. Also, this kind of filter is maintenance demanding. Therefore, only filter press solution is studied.

8.5.4.6.2 Filter-Press Solution

Filter press line organization

The diagram below shows the organization of a filter press line.

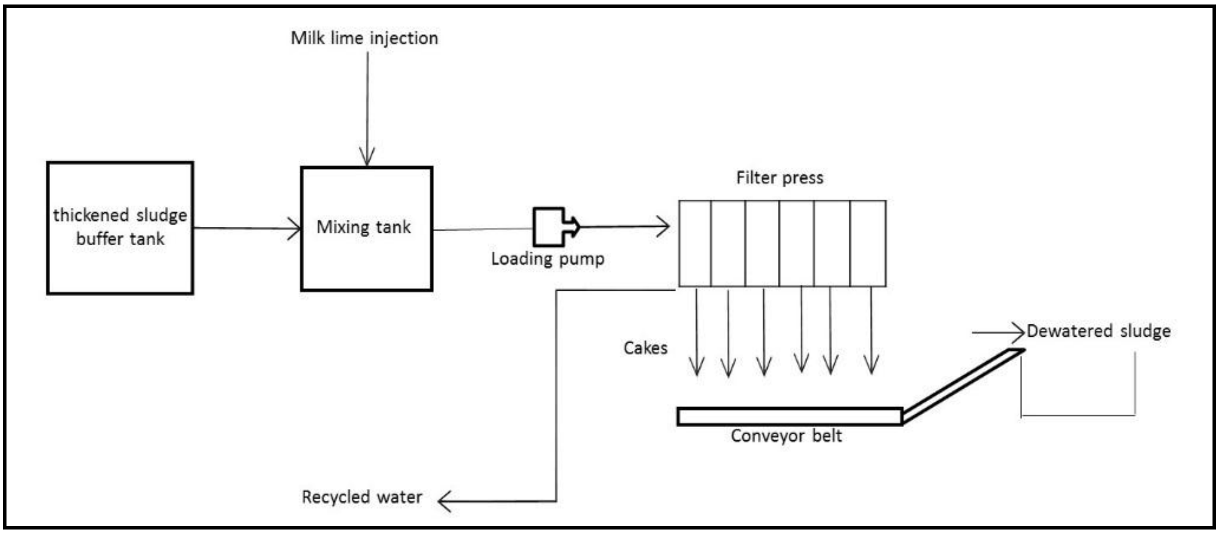


Figure 8.40: Filter press line

Sizing calculation for filter-press solution

The sizing of a filter press plant depends both on mass of sludge to be treated and daily working time. So, sizing could be based on the following assumptions:

- The dewatering plant will work 6 days in a week;
- The maximum time of plant working could reach up to 18 hours per day during peak period when all filters are working;
- The maximum time of plant working could exceptionally reach up to 24 hours per day during peak period when one filter is on maintenance.

Considering that filter-press operation requires the presence on site of several technicians and operators, especially during the debalasting phase, it is assumed that operation staff will be managed according to a system of shift rotation. On the basis of continuous working time of 8 hours per shift, this means that 3 shifts would be required during a peak day. The desirable number of filter has to cope with various constraints: filter capacity available at manufacturer’s, acceptable cost and required area, effective operation flexibility. A 4-filter plant represents the best solution to take into account all these constraints. However, bidders will be admitted to proposing a different number of filters provided they prove their solution presents the best balance between advantages and drawbacks.

The calculation in relation to the sizing of the dewatering plant is shown in **Table 8.36**.

Table 8.36: Sizing of the dewatering plant (4 filters)

Designation	Unit	Peak sizing value	Average sizing value
Hypothesis for calculation			
Thickened sludge concentration	mg/l	20	20
Time of operation per week	day	6	6
Maximum of cycles per filter and per day in normal conditions	u	3	2
Number of filters	u	4	4
Total number of cycles per week	u	72	48
Normal working conditions			
Average daily working time with 4filters	h	12.00	8.00
Working conditions with one filter in maintenance			
Average daily working time with 3 filters (1 filter in maintenance)	h	16.00	10.67
Lime and treated sludge quantities			
Lime treatment rate (reported to sludge treatment mass)	%	40	40
Quantity of lime required per year	t/year		174.3
Treated sludge volume (per year)	m^3/year		1694.9
Equipment sizing			
Press capacity	l		3300

General arrangement and required area

Dewatering equipment will be installed in a two-floor building. Filter press will be set on the upper floor so as to allow sludge cakes to fall down on conveyor belts set on the ground floor. Dosing lime equipment, milk of lime preparation and dosing sets, sludge and lime mixing tanks, pumps and treated sludge skips will be installed on the ground floor. Sludge buffer tanks will be located in the basement of the building. Lime will be supplied and stored in bags as per the practice in Bangladesh at the present time. It will be stored in a 2-month capacity storage room.

However, bidders will be admitted to propose a solution based on the storage of lime in silos provided that they prove that:

- Unpackaged lime is available in Bangladesh;
- There will be no problem related to humidity concerning lime circulation.

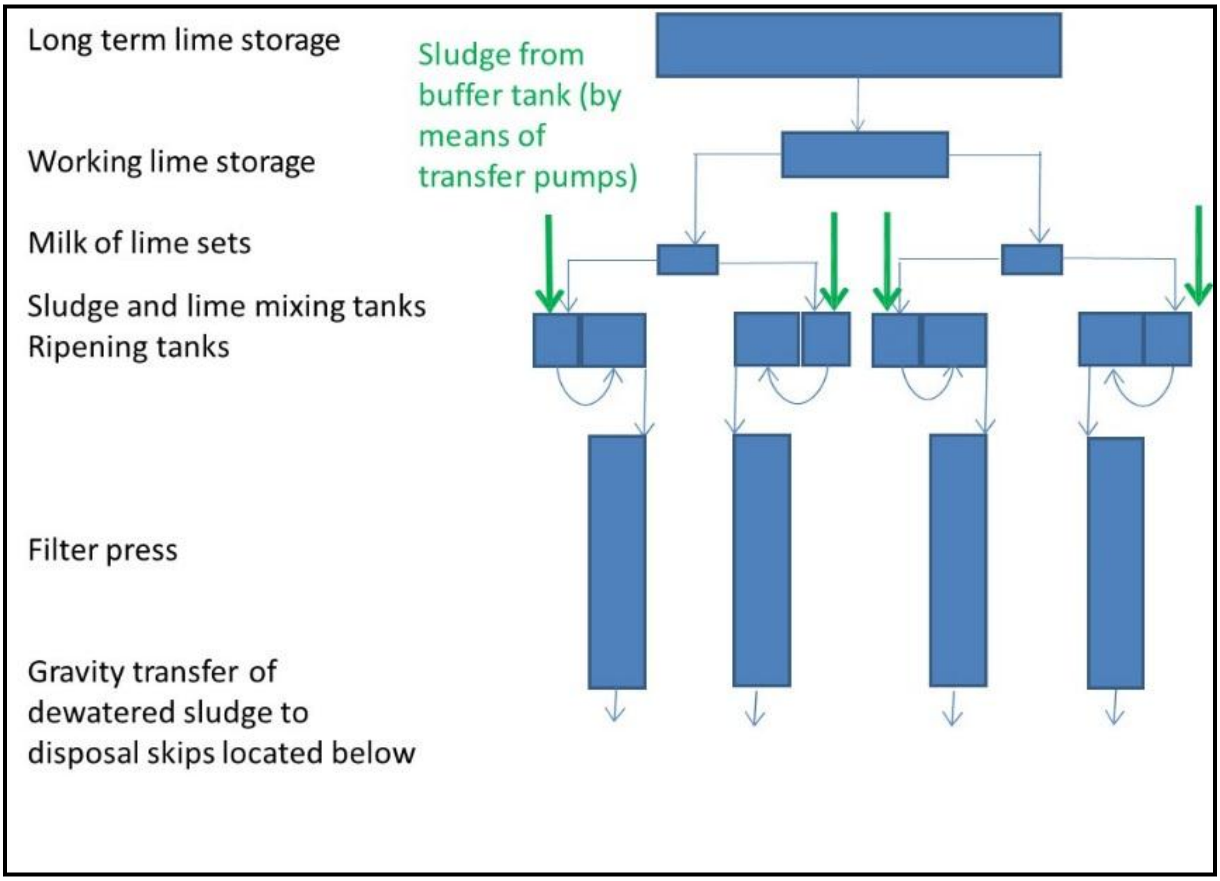


Figure 8.41: Schematic arrangement of the dewatering plant (filter press solution)

The building size and the required total area will be approximately as follows.

Number of filters	Dewatering building				Lime storage shed	
	Ground floor size		Floor size			
	m x m	S (m^2)	m x m	S (m^2)	m x m	S (m^2)
4	23.5 x 33.4	785	23.5 x 22	517	10 x 8	80

8.5.5 Chemicals for Water Treatment

8.5.5.1 Introduction

Treatment of water in the Plant will be based on the chemical process of treatment. The following reagents will be used for water treatment: chlorine, Poly Aluminum Chloride (PAC) and lime.

Chlorine will be received, stored and fed from a building located in the layout plan. The first location of chlorine injection is at the entry of the raw water before mixing with other chemicals. The second injection point is the contact tank for final disinfection. Chlorine will be stored and prepared in a chlorination plant equipped with all equipment required for operator safety (chlorine leak detection, chlorine leakage neutralization).

Poly Aluminum Chloride ($[Al_2(OH)_nCl_{6-n}]m$ ($1 \leq n \leq 5$, $m \leq 10$)) will be added in the mixing chamber for coagulation purpose. The most common PAC for water purification is

$Al_{12}(OH)_{24}Cl_{12}$ when n= 2 and m= 6. A small solution make-up tank will be diluted into a bigger tank, as it is done in existing plants.

In the laboratory test, during the process design, it has been seen that the pH of raw water is about 7 to 8. As pH tends to decrease due to Poly Aluminum Chloride addition, it could be required to add lime in coagulation tank in order to keep pH in the optimum range of 5.8 to 7.2. Lime will be added also at the end of the treatment to keep pH at about 7.5. PAC storage and lime feeding and dosing facilities will be housed in a separate building located near the rapid mixing tanks. The dosing chlorine, PAC and lime contents are shown in **Table 8.37**.

Table 8.37: Dosing of Chlorine, PAC and Lime

SL. No.	Chemicals	Purpose	Plant Capacity (MLD)	Raw Water (MLD)	Maximum Dosing (mg/l)	PAC Required per day (Ton)	PAC Required for 3 Months (Ton)	Density ton/m³	Storage Height in meter	Net Storage Area Required in m²
1	Chlorine [Cl_2]	Pre-chlorination	50	52.5	5	0.3	24	-	-	100
2	PAC [$Al_{12}(OH)_{24}Cl_{12}$]	Coagulation	50	52.5	30	1.6	142	1.7	2	50
3	Lime [$Ca(OH)_2$]	pH adjustment	50	52.5	10	0.5	47	0.5	2	50
4	Chlorine [Cl_2]	Post-chlorination	50	52.5	2	0.1	9	-	-	100
5	Lime [$Ca(OH)_2$]	Final pH adjustment	50	52.5	5	0.3	24	0.5	2	30

8.5.5.2 Chemical Delivery

Aluminum sulfate and hydrated lime are available in Bangladesh in dry form in 50 kg bags for alum and 40 kg for lime. Delivery of Alum and lime to the plant is carried out by lorry in loads of about 13 tons (13,000 kg). Chlorine gas is available in 1 ton containers. All chemical areas will be equipped with overhead bridge crane. Chlorine containers will also be unloaded with bridge crane.

8.5.5.2.1 PAC Storage and Dosing

Chemical dissolving tank will be installed for PAC. Average dose of PAC will be in the range of 25 to 30 mg/l. For 24 hours operation of PAC injection, at least two tanks will be necessary, with capacity of each tank for 12 hours PAC consumption.

Chemical metering pumps will be provided to meter out correct dosage

Details are the followings:

- Construction of the preparation tanks – pipes and fitting – tank baskets, and calibration units;

- Installation of 2 level control devices in the preparation tanks – LSH for alarm before overflowing – LSM to avoid the mixer to be operated at air/water interface – LSL for automatic switch to the second preparation reservoir and alarm if not possible – LSLL for shut of the system, the plant and alarm;
- Installation of 2 pneumatic actuated membrane valves at the outlet of the preparation tanks;
- Installation of 2 preparation mixer units;
- Installation of 2 hoppers for loading powder PAC;
- Installation of 2 (1in standby) single head dosing pumps – suction and delivery mains;
- Automatic rinsing line for each dosing pump based on a timer.

8.5.5.2.2 Lime Storage and Dosing

An anticipated lime dosage will be needed for water conditioning for flocculation (10 mg/l maximum and 5 mg/l on average), to increase pH for allowing complete flocculation. At least two mixing tanks for chemical mixing will be provided for lime, with capacity for each mixing tank of 525 kg of lime at 50 percent lime slurry, so each tank will provide one day supply of lime.

Lime will be added in rapid mixing chamber for pH adjustment (when required) and in treated water reservoir for pH correction. At least two pumps with a standby will be provided to feed lime slurry to the raw water, if ever required for pH adjustment.

Details are as the followings:

- Construction of the preparation tanks – pipes and fitting – tank baskets installation, and calibration units.
- Construction of two units (each couple of units comprising 2 pumps, 1 on duty & 1 standby) for pH correction, one at coagulation level and another at the outlet of the contact time reservoir.
- Installation of 2 level control devices in the preparation tanks – LSH for alarm before overflowing – LSM to avoid the mixer to be operated at air/water interface – LSL for automatic switch to the second preparation reservoir and alarm if not possible – LSLL for shut of the system and alarm;
- Installation of 2 actuated membrane valves at the outlet of the outlet of the preparation tanks;
- Installation of 2 preparation mixer units;
- Automation – Controls:
  - Regulation of the dosing pumps related to the opening of the SWTP inlet valve;
  - Automatic switch between preparation tanks with minimum reserve level (LSL) and visual alarm to operator. If both reservoirs are at LSL – audio alarm – dosing pump working to LSLL. If LSLL reached alarm only;
  - Regulation of 1+1 dosing pumps according to inlet flow - turbidity / aluminum dosage (standard ratio) – fine-tuning with pH coagulation inline monitoring;
  - Regulation of 1+1 dosing pumps according to filter outlet flow – water meter and fine-tuning with the pH at the outlet of the plant.

8.5.5.2.3 Chemical Building

A separate chemical building will be constructed for the following purposes:

i. Storage of lime and PAC;
ii. Preparation of chemicals;
iii. Dosing of chemicals.

All equipment in relation with chemicals (except chlorine) will be installed in this building (preparation tanks, dosing pumps, handling facilities and ancillaries).

The design includes:

- Construction of a chemical building including lighting and ventilation;
- Separation of acid and basic chemicals areas inside the same building;
- Installation of access gate and ladders, installation of appropriate and stand-alone lifting equipment to ease O&M.
- Flexible hose pipe including water supply to be installed for the maintenance.
- Provision for transport equipment forklift type.

8.5.5.2.4 Pre and Post-chlorination Facilities

i. Chlorine use conditions

Chlorine will be used for disinfection purposes and removal of some pollution (organic matter, ammonium). Chlorine will be used in raw water entering to the treatment plant before fixing other chemicals. Chlorine can be used in mixing chamber or ahead of mixing chamber. A small overhead tank will be constructed ahead of mixing chamber. This will serve the average estimated dosage of chlorine for the purposes. The average estimated dosage may be increased or decreased depending on the raw water quality. The demand increase and decrease of chlorine dosage depends on the seasonal variation. At least three months storage of chlorine should be reserved.

Anticipated average chlorination treatment rate are fixed as follows:

- Pre-chlorination: 3 mg/l as Cl_2 (5 mg/l maximum);
- Post-chlorination: 1mg/l as Cl_2 (2 mg/l maximum).

ii. Safety facilities

Chlorine storage feeding facilities will be isolated from other areas. Chlorine areas will be only accessible through entrances which lead directly from outdoors. Chlorine areas will be equipped with chlorine gas detector which will activate alarms located at monitoring and administrative building. Emergency eye wash unit and showers will be provided. In the event of chlorine solution leaks, chlorine neutralization with caustic soda solution will be provided. In addition, manually activated high capacity fans will be installed in the chlorine areas to exhaust chlorine gas leaks from the building when condition permits.

iii. Chlorine equipment

a) Installation of the pre- and post-chlorination systems including:
    - 4 standing chlorinators, 2 for pre- and 2 for post-chlorination on a 1 in operation and 1 in stand-by principle;

  - Pipe work and accessories for the injection of pre- and post-chlorine - 1 injection point for pre-chlorine at the inlet of the SWTP (pipe injection) and 1 injection point for post-chlorine at the inlet of the clear water reservoir;
  - Pressure control on chlorinator inlet valve, automatic switch to the standby tanks and alarm;

b) Installation of handling required accessories: lifting beam, hoist unit. Installation of a suspended weightier;

c) Flexible hose pipe including water supply to be installed for the maintenance;

d) Installation of scales for chlorine consumption monitoring, including local and remote display;

e) Construction of an extraction system in the storage and the chlorination rooms and installation of chlorine gas detectors;

f) Construction of a neutralization system, including tower and related facilities;

g) Supply of safety equipment;

h) Automation – regulation:
  - Regulation of the chlorinators to the opening of the WTP inlet valve;
  - Automatic switch between chlorine "tanks" according to residual pressure and with visual alarm to operator. If both "tanks" are at LSLL - plant shuts down with main audio alarm;
  - Automation and Regulation of the pre-chlorinators according to inlet flow;
  - Automation and Regulation of the post-chlorinators according to filtration flow. Post chlorination to be regulated according to the residual chlorine at the outlet of the contact time reservoir. Fine tuning of the post-chlorination according to the FRC at the outlet of the TWPS.

8.5.6 Outline Design of Electro-Mechanical Works for Water Treatment

8.5.6.1 Raw water pumping station

The pumps have been designed as per auto filling start off with underground raw water storage tank having bottom being 6 m lower than the existing ground level.

To ensure 52.5 MLD at 1.0 bar pressure the pump house will be constructed with unit flow of 0.305m^3/s, 10m head, and matching electric motor of capacity 30 KW for each pump. For average water supply of 52.5 MLD, 2 pumps will be in operation and 2 pumps will be considered as standby. Electric motor shall be selected with 1500 RPM and with 4 Pole-connections. The installation gap between two motors shall be 2m. The power factor (P.F.) of electric motors for the raw water pumps implements the quantified compensation with static power capacitor to ensure a total P.F of 0.95 at the switchboard bus-bar for all load conditions. Summary of the design outputs are given in **Table 8.38**.

Table 8.38: Characteristics of the Raw water pumping station

Size	9 x 13 m
Capacity	52.5 MLD
No of pumps (single stage, double section, horizontal centrifugal group)	4 nos (2 standby)

Capacity of each pump	0.305 m3/s
Head	10 m (1.0 bar)
RPM	500 (4 pole connection)
Hydraulic Efficiency	80%
Nominal power	30 kW
Absorbed power	24 kW

8.5.6.2 Pumps and Motors for Water Treatment Unit

Raw water will be conveyed to the water treatment plant where different treatment units such as clari-flocculators sand filters, chemical dosing & mixing chambers etc. are set to treat the water. Various pumps and motors required for the water treatment plant units are:

- Equipment for Clari-flocculators;
- Pumps for rapid sand filters backwashing;
- Filter blowers;
- Wash water recovery pumps;
- Alum stirrers and dosing pumps;
- PAC stirrers and dosing pumps;
- Chlorine dosing pumps;
- Sampling pumps;
- Sludge pumps;
- Sludge treatment polymer and lime dosing pump;
- Raw water pump before mixing chamber;
- Treated Water Pumps.

The power factor (P.F.) for these units implements the quantified compensation with static power capacity to ensure a total P.F of 0.95 at the switchboard bus-bar for all load conditions.

Characteristics of main pumps and motors have been specified as follows.

8.5.6.3 Backwash Water Pumps for Rapid Sand Filters only by water

Table 8.39: characteristics of the wash water pump by water

No. of Filters	10
Operational mode	Stop, Filtration, Back Washing
No. of operational lines	1
No. of filters under each line	10
Back wash sequence	Drain, Unclogging, Rinsing.
Backwashing time	30 min (water + rinsing)
Required volume per backwash	100 m^3
Water flow rate	37 m/h (Minimum) 50 m/h (Maximum)
No. of wash water pump	3 nos. (1 standby) per battery
Capacity of each pump	
Discharge	0.51 m^3/s

Head	8.4 m
Nominal power	6 KW

8.5.6.4 Wash Water Recovery Unit

Table 8.40: Characteristics of the Wash Water Recovery Pumps

No of tanks	1
Capacity per tank	500 m^3
No. of submersible pump	2 (1standby)
Capacity of each pump	
Discharge	150 m^3/hr
Head	15 m
Absorbed power	9 KW

8.5.6.5 PAC Dosing Unit

Table 8.41: Characteristics of the PAC Dosing Pumps and Motors

Average dosing rate	25 mg/l
Maximum dosing rate	30 mg/l
Hourly consumption at maximum treatment rate	66 kg/hr
Maximum flow of PAC (150 g/l)	438 l/hr
No. of PAC main tank	2
PAC tank capacity (per unit)	16 m^3
No. of PAC metering pumps	2 (1 standby)
Capacity of each pump	
Flow	1,000 l/hr.
Absorbed power	1.1 KW
No. of mixing propeller stirrer	2 nos. (1 standby)
Absorbed power	1.1 KW

8.5.6.6 Lime Dosing Unit

Table 8.42: Characteristics of Lime Dosing Equipment

Average dosing rate (pre-lime + post-lime)	5 mg/l
Maximum dosing rate (pre-lime + post-lime)	10 mg/l
Hourly consumption at maximum treatment rate	22 kg/hr
Maximum flow of milk of lime (50 g/l)	450 l/hr
No. of lime Tank	2 nos.
Lime tank capacity (per unit)	16 m^3
No. of pre-lime pump	2 (1 standby)
No. of post-lime pump	2 (1 standby)
Capacity of Each Pump	
Pre-lime pump flow	1,000 l/hr.

Absorbed power	0.75 KW
Post-lime pump flow	1000 l/hr.
Absorbed power	0.75 KW
No. of Mixing Propeller Stirrer	2 nos. (1 standby)
Absorbed power	1.1 KW

8.5.6.7 Chlorine Dosing Unit

Table 8.43: Characteristics of Chlorine Dosing Pumps and Motors

Average dosing rate (pre-chlorination + post-chlorination)	5.00 mg/l (Cl_2)
Hourly consumption at average treatment rate	10.94 kg/hr
Maximum dosing rate (pre-chlorination + post-chlorination)	7 mg/l (Cl_2)
Hourly consumption at maximum treatment rate	15.32 kg/hr
No of pre-chlorinators	2 (1 standby)
Pre-chlorinator capacity (each)	20 kg/hr
No of pre-motive pump	2 (1 standby)
Flow of pre-motive pump	18 m^3/hr
Head of pre-motive pump	50 m
Absorbed power of pre-motive pump	10 KW
No of post-chlorinators	2 (1 standby)
Post-chlorinator capacity (each)	7.0 kg/hr
No of post-motive pump	2 (1 standby)
Flow of post-motive pump	7.5 m^3/hr
Head of post-motive pump	40 m
Absorbed power of post-motive pump	1.5 KW
Maximum consumption of chlorine per day	370 kg
No of chlorine drums for 1 month at maximum consumption rate, 850 kg each	14
Storage autonomy at maximum consumption	30 days

8.5.6.8 Sampling Pumps

Four sampling pumps will be installed with the necessary pipe connections to the laboratory, in order to measure and control water quality at all process stages: 1) raw water (before mixing of chorine) 2) clarified water 3) filtered water and 4) treated water.

Table 8.44: Characteristics of the Sampling Pumps

Capacity of Raw & Treated Water Sampling Pumps	
Discharge	4 m^3/h
Head	80 m
Absorbed power	1.5 kW
Capacity of Clarifier & Filter Water Sampling Pumps	

Discharge	4 m^3/h
Head	60 m
Absorbed power	1.1 kW

8.5.6.9 Sludge Pumps

These pumps will discharge sludge from clarifier to sludge thickener.

Table 8.45: Characteristics of the Sludge Pumps

No of tanks	1
No. sludge drainage pumps	2 (1 standby)
Capacity of Pumps	
Discharge	200 m^3/h
Head	12 m
Absorbed power	9 kW

8.5.6.10 Treated Water Pumps

The High Lift pump station has been designed as per auto filling start off. The pump area is level with an average elevation of 7 mPWD and as per calculation of the flow of water the reservoir tank will be underground with inner bottom being 4m lower than the existing ground.

The pumping station will be equipped with 5.0 bar mwc (50m) head pumps.

To ensure 50 MLD treated water supply in the system pipe line, the pump station is installed with 4 unit's double suction centrifugal water pumps with unit flow of 0.29 m^3/s, head 50 m and matching electric motor of capacity greater than 200 kW for each pump.

Four (4) identical pumps will be installed. Out of four (4) pumps, two (2) will be fixed speed pumps and two (2) will be variable speed pump. One (1) fixed & one (1) variable speed pumps will be in operation at the same time. The pumps will be vertical turbine pumps and the suction pipe will be connected to treated water reservoir.

Electric motor may be selected having 4 pole connection and 1500 RPM. The installation gap between two motors is minimum 2.7 m. The power factor (PF) of electric motors for the treated water pumps implements the quantified compensation with static power capacity to ensure a total minimum P.F of 0.95 at the switchboard bus- bar for all load conditions.

Summary of design outputs are given below:

Table 8.46: Characteristics of the Treated Water Pumps

Pump building size	20 m x 68 m.
Capacity	50 MLD.
No. of Fixed Speed Pump	2 (1 standby)
Capacity of each pump	
Discharge	0.29 m^3/s
Head	50 m (5.0bar)

RPM	1500 (4 Pole connection)
Nominal power	200 kW
Absorbed power	180 kW
Efficiency	80%
No. of Variable Speed Pump	2 (1standby)

8.5.6.11 Polymer dosing Pumps

Table 8.47: Characteristics of Polymer dosing Pumps

Dosing and storage	
Dosing rate	3 ppm
Used per day	4.725 kg
Storage capacity	60 days
Quantity to be stored	285 kg
Polymer dosing equipment	
Hourly consumption at maximum treatment rate	0.2 kg/h
No of injection pumps	2 (1 standby)
Absorbed power (pump)	0.25 kW

8.5.6.12 Supernatant Drainage Pumps

These pumps will discharge supernatant from sludge thickener water to west Ichakhali khal.

Table 8.48: Characteristics of the Sludge Drainage Pumps

No of tanks	1
No. sludge drainage pumps	2 (1 standby)
Capacity of Pumps	
Discharge	100 m^3/h
Head	8 m
Absorbed power	3.5 kW

8.5.6.13 Buffer tanks and equipment's

Table 8.49: Buffer tanks and equipment characteristics

Buffer tanks capacity storage	One day of sludge peak production or 2days of average sludge peak production
No of buffer tanks	1
Volume per buffer tank	480 m^3
No of pumps	3 (1 standby)
Pump flow	50 m^3/h
Head	12 m
Absorbed power (pump)	3 kW
No of stirrers per tank	4
Absorbed power (stirrer)	0.75 kW

8.5.6.14 Preparation and dosing of lime slurry

Table 8.50: Lime dosing installations and pumps

Maximum dosing rate	40 % of dry solids
Consumption at maximum treatment rate	1.28 t/day
Maximum flow of milk of lime (50 g/l to 100 mg/l)	76.8 m^3 to 38.4 m^3
Maximum flow of milk of lime per filter cycle(maximum of 10 cycles per day)	7.68 m^3
Number of preparation tanks	2
Tank minimum capacity (per unit)	3.84 m^3
No of lime transfer pump	3 (1 standby)
Lime slurry pumps	
Flow of (per unit)	2.0 m^3/h
Absorbed power (per unit)	1 kW
Stirrers	
No of stirrers	4
Absorbed power (per unit)	0.75 kW

8.5.6.15 Sludge conditioning facilities

Sludge conditioning facilities will comprise of 4 tank where sludge and lime will be mixed. Each tank will be divided into two compartments: one compartment for proper mixing and one compartment for the feeding of sludge pumps. Sludge conditioning is done continuously during filter feeding process, for about one hour. Electromechanical equipment for conditioning will include stirrers.

Table 8.51: sludge conditioning facilities

No of tanks	4
Tank capacity (per unit)	15 m^3
No of stirrers	4
Absorbed power (per unit)	0.75 kW

8.5.6.16 Filter press feeding pumps

Filter feeding is done by means of a low pressure pump as well as a high pressure pump. Low pressure pump is used at the first stage of the feeding, to fill the filter. Then high pressure pump allows to increase pressure in the filter so that squeezing becomes sufficient to obtain an efficient filtration. Pumps used are eccentric rotor pumps. Pumps will have the following characteristics:

- Low-pressure pumps:
  - No: 4 (one pump per filter);
  - Capacity: 5 to 15 m^3/h
  - Pressure delivery side: 10 bar;
  - Absorbed power: 6 KW;
  - Drive by means of geared motor for frequency control.
- High-pressure pumps:
  - No: 4 (one pump per filter);
  - Capacity: 5 to 15 m^3/h;
  - Pressure delivery side: 15 bar;

- Absorbed power: 10 KW;
- Drive by means of geared motor for frequency control.

8.5.7 Outline Design of Electrical Installations

8.5.7.1 Power Requirements

A preliminary estimate of power requirement has been made, based on the maximum power absorbed in steady state by units (pumps, motors, and other equipment) and the number of units running simultaneously:

Table 8.52: Power Requirements for BSMSN SWTP

Elements	**Nominal power per unit kW**	**Number of installed units**	**Total installed power kW**	**Number of running units**	**Absorbed power per unit kW**	**Maximum power demand kW**
Water treatment line						
Raw water pumps	30	4	120	2	24	48
Wash water recycling pumps	9	3	27	2	8.5	17
Backwash Water Pumps	6	3	18	2	6	12
PAC dosing pumps	1.1	2	2.2	1	1.1	1.1
PAC tank stirrers	1.1	2	2.2	1	1.1	1.1
Pre-lime dosing pumps	0.75	2	1.5	1	0.75	0.75
Post-lime dosing pumps	0.75	2	1.5	1	0.75	0.75
Lime tank stirrers	1.1	2	2.2	1	1.1	1.1
Pre-chlorine dosing pumps	10	2	20	1	8	8
Post chlorine dosing pumps	1.5	2	3	1	1.2	1.2
Sampling Pumps for Raw &Treated Water	1.5	2	3	2	1.25	2.5
Sampling Pumps for Clarifier & Filter	1.1	2	2.2	2	1	2
Sludge transfer pumps from sludge tank to sludge thickener	3.2	2	6.4	1	2.9	2.9
Total water treatment line			*209.2*			*98.4*
Sludge treatment line						
Polymer dosing pumps	0.25	2	0.5	1	0.25	0.25
Waste water disposal pumps	3.5	2	7	1	3.5	3.5
Buffer tank pumps	2.5	3	7.5	2	2.5	5
Buffer tank stirrer	0.75	4	3	4	0.75	3
Lime dosing pumps	1	3	3	2	1	2
Lime stirrers	0.75	4	3	4	0.75	3

Sludge stirrers	0.75	4	3	4	0.75	3
Low pressure pump as feeding pump	6	4	24	4	6	24
High pressure pump as feeding pump	10	4	40	4	10	40
Total sludge treatment line			*91.0*			*83.75*
Treated water pump station	200	4	800	2	180	360
TOTAL			**1100.22**			**542.1**

With P.F. 0.80 and a provision of 20 % as safety factor, it can be summarized as follows: For water treatment line + sludge treatment line+ treated water pump station

- Application/operation load: 542.1 / 0.80 + 20 % = 813 kVA

8.5.7.2 Power Consumption

Table 8.53: Power Consumption for Mirsharai SWTP

Elements	Nominal power per unit (KW)	Number of Installed units	Number of running units	Absorbed power per unit (KW)	Running hours per day	Power Consumption KWH per day
Water treatment line						
Raw water pumps	30	4	2	24	24	1152
Wash water recycling pumps	9	3	2	8.5	12	204
Backwash Water Pumps	6	3	2	6	24	288
PAC dosing pumps	1.1	2	1	1.1	24	26.4
PAC tank stirrers	1.1	2	1	1.1	24	26.4
Pre-lime dosing pumps	0.75	2	1	0.75	24	18
Post-lime dosing pumps	0.75	2	1	0.75	24	18
Lime tank stirrers	1.1	2	1	1.1	24	26.4
Pre-chlorine dosing pumps	10	2	1	8	24	192
Post chlorine dosing pumps	1.5	2	1	1.2	18	21.6
Sampling Pumps for Raw &Treated Water	1.5	2	2	1.25	18	45
Sampling Pumps for Clarifier & Filter	1.1	2	2	1	20	40
Sludge transfer pumps from sludge tank to sludge thickener	3.2	2	1	2.9	20.0	57.8042
Total water treatment line						*2115.6*
Sludge treatment line						

Polymer dosing pumps	0.25	2	1	0.25	16	4
Waste water disposal pumps	3.5	2	1	3.5	16	56
Buffer tank pumps	2.5	3	2	2.5	16	80
Buffer tank stirrer	0.75	4	4	0.75	16	48
Lime dosing pumps	1	3	2	1	16	32
Lime stirrers	0.75	4	4	0.75	16	48
Sludge stirrers	0.75	4	4	0.75	16	48
Low pressure pump as feeding pump	6	4	4	6	16	384
High pressure pump as feeding pump	10	4	4	10	16	640
Total sludge treatment line						*1340*
Treated water pump station	200	4	2	180	24	8640
TOTAL						**12095.6**

8.5.7.3 Power Distribution

As the usual and main source of energy, the electricity supply for the plant will be taken from Power Development Board (PDB) of Bangladesh. Based on an estimated installed load of 1150 kVA and application / operation load of 850 kVA for the BSMSN surface water treatment plant, one 11 kV/415 V indoor sub-stations equipped with11kV switchgear and P.T., P.C., Bus-bar, Vacuum Circuit Breaker, Meters, DC operating power supply, will be installed.

- One sub-station for water treatment and treated water pump station including 850 KVA transformers;

8.5.7.4 Transformers

The power load of the water treatment unit results from process equipment functioning. Most of water treatment equipment shall use 415 V. Total operational load for water treatment line is estimated at 850 KVA with a Power Factor (PF) of minimum 0.95 on average. One 11 kV/415V transformer of 850 KVA each shall be required, with Oil Nature & Air Nature (ONAM) cooling, near treated water pump station. About 300m^2 floor area shall be needed for sub-station including control room. 11 kV/ 415V transformation & distribution system for water treatment plant units shall be set up in a 415 V load center, i.e. in the low voltage power distribution room near the back washing.

Transformer will be installed in power distribution room. For power distribution to pump motors & treatment units L.T. power distribution panel with PFI shall be required with all protective arrangements and as per requirements of REB/PDB.

8.5.7.5 Stand-by Generator

Optimized Capacity

Instead of covering full load for sludge and water treatment, stand-by generators capacity may be optimized. That shall secure not only plant safety (emergency lighting, sump pumps, air compressors etc.) but also normal operation modes for water treatment lines. Based on the maximum power absorbed in steady state, P.F. 0.95 and 20 % safety factor, optimized generator capacity is 850 kVA.

Specifications

Proposed generators should be standard units, in this case Gen Set unit will be of 800 kVA.

The output voltage of the alternator powered by the generator will be either 415 V to be connected to the Low-Tension distribution panel. The generator room shall be soundproof shielded to reduce noise nuisance.

Diesel

Else truck-supplied diesel fuel should be considered as an option for back-up energy resource. In that case on-site fuel storage would be needed to secure not less than 6 hours operation during power failure (estimated capacity including 25 % reserve: 3,000 liter).

8.5.7.6 Auto-control Design

The following protective items shall be used for 11 kV system load protection:

- Current fast – tripping – applicable for 11kv incoming, self- contained power supply, motors of outgoing feeders
- Over current – applicable for 11kv incoming, self-contained power supply, out-going feeders
- Overload – applicable for self-contained power supply
- Single phase – applicable for motor & outgoing feeders
- Low voltage – applicable for motors
- Over-heating signal – applicable for motors & outgoing feeders

The protection device will be of distribution PC protection type. Each power distribution unit will be provided with one protection device which is connected with the auto-control system through the bus. In addition, the protection device will have the function of monitoring real-time upload of equipment status (opening & closing, breakdown signals) and electric parameters as well as for remote opening & closing to realize the unattended operation between the pumps & motors.

In addition to the operation modes of the above PC protection, the field manual operation mode is also set up for water distribution pumps and main equipment, which shall be carried out by the host-command control appliance.

For the load protection of the low voltage system, automatic air circuit breaker will be used for protection against short circuit, overload and phase unbalance. The operating modes shall be manual and automatic. The automatic operation shall use Programmable Logic Controllers (PLC) in order to collect and store technical parameters of the raw pumping station, water treatment and sludge treatment such as:

- PLC instructions
- Feedback on equipment status

- Parameters to PLC.

The power to control systems shall be supplied through UPS having the function to supply continuously stable power even if the main normal power supply system has any failure. UPS shall be rated to supply the required load for 08 hours in case of a power outage. A redundant power system is essential because a failure in the supply of the control system would cause shut-down of the plant.

8.5.7.6.1 Design of Field Programmable Logic Controllers (PLC)

The water treatment plant shall have 5 sets of large capacity PLC field control units and 24 sets of small capacity.

Table 8.54: Principle PLC Field Control Units

PLC # 1:	Shall be set for the grid, mixing & sedimentation tank control room to collect & control automatically the quality of inlet raw water, process parameters & equipment status.
PLC # 2:	Shall be set for the control room of chlorination & chemical feeder chambers which shall collect & control automatically the process parameters & equipment status.
PLC # 3:	Shall be set up in the control room of back washing pump house (i/c grid filter tank) which shall collect & control automatically the process parameters & equipment status.
PLC # 4:	Shall be set up in the control room of treated water pump house (distribution pump house) which shall collect & control automatically the process parameters & equipment status.
PLC # 5:	Shall be set in the sludge dewatering building which shall collect & control automatically the process parameters & equipment status.

Small sets PLC

12 field control units shall be set in the 12 grid filter tanks which shall collect and control automatically the parameters & status process of filter process & back washing process of filter tanks. All PLC operating panels shall also allow manual control.

Central Control Room

The central control room shall be equipped with 2 operating stations, related equipment for data storage and monitoring purposes, as it shall be controlling the whole BSMSN WTP.

The control room should be located in the office building.

It shall monitor and operate the Electrical system of the water treatment plant, and the auto-control system for comprehensive process monitoring of the whole plant.

8.5.7.6.2 Communication System

Radio communication may be used for voice communication. Internal telephone exchange connecting all the units & duty place / office / quarters & installation of intake treatment plant & booster pumping stations may be adapted with 3 to 5 external telephone line connection and 3 fiber optic lines.

8.5.7.6.3 Control System

The distributed type auto control system with PLC (Programmable Logic Controller) at two stages – field and the central room will be set up. The supplier shall design the control system following the principles of "centralized detection and distribution control". The mode of communication between the field and the central control room will be equipped with 2 workstations, while the configuration of the field control station will be proposed by the supplier. The field control will collect the operational status signals and process parameters of the auto-control process equipment. The workstation of the central control room shall allow to set the control mode of equipment and to carry out the control over individual equipment or systems. The workstation of the central control room shall provide the following information and functions:

- Display the technical procedure diagram real-time equipment operation parameters & status and breakdown information;
- Switch over & status display of auto / manual modes for all control equipment;
- Alarming records;
- Display the real time trends of process variables;
- Display historic trends.

The power to control systems shall be supplied through UPS having the function to supply continuously stable power even if the main normal power supply system has any failure. UPS shall be rated to supply the required load for 08 hours in case of a power outage. A redundant power system is essential because a failure in the supply of the control system would cause shut-down of the high-lift pumping station.

8.5.7.6.4 Print Statements

In case of default with control network, addition or deletion of any node will not affect the operation & communication of their equipment. The system will be controlled with computers mainly for production control, operation, monitoring & management of the whole plant. The control system will have the function of self-diagnosis that can detect any default timely and accurately as well as the breakdown status, time, location and other relevant information. On the other hand the field control station will mainly carry out the auto control over the operation by the field controlled equipment and collect data for central control room. Monitor, control, operation & management of the production process of the treatment plant will be done from the workstation of central control room.

8.5.8 Ancillary Structures of the Water Treatment Plant

8.5.8.1 Administrative Building

8.5.8.1.1 Ground Floor

Ground floor will comprise of the following rooms:

- 24 hours Information & Data Reading Room
- Duty Officers Room (SAE Operation)

- Prayer Room
- Laboratory

8.5.8.1.2 First Floor

First floor will comprise of the following rooms:

- Executive Engineer’s Office
- Administrative Section
- Conference Room
- Sub Divisional Engineer’s/ Assistant Engineer’s Office/Sub Assistant Engineer’s Office

A laboratory will be established in the ground floor of the administrative building for analysis of raw water, clarified water, filtered water and treated water quantity. Chemical dosage for each chemical to be used will be determined in the onsite laboratory on a daily basis. Jar Test on raw water will yield the alum dosage and will determine in any lime is needed for flocculation. Chlorine dosage will be determined by checking raw and filtered water. Lime demand for water conditioning (pH correction) will be determined by the testing the treated water pH and other appropriate components. The daily testing of the following parameters of raw, clarified, filtered and treated water will be necessary for safe drinking water production:

- Temperature;
- Total chlorine residual;
- pH;
- Turbidity;
- Color;
- Alkalinity (carbonate & bicarbonate);
- Jar Testing of PAC dosage;
- Calcium Carbonate Stability;
- Conductivity and other complex analysis such as Heavy metals;
- Bacterial analysis will also be available in the laboratory.

8.5.8.2 Staff Quarter for Officers and Staffs

One-three storied building for officer accommodating 3 persons (One thousand square feet each unit). One-three storied building for staffs accommodating 12 families have been considered (Eight hundred square feet each unit).

8.5.8.3 Provision of Site Utilities

Water use in Premises of Water Treatment Plant

Using of water around the water treatment plant site will be supplied from the water treatment Plant.

Sewerage System

Waste water from both the treatment plant and housing complex will be collected and be treated in a septic tank before disposal.

Telephone System

Empty conduit with pull lines outlet box and terminal cabinet will be provided for use by telephone utility company for installing their system. An intercom telephone system will be developed in the different units of treatment plant and raw water intake and pumping stations.

Site Roads

The main access roads to the water treatment plant will be of asphalt construction and will be designed to carry the weight of lorry delivering chemicals. Roads will be designed with adequate grades to ensure proper runoff to a road side drainage system. The roads and car parking areas of the administrative building will be constructed to similar standard.

Sight Lighting

Adequate site lighting will be provided to ensure satisfactory level of illumination for operating the water treatment plant at night time. In addition, all the approach roads will be provided with sufficient street lighting.

Site Security

The water treatment is a KPI grade-2 area. It is restricted to general public. Site entrance gate will be installed with appropriate security regulation.

8.6 Design of Treated Water Transmission Main

8.6.1 Size and Length

50 MLD treated water will be carried from the proposed SWTP to BSMSN. To do so, single treated water transmission main from treatment plant to Economic Zone 2A, 2B, 3, 4&5. Diameter of transmission main from WTP to Node A 800 mm, Node A to Node B 600 mm, Node B to Node C 600 mm, Node C to Node D 400 mm, Node C to Node E 400 mm and Node A to Node F to Node G 500 mm, Node G to Node H 500 mm, Node H to Node I & J 300 mm shown in **Figure 8.17**. Initial head in the start of the transmission main at the proposed SWTP will be 5.0 bars to ensure at least 1.5 bar pressure at each node of secondary transmission main. The minimum pressure at each distribution main at least 1.0 bar.

8.6.2 Choice of Pipes

The pipe materials considered for treated water transmission mains are as follows:

- Ductile iron (DI)
- Steel
- Glass fiber reinforced plastic (GRP)
- uPVC

These pipes are not locally available except uPVC but available in international market. The summary of the advantages and disadvantages of different proposed types of pipes are follows:

Ductile Iron Pipe

- High mechanical strength and toughness, easy jointing, flexible joints can tolerate some deflection, easy to repair
- Can be cut in the field
- Restrained can be accomplished with restrained joints
- Required little support from pipe surround materials
- Possibility of corrosion is minimum if internal and external coatings provided properly

Steel Pipe

- High mechanical strength and toughness
- Rigid
- Welded joints require skilled welders and special equipment
- Susceptible to corrosion if protection system is damaged
- Require cathodic protection
- Reliant on stable soil support

Glass Fiber Reinforced Plastic Pipe

- Corrosion resistant
- Relatively light weight
- Easy of jointing
- Flexible joint can tolerate some deflection
- Susceptible to impact damage
- Reliant on support soil
- Retrospective installation of fittings/ repair complicated
- Susceptible to structural degradation by certain organic contaminants

uPVC Pipe

- It is not corroded
- It is light in weight easy and quick in installation
- No modification of the water quality
- Excellent resistance to bacteria growth
- Do not have the same strength as DI and GRP pipe

Recommendation

Ductile Iron pipes are considered for design of treated water transmission main these are flexible pipes, characteristically strong and tough and able to withstand earth and live loads with little support from soils. On the other hand, GRP and steel pipes are both rigid/semi rigid and rely heavily on soil support and are therefore not recommended for the project. However, in case of cannel/culvert crossings steel pipes can be used. For primary distribution main DI pipes are considered for 300 mm or more diameter and uPVC pipes are considered for 250 mm or less diameter.

8.6.3 Excavation of Trenches

Trenches for pipe laying by excavating paved road (both flood protection embankment & other roads) will be necessary. In order to minimize disturbance to traffic movement, the works will need to be executed during nighttime. Major excavation for pipe laying particularly on embankment may not be necessary. Necessary access by leveling and dressing will be needed for equipment movement.

8.6.4 Pipe Laying

For pipe laying the trench location, depth, pipe cover, etc. should be analyzed. A safer margin of 2 bars for surcharge overpressure should be considered to size the pipe and appurtenances. Clear cover between the crest of the pipe & the road surface shall be at least 1 meter.

Along flood protection embankment pipes will be laid in the countryside of the embankment to keep undisturbed of the embankment facilities. The sluice gates of the embankment should not be damaged during pipe laying. It will be wise to overcome this situation by laying pipe above the sluice gates and surround the pipe by cement mortar. The transmission main will be laid at least 0.2% up and downslope depending on the position of an air release valve. Air release valve will be installed at 800m to 1000m interval unless otherwise additional requirement.

8.6.5 Bedding

Determination of pipe bedding should be made on case to case basis during final design, depending on the soil condition. However, following bedding can be used:

a) Backfill material will be the soil removed from the trenches or any other materials suggested or directed by engineer in charge;

b) Pipe bedding material will constitute either gravel or crushed bricks;

c) The surrounding material of the pipe will be crushed bricks.

8.6.6 Valves and Chambers

Pressure Reducing Valves &Water Meter

PRV has to be provided at the location where a high-pressure supply will be connected directly to the existing distribution system. The PRV's are an essential control feature for the water supply system, and they will be installed at every injection point to the existing network. It will be mentioned here that, PRV will be supported by the Water Meter and Gate Valves.

The additional benefit of the PRV's is that they also act as flow limiters so that, in addition to varying the supply zone pressures, the daily volume can also be controlled according to actual demand and the condition of the existing distribution system. Furthermore, the primary mains generally designed for a constant flow 24 h/day in order to reduce the investment costs, and such a constant flow can only be achieved by using flow limiters as long as elevated reservoirs acting as buffers are not used.

Valve Chamber or Manholes

All valves and appurtenances will be installed in valve chamber or manholes, the type of each of them being chosen among standardized types.

Washout Arrangements

For cleaning of the treated water transmission mains, washout chambers with necessary valve will need to be provided at suitable location i.e. at lowest points. At least three (3) washout chambers along the route of treated water transmission mains should be provided.

Thrust Block Arrangements

Thrust blocks are required wherever the pipeline: changes direction, changes diameter, terminates or other. Lack of thrust blocks may cause damage to the pipe from forces from the water when the direction of the pipe changes.

Location and size of thrust blocks need to be investigated during detailed design. Thrust blocks will be constructed in reinforced concrete with due regard to pipe forces and ground conditions.

Method of Khal/Rail/Culvert Crossings

According to the field investigation, treated water transmission mains may cross canals and culverts. Pipe can be laid by open excavation during dry period to cross khals/ canals.

For crossing road ad culverts, pipe jacking method is recommended for avoiding disturbance of structures.

Auxiliary Facilities

Auxiliary facilities of the pipelines mainly include isolating valves, air valves etc. Isolating valves will be of the butterfly type and will only be proposed at strategic locations. This will be limited because of the high cost.

Air release valves will be used at each high point in the treated water transmission main and primary & secondary distribution pipes specially at crossing of khals. It is recommended to provide air release valves at an interval of 400 to 800 m though the numbers and locations will be confirmed during detailed design.

8.7 Design of Primary and Secondary Network

8.7.1 Design Objective

The construction of primary and secondary distribution network has been designed in a manner that will provide a fully functional pipeline with:

- Fulfill the domestic and industrial consumption for the priority zones of BSMSN.
- Effective transmission of water from water treatment plants and ground water at capabilities that will address as a minimum need for the proposed development of the BSMSN design for horizon year 2023.

- The design should carefully consider the relevant constructions difficulties and provide tangible solution, taking into due consideration of the limited funds.

8.7.2 Assumptions

Design Horizon	**2023**
Total connected Industries with combination of GW & SW sources	100%
Average water demand	According to Demand table
Hazen-William Coefficient uPVC Pipe	130
Hazen-William Coefficient DI	120
Maximum velocity	1.5 m/s
Maximum head loss	5 m/km
Minimum head at far point of primary distribution network	1.0 bar (10 mH_2O)

Table 8.55: Industry Wise Daily Water Consumption

Type of Industry	**Daily Water Consumption (m^3/ha)**
Garment	399
Garment accessories	302
Integrated textile	1921
Motorbike assembly	70
Automobile assembly	56
Automobile parts	18
Other parts & machine	18
Chemical & other products	700
Food & beverage	33
Rental factory	397
Warehouse zone	20

Table 8.56: Daily Water Consumption of Various Land Use

Type of Land Use	**Daily Water Consumption (m^3/ha)**
Commercial	200
Resident/ housing	100
Warehouse	50
Others (clinics & training, services)	100
Coal-fired power plants & jetty	20

8.7.3 Design Philosophy

While designing the water supply system following considerations has been adopted for the project:

8.7.3.1 Design approach

- To distribute safe potable water produced from Water Treatment Plants
- Ensure efficient distribution of water to the different Zones under BSMSN
- Ensure minimum head in the distribution networks to maintain minimum pressure at consumers end

- Easy operation and maintenance of primary and secondary distribution network
- Minimize imported operation and maintenance items
- Maximize local labor during construction and operation
- Use local materials wherever possible and provide adequate flexibility to their choice.

8.7.3.2 Reliability

- The network must distribute water continuously with required head and subsequently must ensure to produce water from the treatment plant and as well as to ensure the effective operation of the Pumping Station. The staff must understand the process and equipment.
- The mechanical and electrical equipment must be durable
- Spare parts and ability of local personnel to make repair must exists
- Process of distribution networks must be designed to perform under varying water pressure and strengthen oversights of operation personnel
- Reliable local suppliers of equipment and dependable local agents must be available

8.7.3.3 Simplicity

A less complex primary and secondary distribution system will be better to understand and easier to operate. When labor costs are high then automation is often a positive factor, but may mean complex equipment and costly maintenance. If cheap labor is available, then primary and secondary distribution system operation can be handled manually ~~and~~ with minimum automation. Instrumentation and remote control can be installed to measure the flow of different distribution nodes to enable an efficient operation.

8.7.3.4 Use of Local Materials & Labour

Local Materials will be used to the greatest extent as possible

- Cement and Re-bar, Bricks, Stone etc. should not be allowed to procure through import
- Local skilled labor must be given preference in construction works

8.7.3.5 Criteria of Selection for Primary & Secondary Distribution Route

Route of primary and secondary distribution networks have been selected based on following consideration:

- Follow the proposed road network planned under the master plan
- Avoid extra land acquisition
- Minimum obstruction under and above the ground.
- Minimum disturbance to traffic movement
- Minimum bends in pipeline to minimize head loss
- Distribution of water with minimum number of sub-distribution node
- Follow wider roads so that the pipeline can be laid without disturbing other utilities network

8.7.3.6 Choice of Pipes for Primary & Secondary Distribution Mains

The pipe materials considered for inclusion on this project are as follows:

- Ductile iron (DI)
- uPVC

For the pipes having diameter 300 mm or above, Ductile Iron pipes should be used. For the pipes having diameter below 300 mm, uPVC pipes should be used for primary and secondary distribution networks.

8.7.3.7 Allowable velocity of Pipes

- Maximum velocity will be considered 1.5 m/sec,
- Maximum head loss gradient will be considered 5 m/km.
- Minimum head at Injection Point: 1 bar
- Minimum head at Plant: 5 bar

8.7.3.8 Allowance for Surcharge Pressure

A safer margin of 2 bars for surcharge over pressure has been used to design the size of the pipes and appurtenances. For surge protection air vents have been used at different location of the Transmission main, Primary and secondary distribution networks as required. This air vent will release great quantities of air under low pressure when filling the Mains, small quantities of air under pressure during normal operation. Such Air vents will also play an important role in the field surge protection by preventing any water column separation in case of power failure occurs in high lifting pumping station and ground water pump house. Water column separation can also occur during operation of valves by creating vacuum condition. Therefore, to operate under low and normal pressures double air valves with large orifice for low pressure and a small orifice for normal pressure have to be used.

8.8 Outline Design of Distribution Network for Zone2A

A distribution system has been design for zone 2A by developing a mathematical model with the help of WaterGEMS software. The pipe details of distribution networks has been presented **Table 8.57** and shown in **Figure 8.42**. The nodal pressure are shown in **Figure 8.43.** It is observed that the maximum and minimum pressure in the system are about 12.9 mH_2O and 10 mH_2O respectively.

Table 8.57: Details of Primary Distribution Network of Zone 2A

Road Name	Pipe Dia (mm)	Material	Length
Z2A_1	250	uPVC	997
Z2A_2 (North)	300	DI	1805
Z2A_2 (South)	250	uPVC	1301
Z2A_2 (South West)	200	uPVC	510
Z2A_3	200	uPVC	832
Z2A_4	250	uPVC	969
Z2A_5	300	DI	889
Z2A_6	250	uPVC	846
Z2A_6 (Circular End)	110	uPVC	119
Z2A_7	250	uPVC	784

Road Name	Pipe Dia (mm)	Material	Length
Z2A_8	160	uPVC	272
Z2A_8 (Connecting Z2A_2)	250	uPVC	365
Z2A_9	250	uPVC	582
Z2A_9 (End)	110	uPVC	75
Z2A_10	110	uPVC	157
Z2A_11	110	uPVC	157
Z2A_12	110	uPVC	156
Z2A_13	110	uPVC	139

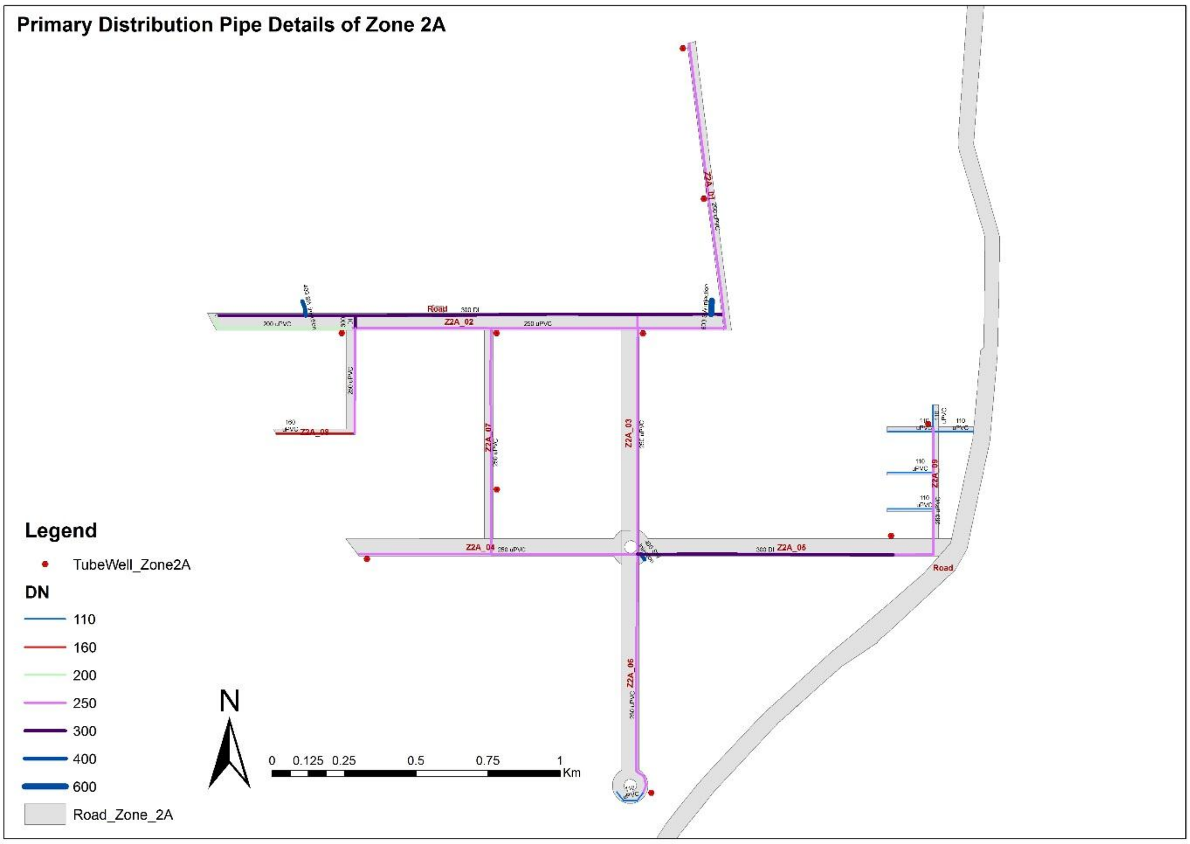


Figure 8.42: Proposed Primary Distribution Pipe Networks of Zone 2A

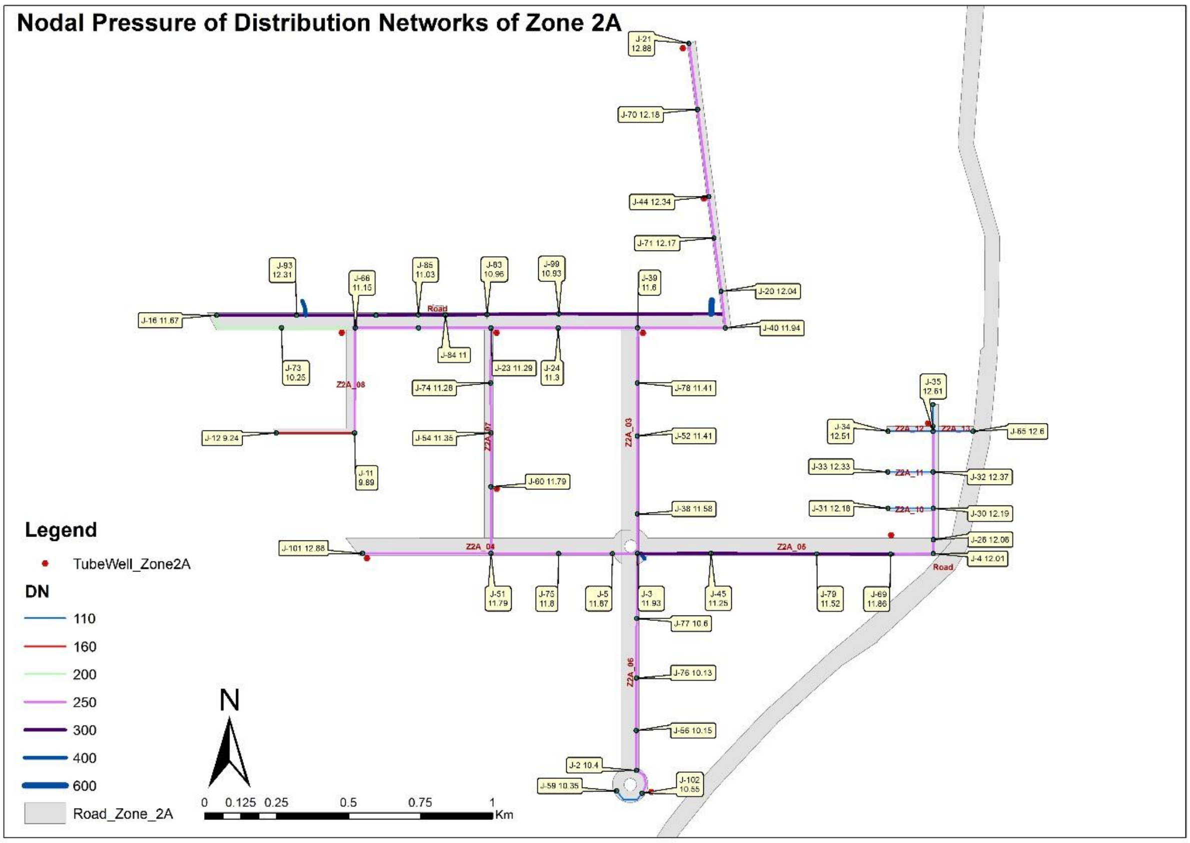


Figure 8.43: Nodal Pressure of Distribution Networks of Zone 2A

8.8.1 Summary of Primary Distribution System of Zone 2A

Table 8.58: Summary of Distribution Network of Zone 2A

Dia (mm)	Materials	Sum of Length
110	uPVC	798
160	uPVC	272
200	uPVC	1285
250	uPVC	5864
300	DI	2674
	Grand Total	**10893**

8.9 Geotechnical Investigation and Foundation Design

8.9.1 Exploratory Work

The exploratory work involves drilling through cohesive and non-cohesive soil on firm ground with recovery of samples. Standard penetration tests and permeability tests have been executed in the boreholes. A summary of the exploratory work is given in **Table 8.59**.

Table 8.59: Summary of Exploratory Work

Site	Structure	No. of Bore Hole	Bore Hole #	Depth of Bore Hole (m)
Azampur	Intake Pumping Station	2	01, 02	20.0
Poshchim Ichakhali, WTP	Chemical Building	1	03	20.0
	Flocculation Chamber	2	04, 05	20.0

Site	Structure	No. of Bore Hole	Bore Hole #	Depth of Bore Hole (m)
	Sediment Chamber	4	06, 07, 08, 09	20.0
	Filter Bed	2	10, 11,	20.0
	Treated water reservoir	4	12, 13, 14, 15	20.0
	Treated water pump house	2	16, 17	20.0
	Chlorine Building	2	18, 19	20.0
	Officer Building	1	20	20.0
	Staff Quarter	2	21, 22	20.0
	Administrative building	2	23, 24	20.0
Approach road	Bridge Site	2	25, 26	20.0

The structure wise location of Bore holes are shown in Site Plan Maps in **Figure 8.44** and **Figure 8.45.**

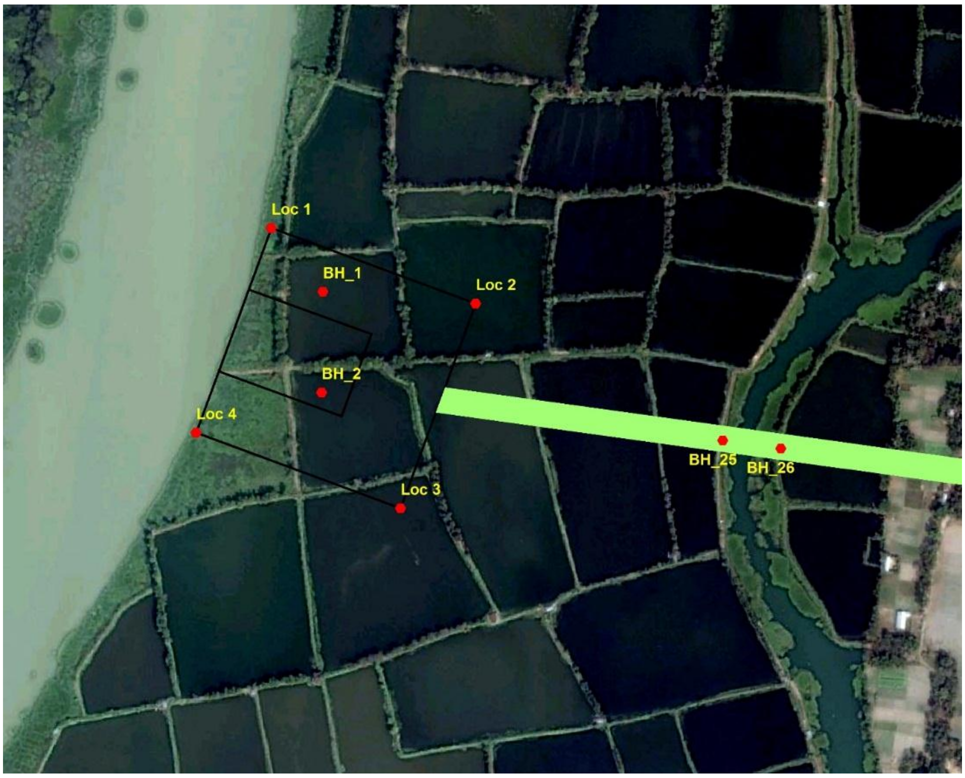


Figure 8.44: Location Map at Intake and Bridge Site

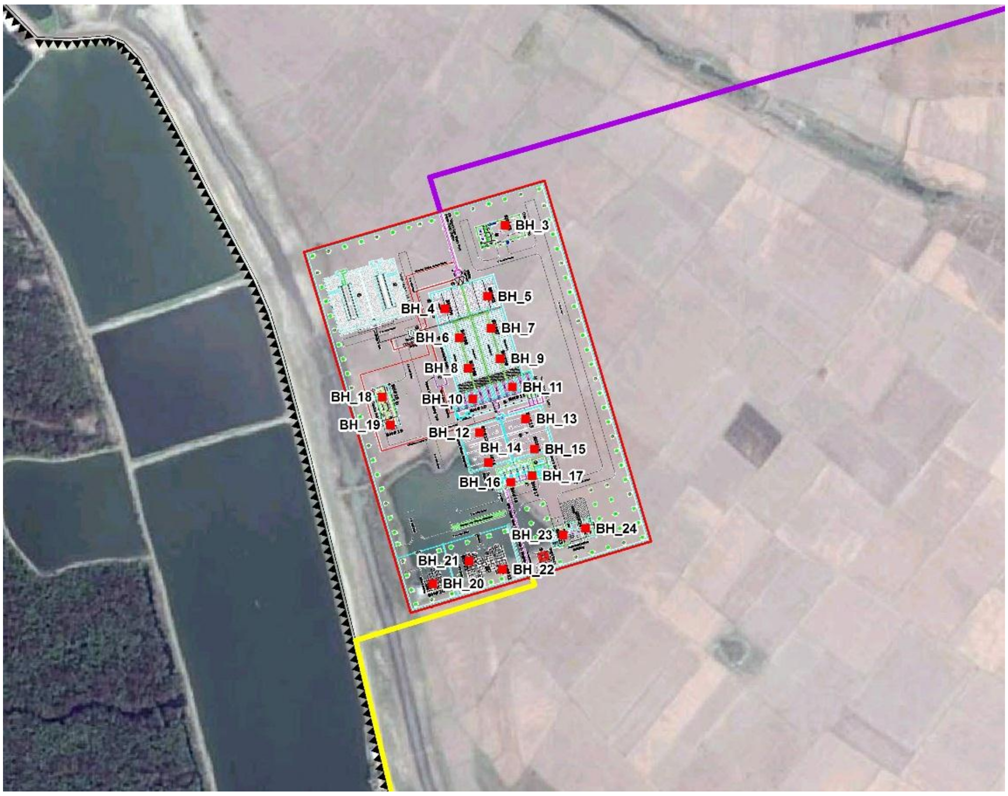


Figure 8.45: Borehole Location Map at Treatment Plant

8.9.2 General Interpretation of Soil and Required Type of Foundation

From the Bore logs for Intake Pumping Station at Azampur site shows soft to medium silty clayey soil with SPT values within 2-3 at shallow depth up to 4.5 m below the ground level and beyond that SPT less than 30 upto a depth of 10.5 is available. The bearing layer consisting of dense sand is available below 13.5 m depth and required length of bored pile will be greater than 13.5 m.

From the bore logs at Poshchim Ichakhali site, it is observed that foundation soil consists of soft silty clay with SPT values within 2-6 at depth up to 6.0 m below the ground level. Most of the bore logs has STP less than 40 upto a depth 10.5 m to 12.0 m is available. The bearing layer consisting of dense to very dense sand is available below depth 12.0 m and the required length of bored pile will be greater than 12.0 m.

Recommendation:

Intake pumping station: Borehole BH-01 to BH-02 has been done. According to geotechnical report, for piles cast in situ of 50cm diameter, the average ultimate pile capacity is 1154kN at 15m depth.

Clarifier: Borehole BH-04 to BH-09 has been done. According to geotechnical report, for piles cast in situ of 50cm diameter, the average ultimate pile capacity is 1189kN at 15m depth.

Filter: Borehole BH-10 to BH-11 has been done. According to geotechnical report, for piles cast in situ of 50cm diameter, the average ultimate pile capacity is 1119kN at 15m depth.

Storage tank: Borehole BH-12 to BH-15 has been done. According to geotechnical report, for piles cast in situ of 50cm diameter, the average ultimate pile capacity is 1450kN at 18m depth.

Treated water pumping station: Borehole BH-16 to BH-17 has been done. According to geotechnical report, for piles cast in situ of 50cm diameter, the average ultimate pile capacity is 1400kN at 18m depth.

8.9.3 The Bole Logs are furnished here with

The summary of test results shown in **Table 8.60** and detail sub-soil investigation is given in **Volume V**.

Table 8.60: Summary Test Result

Bore hole no	Sample no	Depth (m)	Wet unit Weight (KN/m^3)	Dry Unit Weight (KN/m^3)	Natural moisture content %	Liquid limit %	Plastic limit %	Unconfined compression Strength (KN/m^2)	Consolidation test		Direct Shear test		Sand %	Silt %	Clay %	Sp. Gravity
									cc	Max load (KN/m^2)	0º	Cohesion (KN/m^2)				
BH-1	D-1	1.5-1.95			31.5	41	26						12	70	18	
	U-1	2.55-3.0	18.2	13.94	30.6			41.6	0.250							2.673
	D-8	12.0-12.45									36.0	0.0	85	15	0	2.655
BH-2	U-1	2.55-3.0	18.14	13.77	31.7			31.7								2.648
	D-3	4.5-4.95			29.2	30	26						22	72	6	
	D-10	15.0-15.45									38.0	0.0	88	12	0	
BH-3	D-2	3.0-3.45			30.7	42	23						10	70	20	
	U-1	4.05-4.5	18.22	13.98	30.3			44.7	0.240							2.675
	D-12	18.0-18.45									40.0	0.0	92	8	0	2.656
BH-4	U-1	4.05-4.5	18.3	14.21	28.8			52.8								2.650
	D-4	6.0-6.45			28.3	29	25						23	72	5	
	D-10	15.0-15.45											87	13	0	2.660
BH-5	U-1	2.55-3.0	18.23	13.77	32.4			45.6								2.672
	D-3	4.5-4.95			27.4	41	25						12	68	20	
	D-11	16.5-16.95									38.0	0.0	93	7	0	2.660
BH-6	D-2	3.0-3.45			29.4	43	22						8	71	21	2.670
	U-1	4.05-4.5	18.36	14.40	27.5			67.8								
	D-6	9.0-9.45											85	15	0	
BH-7	D-1	1.5-1.95			30.4	40	23						14	67	17	
	D-5	7.5-7.95											42	58	0	
	D-8	12.0-12.45									34.0	0.0	88	12	0	2.660
BH-8	D-3	4.5-4.95			31.4	42	25						7	70	23	
	D-4	6.0-6.45			25.5	35	28						23	70	7	
	D-10	15.0-15.45											86	14	0	2.665
BH-9	D-1	1.5-1.95			28.4	45	26						8	70	22	
	D-4	6.0-6.45			26.5	34	28						21	72	7	
	D-7	10.5-10.95									32.0	0.0	83	17	0	2.665
BH-10	U-1	4.05-4.5	18.18	13.62	33.5			28.7								2.665
	D-3	4.5-4.95			30.5	40	21						14	69	17	
	D-12	18.0-18.45											92	8	0	2.660
BH-11	D-1	1.5-1.95			28.2	43	24						12	67	21	

	D-6	9.0-9.45									32.0	0.0	75	25	0	
	D-10	15.0-15.45											88	12	0	2.660
BH-12	D-1	1.5-1.95			31.7	44	25						8	69	23	
	D-4	6.0-6.45											78	22	0	
	D-8	12.0-12.45											85	15	0	2.655
BH-13	U-1	4.05-4.5	18.3	14.19	29.2			55.6								2.665
	D-3	4.5-4.95			28.4	42	23						15	67	18	
	D-11	16.5-16.95									36.0	0	87	13	0	2.660
BH-14	D-2	3.0-3.45			35.3	42	24						13	69	18	
	D-6	9.0-9.45											77	23	0	
	D-13	19.5-19.95											94	6	0	2.660
BH-15	D-1	1.5-1.95			28.8	43	25						18	73	19	
	D-4	6.0-6.45			24.1	32	27						25	70	5	2.655
	D-10	15.0-15.45									37.0	0.0	86	14	0	
BH-16	D-2	3.0-3.45			31.4	38	21						12	72	16	
	U-1	4.05-4.5	18.25	13.85	31.8			44.3								2.670
	D-12	18.0-18.45											92	8	0	2.662
BH-17	D-1	1.5-1.95			30.4	43	26						8	70	22	
	U-1	4.05-4.5	18.41	14.43	27.6			66.2								2.656
	D-8	12.0-12.45									36.0	0.0				2.658
BH-18	U-1	4.05-4.5	18.5	14.59	26.8			82.3								
	D-4	6.0-6.45			27.4	41	25						13	69	18	
	D-12	18.0-18.45											88	12	0	
BH-19	D-1	1.5 – 1.95			29.2											
	D-4	6 – 6.45			26.6	33							24	70	6	2.658
	D-14	12 – 12.45											89	11	0	
BH-20	D-1	1.5 – 1.95			28.3								10	70	20	
	D - 5	7.5 – 7.95											76	24	0	
	D-12	18 – 18.45									32.0	0.0	87	13	0	2.656
BH-21	D-1	1.5 – 1.95			36.6											
	D-3	4.5 – 4.95											42	58	0	
	D-10	15 – 15.45											83	17	0	
BH-22	D-2	3 – 3.45			30.2											
	D-3	4.5 – 4.95			27.4	32	27						21	73	6	2.667
	D-8	12 – 12.45											85	15	0	
BH-23	D-2	3 – 3.45			31.5											
	U-1	4.05 – 4.5	18.24	13.98	30.5					43.5						2.67

	D-11	16.5 – 16.95									35.0	0.0	86	14	0	
BH-24	D-2	3.0-3.45			28.4	43	25						7	21	22	
	U-1	4.05-4.5	18.35	14.40	27.4			67.6								
	D-8	12.0-12.45											92	8	0	2.654
BH-25	U-1	4.05-4.5	18.31	14.23	28.7			54.2								2.64
	D-3	4.5-4.95			27.6	40	22						12	70	18	
	D-12	18.0-18.45									37.0	0.0	87	13	0	

8.10 Cost Estimation

8.10.1 Basis of Estimation

8.10.1.1 Construction

The cost of civil works has been prepared by estimating the quantities of the principal construction items. The pricing of these civil works items has been done on the basis of construction rate obtained from current ongoing works of Dhaka WASA and recently completed treatment plant of Saidabad water treatment plant Phase-2.

8.10.1.2 Equipment Cost

The cost of major equipment items has been based on the current ongoing project of similar nature & allowances were added to cover shipment, installation, associated minor equipment and general contractors cost.

8.10.1.3 Cost of Pipeline Material

Pipeline material costs have been estimated on the basis of using ductile iron pipe. The values are based on budget quotation received from major international suppliers. Additional supply cost for handling within Bangladesh and delivery in a central pipe yard in the Mirsharai area has been estimated. This rate per meter for construction of pipe under different laying condition have been collected from the recent submission rate of an international construction company & used for estimation.

8.10.1.4 Duties

Customs duty and VAT is payable on imported equipment and materials. The total Customs duty and VAT estimated are shown in cost summery. The duties have been taken from the latest available amendment to the import tariff schedule. The main duties are customs duty, value added tax (VAT) and development surcharge.

8.10.2 Capital Cost for SWTP and Water Supply Network

Summary of estimated capital cost for the surface water treatment plant of 50MLD capacity (Phase-1), transmission and distribution network and road & bridge cost along the transmission line is given in **Table 8.61**:

Table 8.61: Summary of Capital Cost for SWTP and pipeline

Sl. No.	Description	Total Price in Million BDT	Remarks
A)	**SWTP and water supply network**		
	I) Civil Works for SWTP and Intake structure (including general cost items)	1375.24	Detailed in Annex-6
	ii) Water supply network (Transmission and Distribution pipeline)	1552.26	Detailed in Annex-6
	iIi) Mechanical Equipment	754.04	Detailed in Annex-6
	iv) Electricity Equipment	378.56	Detailed in Annex-6
	v) Land development for intake and SWTP site	115.26	Detailed in Annex-6
	Sub-total of A=	**4175.76**	

B)	**CD & VAT for pipe materials, mechanical and electrical equipment**	**988.06**	Detailed in Annex-7
	Sub-total of B=	**988.06**	
C)	**Linking road**		
	ii) Approach road	131.57	Detailed in Annex-8
	i) Bridge (62.5m)	78.9	Detailed in Annex-8
	Sub-total of C=	**210.47**	
D)	**Land Acquisition**		
	i) Land acquisition for intake and approach road	166.85	Detailed in Annex-9
	Sub-total of D=	**166.85**	
E)	**Consultancy**		
	i) Consultant for Design Supervision and Construction Supervision of Treatment Plant including Intake and Transmission Main and Distribution Network	75.10	Detailed in Annex-11
	Sub-total of E=	**75.1**	
F)	**Contingency**		
	i) Physical contingency (1% of A+C cost)	43.86	
	ii) Price contingency (5% of A+C cost)	219.31	
	Sub-total of F=	**263.17**	
	Total cost (A+B+C+D+E+F)	**5879.41**	

8.10.3 Operation & Maintenance Costs for SWTP

Annual operating costs have been estimated separately for labor, chemicals, electricity & miscellaneous costs. Labor costs have been estimated and allowance at current government salary scale. Chemical costs are computed based on rate in Bangladesh at the present time. The electricity has been estimated based on the present electricity rate of REB. Miscellaneous costs are estimated based on the existing (O&M) cost of Saidabad Water Treatment Plant Phase-1. Summary of estimated operation & maintenance cost are presented in the **Table 8.62.**

Table 8.62: Summary of Operation & Maintenance Cost of SWTP per Year

SI. No.	Items	Cost (Million BDT) per Year
1	Manpower cost	5.00
2	Chemicals (Alum, Chlorine and Lime)	17.16
3	Electricity Cost	81.71
4	Spare Parts	0.50
Total		**104.36**

8.11 Tender Document

Tender documents have been prepared and submitted to BEZA as supporting documents for Contractors or lead joint ventures to bid for the BSMSN surface Water Treatment Plant. The project contains four components. Among these components construction of Intake Pumping

Station, construction of Surface Water treatment Plant and construction of Raw & Treated Water Transmission Main will be by Plant and Design Build (FIDIC Yellow Book) contract. Component IV is for Operation and Maintenance of the Component I, II & III for a period of three (03) years.

The Tender document is consists of six volumes as follows:

Volume 1 - Instructions to Tenderers

Volume 2 - Conditions of Contracts

Volume 3 - Employer’s Requirements

Volume 4 - Preamble, Schedules of Prices and Particulars

Volume 5 - Drawings

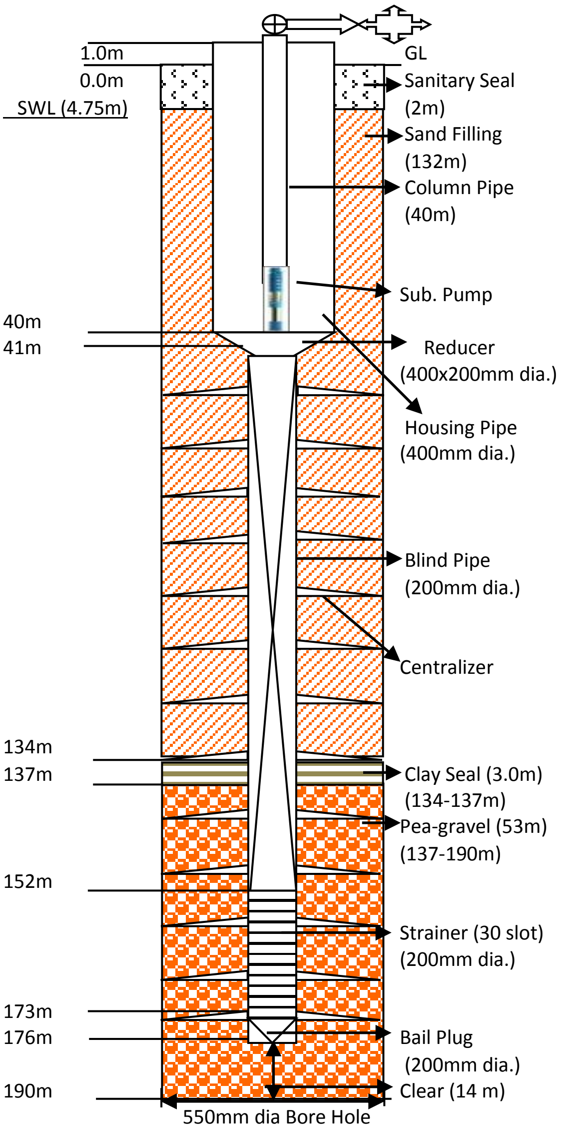
Volume 6 - Feasibility Study

9 Groundwater Wells

9.1 Design of PTW

According to the resource estimation a sample well design and its component dimension is given below:

0.0	Depth (m)	Lithology
	6.10	Grey silty clay
	12.20	Grey Plastic Clay
	24.39	Grey Silty clay
	33.54	Grey silty fine sand
50	73.17	Grey silty clay
	79.27	Grey fine to medium sand trace mica
	94.51	Grey Silty fine sand
100	121.95	Light grey fine to medium sand trace mica
	128.05	Grey fine sand trace mica
	134.15	Grey fine to medium sand
	146.34	Grey plastic clay
150	176.83	Light grey fine to medium sand trace mica
200 250 300		Grey Plastic Clay



Item	Diameter (mm)	Material Type	Range (m)	Quantity
Housing Pipe	400	MS	**0.0 (GL) to 1.0m above**	41 m
			0.0 - 40	
Reducer	400 X 200	MS	40 - 41	1 m
Blind Pipe	200	MS	41 - 152	111.00 m
Screen	200	SS	152 - 173	21 m
Bail Plug	200	MS	173 - 176	3 m
Total Length of Fixture				177 m
Total Depth of Drilling				190 m
Centralizes		MS	65 -195	18 nos.
Pea-gravel		Natural	137.-190	9.90 m^3

Calculation for Upper Well Casing (Length)		
Considerations	**(m)**	**Remarks**
Lowest GWL of the year	5	Measured Static water level
Seasonal Fluctuation	4	Difference in water level during dry and wet season
Rated Drawdown	5	5m rated drawdown
Pump Motor Length	3	-
Pump Submergence Depth	5	-
Safety Factor	15	Storage of water in the Lowermost Part of Housing to balance Entrance Velocity
Total Housing pipe Length 37 m say 40 m	**40**	

Calculation for Well Screen (Length)		
Q = лDL*0.5*0.22*0.03 m		
Hence, L = Q/лD*0.5*0.22*0.03 m		
Considerations		**Remarks**
л	=	3.14
Q_d (m^3/sec), Design Discharge	=	0.028
Screen Diameter, D (m)	=	0.20
Assumed Blockage (50% of Strainer)	=	0.50
Assumed Open Area (22%)	=	0.22
Assumed Entrance Velocity (0.03 m/Sec)	=	0.03
Required Screen Length, L (m)	=	**14.00**

If 70 % of Efficiency	**=**	**20.00**
Socket Blockage (m)	=	**1.00**
Total Length of Screen, L (m)	=	**21.00**

9.2 Proposed Locations of PTWs

It has been proposed to construct 25 nos. deep tube wells to abstract groundwater and supply in Zone 2A, 2B, 3, 4 & 5. The locations of these 25 nos. deep tube wells are proposed in such a way that the aerial distance between 2(two) wells should be at least 500m. Among the 25 wells, 10 wells in Zone 2A has been proposed with consultation of BEZA officials. The wells' locations are given in **Figure 9.1**.

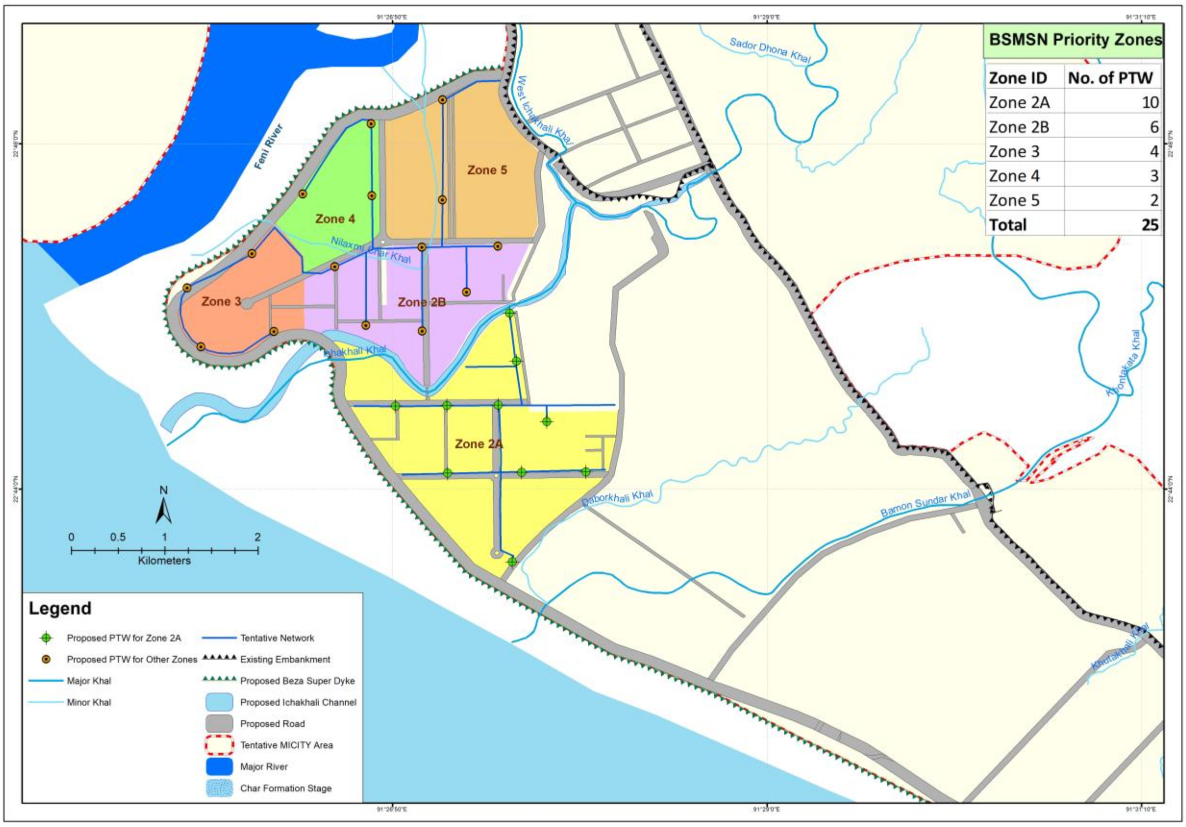


Figure 9.1: Proposed locations of 25 nos. deep tube wells

9.3 Cost Estimate

Cost Estimate for 25nos. deep tube well is summarized in **Table 9.1.**

Table 9.1: Summary of Capital Cost

Sl. No.	Description	Total Price in Million BDT	Remarks
A)	**25 nos. Production Well**		
	i) Construction of Tube well and ancillary structures	303.66	Detailed in Annex-10
	a) Construction of 350mmx200mm diameter Deep Tube Well with related works including supply of all necessary materials	146.46	
	b) Construction of Pump house, Chlorine Room of DTW with related works including supply of all necessary materials	35.64	
	c) Construction of RCC Column with R.S. Joist of DTW with related works including supply of all necessary materials	4.22	
	d) Construction of 11/0.415KV 200KVA Pad Mounted Sub-Station of DTW Compound with related works including supply of all necessary	56.22	

Sl. No.	Description	Total Price in Million BDT	Remarks
	materials		
	e) Installation of Submersible Pump Set and Chlorine Set with related works including supply of all necessary materials	26.49	
	f) Construction of boundary wall and approach road of DTW compound with related works including supply of all necessary materials	34.63	
	ii) Land Development of PWT site	80.00	Detailed in Annex-10
	Sub-total of A=	**383.66**	
B)	**Consultancy**		
	i) Consultant for Design Supervision and Construction Supervision of Deep Tube Well (25nos.)	7.53	Detailed in Annex-11
	Sub-total of B=	**7.53**	
C)	**Contingency**		
	i) Physical contingency (1% of A cost)	3.84	
	ii) Price contingency (5% of A cost)	19.18	
	Sub-total of C=	**23.02**	
	Total cost (A+B+C)	**414.21**	

9.3.1 Operation & Maintenance Costs for PTW

Annual operating costs have been estimated separately for labor, electricity & others (misc.). Labor costs have been estimated based on approved current allowances at government salary scale. The cost for electricity has been estimated based on the present rate of electricity of REB. Miscellaneous costs are estimated based on the average existing (O&M) cost of other projects of similar nature. Summary of estimated operation & maintenance cost are presented in **Table 9.2.**

Table 9.2: Summary of Operation & Maintenance Cost for 25 nos. PTW per Year

Sl. No.	Items	Cost (Million BDT) per Year
1	Manpower cost	4.16
2	Electricity Cost	10
3	Spare Parts and Repair & Maintenance	2.5
Total		**16.66**

10 Project Implementation & Operation (Phase I)

10.1 Project Implementation Plan

10.1.1 The Executing Agency

Bangladesh Economic Zone Authority (BEZA) will be the Executing Agency of the water supply project, responsible for the overall technical supervision and execution of the projects. A Project Implementation Unit (PIU) headed by a Project Director (PD) will be set up in BEZA. The staffing of the PIU will include expertise in project management, water supply engineering, installation and finance. The PIU will also incorporate all consultancy services under the projects including liaison and discussion with the consultants of the other projects of water supply relevant to similar projects implemented by other organizations.

10.1.2 Implementation Arrangement

The overall coordination, monitoring and guidance on the policy aspects related to the project will be provided by chairperson of the concerned implementation agency i.e. BEZA, Prime Minister Office. An inter-ministerial Project Implementation Committee (PIC), chaired by the Chairmen, BEZA, Prime Minister Office will be set up. Its membership will include the Representative from the Planning Wing of the concerned Ministry/Division, Representative from the Development Wing of the Concerned Ministry/Division, Representative from the Concerned Wing/Sector- Division of the Planning Commission, Representative from the Programming Division of the Planning Commission, Representative of NEC-ECNEC & Coordination Wing of the Planning Division, Representative from the Concerned Sector of IMED, Representative from Finance Division, Representative from Department of Environment (DoE), Project Director, Representative from Department of Public Health Engineering (DPHE) and Concerned Desk Officer of the Implementing Agency.

Terms of Reference of the PIC will be given as follows:

- To provide necessary assistance or suggestion for implementing project activities.
- To provide necessary decision, to solve if any problem, arise during project implementation.
- The committee will meet at least once in every three months.
- The committee may co-opt members, if necessary.

BEZA will setup a Project Implementation Unit (PIU) headed by a Project Director (PD). The PD will be in-charge exclusively with its project execution and will have no other duty with BEZA. The PD supported by the PIU will be directly responsible for overall project implementation, monitoring, supervision, under the guidance of the Engineering Chief and will report to the Chairmen BEZA. The PIU shall be responsible to process international/ local tenders, issue of work orders for respective packages and the consultants will assist PIU during evaluation of tenders, selection of contractors and suppliers. The PIU will be responsible for day to day management of the project including but not limited to the following:

- Prepare overall Project Implementation Plan (PIP)
- Provide overall construction supervision works of the project components

- Initiate tendering and executing contracts
- Monitor and supervise all project management activities
- Organize monitoring and evaluation activities
- Prepare Project Progress Report (PPR) and Project Completion Report (PCR)
- Ensure full compliance with resettlement, environmental and other safeguard issues and policies.
- The PIU will be assisted by the consultants for design supervision and construction supervision.
- PIU will continue the O&M of the project up to defect liability period and then PIU will hand over the operation and maintenance of the project to the Executive Engineer O&M division for proper operation and maintenance of the Project. A proposed organizational structure of operation and maintenance of the project has been given in **section 10.2.**

Other responsibilities of the Project Director are handing over site to the contractor. Any dispute arises in the sites for instances, land dispute, access road and the route of the transmission main will be solved by the PD without any delay with the assistance of PIU.

A proposed organizational structure for Project Implementation unit (PIU) has been given **Figure 10.1**.

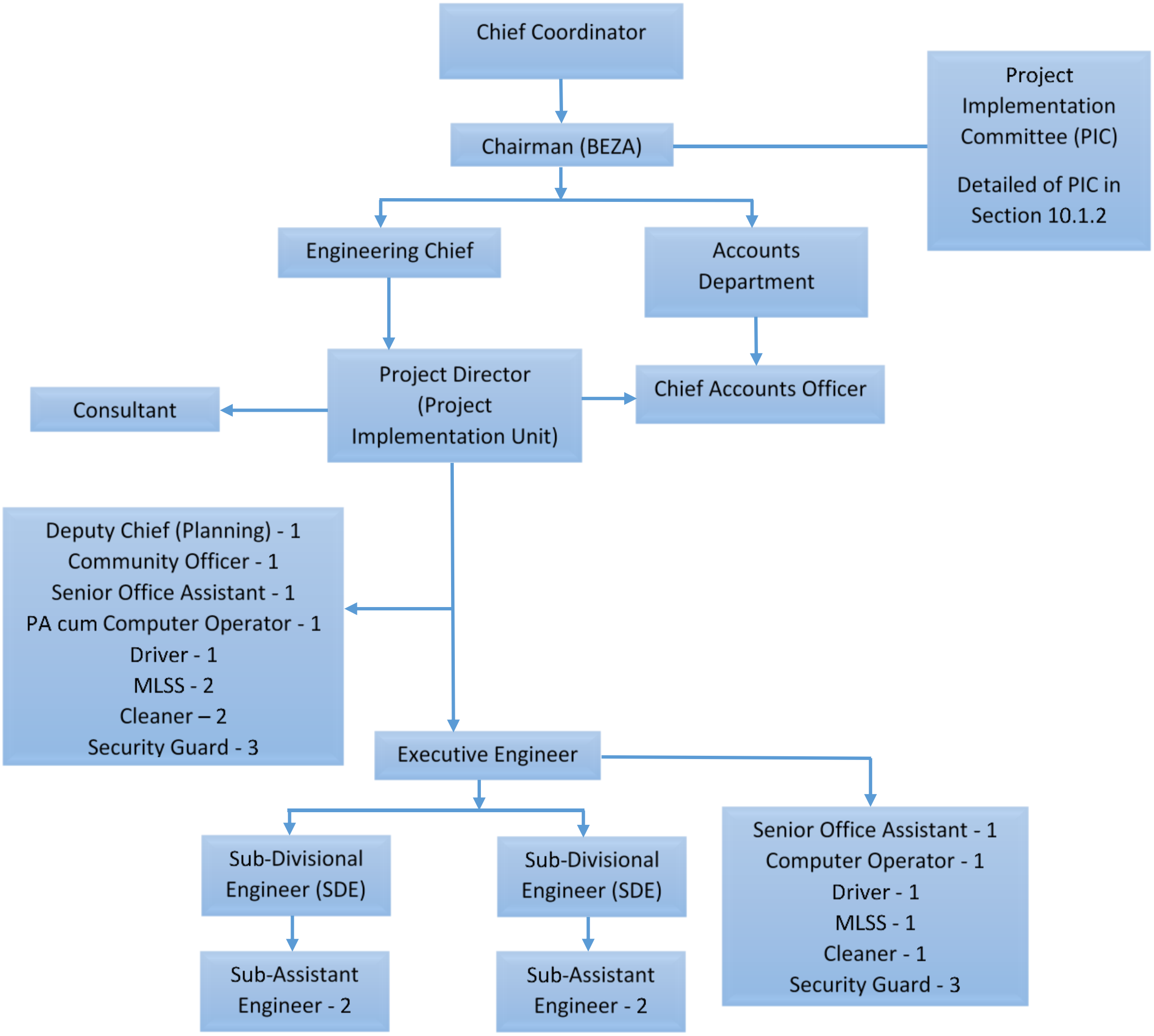


Figure 10.1: Proposed organizational structure for Project Implementation Unit (PIU)

10.2 Proposed Organogram for the Operation of Water Supply System

BEZA will setup a Unit for operation and maintenance (O&M) of Water Treatment Plants and Ground Water Wells including Transmission and Distribution System by an Executive Engineer. The O&M unit will be responsible for

a) Procurement of chemicals, operation and maintenance of different units of SWTP

b) Operation and maintenance of

- raw water transmission main
- treated water transmission
- distribution network

– groundwater wells

c) Providing service connection to the consumers

d) Receive complains and provide emergency services

Proposed Organizational Structure for O&M unit of the overall water supply system is shown in **Figure 10.2.**

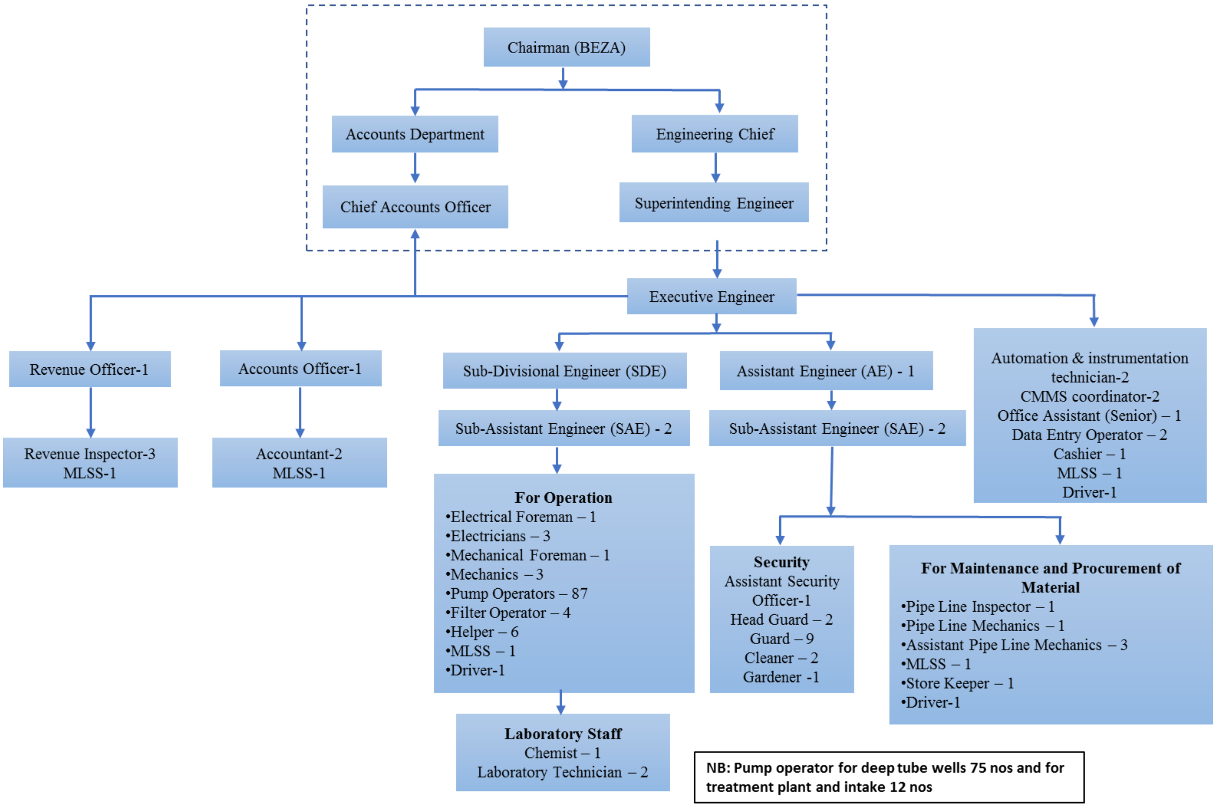


Figure 10.2: Proposed Organogram for O&M Unit of Water Supply System

10.2.1 Staff Position and Duties

A proposed organogram for the Operation and Maintenance of the Treatment Plant has been established in **Figure 10.2**. The plant will be operated under an Executive Engineer. He will be sole responsible for operation and maintenance (O&M) of the plant and collection of revenue and maintenance of accounts.

Executive engineer will be assisted by following officers and staffs for O&M and procurement of chemicals, use and preservation of the chemicals. The plant will be operated 24 hours basis and according the staffs will be engaged in operation & maintenance of the plant. The proposed supporting officers & staffs of the plant are given below:

a) Executive Engineer
b) Sub Divisional Engineer (SDE)
c) Assistant Engineer
d) Sub Assistant Engineer
e) Accounts Officer
f) Accountant
g) Revenue Officer
h) Revenue Inspector

i) Foreman (Electrical and Mechanical)
j) Electricians
k) Mechanics
l) Pipeline Inspector
m) Assistant Pipeline Mechanics
n) Assistant Security Officer
o) Head Guard, Guard
p) Pump operator
q) Filter Operator
r) Helper
s) cleaner
t) MLSS

Duty of the Sub Divisional Engineer and Assistant Engineer are to engage the staffs & operators in different units of the treatment plan. The different units are intake pump station, mixing chamber, chemical building, chlorination building, cleaning of filters, high lift pumping station. Operator and maintenance staffs will be engaged in such a way that, the plant will be in operation on 24 hours basis. The schedule of the O&M staffs will be prepared in such a way so that each and every staff will be on duty at least for 8 hours.

In addition to that there will be several DTW and all the tube wells will run for 24 hours. So for each DTW, at least 3 operators will be necessary. Considering the above facts, O&M staffs have been estimated.

Under Executive Engineer, revenue officer with revenue inspectors will be engaged for billing & collection of revenue. The revenue officer will be liable to maintain all records of billing and collection of the revenue. He will work under the Executive Engineer.

One no accounts officer with two accountants will be worked for maintenance of the accounts. He will work under the Executive Engineer.

The overall responsibility of O&M of the treatment plant including procurement of chemicals, collection of revenues and maintenance of ledger, maintenance of the account’s property will be the Executive Engineer. Other supporting staffs will be responsible for assisting their seniors.

11 Desalination Plant

11.1 Introduction

Desalination is a process of removing dissolved salts from seawater 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 filtre (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%).

Developed countries such as France, Germany and Spain have led the technologies in the global desalination market. France and Germany make heavy use of their abundant natural water resources, but they have also invested in the development of desalination technologies and related products for export. Spain, a leading exporter of desalination technologies, also makes use of the technologies to produce desalinated water for domestic consumption. This fact sheet aims to provide the Panel on Development with information on the different features of the RO, MSF and MED technologies.

11.2 Three major seawater desalination technologies

11.2.1 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 11.1**.

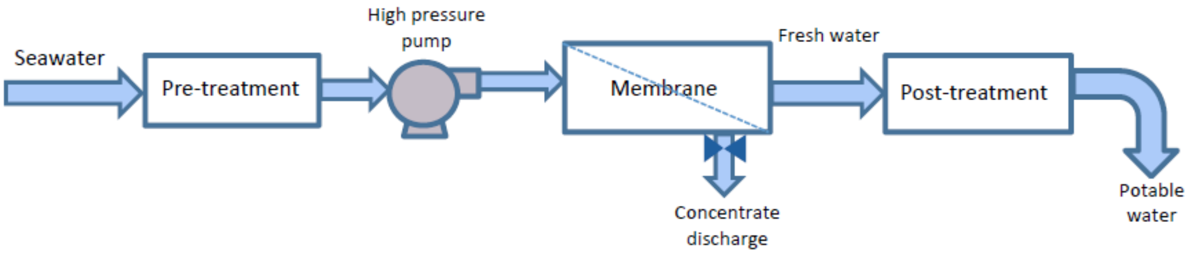


Figure 11.1: Basic process of reverse osmosis

11.2.2 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 11.2**). 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.

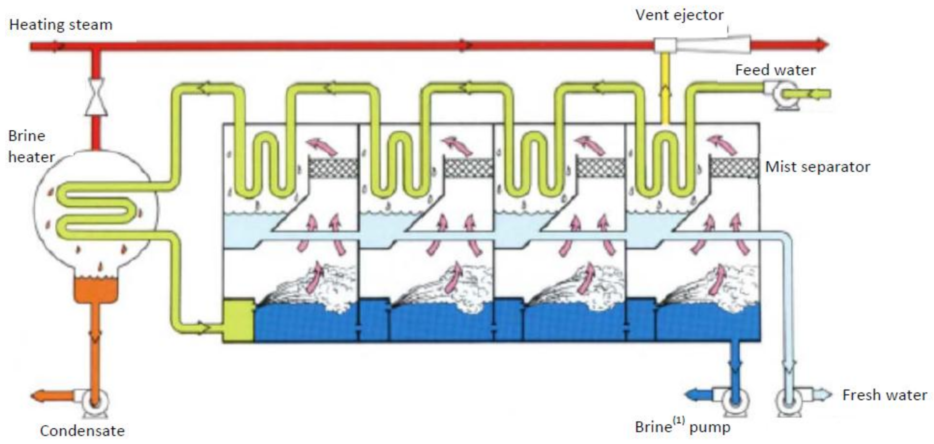


Figure 11.2: Basic Process of multi-stage flash evaporation

11.2.3 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 11.3**, 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 11.3**, 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.

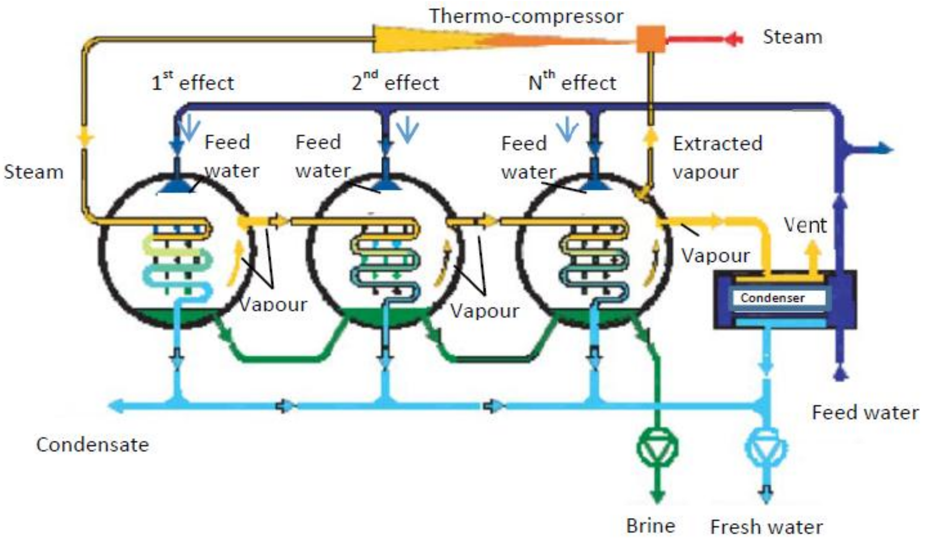


Figure 11.3: Basic Process of multi-effect distillation

11.3 Comparison of the three major desalination technologies

11.3.1 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.

11.3.2 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.

11.3.3 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.

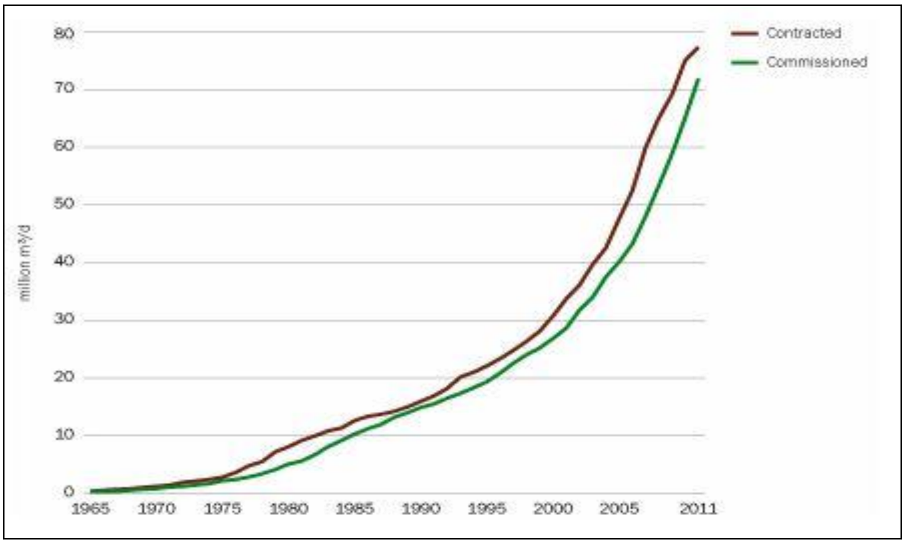
The strengths and weaknesses of the RO, MSF and MED technologies are summarized in **Table 11.1**:

Table 11.1: 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 • Requirement for thorough seawater pre-treatment	• Higher energy requirement • Lower water recovery

11.4 Global Desalination Industry

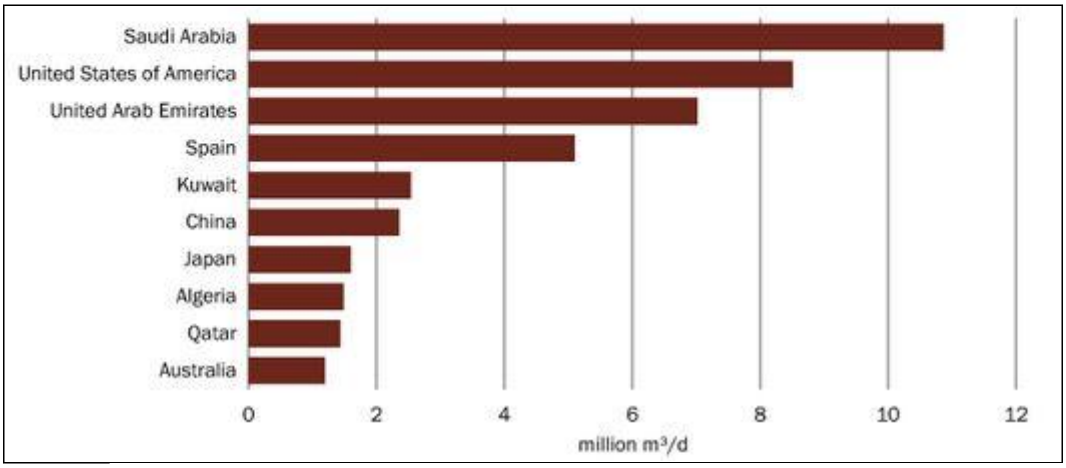
Freshwater is often talked about as being "the next gold", and for good reason. 97.5% of all water on Earth is saltwater, leaving only 2.5% as freshwater. 70% of that freshwater is frozen in the icecaps of Antarctica and Greenland and < 1% of the world's freshwater is accessible for direct human use. 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 11.4**.



Source: www.desalination.com

Figure 11.4: Cumulative contracted and commissioned desalination capacity from 1965-2011

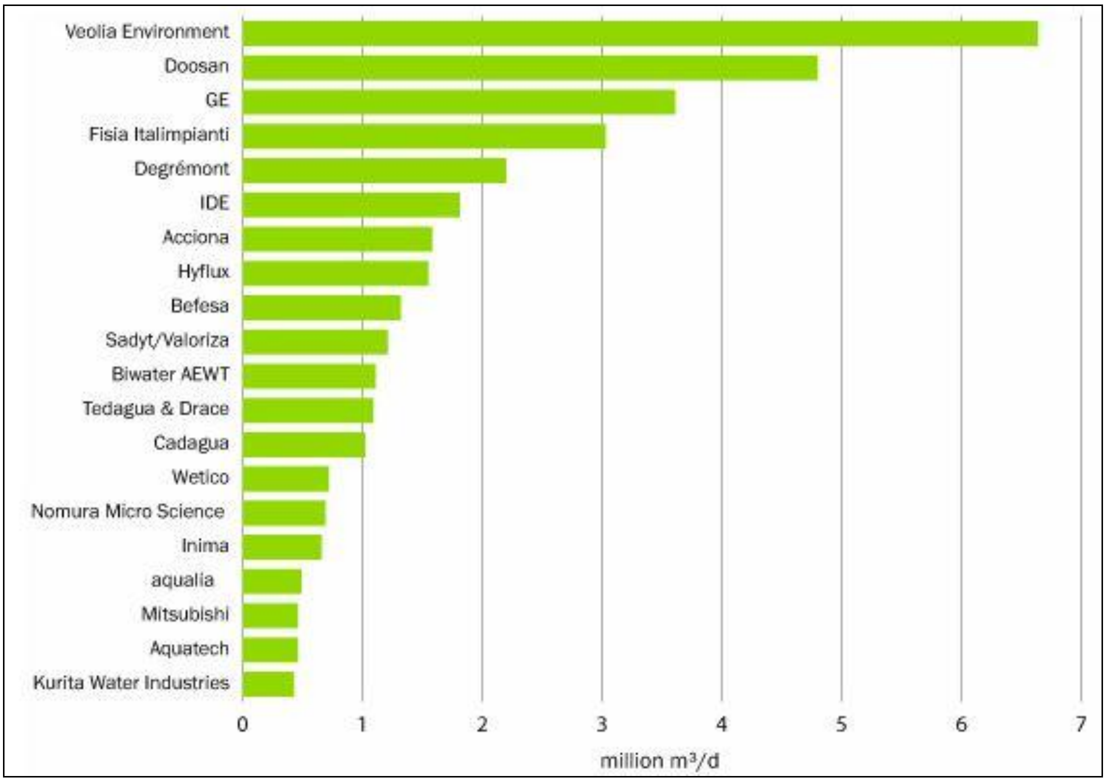
With such a huge number of desalination plants being built, the question is where `they are located. The below chart in **Figure 11.5** shows the distribution of desalination plants by country.



Source: www.desalination.com

Figure 11.5: Desalination plants in different countries

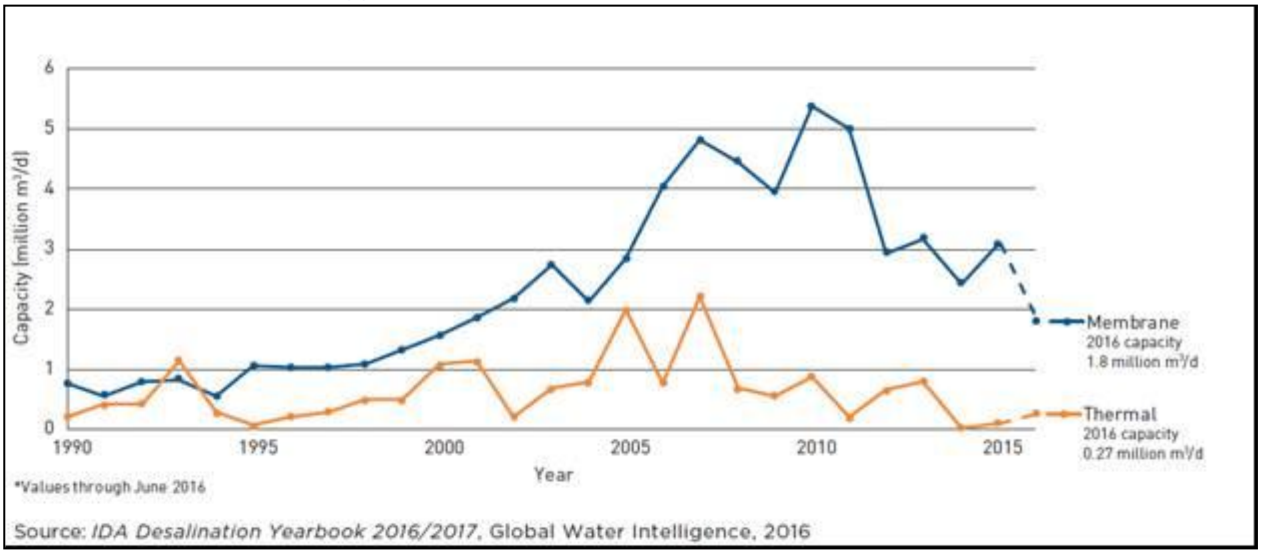
The chart in **Figure 11.6** shows the top engineering, procurement and construction contractors for desalination plants constructed from 2000-2011.



Source: www.desalination.com

Figure 11.6: Contractors to build desalination plants

11.4.1 Technology trends



Source: *IDA Desalination Yearbook 2016/2017*, Global Water Intelligence, 2016

Figure 11.7: 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.

11.4.2 General Cost

The installed cost of desalination plants is approximately **$1million** for every 1,000 m^3/day of installed capacity. Therefore, a large-scale desalination plant serving 300,000 people typically costs in the region of **$100 million**. The costs of infrastructure to distribute water must be added to this.

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.

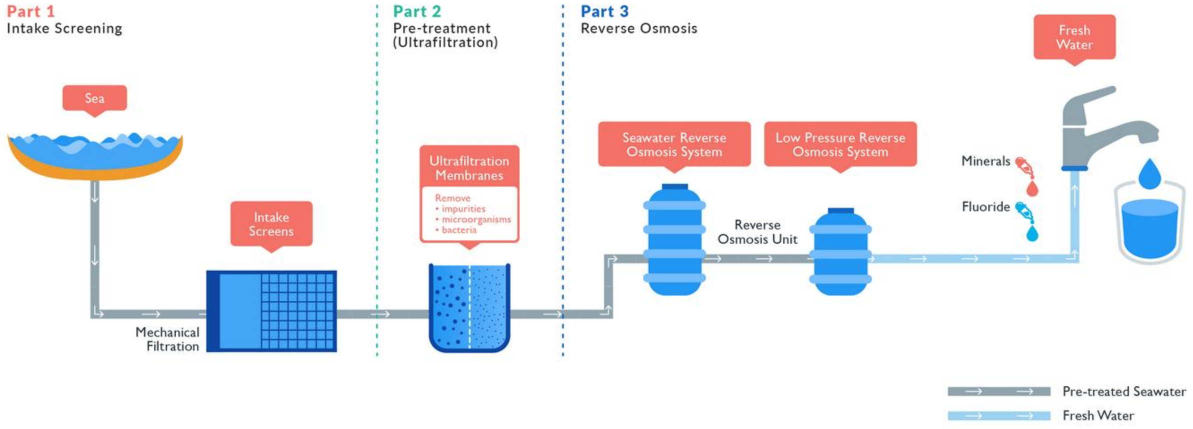


Figure 11.8: Flow diagram of Tuaspring Desalination Plant in Singapore

11.4.3 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).

11.5 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.

11.5.1 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.

11.5.2 Location

The site where a desalination facility is constructed can have a major impact on the overall costs of the project. For example, for an SWRO (Sea Water Reverse Osmosis) desalination plant, the plant should be located as close as possible to the seawater 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. However, real estate acquisition cost is a significant factor that may require greater water transmission in locations where land cost may exhibit orders of magnitude differences in relatively short distances. From a construction point of view, 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.

11.5.3 Raw water quality

The site-specific raw water quality can have a major impact on the number and type of pretreatment steps required ahead of the desalination step itself, and the overall sizing of the desalination plant. The total dissolved solids (TDS) level 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. In the case of SWRO, in areas such as small bays, gulfs or channels, seawater currents, and the resultant natural mixing from the larger body of seawater (i.e., the ocean) may be minimal. These areas 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.

Furthermore, feed water temperature has a large impact on RO operating pressure costs, with feed pressure increasing by 10% to 15% for a 10^{o}F drop in feed water temperature below 70^{o}F (WRA, 2012).

For a RO system, the required product water quality will dictate the number of membrane passes required, thereby impacting costs.

11.5.4 Intake and Outfall

The type of intake and outfall selected for a desalination plant is one of the most important technical considerations for a plant's cost-efficient design and optimum operation. Important factors need to be evaluated such as the most suitable intake type (submerged vs. open intake), the distance of the intake relative to the plant, the type of intake screens, the 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).

To illustrate the potential significance of intake and discharge structure costs, SWRO plant discharges located close to marine habitats that are highly sensitive to elevated salinity require elaborate concentrate discharge diffuser systems, with costs that can exceed 30% of the total desalination project expenditures. In contrast, the desalination plants with the lowest water production costs have concentrate discharges either located in coastal areas with very high natural mixing or are combined with power plant outfall structures, allowing good initial mixing and better discharge plume dissipation. The intake and discharge facility costs for these plants are usually less than 10% of the total desalination plant costs (WRA, 2012).

11.5.5 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.

Pretreatment costs are typically greater if the water source is wastewater. This may be due to many factors, such as the necessity to remove high calcium and magnesium (hardness) levels, the addition of chlorination and dechlorination steps to destroy microbes, or the necessity of using UF to remove high molecular weight organic compounds.

11.5.6 Energy recovery

RO systems use high-pressure pumps to overcome the osmotic pressure of the raw feed water. For example, some 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.

11.5.7 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.

11.5.8 Post-treatment

Final product water quality will determine the specific type of post-treatment that is required. Post-treatment steps add additional costs. The need for a second RO pass 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).

Post-treatment costs are typically greater if the water source is wastewater. This may be due to many factors, such as post-treatment oxidation to inactivate viruses and higher costs for waste brine or solids disposal.

11.5.9 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.

11.5.10 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. In fact, the number of years required to develop and permit a project in a state like California, with very stringent regulations, may be significantly longer than the time necessary to construct the plant and initiate start-up. (WRA, 2012)

11.6 Cost Components of a Desalination Plant

11.6.1 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 11.9** shows one example of a CAPEX cost breakdown for an SWRO plant.

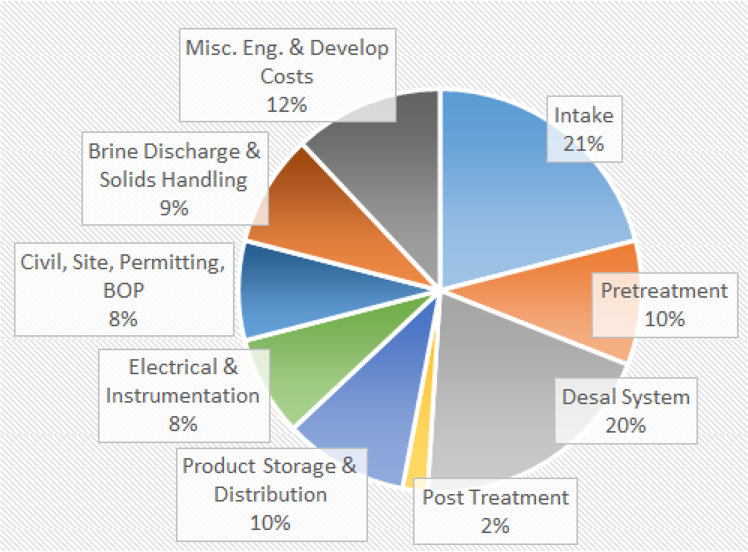


Figure 11.9: Typical SWRO desalination plant CAPEX breakdown

CAPEX, to a significant extent, depends on scale with larger desalination plants costing less per million gallons of installed capacity. Based on **Figure 11.10** below, 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 11.10: Unit construction cost vs. capacity for SWRO plants

11.6.2 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 the following: 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 11.11**.

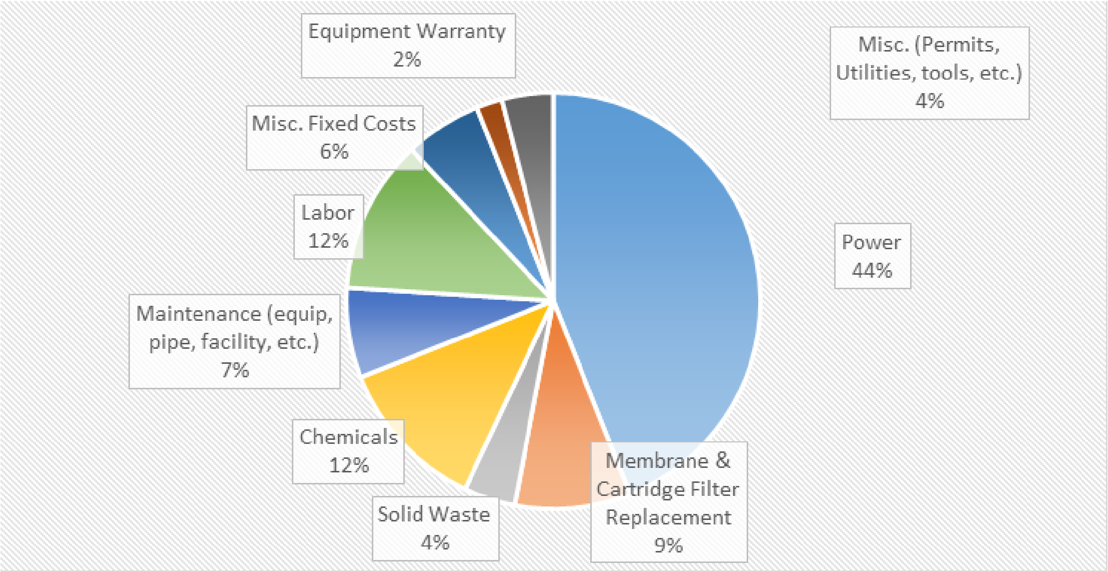


Figure 11.11: Typical SWRO desalination plant OPEX breakdown

[Source: Advisian]

11.6.3 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 11.12 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).

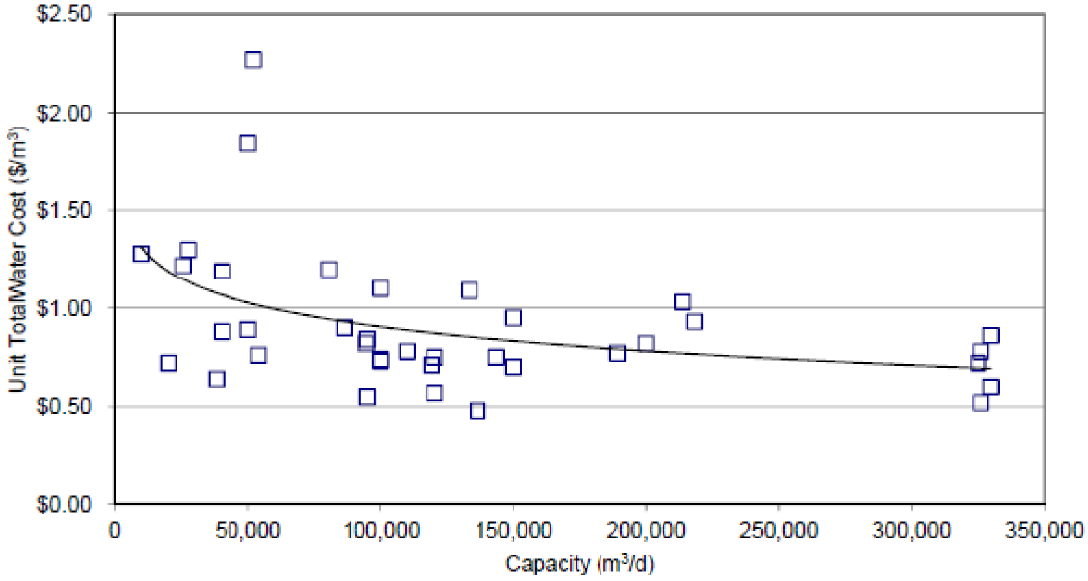


Figure 11.12: RO plant unit production cost vs. project capacity

[Source: Ludwig, H., 2010]

Figure 11.13 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.

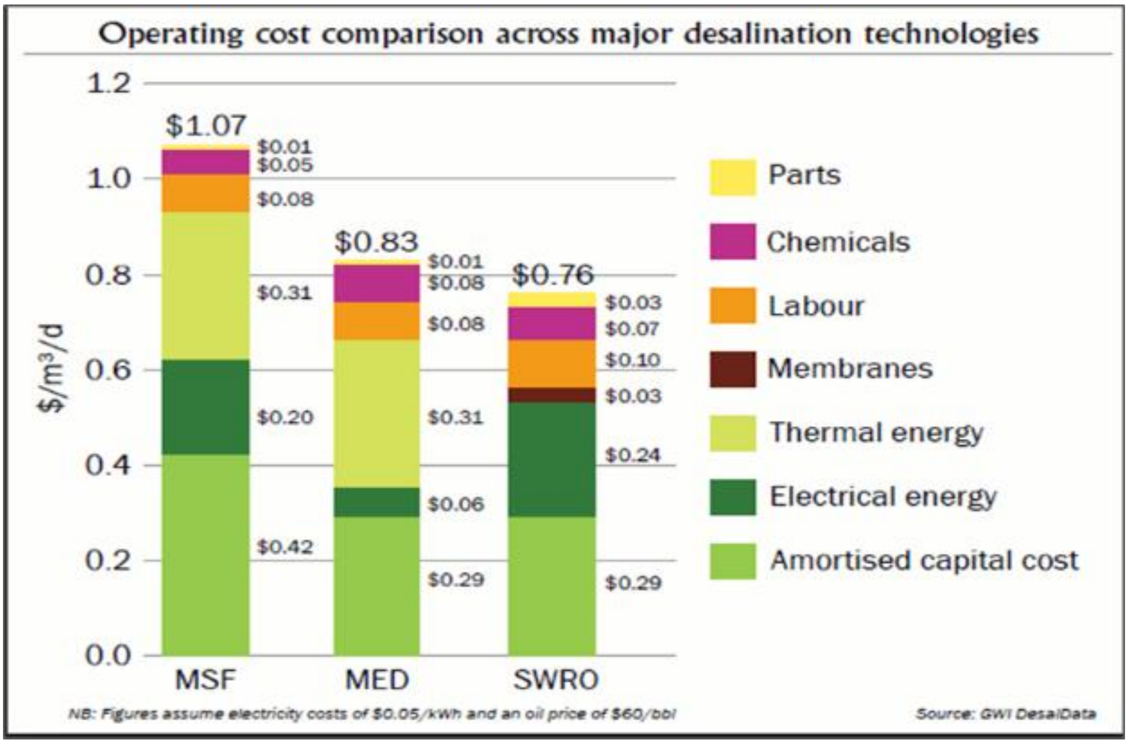


Figure 11.13: Unit production cost of water for desalination technologies

[Source: Instituto Murciano (2012)]

11.7 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 relive 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 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 11.14**) 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.

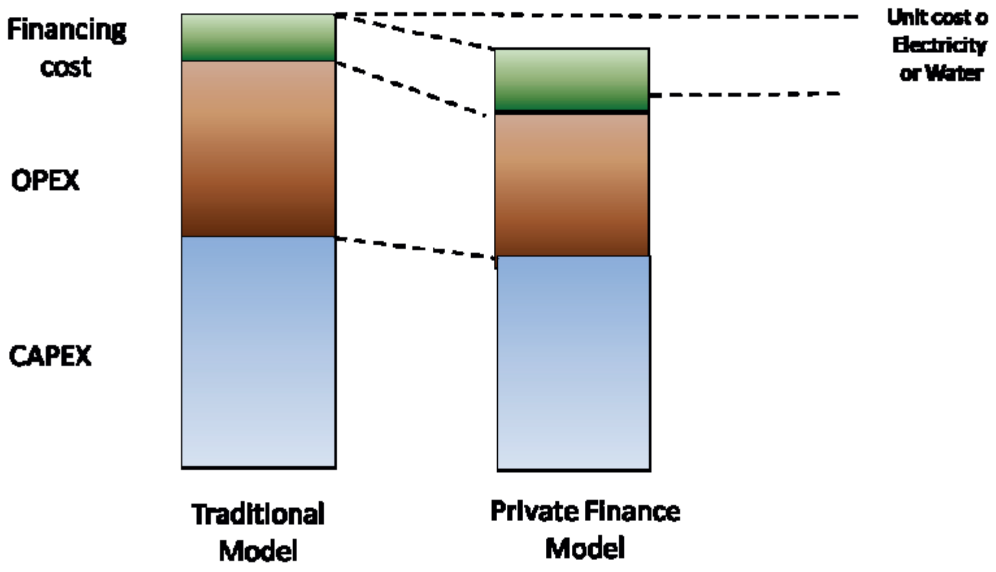


Figure 11.14: Comparison of CAPEX and OPEX between traditional and private finance project

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.

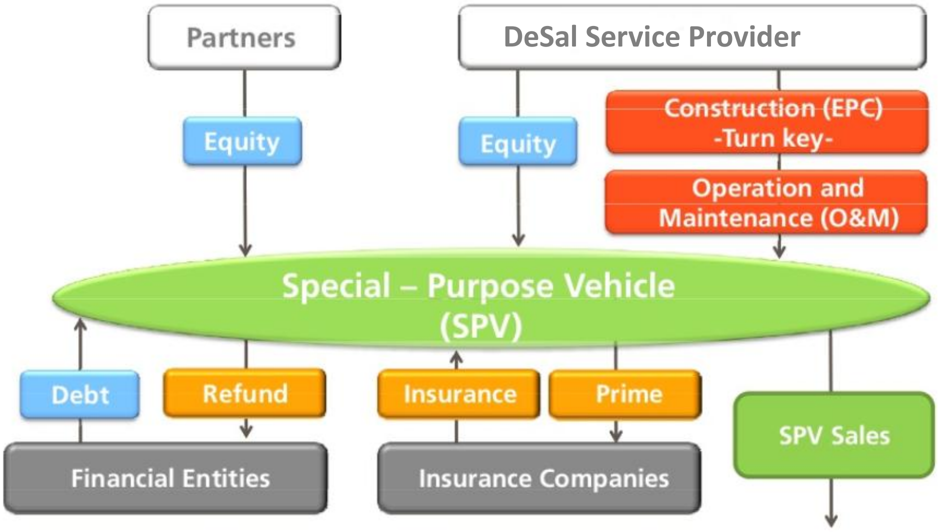


Figure 11.15: Financing of a BOOT project

11.8 Consideration for BSMSN

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 the following approximate costs can be assumed for the 50MLD desaliation

- Capital Cost - $50 million
- Operating Cost - $6 million/yr
- Cost of Water – 50 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.

12 Water Management Plan

12.1 Use of Available Resources and Phasing

Water demand for Bangabandhu Sheikh Mujib Shilpanagar has been estimated for industrial, domestic, non-domestic and other uses. The main basis of estimating the demand is industrial, employment and population projection based on Master Plan of Bangabandhu Sheikh Mujib Shilpanagar conducted by Sheltech Consultants (Pvt.) Limited and STUP Consultants Private Limited. The total production capacity, however, considers physical loss or leakage from the treated water transmission and distribution pipelines and appurtenances. It is estimated that the total production capacity will be 965 MLD in 2040 at the end of full development of BSMSN. The water requirement will be 343 MLD at the end of 2025, 482 MLD at the end of 2030, 683 MLD at the end of 2035 and 965 MLD at the end of 2040.

From the surface water resource assessment of Feni River (Sec. 4.3) it has been estimated that about 100 MLD water can be supplied from Feni river reservoir. The plant has been proposed to construct in two phases. In first phase 50 MLD treatment plant with 25 nos. DTW will be constructed for supplying water in priority zone 2A, 2B, 3, 4 & 5. The completion of this first phase surface water treatment plant is recommended by 2023. The detailed study of the proposed SWTP has been described in Section 8.

In the 2nd phase, another surface water treatment plant from Feni River will be constructed for next priority zones. It is proposed to complete the construction works of this treatment plant by 2025. The location for 50 MLD water treatment plant (phase II) should be close to the supply area. This plant can be constructed close to the phase I plant if supplied at the adjacent area.

Another potential source of surface water is Mohra treatment plant Phase-2 (**Figure 12.2**). The source of this treatment plant is Halda River in Chittagong. About 65km transmission line is required to carry the treated water from the treatment plant to BSMSN area. The location of the treatment plant is too far. Therefore a treated water transmission main of 1000 mm diameter Ductile Iron pipe or steel pipe with 2 (two) number booster pump stations will be required. If the combined cost of treatment, transmission main and booster pump station is considered, this option is likely to be more expensive. Further study is necessary whether this option is acceptable for the supplying of water to the industrial park. To fulfil the water demand it is recommended to complete Mohra treatment plant by 2024.

Little Feni river is another source of surface water to meet water demand of BSMSN area. From the surface water resource assessment of Little Feni River (Sec. 4.4) it has been estimated that about 40MLD capacity treatment plant can be constructed to supply water in the western zones beside the right bank of Feni River. About 6km raw water transmission line is required to carry the river water to the treatment plant in BSMSN area. The raw water transmission main of 1000 mm diameter Ductile Iron pipe or steel pipe will be required. Further detail study is necessary for the supplying of water to the economic zone. It is recommended to complete Mohra treatment plant by 2028.

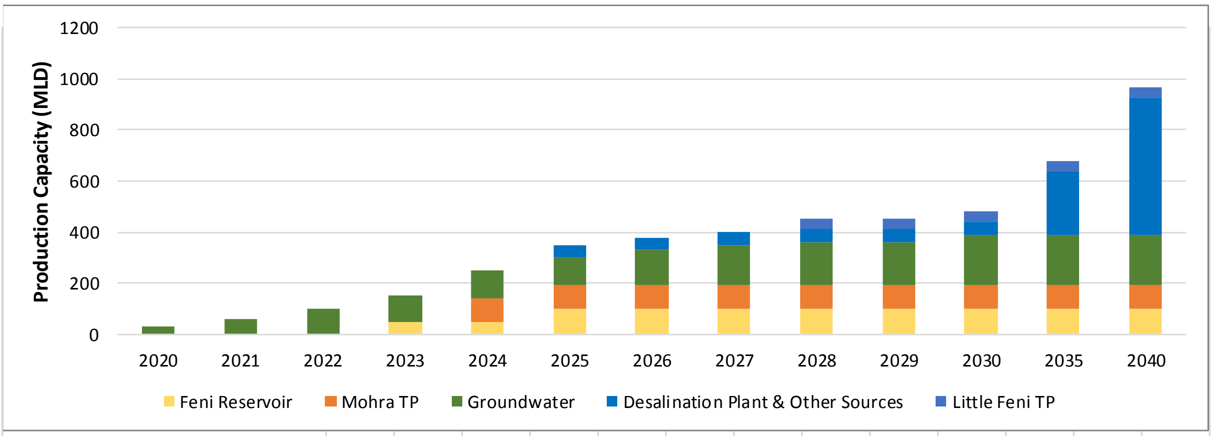
Detailed groundwater investigation in BSMSN area reveals that average thickness of deeper aquifer in this area varies from 120m to 205m. The available water that can be extracted from groundwater is maximum 205 MLD. The development of production wells is divided in three phases. In the 1st phase 50 MLD water will be available by installing 25nos PTWs within 2021. In the 2nd phase additional 50 MLD water will be available by installing 25nos new PTWs within 2022. In the 3rd phase additional 100 MLD water will be available by installing 50nos new PTWs within 2030.

The total amount of water that will be available from surface water and groundwater source is about 430 MLD. The additional water that will be required to fulfil the water demand of the whole project area will be about 535MLD. This amount of water will need to be managed by using treatment of sea water and other sources.

It has been observed that by using Reverse Osmosis process (RO), this sea water can be treated. This technology is relatively less energy intensive comparing other desalination technology available at present. Total 11 nos. RO desalination plant will be required with development. According to the plan the 1st two desalination plant will be required in 2025. The capacity of the desalination plant will be about 50MLD.

If reuse of water or rainwater harvesting is found feasible then the no of desalination plant can be reduced. Feasibility study is required for those options.

In the Master Plan the development of BSMSN area has been divided into four main time horizon- 2020-2025, 2026-2030. 2031-2035 and 2036-2040. Accordingly, the production water from surface water, groundwater and desalination plant has been planned for BSMSN as shown in **Figure 12.1**.



Planning hoizone	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040
Water Demand	**30**	**60**	**100**	**150**	**250**	**344**	**380**	**400**	**450**	**450**	**482**	**682**	**965**
Feni Reservoir - Phase I				50	50	50	50	50	50	50	50	50	50
Feni Reservoir - Phase II						50	50	50	50	50	50	50	50
Total Feni Reservoir	**0**	**0**	**0**	**50**	**50**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Goundwater Phase I	30	50	50	50	50	50	50	50	50	50	50	50	50
Goundwater Phase II		10	50	50	50	50	50	50	50	50	50	50	50
Goundwater Phase III					10	10	40	60	70	70	100	100	100
Total Groundwater	**30**	**60**	**100**	**100**	**110**	**110**	**140**	**160**	**170**	**170**	**200**	**200**	**200**
Mohra Treatment Plant					90	90	90	90	90	90	90	90	90
Little Feni Treatment Plant									40	40	40	40	40
Offstream Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0
Mahamaya Reservoir	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Reservoirs	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total (SW+GW)	**30**	**60**	**100**	**150**	**250**	**300**	**330**	**350**	**400**	**400**	**430**	**430**	**430**
Gap	0	0	0	0	0	44	50	50	50	50	52	252	535
Desalination Plant (sea water) & other sources				**0**	**0**	**50**	**50**	**50**	**50**	**50**	**50**	**250**	**535**
Required Production Capacity	**30**	**60**	**100**	**150**	**250**	**350**	**380**	**400**	**450**	**450**	**480**	**680**	**965**

Figure 12.1: Future Sources of Supply for BSMSN

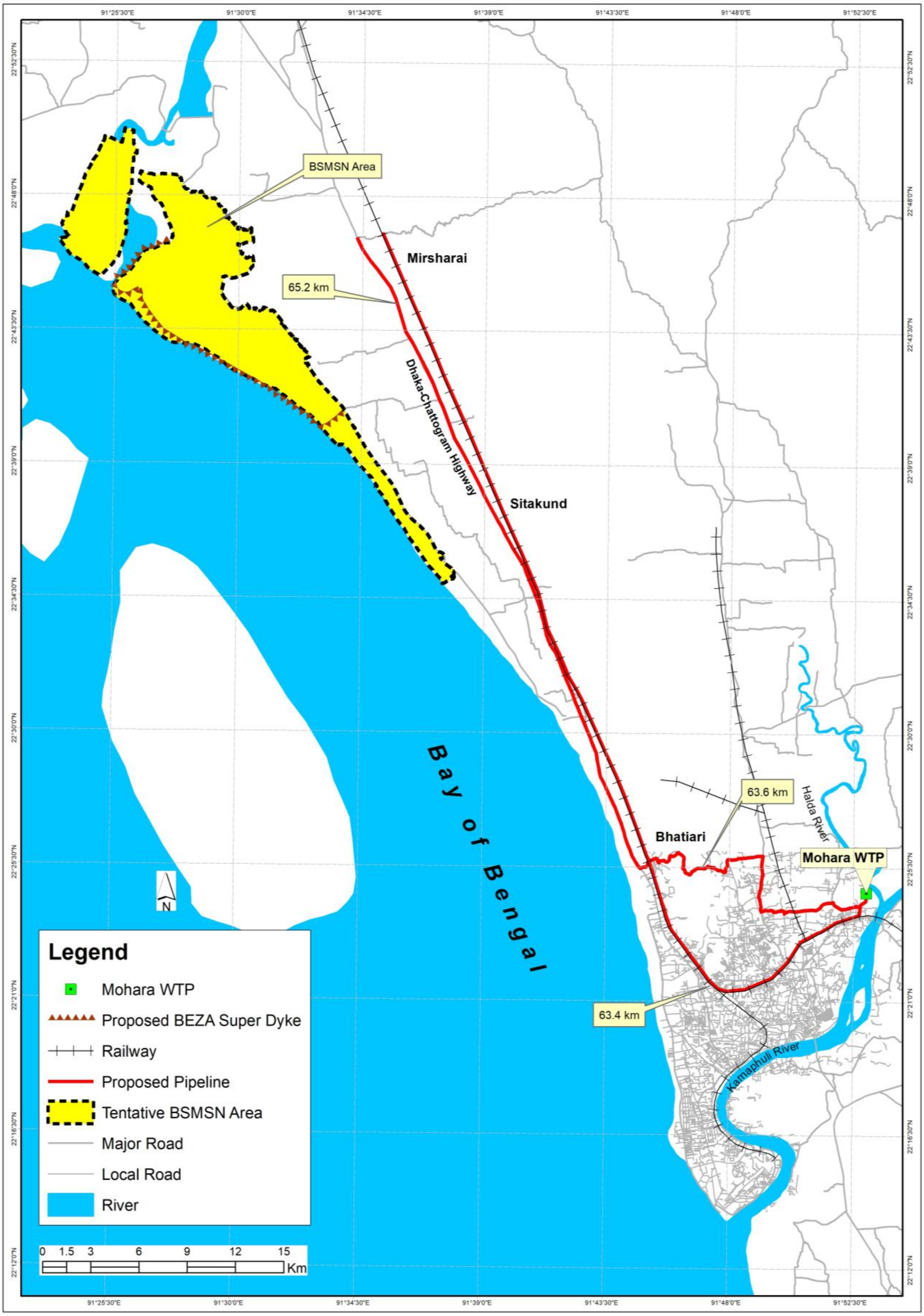


Figure 12.2: Proposed pipeline for Mohra treatment plant

12.2 Uncertainties in Resource Availability and Management

There could be several uncertainties associated with availability of water from surface water sources or groundwater sources. Also issues such as reduced water demand or damage to the infrastructures due to natural disaster can immerge. Therefore, it is necessary to have a management plan so that these uncertainties can be overcome. The probable uncertainties which can immerge, their impacts and mitigation measures for overcoming the uncertainties are discussed in following.

12.2.1 Decrease in Surface Water and Groundwater Availability

Over the years, availability of freshwater in the Feni river reservoir can get hampered due to Trans-boundary withdrawal, extended draught governed by climate change and water quality issue such as river pollution. Besides availability of groundwater can get reduced over the time due to excessive withdrawal, reduced natural recharge governed by climate change impacts and quality issues such groundwater pollution, salinity instruction etc.

Impacts: The probable impact would be less production in the surface water treatment plants and less production or shutdown of the deep tube wells.

Mitigation Measures: Following measures shall be taken to mitigate the impacts:

- Signing water sharing treaties or MoU with the neighboring countries.
- Establishing a monitoring mechanism both for surface water and groundwater sources. There are monitoring stations (water level, discharge) at the upstream of Feni river reservoir. The component of water quality monitoring should be included at those monitoring stations. Besides there should be a monitoring wells for observing periodical changes in groundwater level and groundwater quality.
- In case the reduction in water availability is emerged as a result of quantity issues, the probable deficiency in supply requirement shall be managed by installing additional desalination plants.
- Wastewater with or without treatment from the industries, domestic and non-domestic should not be discharged from upstream of Intake to Feni regulator.
- However, in case of quality issues additional treatment steps shall be added to the SWTPs for maintaining treated water quality standard. Additional treatment facilities (RO, chlorination, aeration etc.) shall be installed for DTWs in groundwater quality issue arises.
- Efficient management of produced water from SWTPs and DTWs such as reducing system loss, installing water recycling facilities in industries where feasible.

12.2.2 Reduction in Water Requirement

Requirement of water is likely to decrease during vacations such as Eid festivals or during labour strikes and shutdown of industries due to financial or other implications. This will lead to shortfall in requirement for a limited period. In addition, the future growth in industries may not follow the projected pattern which will result reduction in long term water requirement.

Impacts: Financial loss of the investments for water production

Mitigation Measures: Following measures shall be taken to mitigate the impacts:

- Limited operation of the SWTPs and DTWs during vacation or period of labour strike
- Periodical updating of the implementation plans of different phases based on the actual water requirement at different time frames.

12.2.3 Natural Disasters

Natural disasters in the form of cyclone, earthquake etc. may occur and cause longer time power failure, partial damage to the infrastructures related to SWTP, DTW and transmission and distribution network.

Mitigation Measures:

Following measures shall be taken to mitigate the impacts:

- Design of structures shall include consideration of seismic load according to the guidelines of BNBC
- Warning system shall be established in the industrial park to limit probable damage due to natural disasters.
- Rapid action shall be taken for restoration of power supply and damaged infrastructures.
- The officer in charge of the industrial park will take immediate actions with the assistance from the O&M team. In case he is unable to act by his own capacity, he will involve the top management of BEZA to undertake the matter.
- The damage shall be considered as an act of God and immediate action for assessment of damage and restoration of the same shall be taken.

13 Project Cost and Financial & Economic Analysis

13.1 Project Cost estimation

This chapter include overall project cost to mitigate total water demand of proposed BSMSN and financial and economic analysis of phase I. The overall project components includes 2 nos. 50 MLD surface water treatment plant from Feni River, 90 MLD surface water treatment plant from Halda river (Mohra), 40 MLD surface water treatment plant from Little Feni river, installation of 100 nos DTW each of 2.0 MLD , 11 nos @50 MLD desalination plant and transmission main & distribution networks. The tentative total cost to meet the water requirement for 30,000 acre area of BSMSN is about 83,387 Million BDT. The summary of tentative cost is shown in **Table 13.1.**

Table 13.1: Summary of cost for full filled the total water demand

SL No.	Description	Total Price in Million BDT
1	50 MLD Surface Water Treatment Plant (Phase I) including Intake for 105 MLD	5,676
2	50 MLD Surface Water Treatment Plant (Phase II)	4,898
3	90 MLD Surface Water Treatment Plant (Mohra)	5,565
3.1	About 65 km Transmission Main with 2 nos. Booster Pump from Mohra to BSMSN	10,022
4	40 MLD Surface Water Treatment Plant (Little Feni River)	2,968
4.1	12 Km Raw &T Water Transmission for 40 MLD SWTP	828
5	205 MLD Groundwater (100 nos. DTW)	1,657
6	11 nos @ 50 MLD Sea Water Desalination Plant	46,750
7	About 380 km water distribution networks	5,022
Total		**83,387**

13.2 Financial and Economic Analysis for 50 MLD SWTP & 25 nos. DTW (Phase I)

In the 1st phase of water supply system 50 MLD SWTP of the Feni River and 25 nos DTW of each capacity about 2 MLD will be installed. This phase is planned to supply water in priority area of zone 2A, 2B, 3, 4 & 5 of BSMSN. The total production capacity of surface water treatment plant (50 MLD) and 25 DTWs (51 MLD) will be 101 MLD. However, with time the production capacity of the DTWs are expected to reduce to 74%. Therefore, the resultant production by two sources have been estimated as 87 MLD. The total cost of the project is about 629.36 crore BDT while the initial operating cost is approximately 12.1 crore BDT per year (excluding depreciation). The lifetime of the said WTP is assumed to be 50 years and tube wells are for 20 years.

13.2.1 Project Benefit (Financial)

The project cost for 87 MLD capacity is 629.36 crore BDT. In addition, there will be operating cost needed equivalent of 12.1 crore BDT. The year of the completion of works is 2023. For cost benefit analysis 10% system loss has been considered. And the average tariff rate (cost per 1000 litter) of the project has been increased @ 5% per annum.

Table 13.2: Yearly Breakdown of the Project Cost

Sl. No.	Expected Investment Year		Cost in BDT in lakh
1.	FY 2020-21	:	15000.00
2.	FY 2021-22	:	24942.10
3.	FY 2022-23	:	22994.13
	Total	**:**	**62936.23**

Calculating the Cost-Benefit analysis of this project the financial Benefit Cost Ratio (BCR) stands at 1.5 and the Net Present Value (NPV) is 32318.77 Lakh BDT. The Internal Rate of Return (IRR) has been computed as 17.82% of this project. The summary of the analysis is shown in **Table 13.3** and the detail analysis is given in **Annex-12**.

Table 13.3: Financial Analysis of the Project

BCR	NPV (BDT In Lakh)	FIRR (%)
1.5	32318.77	17.82%

13.2.2 Project Benefits (Economic)

The project will enhance the capacity of BEZA for the water supply. The water facilities could be delivered to the manufacturing industries which have already setup their plants and or to the other enterprises who wishes to setup their plants for a long period of 50 years. The project will produce 87 MLD water per day which will ultimately help to improve the economic conditions of the nation.

In analyzing the economic benefit, CD, VAT and the depreciation cost have been deducted from the total invested cost. Calculating the cost-benefit of this project the economic Benefit Cost Ratio (BCR) stands at 1.82 and the Net Present Value (NPV) is 43687.00 Lakh BDT. The Internal Rate of Return (IRR) has been computed as 20.49% of this project. The summary of the analysis is shown in **Table 13.4** and the detail analysis is given in **Annex-12**.

Table 13.4: Economic Analysis of the Project

BCR	NPV (BDT In Lakh)	EIRR (%)
1.82	43687.00	20.49%

13.2.3 Pricing

The price of the treated water has been considered for 1unit (1000 liter) for industrial 45.03 BDT and 14.06 BDT per 1000 liter for non-industrial uses in 2023-24 in terms of tariff. The tariff could need be increased gradually per annum. For the viability of the project we considered the said tariff of the treated water to be raised every year by 5% for all users and the system loss has been accounted 10% of the billable quantity. The summary is shown in **Table 13.5** and detail in **Annex-12**.

Table 13.5: Tariff Rate for the Industrial and Non-industrial users

year	User Types		Tariff rate in BDT for per 1000 litter	
	Industrial	Others	Industrial	Non-industrial
2025	62.64 MLD	15.66 MLD	49.64	15.51

2030	62.64 MLD	15.66 MLD	63.36	19.79
2035	62.62 MLD	15.66 MLD	80.86	25.26
2065	36.00 MLD	9.00 MLD	301.90	94.30
2070	36.00 MLD	9.00 MLD	385.30	120.35
2075	36.00 MLD	9.00 MLD	491.76	153.60

13.2.4 Sensitivity Analysis

Sensitivity analyses are core parts of the Project's viability. Sensitivity analyses determine how a positive or negative change in different values will impact a result (FIRR, EIRR, NPV, etc.) under a given set of assumptions.

A sensitivity analysis is undertaken in order to assess robustness of the analysis. Different iterations have been realized based on modifications of the investments costs, the benefits and the discount rate. The results are shown **Table 13.6.** The detail sensitivity analysis is given in **Annex-12.**

Table 13.6: Sensitivity Analysis for Different Option

Study case	Financial Analysis			Economic Analysis			Tariff Rate	
	FIRR	NPV	BCR	EIRR	NPV	BCR	Indus.	Others
Base Case	17.82%	32318.77	1.50	20.49%	43687.00	1.82	45.03	14.06
a. Increase by 10% Investment cost	16.40%	26610.41	1.38	19.10%	38722.66	1.66	45.03	14.06
b. Decrease by 10% Investment cost	19.14%	38027.13	1.64	22.78%	48651.33	2.00	45.03	14.06
c. Increase by 20% Investment cost	14.90%	20902.05	1.27	17.92%	33758.33	1.53	45.03	14.06
d. Decrease by 20% Investment cost	20.82%	43735.49	1.82	24.82%	53615.66	2.23	45.03	14.06
e. Increase by 10% operating cost	17.65%	31137.23	1.47	20.23%	42506.09	1.78	45.03	14.06
f. Increase by 20% operating cost	18.88%	29955.69	1.45	19.97%	41325.19	1.74	45.03	14.06
g. Increase by 10% Benefits	19.10%	42026.79	1.65	22.43%	53395.01	2.00	49.53	15.47
h. Increase by 20% Benefits	20.20%	51734.80	1.80	23.92%	63103.02	2.18	54.03	16.88
i. Decrease by 10% Benefits	16.10%	22610.76	1.35	19.03%	33978.98	1.64	40.52	12.66
j. Decrease by 20% Benefits	14.38%	12902.75	1.20	17.39%	24270.97	1.45	36.02	11.25
k. One year delay the project benefits	16.29%	28513.22	1.44	18.85%	39882.67	1.75	45.03	14.06
l. Discount rate @ 10 %	17.82%	57344.06	1.80	20.49%	69842.10	2.17	45.03	14.06
m. Discount rate @ 8 %	17.82%	98174.84	2.18	20.49%	112232.41	2.62	45.03	14.06

Even substantial changes in the parameters will not change the above conclusion in terms of viability of the project, the NPV and the EIRR remaining at very acceptable levels. Such rates and figures are a strong indication that the recommended project is both financially and economically viable for BEZA as a whole.

14 Training and Capacity Building

A training program to transfer the knowledge and capacity building of the BEZA officials has been conducted from 25th November to 29th November 2019 on BEZA conference room (**Figure 14.1**). The list of participants is given below:

Sl. No.	Name of Participants	Designation
1.	Md. Moniruzzaman	Joint Secretary General Manager (Investment Promotion)
2.	Md. Shoab	Joint Secretary General Manager (Administration & Finance)
3.	Mohammed Shoheler Rahman Chowdhury	Joint Secretary General Manager (Planning & Development)
4.	Abdullah Al Mahmud Faruk	Deputy Project Director Bangladesh Economic Zones Development Project (Phase -1)
5.	Saleh Ahmed	Project Director (Deputy Secretary) Infrastructure Development for Japanese Economic Zone
6.	Mohammad Hasan Arif	Deputy Secretary MIDI Cell
7.	Doyananda Debnath	Deputy Chief Manager (MIS and Research)
8.	Md. Khurshid Alam Patwary	Deputy Secretary Manager (Administration)
9.	Md. Helal Ahmed	Deputy Secretary Manager (P&D-5)
10.	Md. A. Alim Khan	Deputy Secretary Manager (P&D-2)
11.	Md. Mahbubur Rahman,	Deputy Secretary Naf & Sabrang Tourism Park and Sonadia Eco-tourism Park
12.	Nasiruddin Mahmud Chowdhury	Infrastructure Consultant

Different topics were covered during training program which include the following:

- Environmental and Social Impact Assessment of Economic Zones
- Operation management of surface water treatment plant
- Water pollution management
- Management of land acquisition and resettlement
- Economic and Financial Analysis of Economic Zones
- Rainwater harvesting in industrial area
- Implementation management of surface water treatment plant
- Use of GIS in water management planning
- Groundwater Resource Monitoring
- Water distribution modelling and network design
- Surface water resource assessment using mathematical modelling

The training was very participatory. Professional expert in each topics gave their lecture and presentations and the participants took interest to learn from them. The training program have helped BEZA officials to build up their capacity in field of environment and social impact assessment, economic and financial analysis of different economic zones, implementation and operation management of surface water treatment plant, water pollution management due to industrialization, land acquisition and resettlement planning, rainwater harvesting analysis, water management planning, groundwater resource monitoring and use of different mathematical modelling for water distribution network design and surface water resource assessment.

Figure 14.1: Some snap during the training program

15 Findings and Recommendations

The Final Report has covered water demand estimation, resource assessment of surface water and groundwater, water management plant, project cost estimation, selection of sites and outline design of a 50 MLD surface water treatment plant and related structures and production tube wells.

15.1 Findings

- Total water demand for the Bangabandhu Sheikh Mujib Shilpanagar will likely to be around 839 MLD in 2040 after the full development of the economic zone. Considering losses in the distribution system, the production capacity required is about 965 MLD.
- Average thickness of deeper aquifer in the project area varies between 120m to 205m.
- Estimated maximum drainable storage volume stands at 205 MLD for the whole project area.
- Discharge of the production well should not be more than 1 cusec (28.3 litre/sec). Maximum 100 wells can be installed for 20 hours operation/ day.
- Muhuri reservoir on Feni River is suitable for water abstraction and supply to BSMAN area after treatment.
- Considering the shortage of water in dry period a maximum of 100 MLD plant can be constructed for BSMSN from Feni reservoir.
- Considering the morphology of the rivers and other technical and socioeconomic aspects Azampur (About 2.5 km upstream of the Feni Regulator) has been selected as intake location. The location is finalized after field verification and discussion with stakeholder, local people and BEZA.
- Pipe intake solution appears to be feasible considering initial and recurrent operation and maintenance cost.
- Route of raw water transmission main has been chosen along the existing Vanghani road (BWDB old embankment) and proposed project road. The length of raw water transmission main from intake site to treatment plant is about 9.56km.
- The proposed surface water treatment plant will be located at Poshchim Ichakhali Mouza in the east side of CDSP embankment. The capacity of the treatment plant will be 50 MLD in Phase-1 and another 50 MLD in Phase-2. The location of phase I treatment plant is finalized after field verification and discussion with BEZA officials.
- Route of treated water transmission main has been chosen along the existing CDSP embankment cum road and then Vanghani road (BWDB old embankment). The length of treated water transmission main is about 10.44 km.

- The project would require acquisition of about 23.15 acre of land for intake and raw water transmission main.
- Preliminary cost of the SWTP including intake, transmission and distribution of 50MLD capacity has been estimated to be about 5,751 million BDT.
- Preliminary cost of 25 nos. Production well field system has been estimated to be about 414 million BDT.
- Mohra surface water treatment plant is a potential water source which production capacity is 90MLD.
- Little Feni River is another potential water source to supply water of about 40MLD after proper treatment.
- Desalination RO plant is required in future to fulfill the water requirement of the economic zone. A 50MLD desaliation may required $50 million as capital cost.
- The tentative total cost to meet the water requirement for 30,000 acre area of BSMSN is about 83,387 Million BDT.

15.2 Recommendations

- Maintenance dredging arrangement will need to be kept to assure water availability in the Feni River at intake throughout the design life of the treatment plant.
- Continuous monitoring and maintenance of the river training works are important for the safety of intake.
- Preparation of Sewerage Master Plan for the BSNSN area and engagement of relevant consultant is recommended strongly for proper management of waste water.
- For appropriate technology transfer and maintenance of the plant, the required staffs need to be in place, properly trained both on the job and at abroad.
- Necessary MoU has to be signed between the Ministry of Water Resources and BEZA to abstract water from the Feni River and use of land for laying of raw water transmission main owned by Bangladesh Water Development Board (BWDB).
- If needed in future, water sharing treaties or MoU should be signed with neighboring countries.
- Waste water with or without treatment from the industries, domestic and non-domestic should not be discharged from upstream of Intake to Feni regulator.
- The surface water quality monitoring should be included at discharge monitoring stations. Besides there should be a monitoring wells for observing periodical changes in groundwater level and groundwater quality.
- The monitoring of river function requires specialization, BEZA may borrow the services of BWDB under some long term contract.

- Further study is necessary to check whether the option carrying treated water from Mohra water treated plant to the BSMSN area is technically and financially acceptable.
- A detail study is necessary for withdrawn and supply water from Little Feni River.
- Metering system should be installed with the water supply pipeline at every industry and other 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.

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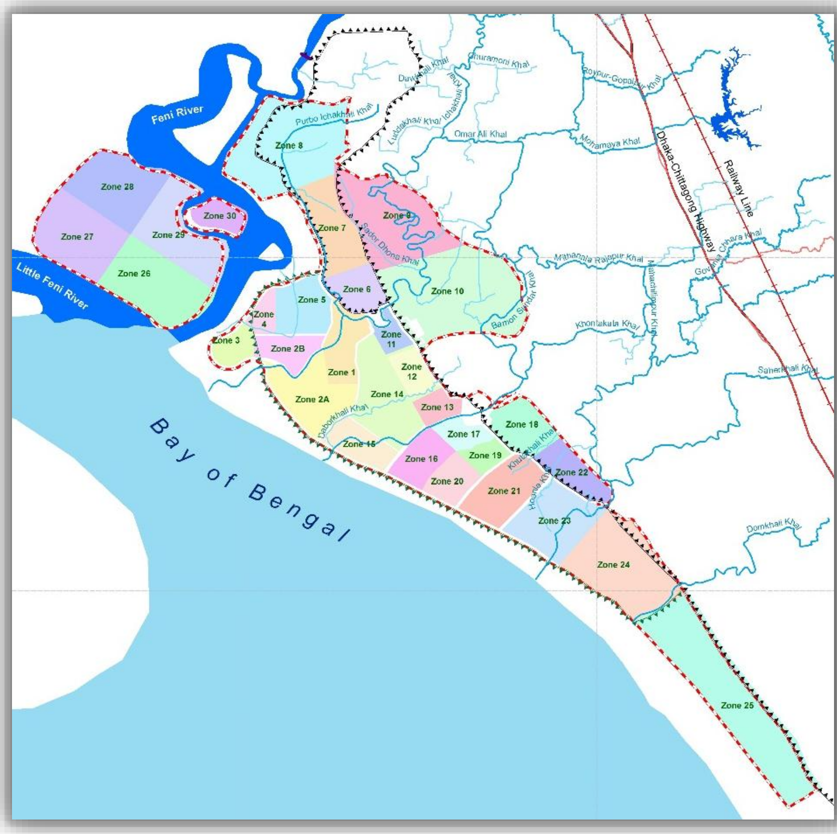
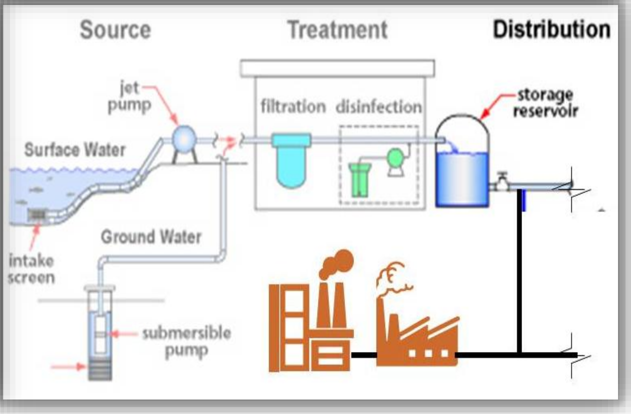
DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR





Final Report

Volume III: Annex 1 to 5

February, 2020

Water Environment & Climate

INSTITUTE OF WATER MODELLING

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DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR

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Annex-1: Data and Survey

A.1.1Secondary Data Collection

A.1.1.1 Meteorological and Hydraulic data

The rainfall and evaporation data of the surrounding area of BSMSN and water level and discharge data of Feni, Muhuri, Selona and Little Feni have been collected from BWDB. A summary of the meteorological and hydraulic data collected is shown in **Table A.1.1** and **Table A.1.2**:

Table A.1.1: Inventory of meteorological Data

Station ID	Station Name	Availability	Data Type	Station ID	Station Name	Availability	Data Type
E09	Comilla	1965-98, 2005-12	Evaporation	R314	Hiakhu	1962-2012	Rainfall
E27	Noakhali	1965-95, 2005-17	Evaporation	R363	Laksam	1961-2017	Rainfall
E31	Ramgarh	1965-95, 2005-17	Evaporation	R320	Mirsharai	1961-2016	Rainfall
R301	Amtali	1962-2017	Rainfall	R321	Mirzahat	1962-2008	Rainfall
R352	Barura	1962-2017	Rainfall	R323	Narayanhat	1962-2012, 201-2017	Rainfall
R353	Basurhat	1962-2017	Rainfall	R369	Noakhali	1961-2017	Rainfall
R305	Chandarkhil	1962-79	Rainfall	R370	Parshuram	1962-2017	Rainfall
R051	Chauddagram	1997-2017	Rainfall	R326	Rajbaritilla	1966-79	Rainfall
R355	Chhagalnaya	1961-2017	Rainfall	R327	Ramgarh	1961-2017	Rainfall
R356	Comilla	1961-2017	Rainfall	R376	Senbag	1961-2017	Rainfall
R358	Feni	1961-2017	Rainfall	R333	Sikderhat	1962-2004	Rainfall
R359	Gunabati	1962-2017	Rainfall	R377	Sonaimuri	1962-2017	Rainfall

Table A.1.2: Inventory of hydraulic Data

Station ID	Station Name	River Name	Availability	Data Type
87	Sonapur	Feni	1958-2017	WL
86	Dhumghat	Feni	1956-2007, 2015-2017	WL
85	Sobhapur	Feni	1999-2009	WL
84.1	Kaliachari	Feni	1975-2017	WL and Q
84	Ramgarh	Feni	1965-2017	WL
334	Miar Bazar	Kakri	1988-2017	WL
182	Companyganj	Little Feni	1968-2014, 2017	WL
181	Gunabati Rly.Bridge	Little Feni	1965-2017	WL and Q
213	Haripur (C&B Road)	Muhuri	1968-2017	WL
212	Parshuram	Muhuri	1958-2017	WL and Q
257	Malipur (C&B Rd)	Selonia	1962-2017	WL

A.1.1.2 Topographic Data

The topography data of the total study area have been collected from ASTER Global Digital Elevation Model data, SRTM digital elevation data and National DEM of Bangladesh. The ASTER

GDEM maintains the GeoTIFF format and with 30-meter postings and 1 x 1 degree tiles. The NASA Shuttle Radar Topographic Mission (SRTM) data have a resolution of 90m at the equator, and are provided in mosaiced 5 deg x 5 deg tile. The national DEM of Bangladesh was prepared in 1991 based on some survey data conducted by Survey of Bangladesh with resolution of 300mX300m grid. For this current study the national DEM is found more appropriate. The national DEM for the study area is shown in **Figure A.1.1**. This DEM has been used for delineation of the river catchments.

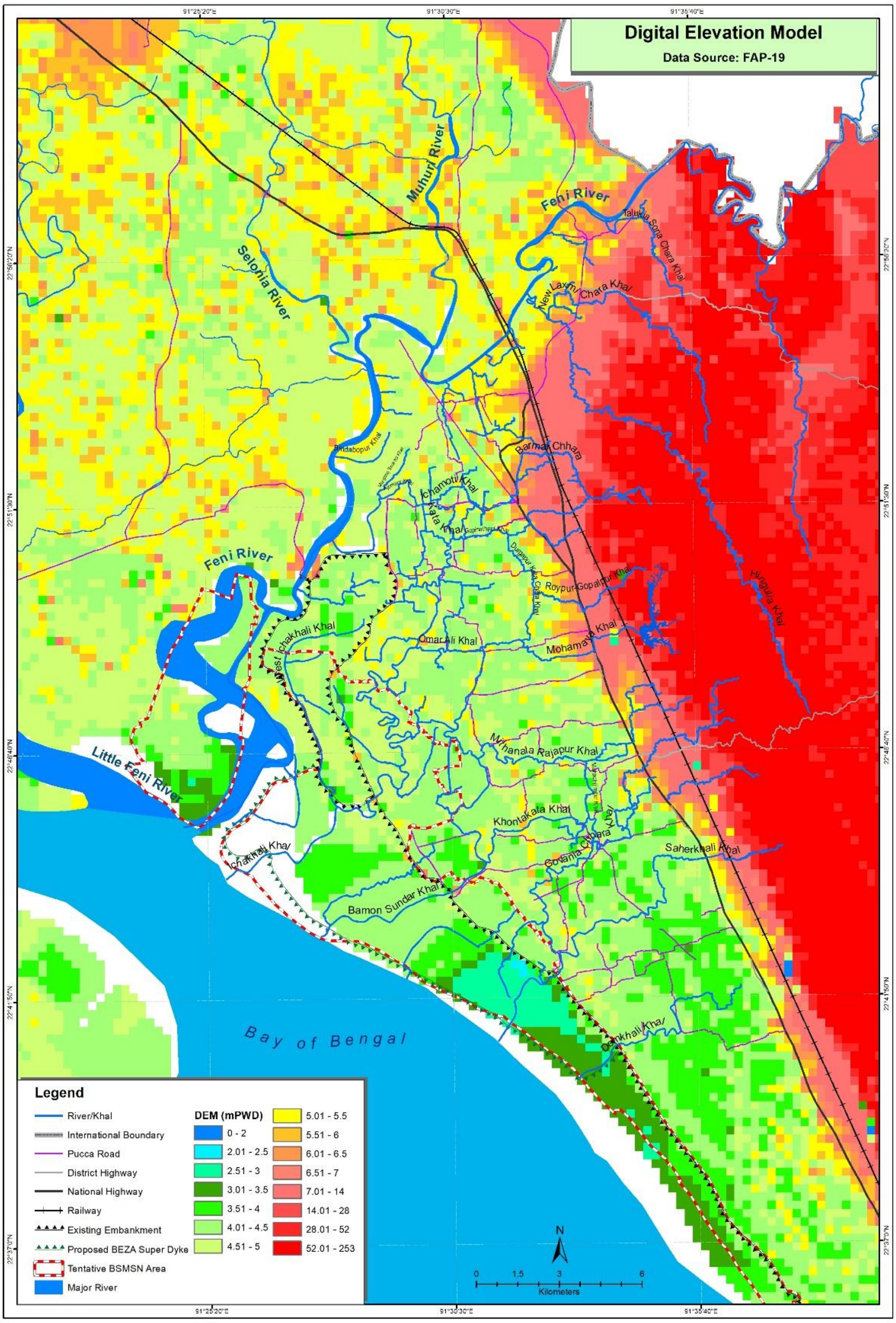


Figure A.1.1: National DEM of the total study area

A.1.1.3 Cross Section Data

IWM carried out survey campaign in 2011 to collect cross section information of Feni, Muhuri and Selona River and some khals under Muhuri Irrigation Project. The cross section data of the khals are collected and processed for the modelling works. The longitudinal profile of Feni, Muhuri and Selona River are shown in **Figure A.1.2 to A.1.4**.

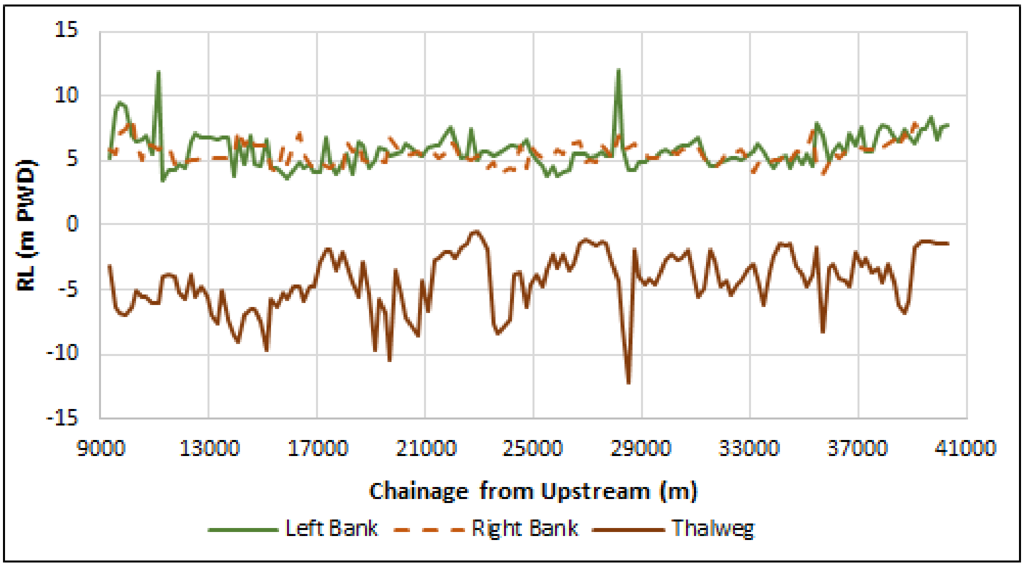


Figure A.1.2: Longitudinal Profile of Feni River

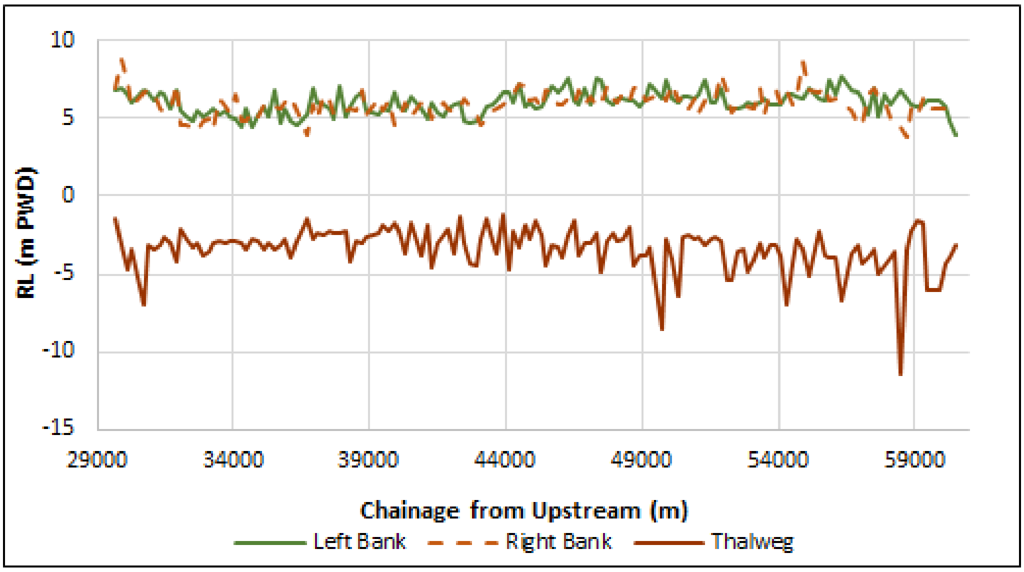


Figure A.1.3: Longitudinal Profile of Muhuri River

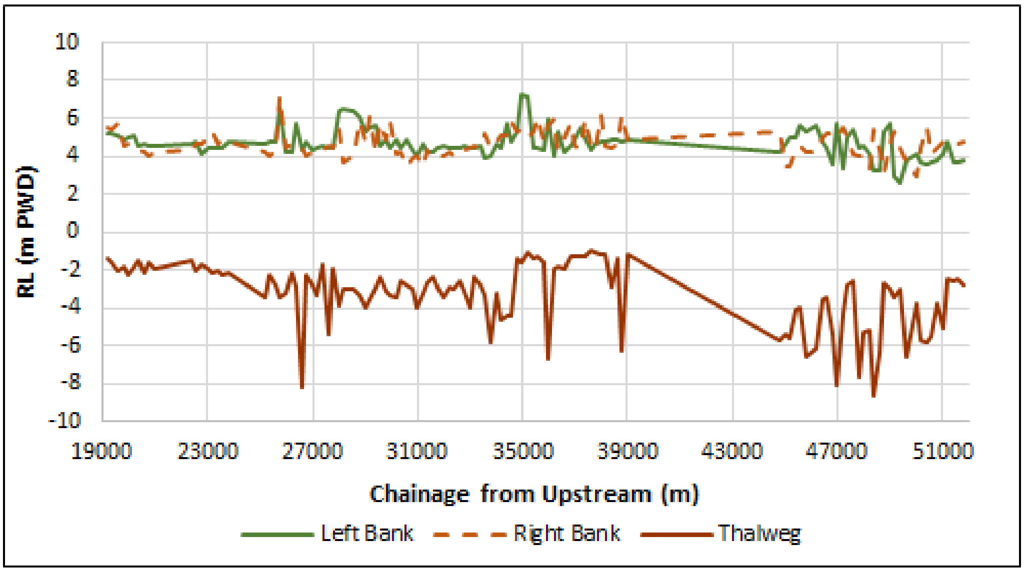


Figure A.1.4: Longitudinal Profile of Selonia River

A.1.2 Primary Data Collection and Analysis

A.1.2.1 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 Project area. These BM Pillars are being used as reference for conducting cross sections survey and observing tidal and Non-tidal water level in Mean Sea level (MSL) datum. List of SOB BM pillars given in the **Table A.1.2** and **Figure A.1.27** show location map of SOB BMs.

Table A.1.2: List of SoB BM Pillars

Sl. No.	Pillar ID	Easting (UTM)	Northing (UTM)	Height Above MSL (m)
1	FM GPS 145	354672	2509424	4.772
2	BM 5317A	347914	2515462	5.298
3	BM 564	344719	2538752	6.414
4	BM 6059	327666	2538887	5.705
5	BM 5316	326488	2525072	5.642

For establishing vertical datum in the project area in reference of SOB pillars, experienced surveyors were deployed for BM fly using optical level. TBMs have been kept near the Water level stations and also enter survey area for conducting cross sections survey. To avoid reading error three crosshair 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 elevations established for TBMs are consistent. List of TBMs kept at different locations is shown in **Table A.1.3**.

Table A.1.3: List of established TBM Pillars

Sl. No.	TBM ID	Description	Easting (UTM)	Northing (UTM)	RL (MSL)
1	TBMK-09	TBMK-09 kept on the NE corner of the railing base of the bridge. Vill.: Chakhali; PS: Mirsharai; Dis.: Chittagong	341781	2516814	7.765
2	TBMK-10	TBMK-10 kept on the NW corner of the Parapet Wall of the culvert. Vill.: Kartoli; PS: Pahartoli; Dis.: Chittagong	372445	2471813	3.978
3	TBMK-11	TBMK-11 kept on the NE corner of the Retaining Wall of the culvert. Vill.: Bagchator; PS: Shitakundo; Dis.: Chittagong	354984	2507019	4.104
4	TBMK-12	TBMK-12 kept on the SE corner of the railing base of the culvert. Vill.: Mohongar; PS: Shitakundo; Dis.: Chittagong	355466	2506014	4.465
5	TBMK-13	TBMK-13 kept on the SW corner of the wing wall of the 2 vent sluice gate. Vill.: Bakkhali; PS: Shitakundo; Dis.: Chittagong	356008	2503152	5.857
6	TBMK-14	TBMK-14 kept on the NE corner of the Wing wall of the 3 vent sluice gate. Vill.: Saidpur; PS: Shitakundo; Dis.: Chittagong	356504	2502387	3.794
8	TBMK-16	TBMK-16 kept on the SW corner of the Wing wall of the 9 vent sluice gate. Vill.: Noapara; PS: Mirsharai; Dis.: Chittagong	346484	2514715	5.268
9	TBMK-17	TBMK-17 kept on the NW corner of the Head wall of the 1 vent sluice gate. Vill.: Charsharot; PS: Mirsharai; Dis.: Chittagong	345215	2515761	6.107
10	TBMK-18	TBMK-18 kept on the SE corner of the Head wall of the 9 vent sluice gate. Vill.: 1 Chakkhali; PS: Mirsharai; Dis.: Chittagong	343794	2518197	5.271
11	TBMK-19	TBMK-19 kept on the SW corner of the Wing wall of the bridge. Vill.: 1 Chakkhali; PS: Mirsharai; Dis.: Chittagong	343044	2517814	7.44
12	TBMK-20	TBMK-20 kept on the SW corner of the Head wall of the 1 vent sluice gate. Vill.: South Mogardia Ghona; PS: Mirsharai; Dis.: Chittagong	348611	2512618	5.048
13	TBMK-21	TBMK-21 kept on the NW corner of the Head wall of the 1 vent sluice	349719	2511825	6.003

Sl. No.	TBM ID	Description	Easting (UTM)	Northing (UTM)	RL (MSL)
		gate. Vill.: South Mogardia Ghona; PS: Mirsharai; Dis.: Chittagong			
14	TBMK-22	TBMK-22 kept on the NW corner of the Head wall of the 6 vent sluice gate. Vill.: Shaherkhali; PS: Mirsharai; Dis.: Chittagong	350185	2511628	4.494
15	TBMK-24	TBMK-24 kept on the SW corner of the Wing wall of the bridge. Vill.: Chalimpuri; PS: Shitakundo; Dis.: Chittagong	371900	2475837	6.55
19	TBMK-28	TBMK-28 kept on the SE corner of the Perapet Wall of the culvert. Vill.: Domkhali; PS: Shitakundo; Dis.: Chittagong	353450	2509271	4.868
20	TBMK-29	TBMK-29 kept on the SE corner of the Parapet Wall of the culvert. Vill.: Gajaria; PS: Mirsharai; Dis.: Chittagong	352450	2511338	4.76
21	BM-003; BEZA	BM-003; BEZA, Vill.: Char-Sharot; PS: Mirsharai; Dis.: Chittagong.	344487	2517098	4.727
22	Close to WL Gauge	Boro Komoldoho	358073	2509726	6.947
23	Close to WL Gauge	Torab Ali Bazar	351605	2516143	4.942
24	Close to WL Gauge	Jhulon pur	345261	2523597	4.848
25	Close to WL Gauge	Sufia Bazar	347828	2519155	4.818
26	Close to WL Gauge	Musapur 23 vent Regulator	330537	2518926	6.612
27	Close to WL Gauge	Bakkhali Sluice gate	356008	2503152	5.857
28	Close to WL Gauge	Mocadia Khal	355143	2515710	6.359

Projection System

Bangladesh Transverse Mercator (BTM) projection shall be used during the survey. The parameters used in BTM projection system are given 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

A.1.2.2 Cross-section/Bathymetry Survey

Cross sections are important to develop hydraulic model. Cross section survey campaign has started on 1st week of March 2018. Cross section survey has been conducted for about 600nos. from 16khals for which cross section data are not available in IWM database. The cross-section survey of the small khals having shallow depths has been done using Auto Level followed by conventional method (**Figure A.1.5**). The cross-sections are being taken at 200 m intervals. However, additional sections are being taken at the bend and at the intersections.

Figure A.1.5: Sample Conventional method Cross Section Survey

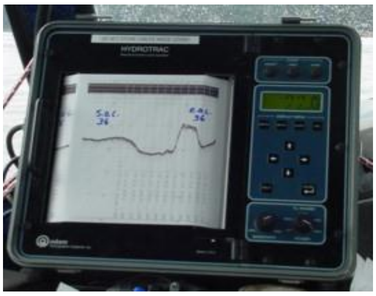


Figure A.1.6: Digital Echo-sounder

Bathymetric survey for major river Little Feni has been conducted using Digital Echo-sounder (**Figure A.1.6**) supported by DGPS and notebook computer installed with Hydro Pro survey software. The Hydro Pro navigation software guides the survey boat on the desired alignment (preset transects at suitable interval) of the sections. All survey data have been stored in tabular format MS Access database during survey. The Nav Edit module of the software has compiled depth of water column and position of sounding with time. The depth and position data have been viewed both graphically and in tabular form in the software. The erroneous data has been removed by checking the sections. The depth data were then reduced to the MSL/PWD datum using water level observed at the survey location. The edited data was then exported into ASCII format from the Nav-edit module of Hydro-Pro software. The profile of the Lille Feni River is given in **Figure A.1.7**.

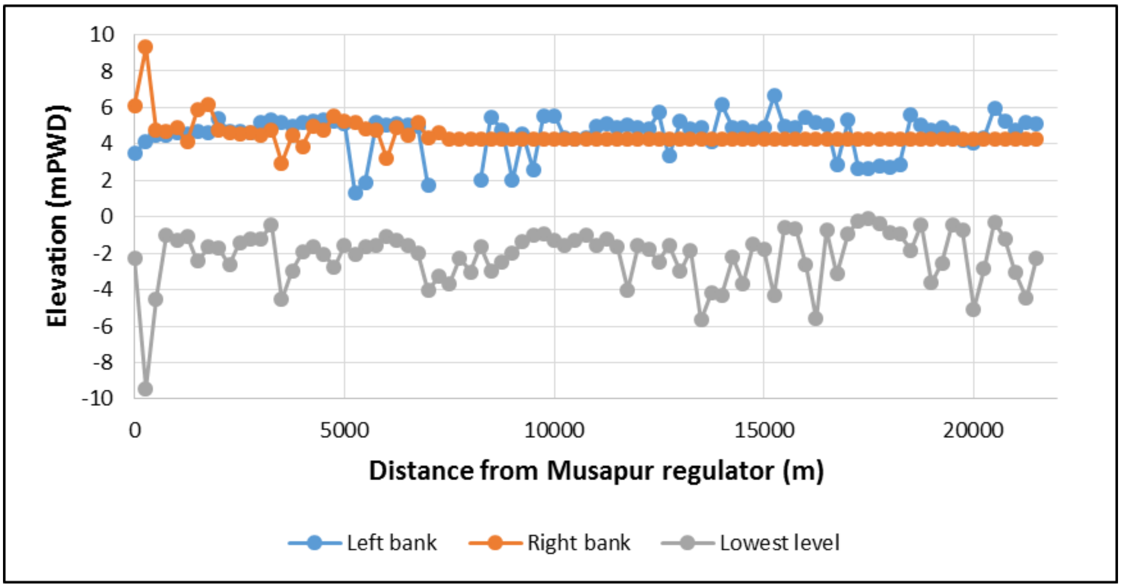


Figure A.1.7: Long profile of Little Feni River

A.1.2.3 Water Level Observation

Time series water level data are being collected at 9 locations for a period of 7-12 months as shown in **Table A.1.4**. Among these, 2 stations are tidal WL station for a period of one year started from 2nd week of February 2018 on the Sandwip channel. Remaining Non-tidal 7 WL stations installed at the different location within the project area shown in the **Figure A.1.27**. One pressure cell as well as staff gauges were installed at each location where applicable. For tidal WL, manual gauge readings were taken by gauge readers at 30 minute interval during day time only (wherever possible). Automatic data were recorded at 10 minute interval by pressure cell (continuously). The gauges have been connected from a Temporary Bench Mark (TBM) kept nearby, which was connected with the SoB Benchmark. A dedicated team was involved in monitoring tide gauge and downloading sensor data time to time.

Table A.1.4: List of water level data collection stations

Sl. No	Name of the river/khal	Name of Station	Data Type
1	Domkhali khal	Komoldoho Bazar	Non-Tidal 3 hourly WL
2	Sandwip channel	Saidpur	Tidal WL @10 minute interval
3	Ichakhali khal	Julan Pull Bazar	Non-Tidal 3 hourly WL
4	Bamon Sundor khal	Sufia Bazar	Non-Tidal 3 hourly WL
5	Govania Chhara khal	Abu Torab Ali Bazar	Non-Tidal 3 hourly WL
6	Shaherkhali khal	Boro Takia	Non-Tidal 3 hourly WL
7	Feni River	U/s of Feni Regulator	Non-Tidal 3 hourly WL
8	Little Feni River	U/s of Musapur Regulator	Non-Tidal 3 hourly WL
9	Sandwip channel	Feni River Mouth	Tidal WL @10 minute interval

A.1.2.3.1 Tidal Water Level Observation

The water level data collected for Feni River mouth and Saidpur are presented in **Figure A.1.8** and **Figure A.1.9**. Tidal water level data have been collected at Feni River mouth station from February 2018 to May 2018. The data has been collected at Saidpur station from February 2018 to July 2018. During the tidal water level collection the pressure cell lost for 3 times and so it was not possible to maintain pressure cell and manual gauge was utilized for the rest of the time. After that the observed station has been shifted to nearby Bakkhali khal where the only high tide measurement taken as shown in **Figure A.1.10**.

It is observed that the water level fluctuated between -2.6 to 3.2 mPWD at Feni River mouth and -3 to 3.75 mPWD at Saidpur in the Sandwip channel during February to May. The distance between these two stations is 25 km and water level difference is almost 0.5m. Moreover tidal water levels become high in June to August and lower in December to February.

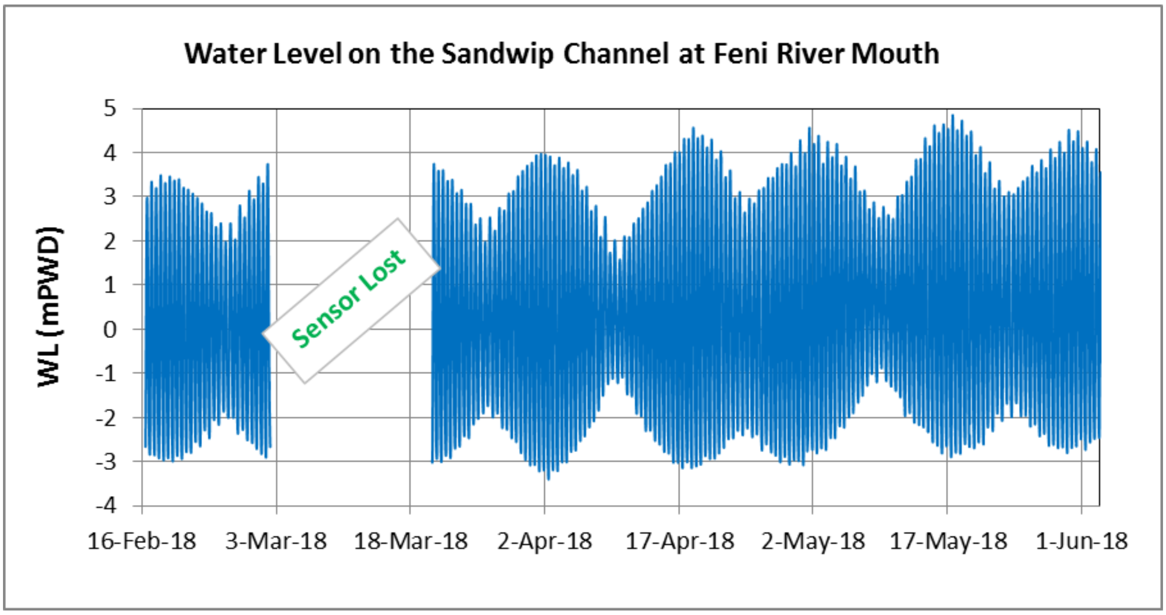


Figure A.1.8: Water Level on the Sandwip channel at Feni river mouth

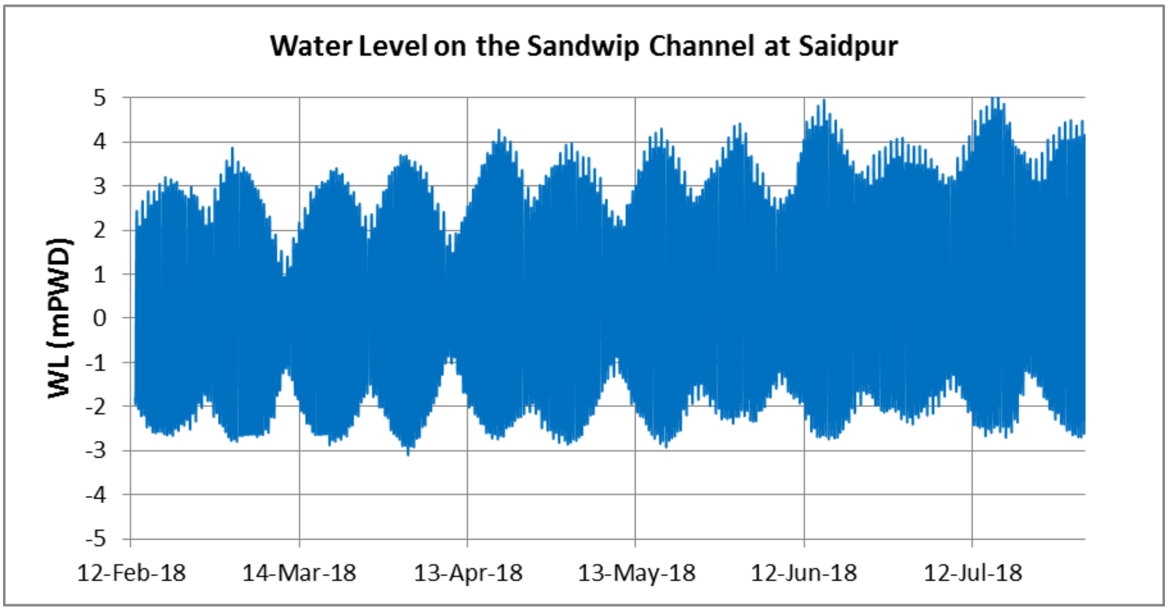


Figure A.1.9: Water Level on the Sandwip channel at Saidpur

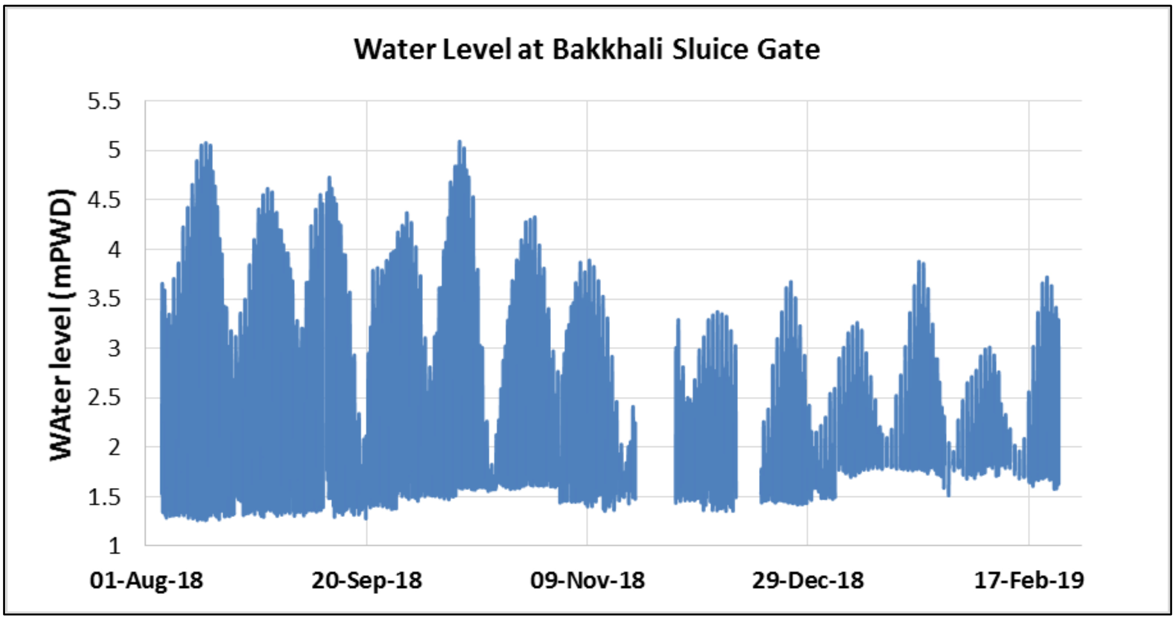


Figure A.1.10: Water Level on the Bakkhali khal

A.1.2.3.2 Non-tidal Water Level Observation

Ichakhali khal

Figure A.1.11 shows the water level hydrograph collected from Ichakhali khal near Jhulon Pull Bazar from 27 March-1 November 2018. It shows that maximum water level occurred at these point is 4.67 mPWD. But sometimes the khal became dry with no or little water depth in the khal. Thus the water depth varied between 0 to 2.85 m near Jhulon Pull Bazar in 2018.

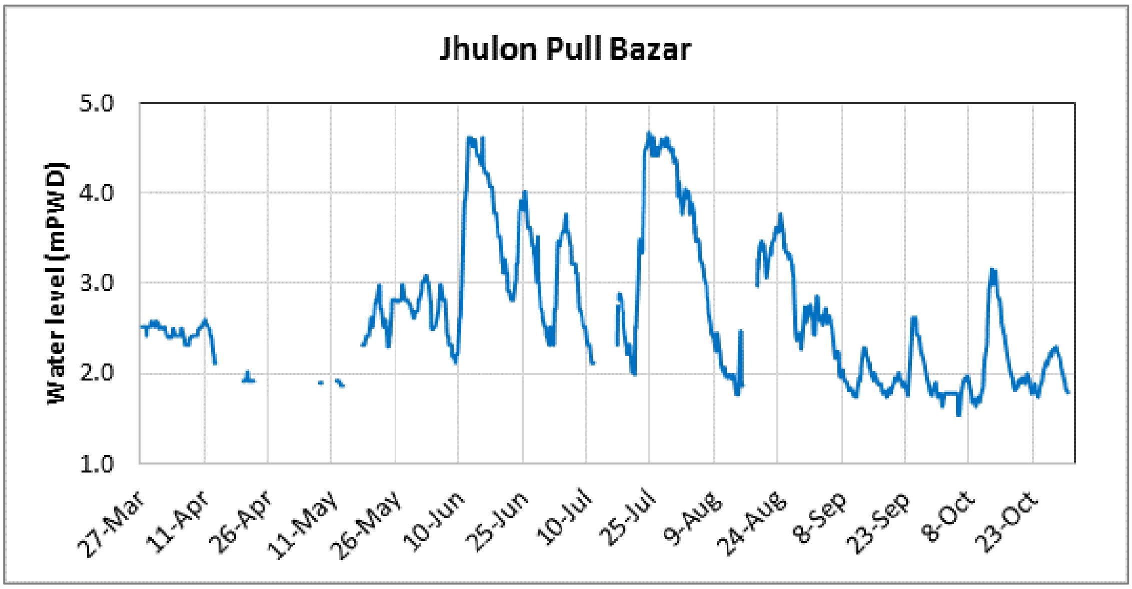


Figure A.1.11: Water Level on the Ichakhali Khal near Jhulon Pull Bazar

Bamon Sundar khal

Figure A.1.12 shows the water level profile collected from Bamon Sundar khal near Sufia Bazar from 27 March-1 November 2018. It shows in March sometimes the khal became dry with no water on it. Thus the water depth varied between 0 to 2.92m and maximum water level become 4.28mPWD near Sufia Bazar in 2018.

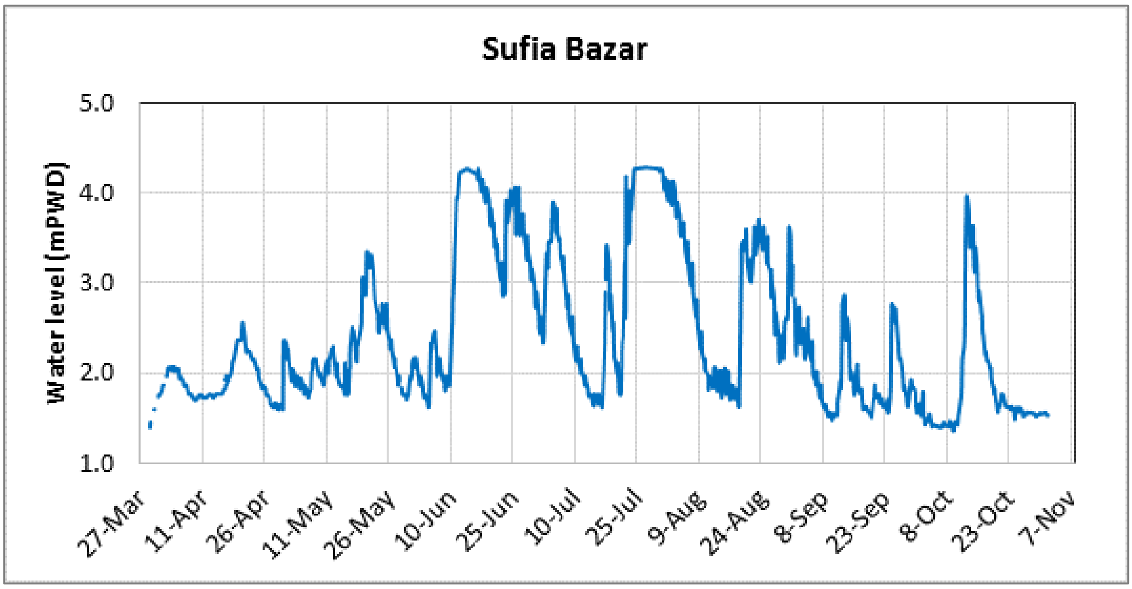


Figure A.1.12: Water Level on the Bamon Sundar Khal near Sufia Bazar

Govania khal

Figure A.1.13 shows the water level profile collected from Govania khal near Abu Torab Ali Bazar from 26 March-27 October 2018. It shows in March-April the khal remained dry for most of the time with no water on it. The maximum water level occurred at these point was 4.69 mPWD in July. Thus the water depth varied between 0 to 2.76 m near Abu Torab Ali Bazar in 2018.

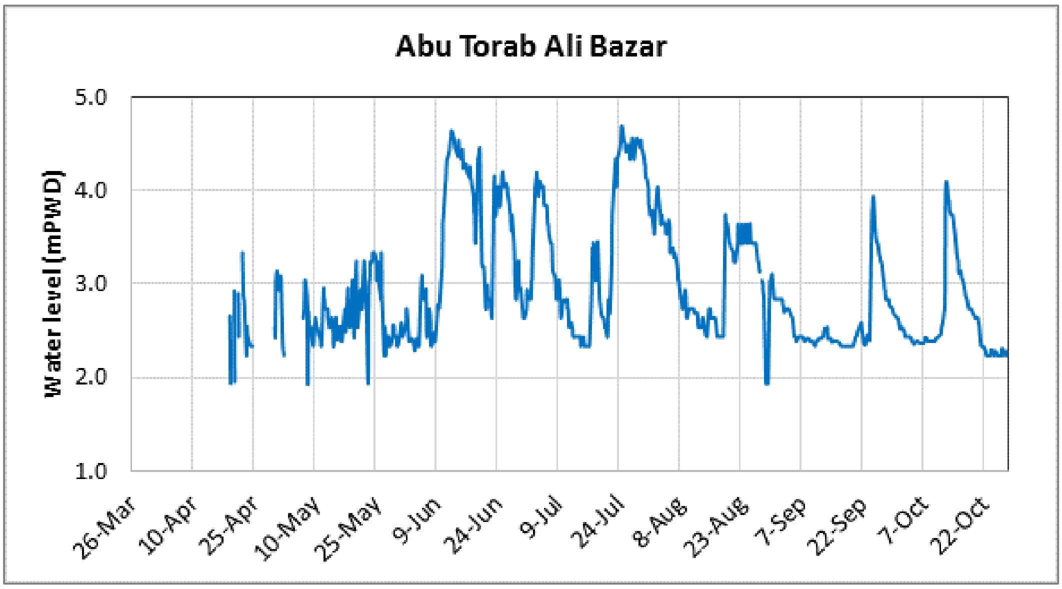


Figure A.1.13: Water Level on the Govania Khal near Abu Torab Ali Bazar

Saherkhali khal

Figure A.1.14 shows the water level profile collected from Saherkhali khal near Boro Takia from 26 March-27 October 2018. It shows in most days in March-April, the khal remained dry with no water on it. The maximum water level occurred at these point is 5.88 mPWD in June as well as July. Thus the water depth varied between 0 to 1.93 m near Boro Takia in 2018.

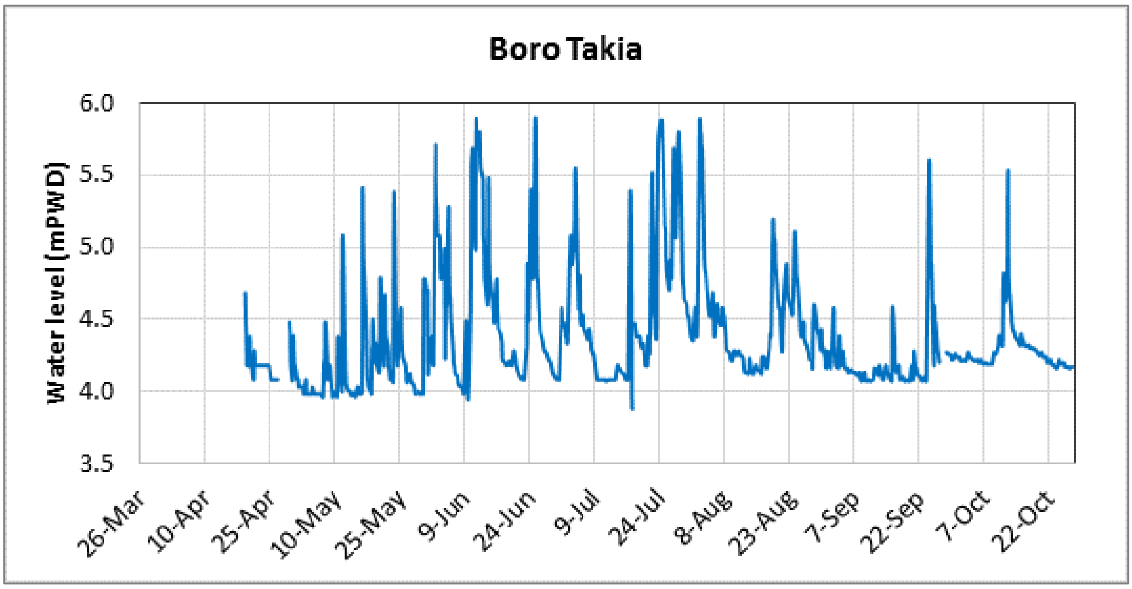


Figure A.1.14: Water Level on the Saherkhali Khal near Boro Takia

Domkhali khal

Figure A.1.15 shows the water level profile collected from Domkhali khal near Komoldoho Bazar from 28 March-27 October 2018. It shows in most days in March-April, the khal remained dry with no water on it. The maximum water level occurred at these point is 7.36 mPWD in August. But dryness occured also in monsoon. Thus the water depth varied between 0 to 3.04 m near Komoldoho Bazar in 2018.

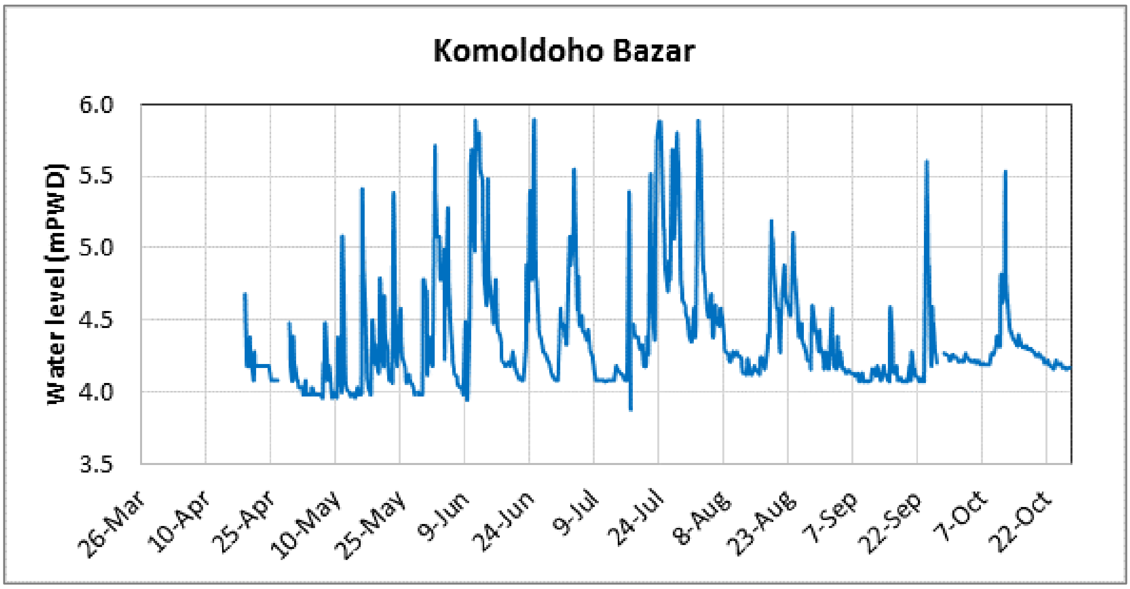


Figure A.1.15: Water Level on the Domkhali Khal near Komoldoho Bazar

Feni River

Figure A.1.16 shows the water level hydrograph collected just at upstream of Feni regulator in the Feni River from 25 March-3 November 2018. During this time the radial gates were open, so upstream water could easily drain out when the downstream water level was favorable. The maximum water level occurred during monsoon 2018 is 4.992 mPWD in June.

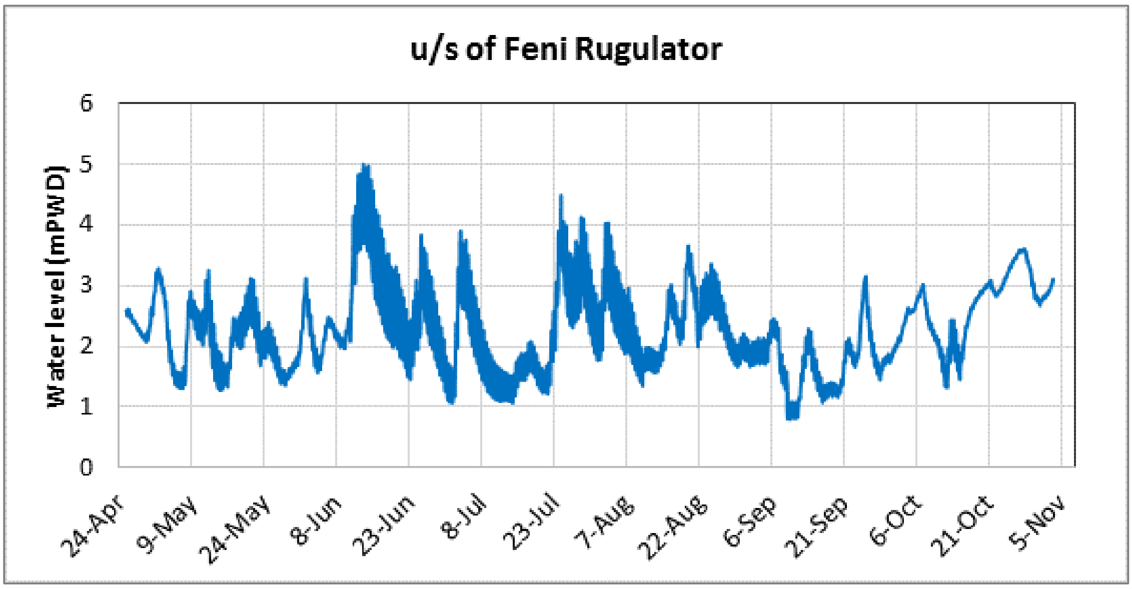


Figure A.1.16: Water Level at upstream of Feni River

Little Feni River

Figure A.1.17 shows the water level hydrograph collected just at upstream of Musapur regulator in the Little Feni River from 1 March-4 November 2018. It is observed from the hydrograph that in the period of March to June the gates of the regulator were kept closed for most of the time. The gates were opened twice in March and April and once in May and June. In April, May and June water abstraction is detected which is mainly due to local irrigation. The maximum water level occurred during the observation period is 2.74mPWD and minimum water level is 0.15mPWD.

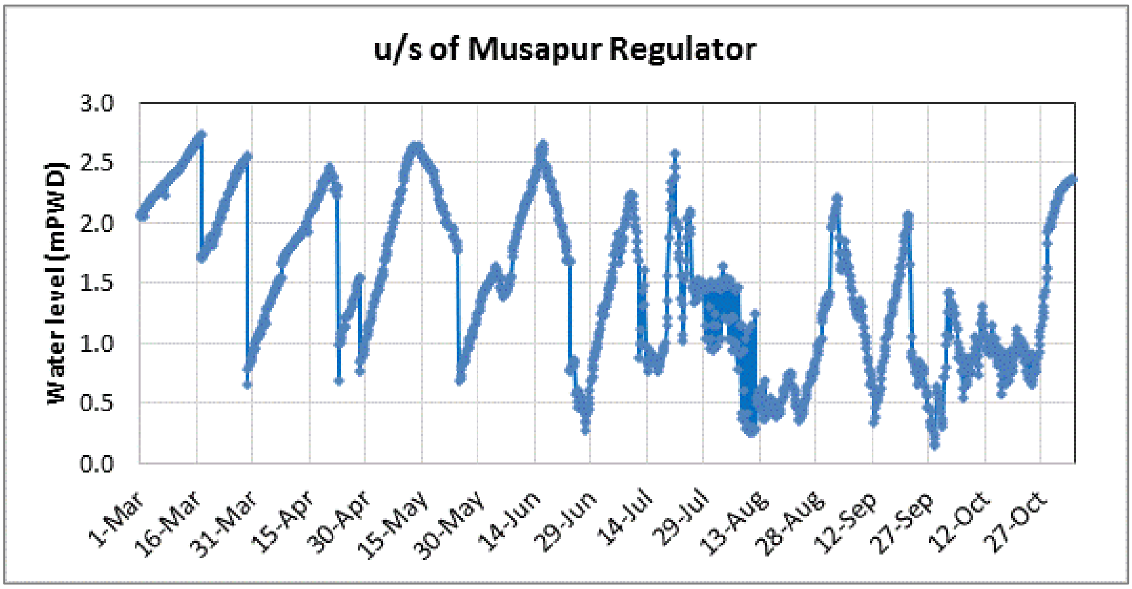


Figure A.1.17: Water Level at upstream of Musapur Regulator in Little Feni River

A.1.2.4 Discharge Measurement

Non-tidal discharge data are being collected at different locations as shown in **Figure A.1.27** and given in **Table A.1.5** of the project area at different Rivers and khals during March-September 2018 for hydrodynamic calibration of the 1D models. As per the requirement of the model, fortnightly discharge data are being collected for 8 months from March to September

2018. Following the schedule, discharge data at specified locations are being collected as shown in **Figure A.1.18** to **A.1.26**. It is observed that in March-April, there is no discharge in the khals.

Table A.1.5: List of discharge measurement stations

Sl. No	Name of the river/khal	Name of Station	Data Type
1	Feni River	Suvopur Bridge	2 times a month
2	Muhuri River	Daulatpur	2 times a month
3	Selonia River	Selonia Highway Bazar (Lemua Bridge)	2 times a month
4	Little Feni River	Taltoli Ghat	2 times a month
5	Ichakhali khal	Julan Pull Bazar	2 times a month
6	Bamon Sundor khal	Sufia Bazar	2 times a month
7	Govania Chhara khal	Abu Torab Ali Bazar	2 times a month
8	Shaherkhali khal	Boro Takia	2 times a month
9	Domkhali khal	Komoldoho Bazar	2 times a month

Feni River

Maximum 173m^3/sec discharge is observed in 27th June whereas the minimum flow is observed in 30th March about 24m^3/sec (**Figure 1.13**).

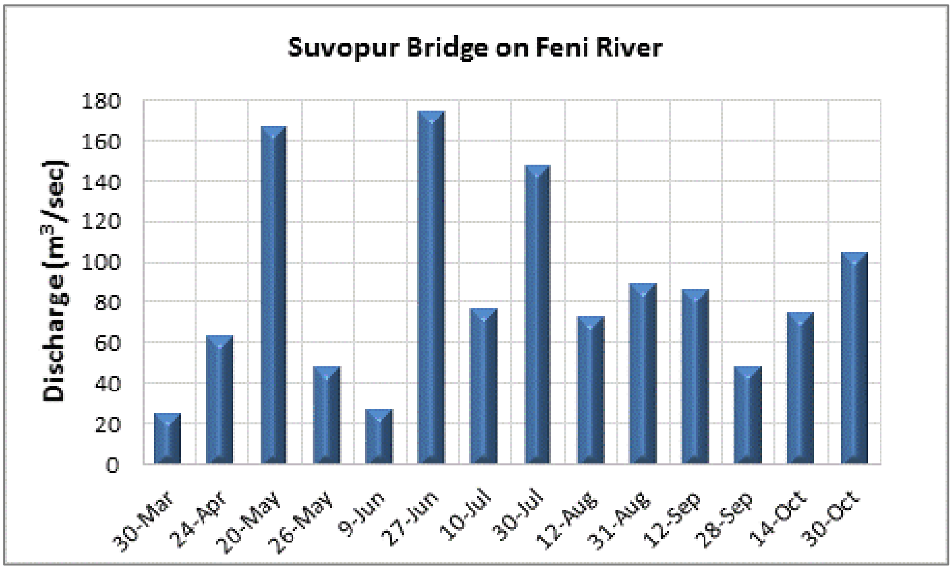


Figure A.1.18: Discharge data on Feni River

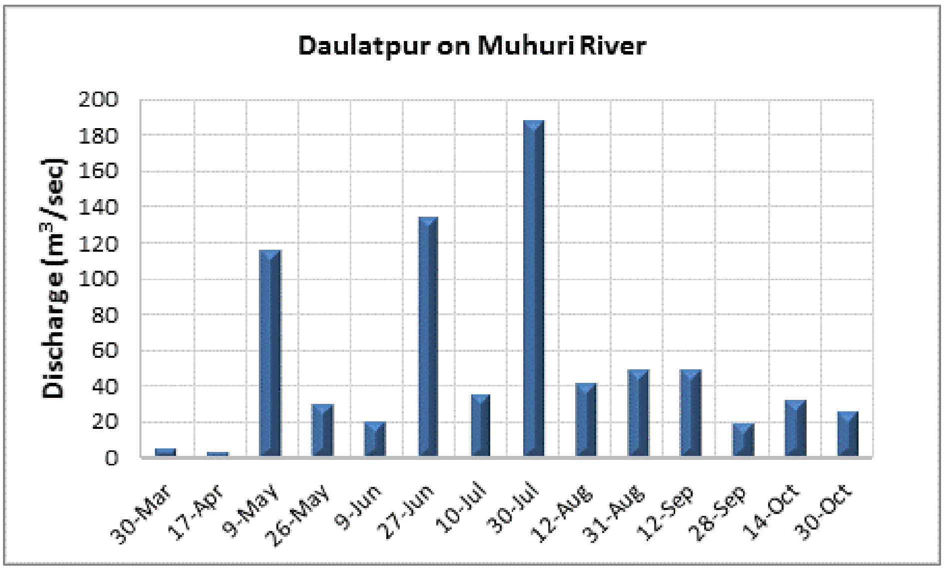


Figure A.1.19: Discharge data on Muhuri River

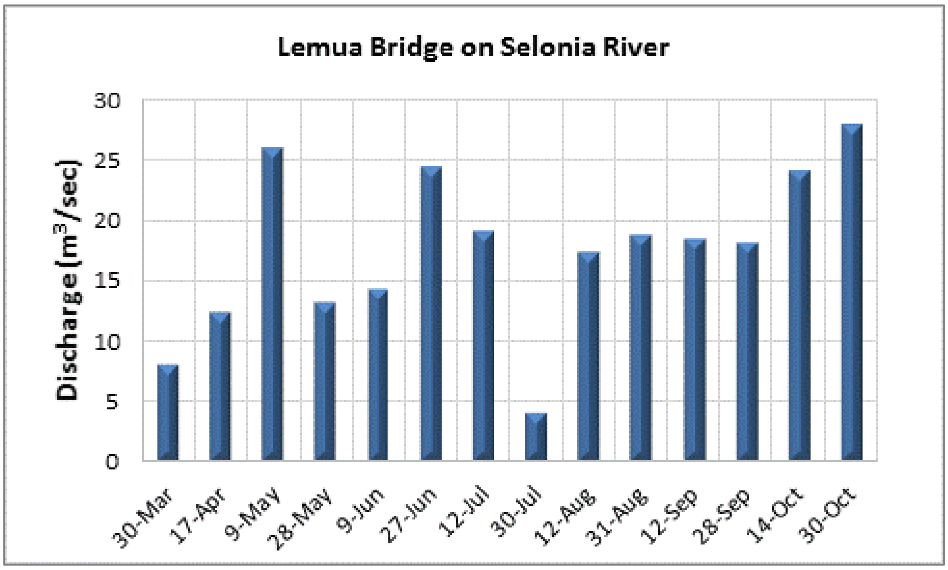


Figure A.1.20: Discharge data on Selonia River

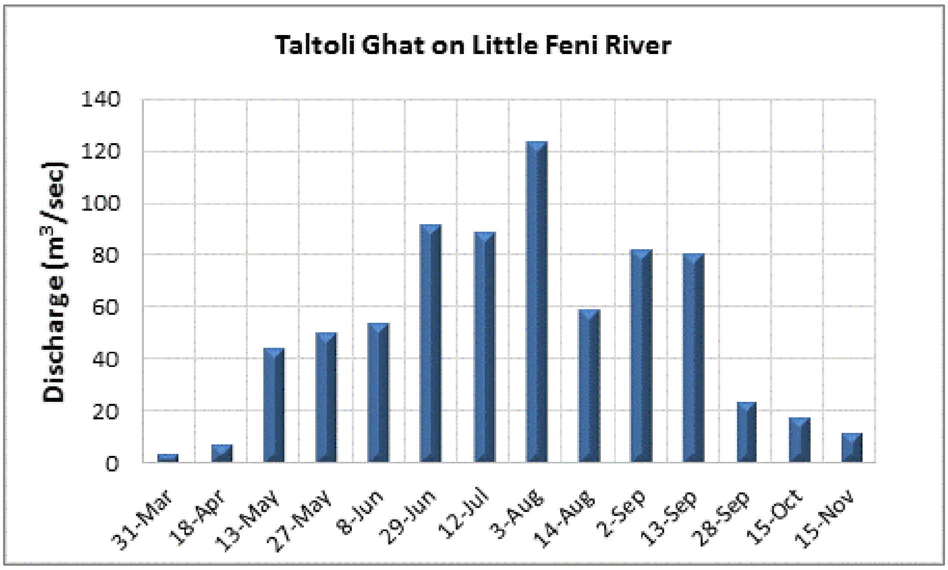


Figure A.1.21: Discharge data on Little Feni River

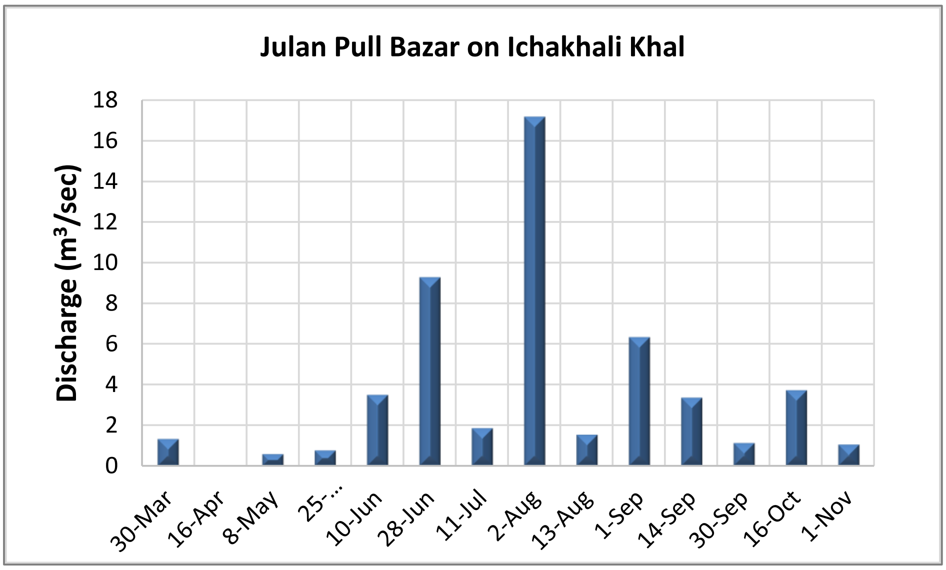


Figure A.1.22: Discharge data on Ichakhali khal

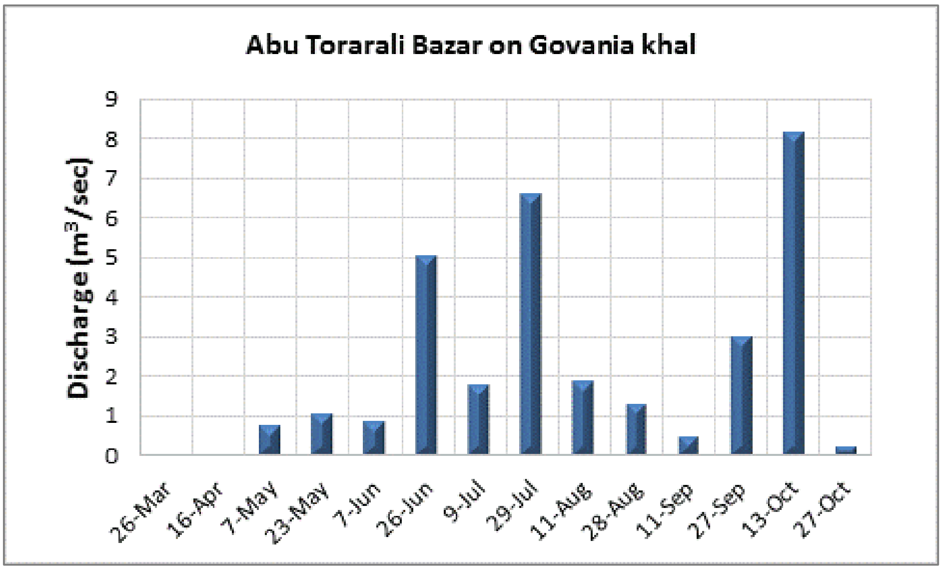


Figure A.1.23: Discharge data on Govania khal

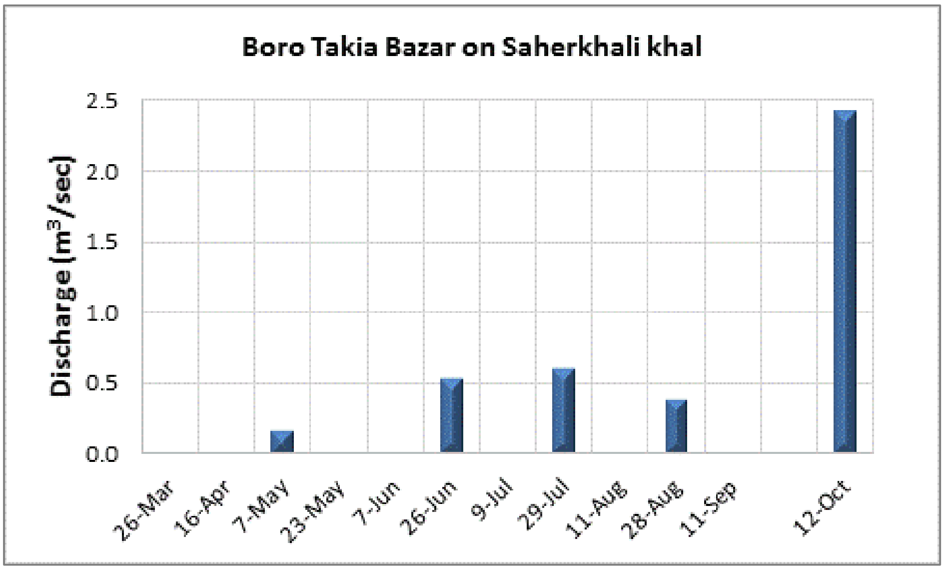


Figure A.1.24: Discharge data on Saherkhali khal

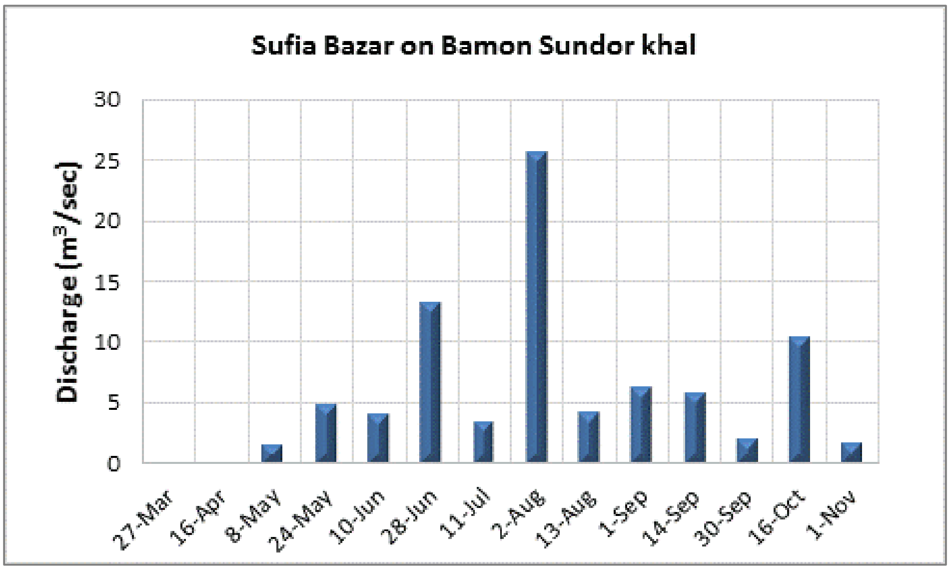


Figure A.1.25: Discharge data on Bamon Sundor khal

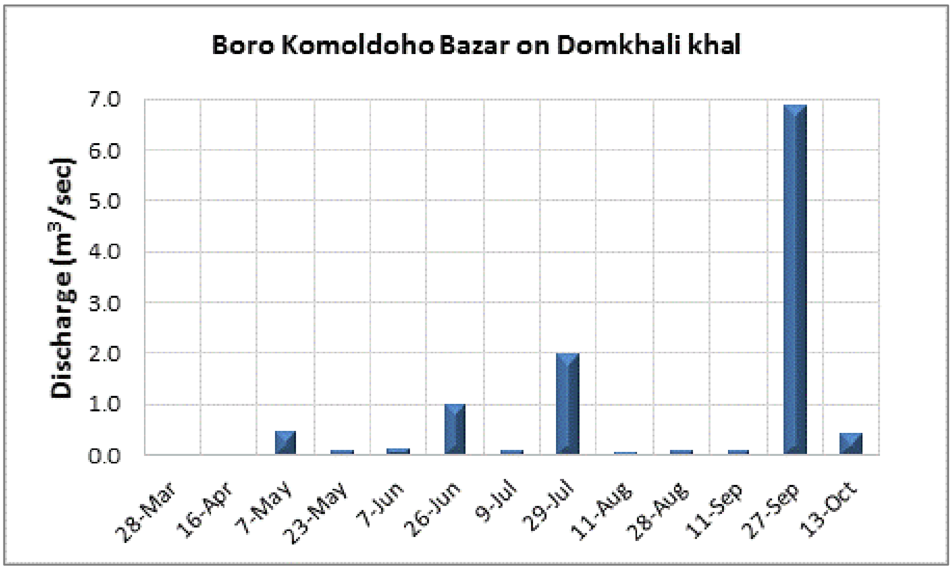


Figure A.1.26: Discharge data on Domkhali khal

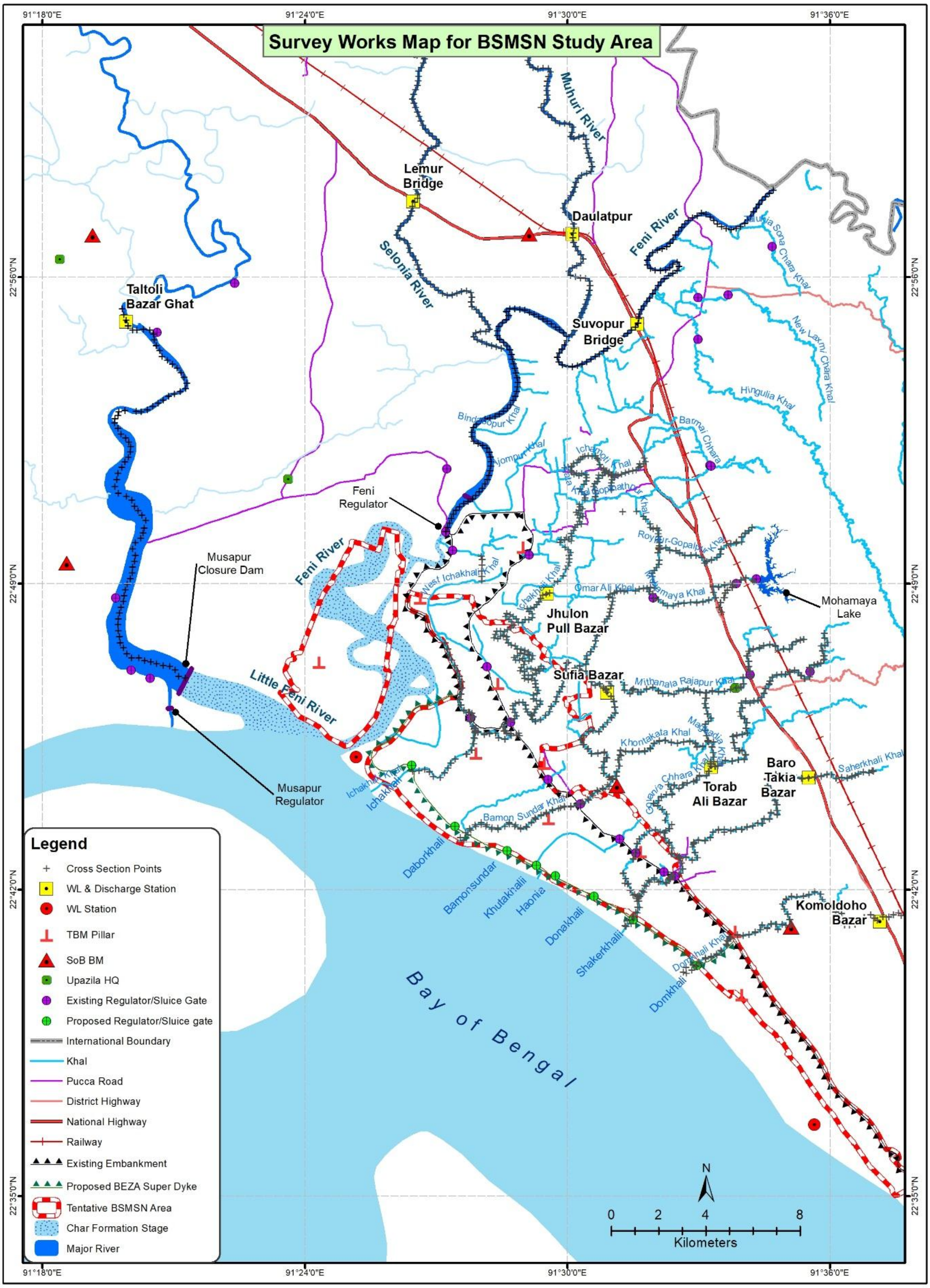


Figure A.1.27: Primary data collection locations for BSMSN

A.1.2.5 Spot Level Survey

Spot level data have been collected at the location of Intake pump house, surface water treatment plant and along the raw water and treated water transmission line.

Intake pump house site

At the intake pump house site the spot level has been taken at 10m X 10m grid interval for an area of 2.5ha. At this location the area is relatively high except one fish pond. The spot levels at this location varies from 0.57 to 5.74 mPWD.

Surface water treatment plant site

At the SWTP site the spot level has been taken at 10m X 10m grid interval for an area of 7.5ha. At this location the area is currently using for fish farming. So the area is relatively low lying except the areas for boundary. The spot levels at this location varies from 1.78 to 6.46mPWD.

Raw water and treated water transmission line

Spot Levels hves been be taken along the raw water and treated water transmission line of about 20km at 50m interval extended to 50m on both sides of the centre line.

Annex-2: Modelling of Surface Water System

A.2.1 Development of River Model

Mathematical model is a tool, which is widely used for planning and designing of project infrastructures considering the interactive responses of other project components or other projects. In Bangladesh, the application of mathematical model in water resource started since 1986 through a program named "Surface Water Simulation Modelling Programme, Phase-I (SWSMP-I)" with the technical assistance of DHI, Denmark. Now the use of mathematical model in water resource is widespread, ranging from project based planning to regional or basin water management. Mathematical model available at IWM is based on tools developed by DHI, and is under continuous up-gradation as well as verification. There are a number of modules included in DHI tool, among which two modules has been used in carrying out modelling for this study, which include: Rainfall-Runoff (MIKE11 RR) for hydrological modelling and one dimensional hydrodynamic (MIKE 11 HD) for hydraulic modelling.

The advantages of MIKE11 modelling systems are:

1. Accurate hydraulic description in rivers/channels which behave pre-dominantly one-dimensional.
2. It requires less computational time i.e. less CPU time
3. Easy to overview and comprehend results
4. Can be modelled many different and complicated structures
5. Other problems such as water quality, sedimentation, flood forecasting can be addressed with the same model.

A.2.1.1 Development of Hydrological Model

In MIKE 11 software package, NAM module has been used to develop the hydrological model. The MIKE11 NAM is a lumped conceptual model which simulates the overland, interflow, and base flow components as a function of the moisture contents in four storages. The NAM module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to a river network. In this manner it is possible to treat a single catchment or a large river basin containing numerous catchments and a complex network of rivers and channels within the same modelling framework.

The existing South East Regional Model (SERM) available in IWM has been truncated and used for developing BSMSN model for simulating the main river system: Feni River, Muhuri River, Selonia River and Little Feni River. The catchments used to simulating the rainfall-runoff of the catchments for the main rivers are stated in **Table A.2.1**.

Table A.2.1: SERM catchments used to develop BSMSN model

Name of the catchment	Area (km^2)	Name of the catchment	Area (km^2)
SE-05	1	SE-29	404
SE-06	186	SE-30	301
SE-12	88.32	SE-31	607

Name of the catchment	Area (km^2)	Name of the catchment	Area (km^2)
SE-15	150	SE-32	645
SE-16	131	SE-36	124.59
SE-27	131		

For detail modelling of the khal system in and around the BSMSN study area, four major catchments have been identified and delineated based on DEM (**Figure A.1.1**). The four catchment are:

(i) Ichakhali khal catchment,
(ii) Bamonsundor khal catchment,
(iii) Saherkhali khal catchment, and
(iv) Domkhali khal catchment.

The catchments areas are generated from the contribution of the major khal along with its tributaries. These major catchments further divided into sub- catchments to assess the run-off pattern of the khals.

The Hydrological Model has been developed using the rainfall and evapotranspiration data collected from BWDB.

A.2.1.1.1 Delineation of Catchment Area based on DEM

The generated catchments have been characterized and classified according to the surface terrain, land cover dynamics (slope, vegetation, obstruction etc.) and run-off flow pattern. There are three methods available for catchment delineation: (i) depending on flow paths from contour lines, (ii) triangulated irregular network and (iii) grid cell elevation model. This study uses grid cell elevation models using the data sets: stream shape, i.e., chhara/khal alignment, DEM generated from topographic (spot level) data, major road network and structural barrier (obstruction). The supporting required software is ArcGIS Map (it is an integration module of Arc-Hydro and HEC HMS which can generate shape files for required data sets using DEM). HEC HMS tools used for grid cell slope calculation and Arc-Hydro used for delineation of catchment & generation of watershed for individual chhara/drainage system.

The catchment of the study area has been delineated following four steps:

(i) The generated DEM has been smoothed to avoid the sharp rise/fall of topography and follow the paths of stream lines of drainage pattern;
(ii) A flow path has been defined following the lowest gradients to receive the water from a pocket cell/area, which is surrounded by higher elevation, into the drainage path;
(iii) The catchment has been delineated for each drainage sub-systems on the basis of digital elevation topo data, land gradients with contour profiles and following path/route of drainage pattern;
(iv) The delineated catchment has been checked/verified with local physical interventions, i.e., road, rail, structures and flow pattern along the drainage routes.

If needed, the catchment has again been re-delineated by adjusting the existing physical features.

The generated catchment area is shown in **Figure A.2.1**.

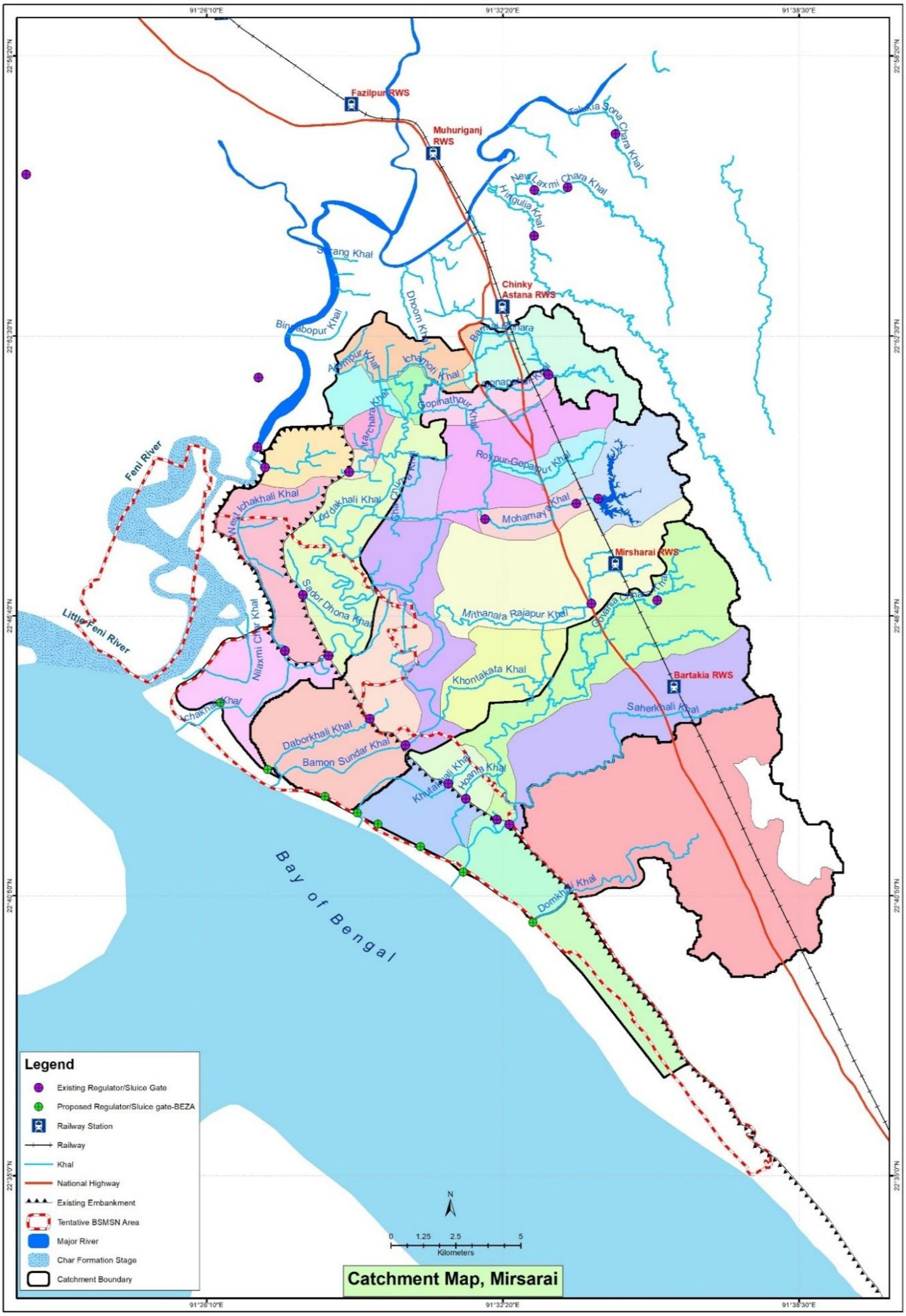


Figure A.2.1: Catchment delineation for BSMSN Model

A.2.1.1.2 Description of Catchment Area

Ichakhali khal catchment

The catchment area of Ichakhali khal catchment is about 86 km^2. The Ichakhali khal receives water from Feni reservoir site for irrigation purpose. Barmai Chhara and its distributaries convey water to Ichakhali khal extending to eastern hills. There are some other local khals which contribute to Ichakhali khal and they all together make the Ichakhali system. It is divided into 10 sub-catchments which are Barmi, Dakhin Tajpur, Dawkhali, Ichakhali, Ichakhali dn, Ichamoti, Irarchara, Kata, Mn Drainage-1 and West Ichakhali. The elevation of this catchment varies from 2.7-158 mPWD.

Bamonsundor khal catchment

The catchment area of Bamonsundor khal catchment is about 129 km^2. Mohamaya Khal, Mithanala Rajapur khal and Khontakata khal are the major tributaries of Bamon Sundar khal and make the Bamon Sundar khal system. These tributaries and some other local minor khals convey water from eastern hills to Bamon Sundar khal. It is divided into 10 sub-catchments which are Bamon Sundor, Daborkhali, Durgapur kata chhara, Gopinathpur, Khontakata, Mithanala Rajapur, Mohamaya Khal, Mohamaya Reservoir, Omar Ali and Roypur-Gopalpur. The elevation of this catchment varies from 1.2-258 mPWD.

Saherkhali khal catchment

The catchment area of Saherkhali khal catchment is about 74 km^2. Saherkhali khal together with its major tributary Gobania khal make the Saherkhali khal system. Its catchment extends to Boalia in eastern hills and divided into 5 sub-catchments. Its sub-catchments are Gobania, Haonia, Haonia down, Shahekhali and Shaherkhali down. The elevation of this catchment varies from 0.8-277 mPWD.

Domkhali khal catchment

The catchment area of Saherkhali khal catchment is about 79 km^2. Domkhali khal extends to Komoldoho in eastern hills and its catchment is divided into 2 sub-catchments. Its sub-catchments are Domkhali and Domkhali down. The elevation of this catchment varies from 0.6-237 mPWD.

A.2.1.1.3 Hydrological Model Calibration

Parameters of NAM have been calibrated for catchments SE-31 and SE-32 against the observed discharge data near the outlet of the catchments. The two discharge data collection stations near the outlet of catchments SE-31 and SE-32 are: Parsuram on the Muhuri River and Kaliarchari on the Feni River respectively. Simulated runoff data show good match with the observe discharge data mainly in dry season (**Figure A.2.2** and **Figure A.2.3**). Observed highest discharge data in monsoon is not available for both the stations. That’s why simulated pick runoff data can’t be compared. Except the pick values, the available monsoon discharge data show good match with the simulated runoff.

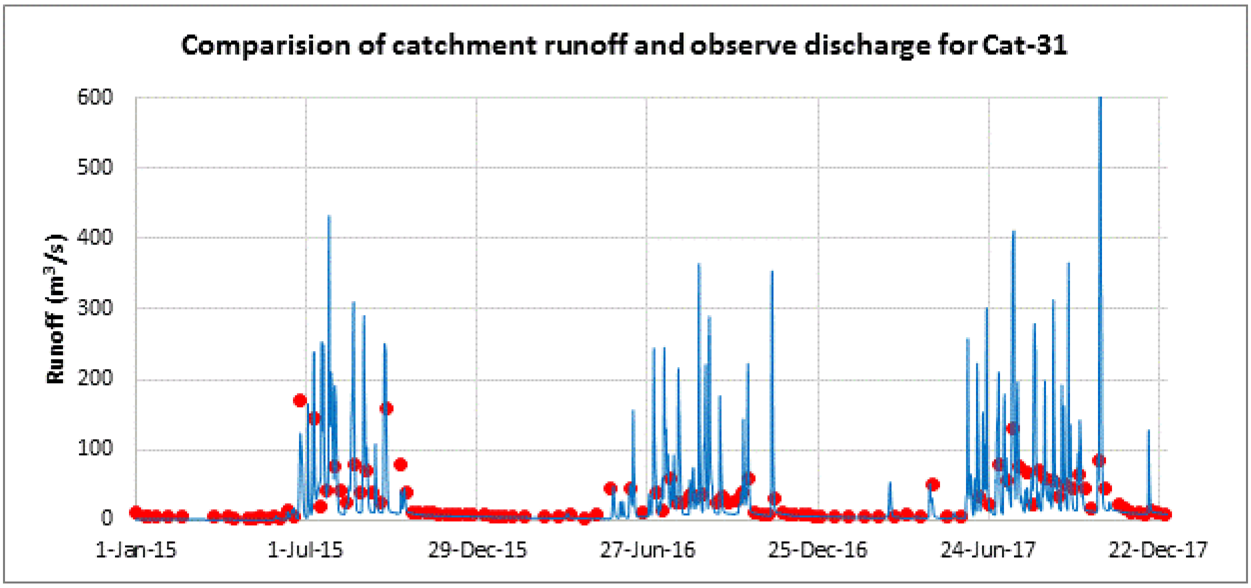


Figure A.2.2: Calibration plot of catchment-31

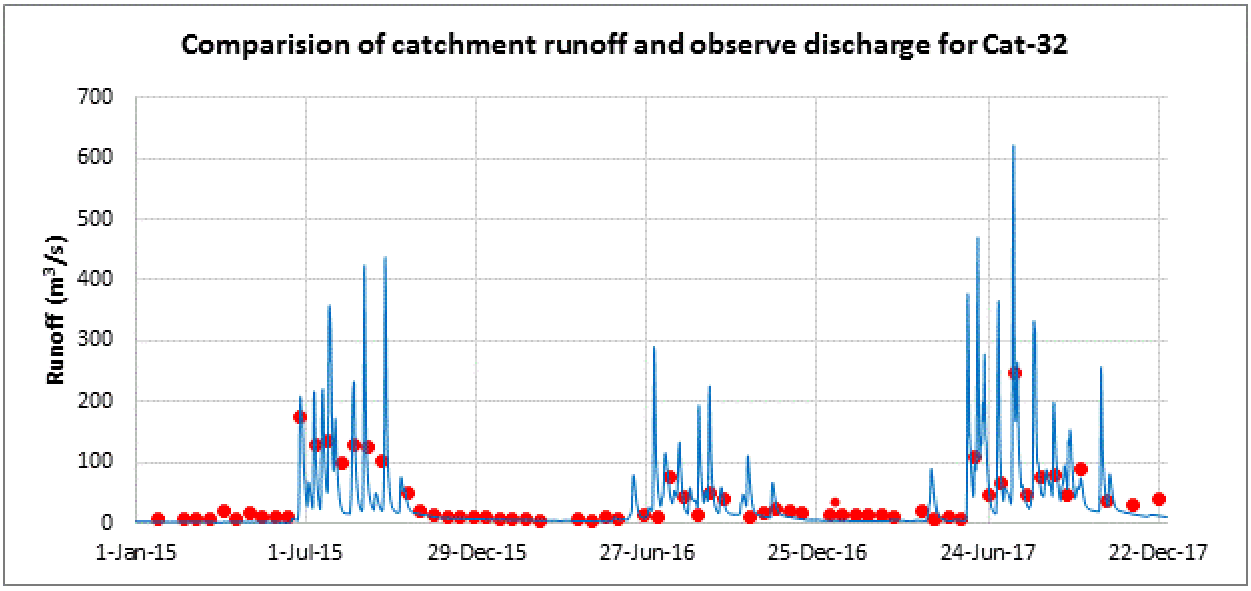


Figure A.2.3: Calibration plot of catchment-32

A.2.1.2 Development of Hydraulic Model

In MIKE 11 software package, hydrodynamic module (HD) has been used to develop the hydraulic model. The MIKE 11 HD module uses an implicit, finite difference scheme for the computation of unsteady flows in rivers and estuaries. The module can describe sub-critical as well as supercritical flow conditions through a numerical scheme which adapts according to the local flow conditions (in time and space). The output of MIKE11 NAM model will be used as input of MIKE11 HD model. The internal khal network has been incorporated with the truncate SERM model to develop BSMSN HD model after field data collection and processing. The river/khal network of the BSMSN model is given in **Figure A.2.4**.

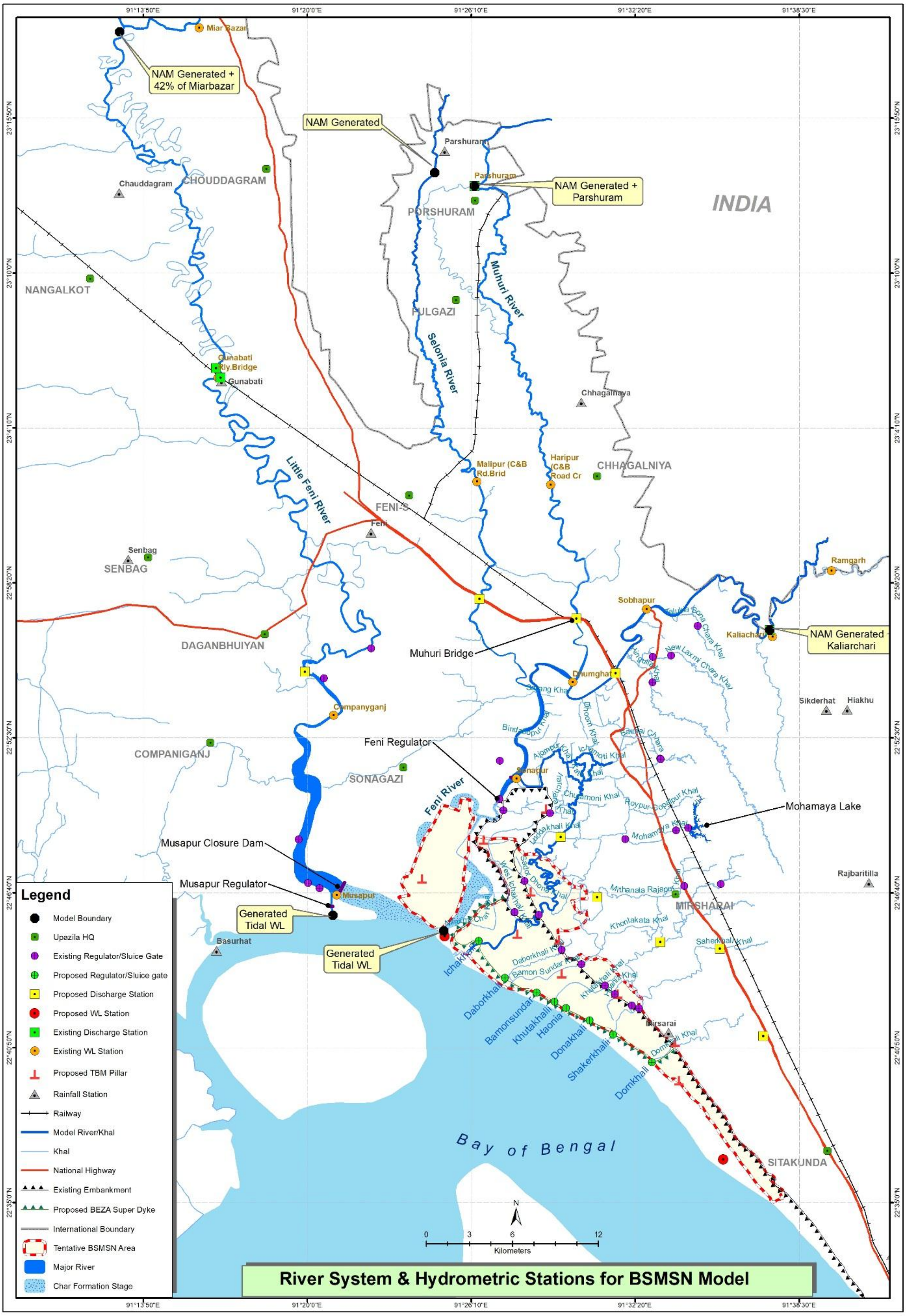


Figure A.2.4: River network for BSMSN model

A.2.1.2.1 Hydraulic Model Calibration

Parameters of HD model have been calibrated near Dhumghat on Feni River and u/s of Feni Regulator against observed water level data. Simulated water level data show good match with the observe water level data mainly in monsoon season (**Figure A.2.5** and **Figure A.2.6**). As the operation of gates of the regulator do not follow any rule curve so dry season calibration is not possible.

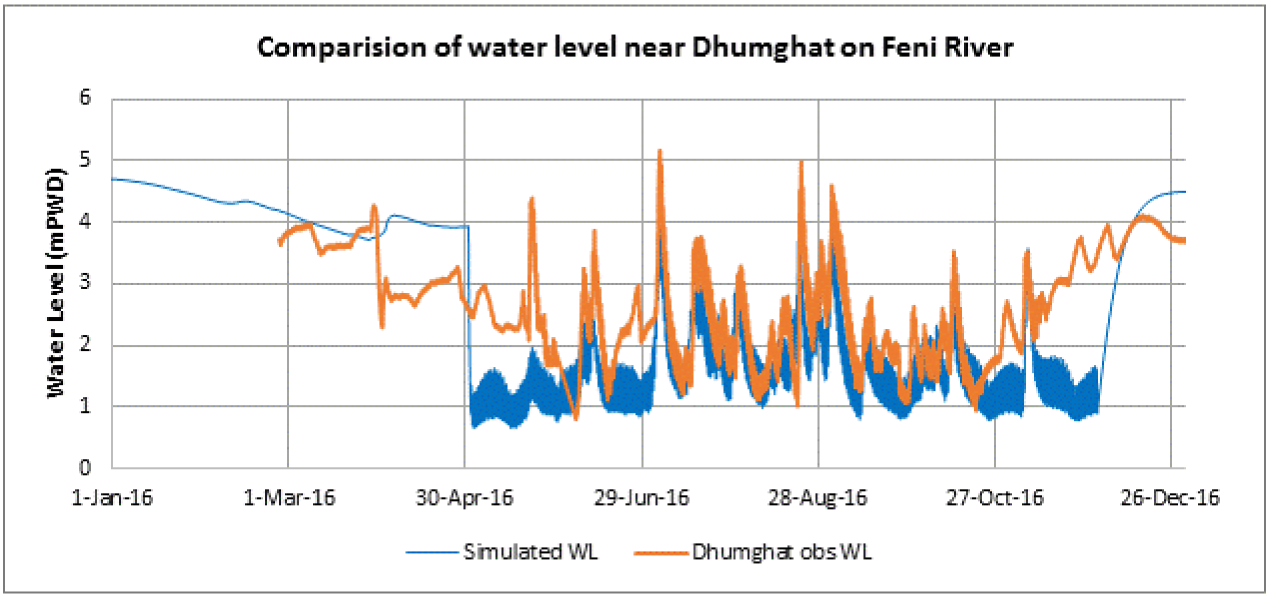


Figure A.2.5: Water level calibration plot near Dhumghat on Feni River

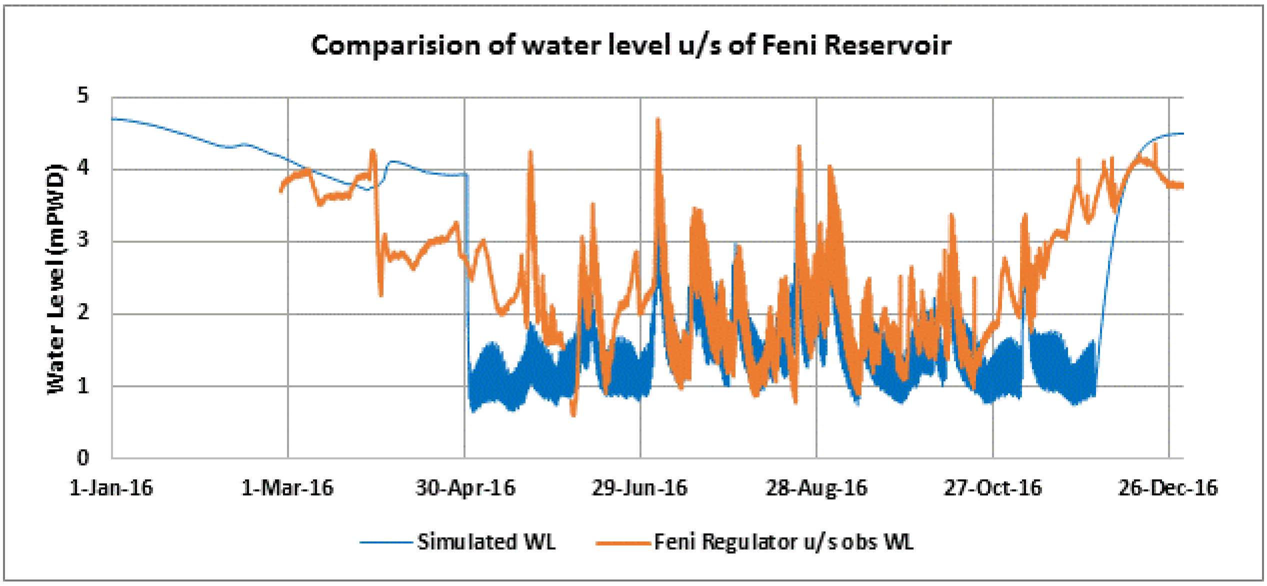


Figure A.2.6: Water level calibration plot u/s of Feni Reservoir

Annex-3: Water Distribution Modelling for Zone 2A (Tertiary Distribution Networks)

A.3.1 Model Design

A.3.1.1 Design Philosophy

The prime goal of the design of this water supply distribution system considering DMA concept is to satisfy consumer needs providing with reliable, continuous and 24-hour pressurized water supply system as well as minimizing cost for the implementation and operation of the system. Considering the rapidly depleting groundwater level, surface water from transmission main has been considered along with groundwater source. Incorporating identified sources in model, design has been finalized. System was improved by minimizing head losses in pipes and utilizing the heads provided from sources. Conventional design criteria of head loss gradient are 5m/km. To minimize the overall construction costs, pipe diameters were determined keeping consistency with road pattern. Considering master plan, proposed infrastructure development were incorporated in the model to get the best design of the system. Considering the head loss gradient criteria (if possible) and implementation risks, pipes have been downsized to minimize the cost. For optimum operation, the system was checked for possible segment shut down to minimize the offline areas during maintenance work. Contingency plans were developed to satisfy consumer needs in the event of a key facility such as pump station fails. To ensure the robustness of the model risk analysis, sensitivity analysis, etc. were carried out and optimized the model until it was satisfactory.

A.3.1.2 Hydraulic Design Assumptions and Other Considerations

- Two types of sources have been considered i.e. Groundwater and Surface Water. As the ground water level is depleting at a very rapid rate, there is a great possibility that every DTW may be inoperable within next 20 years. Considering the above facts conjunctive use of groundwater and surface water has been proposed to fulfill the Zone demand.
- Maximum value of head loss gradient has been considered – 5 m/Km, with some exception for small length of pipeline, especially for the bigger Diameter where negligible contribution is noted within the Zone for minimum system pressure, as well as in the pumping zone.
- Guaranteed minimum pressure at any point within the project area has been ensured at 10 m (1 bar).
- Surface water will be injected using single feeding point or inlet for the Zone.
- In model design, standard Pumps have been used for all DTWs with capacity 1 cusec, stage-3.
- Hazen Williams Roughness Coefficients “C” value has been used as 130 for uPVC pipe and 120 for DI pipe.
- Node elevation is assumed to be 1 m below the road surface, which is found from topographic survey as (PWD – 1.0m).

- Whatever the road surface level found during topographic survey; contractor should maintain the depth of top level of pipe minimum 1 m from existing road formation level during construction.

A.3.1.3 Design Parameters

A.3.1.3.1 Roughness and Minor Loss Parameters

The standard Hazen-William Coefficient (C) for uPVC pipe is 150 for new and smoother pipes. Generally, it is considered that uPVC pipe has a smooth inner surface and maintains its flow capability over time - Hazen Williams's factor remains 150, even after years of use. Nevertheless, the ageing effect on the roughness might come along, so this fact should be taken into consideration. The losses in the pipes comes not just from the friction between water and internal wall but also on local points along the pipe network such as tees, elbows, valves and etc. These losses are called minor losses. Minor losses will not be counted within model but their effect has been incorporated in final value for Hazen - William's coefficient C. In this stage it's not possible to calculate exact value for coefficient C, because the exact value shall be estimated running the model calibration using observed data on the field.

A.3.1.3.2 Pipe Material

For the pipes having diameter 300 mm or above, Ductile Iron pipe has been proposed use. For the pipe diameter below 300 mm, uPVC pipe has been recommended for tertiary distribution networks. The friction properties of DI and uPVC pipes have been incorporated in model design accordingly. In selection of uPVC pipe as pipe material, other issues such as design life, tensile strength, joint strengths etc. were considered.

A.3.1.3.3 Pipe Diameter

Accurate internal Diameter of different sizes of uPVC Pipe (PN 10) SDR 17, ISO 4427-2: 2007(E) used in the model, which is presented in **Table A.3.1**.

Table A.3.1: uPVC (PN 10) Internal Diameter in (mm)

uPVC Piped Dimensions		
Nominal outside Diameter	**Mean outside Diameter**	**Internal Diameter**
DN	**(mm)**	**(mm)**
110	110	101.6
160	160	147.6
200	200	184.6
250	250	230.8
315	315	290.8
400	400	369.8
450	450	415.6

Note: uPVC pipes more than 9 bar of any international recognized standard such as BS 3505 may also be used.

A.3.1.4 Model Build up

The pipe network has been digitized from road network information available. Network data describes all physical components of the water distribution system and defines how those elements are interconnected. Networks are made up of nodes and links. Nodes represent water system features at specific locations and links define relationships between nodes. Network data can include traditional data mainly composed of two primary types – pipe and node data.

A.3.1.4.1 Nodal Elevation data

Nodal elevation is considered 6.5 mPWD as per master plan design road level. For design purpose, the proposed road crest level has been considered as base. Pipe is considered to be laid 1m below of road surface level.

A.3.1.4.2 Nodal Demand

Demands can be allocated to the junctions using various methods. Many methods are based on observed data, such as billing meters, known flows in certain points of the network, by land use or by population settled. In this project, the number and location of plots has been defined and demand of buildings have been allocated to nearest specific nodes by landuse method & considered demand as losses is allocated by unit line method. For illustration a portion of network has been shown in **Figure A.3.1**.

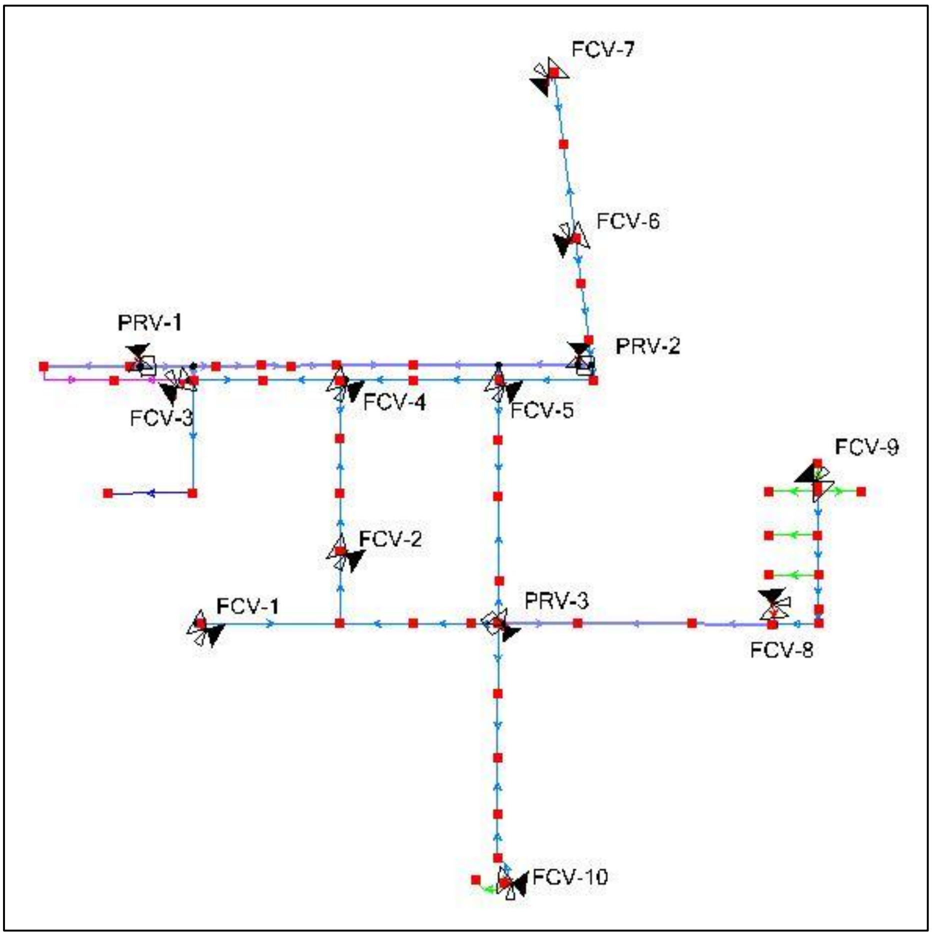


Figure A.3.1: Nodal Demand allocation in Specific Nodes

A.3.1.5 Model Scenario (Conjunctive Use)

One model scenario i.e. Conjunctive use of Groundwater and Surface Water has been considered in this model.

Total demand for this scenario is 671.84 l/s. Ten (10) Deep Tube Wells (DTWs) along with three (3) Surface Water Injection Point (SWIPs) have been considered as water source. All DTWs in the model have been controlled by FCV and the SWIPs have been controlled by PRV.

A.3.1.6 Network Sizing Models

Distribution Network Model has been prepared & analyzed for the above-mentioned scenario i.e. Conjunctive use. Network pipe sizing have been done for specific hydraulic criteria and improved by giving several trials. The final pipe size found from model is provided in **Table A.3.2** and **Figure A.3.2**. However, pipe lengths can be varied during construction period based on field condition.

Table A.3.2: Diameter wise Pipe size found from Model

Nominal Dia (inch)	Nominal Dia (mm)	Material	Distribution Network Pipe Length (m)
4	110	uPVC	875
6	160	uPVC	272
8	200	uPVC	747
10	250	uPVC	6,675
12	300	DI	2,695
Total			**11,264**

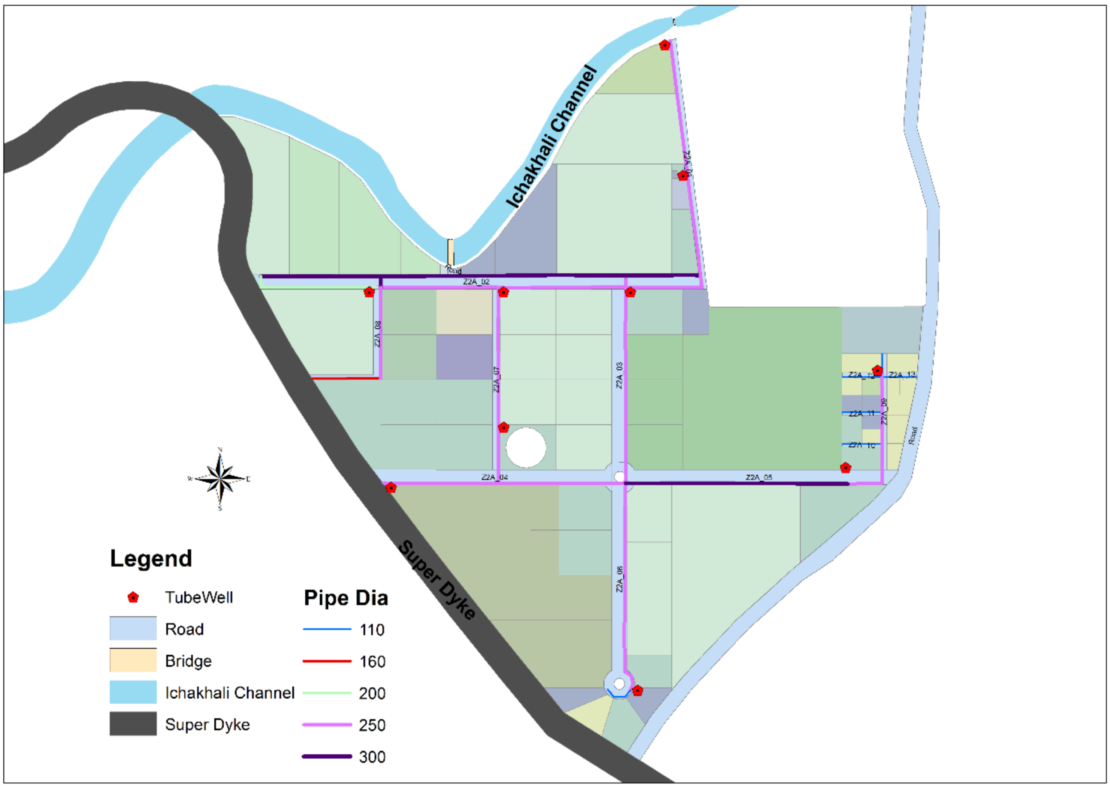


Figure A.3.2: Proposed Distribution Network for Zone 2A

A.3.1.7 Valves

- Total 29 nos. of network gate valves (GV) have been proposed in order to facilitate proper functioning including Operation and Maintenance (O&M) of the distribution networks, when required and with least disturbance to the adjacent beneficiaries of the water supply system. Criticality Analysis for isolation valves has been conducted. And to reduce the outage segments, some additional valves have been proposed. Details of criticality analysis are given in **sec. A.3.2.1**.

- 3 Air Release Valves (ARV) have been proposed (each 50 mm diameter) near nodes with relatively high elevations within the distribution networks,
- 5 Wash out (WO) valves have been proposed at nodes, where there is facility for easy draining out of water. All valves are provided with 160 mm diameter. Location of Air Release Valves and Wash outs are shown in **Figure A.3.3.**
- All gate valves, ARVs and WOs within the network have been shown in Model drawing Map. Quantity summary of valves and dead-ends of the distribution network is listed in **Table A.3.3**.

Table A.3.3: Summary of Valves and Washouts

Zone	Valve Type	Diameter (mm)							
		50	100	150	200	250	300	400	Total
Zone 2A	Gate Valve	-	-	-	1	19	9	-	**29**
	Air Release Valve	3	-	-	-	-	-	-	**3**
	Wash Out	-		5	-	-	-	-	**3**
	End Cap	-	6	1	-	-	-	-	**9**
Total		**3**	**6**	**6**	**1**	**19**	**9**	**-**	**44**

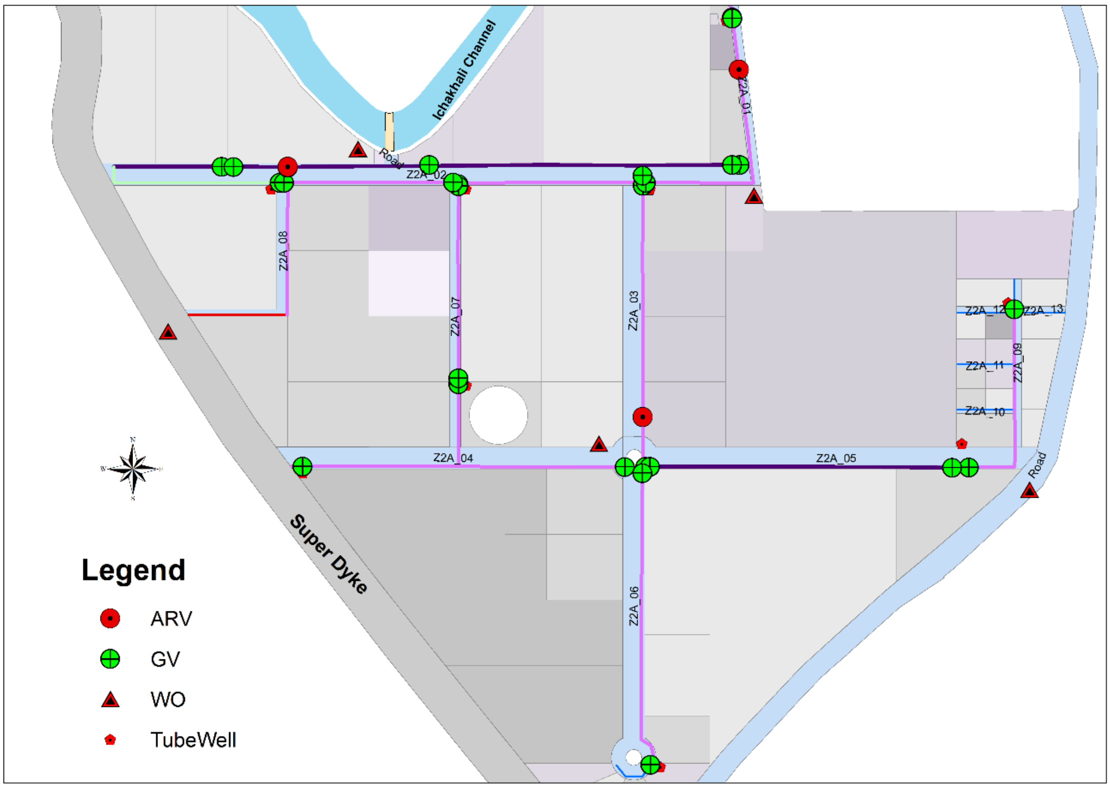
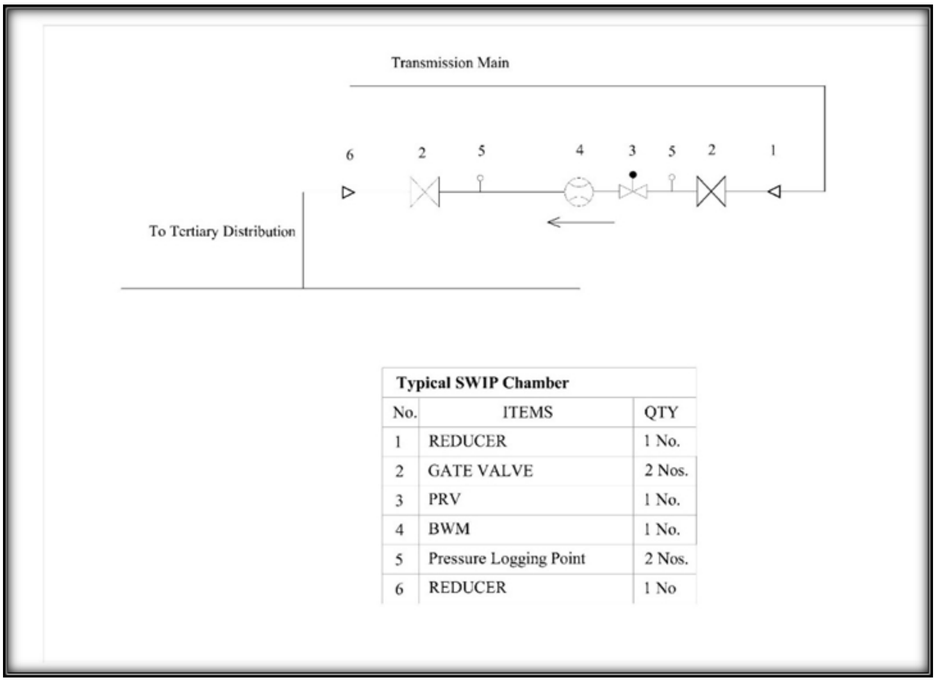


Figure A.3.3: Location of ARV, Washouts and Gate Valve

A.3.1.7.1 Chambers and Water Meter

Three (3) Surface Water Injection Point (SWIPs) has been proposed in design model for this Zone. These surface water interconnections have been considered from proposed treated transmission line from surface water treatment plant. This chamber will serve the purpose of connecting the distribution system to transmission mains. Details of a typical interconnection chamber is shown in **Figure A.3.4**.



Typical SWIP Chamber

No.	ITEMS	QTY
1	REDUCER	1 No.
2	GATE VALVE	2 Nos.
3	PRV	1 No.
4	BWM	1 No.
5	Pressure Logging Point	2 Nos.
6	REDUCER	1 No

Figure A.3.4: Details of Typical Surface Water Interconnection Chamber

- **Gate Valves** to be used in the water supply system, shall resilient sealed complying ISO 5996: 1984 or any other approved equivalent.
- **Non-Return Valve or Check Valve** shall comply to BS 5151 PN 16 and shall be quick action single door type. All materials used in the manufacture of Non-Return Valve or Check Valve shall conform to the following requirements:
    - Cast iron BS 1452 Grade 220,
    - Gunmetal BS 1400 Grade LG2,
    - Stainless steel BS 970 Grade 431S29,
    - O-rings Molded rubber
- **Bulk Water Meter** shall be of approved brand but must be water resistant and hermetically sealed.
- **Pressure Sustaining Valve (PSV)** shall be capable of maintaining a constant pressure in the main upstream of the valve. PSV shall be used to reduce excess pressure when installed in a branch main. Construction of PSV shall generally be in accordance with the specification for PRV i.e. shall comply with the requirements of ISO 6264:1998.
- **Pressure Reducing Valve (PRV)** shall be designed to reduce a constant or variable inlet pressure to a predetermined constant outlet pressure, at flows varying from the maximum capacity of the valve to zero flow. PRV shall comply with the requirements of ISO 6264:1998.
- **Washout (Valve) chamber** shall be fitted with a Gate Valve and to be resilient sealed: 2004 and complying ISO 5996: 1984 or any other approved equivalent.

- **Determination of Equipment Sizes in Interconnection Chamber** In general, equipment sizes had been determined considering the head loss at BWM below 0.5 m; and the total head loss at interconnection chamber for unidirectional flow nearly 1 m. However, exceptions may occur at some special cases.

Table A.3.4 shows sample calculations of head loss at the future inter-Transmission chamber. The pressure drop at BWM and PRV/PSV has been illustrated in **Figure A.3.5** and **Figure A.3.6**.

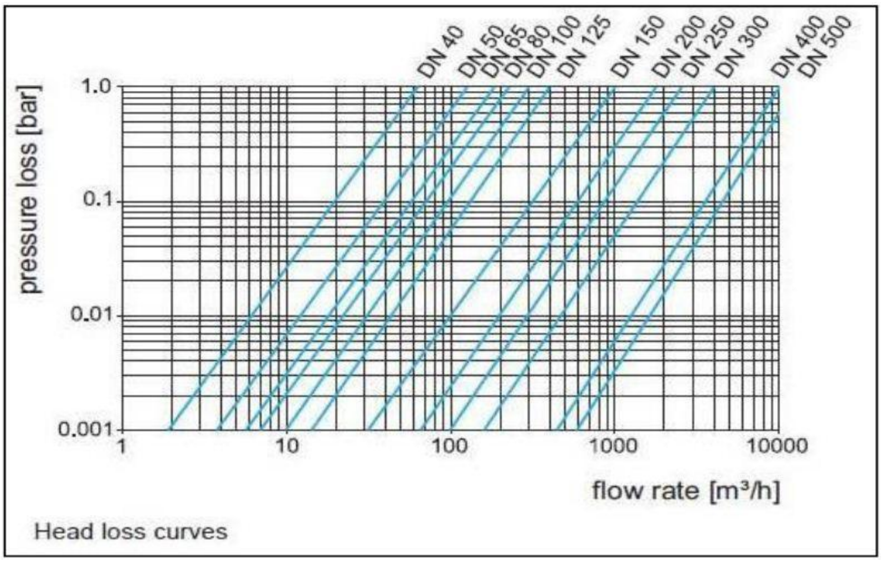


Figure A.3.5: Head Loss Curves of ZENNER Bulk Water Meter

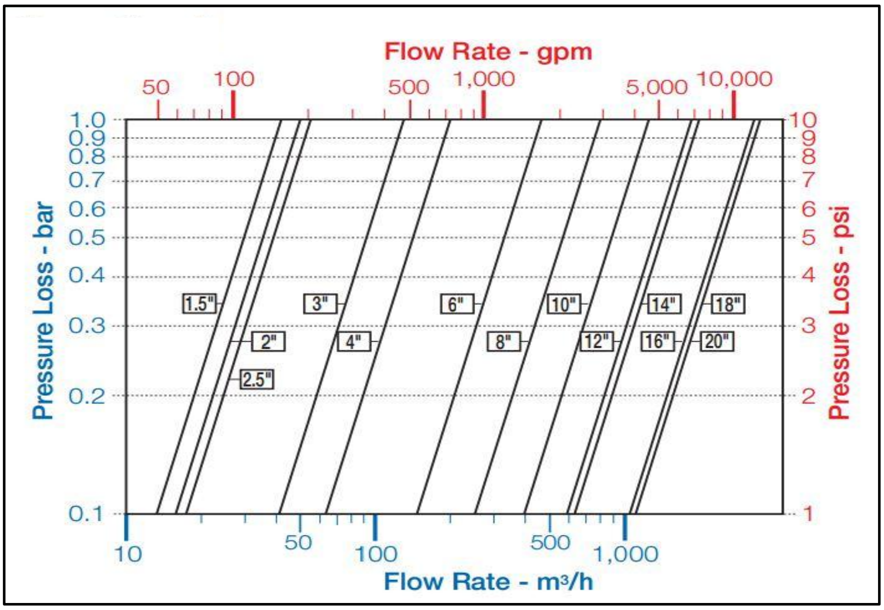


Figure A.3.6: Head Loss Curves of PRV/PSV

Table A.3.4: Sample Head Loss Calculation in SWIP Chamber

Inter Connection		**SWIP Chamber**		
Input Parameters		Valve Type		Bulk Meter
		Gate Valve	Check Valve	
From Model	Fitting Diameter, mm	400	400	400
	Pipe Diameter (int.), mm	400	400	400
	Pipe Flow Rate, Q, L/s	182.15	182.15	182.15

Inter Connection		**SWIP Chamber**		
	Pipe Flow Velocity, V, m/s	1.45	1.45	1.45
	Number of Valves	2	1	1
From Chart/ Graph/ Value	Le/D	8	100	
	fT	0.013	0.013	
	Head Loss at Bulk Meter, m			0.025
Results	$V^2/2g$	0.107	0.107	
	K	0.104	1.300	
	Total Head Loss, HL	0.02	0.14	0.03
	Total Fittings Head Loss	**0.19**		

A.3.1.8 Model Results

A.3.1.8.1 Initial Target Pressure

The objective is to keep all networks under pressure (at least 10 m) for 24 hours. If there is not enough pressure at sources (DTWs and Transmission mains), it will not be possible to pressurize the system with desired pressure level. **Figure A.3.7** represents nodal pressure for Conjunctive water source in designed condition of this Zone. The model results shows that, the pressure only at two nodes are below 1 bar (9.17 and 9.83 mH_2O) which is acceptable because these nodes are at dead end.

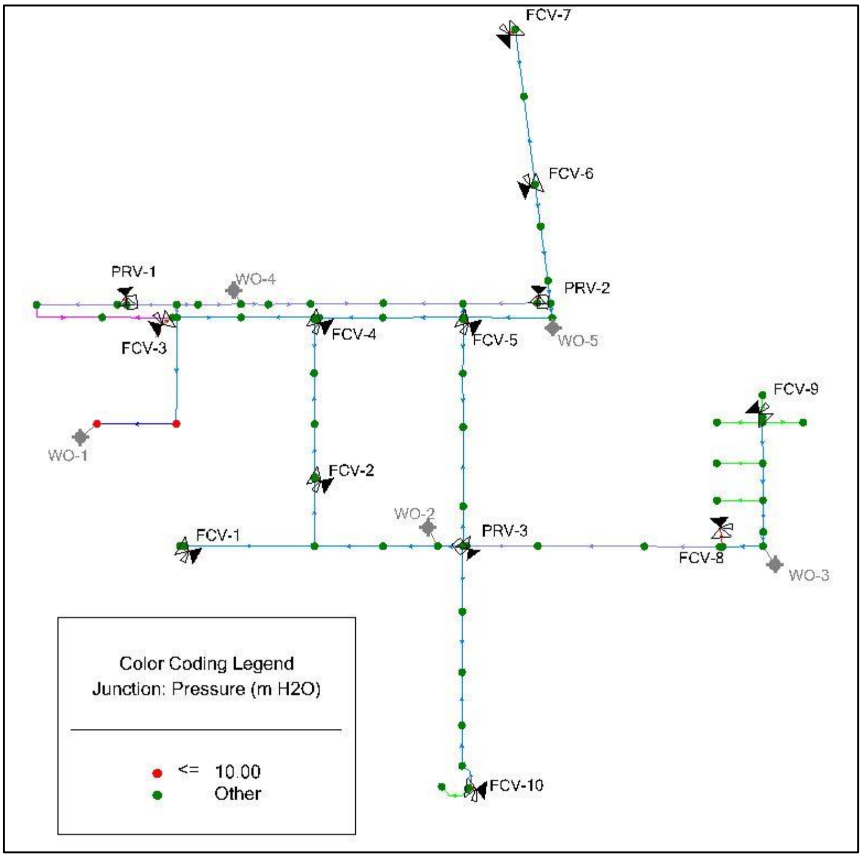


Figure A.3.7: Nodal Pressure for Conjunctive Water Source Scenario

A.3.1.8.2 Target Head Loss Gradient

Maximum allowable value of head loss gradient has been considered as 5 m/Km. The following **Figure A.3.8** shows head-loss gradient in pipes for Conjunctive water source of this Zone. Some portion of pipes have head loss gradient between 5 to 7 m/Km, which is acceptable because these pipes are located near sources.

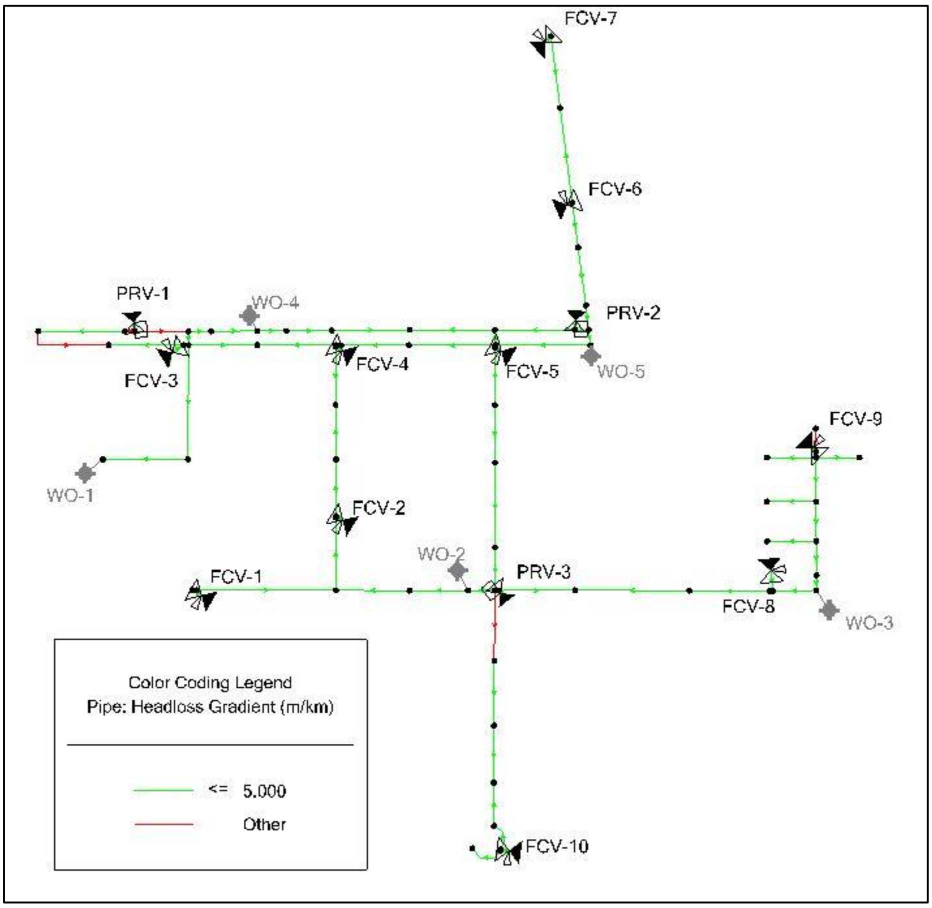


Figure A.3.8: Headloss Gradient in Pipes for Conjunctive Water Source Scenario

A.3.2 Network Analysis

Several types of analysis were carried out to ensure the robustness of designed model and interpret the behaviour of the network in different conditions. The Criticality Analysis and Analysis for Flushing time has been performed in the design model.

A.3.2.1 Criticality Analysis

To ensure the optimum behaviour of the system during preparation or maintenance work, isolation valves are necessary in the network. Number and location of isolation valves have been determined and optimized by criticality analysis which was performed by using the WaterGems software.

A.3.2.1.1 Assumptions and Approaches

- Complete isolation from the network is the first criteria for putting isolation valves in the pipes.

- Isolation valves must be located such that during operation and maintenance work, possible stoppage of sources can be avoided as much as possible.
- Minimize the offline areas as much as possible considering the maintenance work at network.
- Minimize the number and length of outage segments in the network.
- Minimize the number of valves that need to be closed for isolating a segment. The more no. of valves required closing at a time decreases the network reliability during the operation of those valves.
- Total cost considerations.

Major Criterions for Isolation Valves are:

1. Average Length of Isolation Segment

Average Length of Isolation Segment

- For Grid system, in the range of 1000 m
- For branch system, depends on pattern and outage segment.

Additional Considerations

- Maximum length of one segment below 2000 m
- Avoid larger diameters (≥ 250 mm) as much as possible.
- Maximum number of GV for one segment closure is within 15
- Maximum length of outage segment is within 1000 m (except dead end branch) at the downstream of network

A.3.2.1.2 Segmentation of the Network

At first, a tentative number of isolation valves were digitized in the model. Isolation valve diameter was modified to conform to corresponding pipe diameter. After that, criticality analysis were carried out for entire network to check the isolation and isolated segment properties in the system. Finally, the number and location of isolation valves had been modified until desirable outputs were obtained. Different isolated segments of the network in Zone 2A are shown in **Figure A.3.9**.

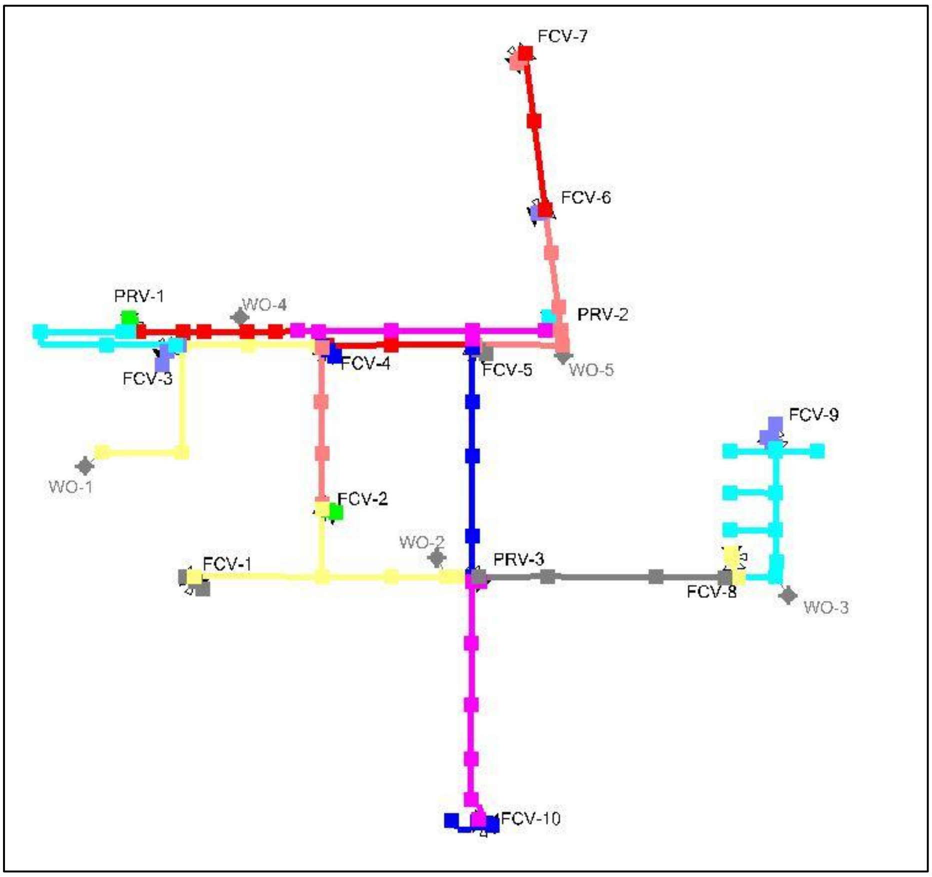


Figure A.3.9: Different Isolated Segments of the Distribution Network

A.3.2.1.3 Outputs of Criticality Analysis

By incorporation of isolation valves in the network and by performing criticality analysis, it is possible to identify the customers whose connections will be interrupted during isolation events. The valves that are needed to be closed for isolating any segment can be identified also. The output results of the criticality analysis of the network are shown in **Table A.3.5**.

Table A.3.5: Summary of Criticality Analysis of the Network

Description	Value	Remarks
a) No. of Proposed Gate Valves	29	Nos. of Isolation Valve from flex tables
b) No. of Isolated Segments	26	
c) Maximum Segment Length	1,171	m
d) Average Segment Length	764	m
e) Maximum No. of Valves Needed to be Closed	5	
f) Total No. of Outage Segment	0	
g) Maximum Outage Segment Length	0	m
h) Maximum Demand Shortfall	16.3	% (if no sources are shutdown)
Total Pipe Length	**11.943**	**km**
Nos. of Proposed Gate Valves per km of pipe length	**2.44**	

A.3.2.2 Flushing Time Analysis

After design completion, an analysis has been carried out to determine the time required for flushing event of distribution pipes that are connected with washouts. Required water for washing has been assumed to be supplied by existing DTWs. To facilitate quick and comprehensive flushing, WOs have been provided near suitable and low-elevation regions in the model. Location of the washout will be finalized during detailed design of the network. The simulation has been done with water discharge at atmospheric pressure through wash-out pipes. Details of these WOs have been listed in **Table A.3.6**.

Table A.3.6: Flushing Time Table

SI No	Flushing Layout	Pipe Diameter (mm)	Segment Flushing (L/s)	Velocity (m/s)	Network Volume (L)	Total Flushing (L/s)	Flushing Time (min)
WO-1	Total Network	160	26.81	1.57	499824	281.94	29.55
WO-2		160	59.32	3.47			
WO-3		160	57.33	3.35			
WO-4		160	64.99	3.8			
WO-5		160	73.49	4.3			

A.3.2.3 Analysis for Dead End Pipes

Considering the small length of dead-end pipes, low flow and velocity, it is ensured that there will be no stagnation of water at dead ends and water quality will not be deteriorated. **Table A.3.7** shows the particulars of dead-end pipes data.

Table A.3.7: Dead End Pipes

Pipe ID	Pipe Length (m)	Pipe Dia (mm)	End Junction	Elevation (mPWD)
P-10	272	160	J-12	6.50
P-28	157	110	J-31	6.50
P-31	157	110	J-33	6.50
P-34	156	110	J-35	6.50
P-120	139	110	J-65	6.50
P-129	75	110	J-27	6.50
P-235	114	110	J-102	6.50

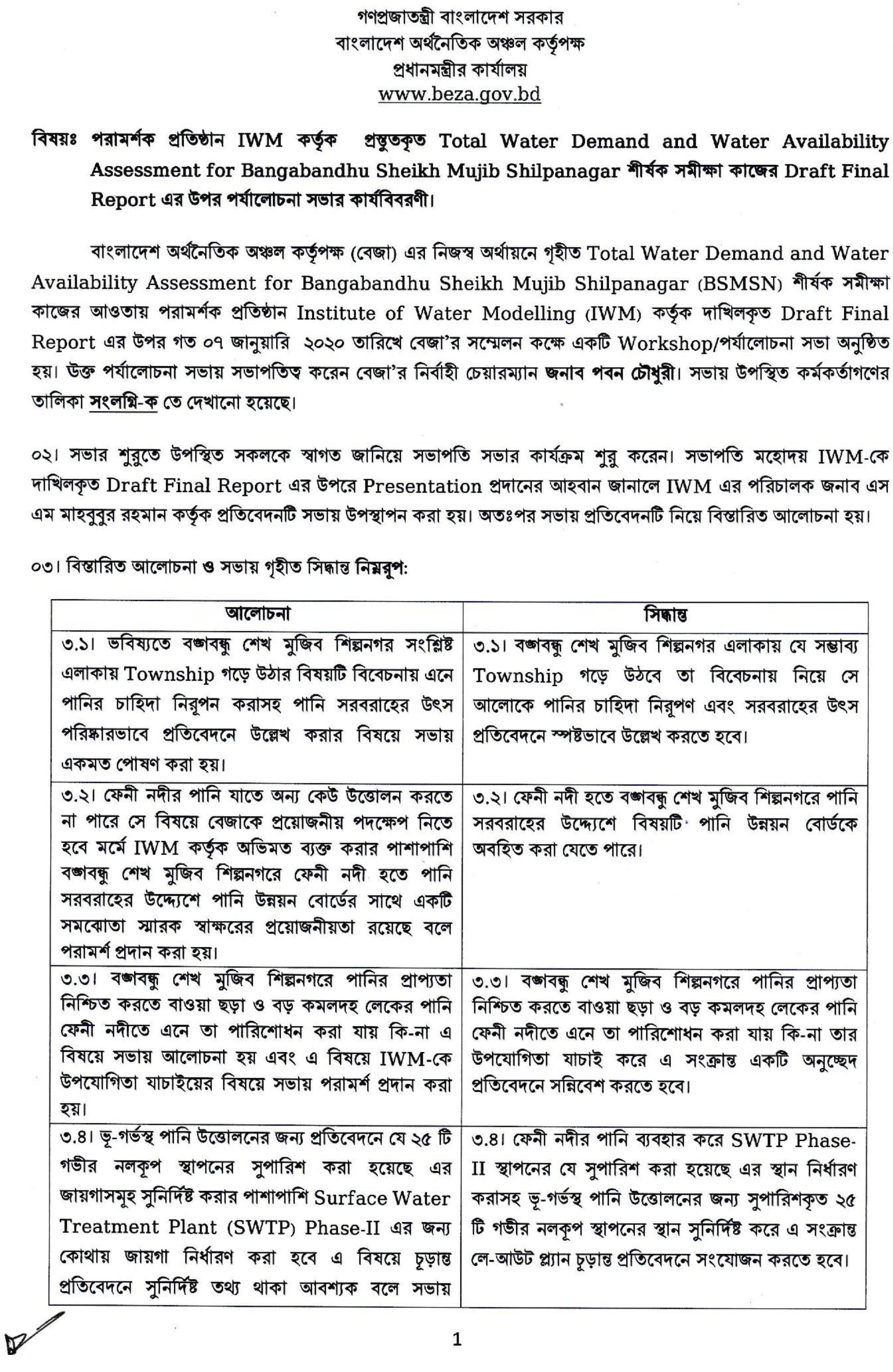
A.3.3 Model Output

A summary of model output has been tabulated in **Table A.3.8**. Details data are available as annex which is attached with this report.

Table A.3.8: Summary of Model Output

Scenario	Unit	Value	Remarks
Conjunctive Use for Design Demand	(m H_2O)	9.17	Minimum pressure has not been governed
Conjunctive Use for 75% of Design Demand	(m H2O)	10.67	Minimum pressure has been governed
Conjunctive Use for 50% of Design Demand	(m H_2O)	11.83	Minimum pressure has been governed
Conjunctive Use for Design Demand	(m/km)	7.75	Maximum head loss gradient has been exceeded
Conjunctive Use for 75% of Design Demand	(m/km)	4.55	Allowable head loss gradient
Conjunctive Use for 50% of Design Demand	(m/km)	2.99	Allowable head loss gradient
Maximum Velocity in Pipe in Conjunctive Use Scenario	(m/s)	1.39	Allowable velocity has been achieved
Number of Isolation Valves	nos.	29	
Number of Washout	nos.	5	
Number of Air release Valves	nos.	3	

Annex-4: Meeting Minutes of Draft Final Report Presentation Workshop



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বিষয়ঃ পরামর্শক প্রতিষ্ঠান IWM কর্তৃক প্রস্তুতকৃত Total Water Demand and Water Availability Assessment for Bangabandhu Sheikh Mujib Shilpanagar শীর্ষক সমীক্ষা কাজের Draft Final Report এর উপর পর্যালোচনা সভার কার্যবিবরণী।

বাংলাদেশ অর্থনৈতিক অঞ্চল কর্তৃপক্ষ (বেজা) এর নিজস্ব অর্থায়নে গৃহীত Total Water Demand and Water Availability Assessment for Bangabandhu Sheikh Mujib Shilpanagar (BSMSN) শীর্ষক সমীক্ষা কাজের আওতায় পরামর্শক প্রতিষ্ঠান Institute of Water Modelling (IWM) কর্তৃক দাখিলকৃত Draft Final Report এর উপর গত ০৭ জানুয়ারি ২০২০ তারিখে বেজা'র সম্মেলন কক্ষে একটি Workshop/পর্যালোচনা সভা অনুষ্ঠিত হয়। উক্ত পর্যালোচনা সভায় সভাপতিত্ব করেন বেজা'র নির্বাহী চেয়ারম্যান **জনাব পবন চৌধুরী**। সভায় উপস্থিত কর্মকর্তাগণের তালিকা **সংলগ্নি-ক** তে দেখানো হয়েছে।

০২। সভার শুরুতে উপস্থিত সকলকে স্বাগত জানিয়ে সভাপতি সভার কার্যক্রম শুরু করেন। সভাপতি মহোদয় IWM-কে দাখিলকৃত Draft Final Report এর উপরে Presentation প্রদানের আহবান জানালে IWM এর পরিচালক জনাব এস এম মাহবুবুর রহমান কর্তৃক প্রতিবেদনটি সভায় উপস্থাপন করা হয়। অতঃপর সভায় প্রতিবেদনটি নিয়ে বিস্তারিত আলোচনা হয়।

০৩। বিস্তারিত আলোচনা ও সভায় গৃহীত সিদ্ধান্ত **নিম্নরূপ**:

আলোচনা	সিদ্ধান্ত
৩.১। ভবিষ্যতে বঙ্গবন্ধু শেখ মুজিব শিল্পনগর সংশ্লিষ্ট এলাকায় Township গড়ে উঠার বিষয়টি বিবেচনায় এনে পানির চাহিদা নিরূপন করাসহ পানি সরবরাহের উৎস পরিষ্কারভাবে প্রতিবেদনে উল্লেখ করার বিষয়ে সভায় একমত পোষণ করা হয়।	৩.১। বঙ্গবন্ধু শেখ মুজিব শিল্পনগর এলাকায় যে সম্ভাব্য Township গড়ে উঠবে তা বিবেচনায় নিয়ে সে আলোকে পানির চাহিদা নিরূপণ এবং সরবরাহের উৎস প্রতিবেদনে স্পষ্টভাবে উল্লেখ করতে হবে।
৩.২। ফেনী নদীর পানি যাতে অন্য কেউ উত্তোলন করতে না পারে সে বিষয়ে বেজাকে প্রয়োজনীয় পদক্ষেপ নিতে হবে মর্মে IWM কর্তৃক অভিমত ব্যক্ত করার পাশাপাশি বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে ফেনী নদী হতে পানি সরবরাহের উদ্দেশ্যে পানি উন্নয়ন বোর্ডের সাথে একটি সমঝোতা স্মারক স্বাক্ষরের প্রয়োজনীয়তা রয়েছে বলে পরামর্শ প্রদান করা হয়।	৩.২। ফেনী নদী হতে বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানি সরবরাহের উদ্দেশে বিষয়টি পানি উন্নয়ন বোর্ডকে অবহিত করা যেতে পারে।
৩.৩। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানির প্রাপ্যতা নিশ্চিত করতে বাওয়া ছড়া ও বড় কমলদহ লেকের পানি ফেনী নদীতে এনে তা পারিশোধন করা যায় কি-না এ বিষয়ে সভায় আলোচনা হয় এবং এ বিষয়ে IWM-কে উপযোগিতা যাচাইয়ের বিষয়ে সভায় পরামর্শ প্রদান করা হয়।	৩.৩। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানির প্রাপ্যতা নিশ্চিত করতে বাওয়া ছড়া ও বড় কমলদহ লেকের পানি ফেনী নদীতে এনে তা পারিশোধন করা যায় কি-না তার উপযোগিতা যাচাই করে এ সংক্রান্ত একটি অনুচ্ছেদ প্রতিবেদনে সন্নিবেশ করতে হবে।
৩.৪। ভূ-গর্ভস্থ পানি উত্তোলনের জন্য প্রতিবেদনে যে ২৫ টি গভীর নলকূপ স্থাপনের সুপারিশ করা হয়েছে এর জায়গাসমূহ সুনির্দিষ্ট করার পাশাপাশি Surface Water Treatment Plant (SWTP) Phase-II এর জন্য কোথায় জায়গা নির্ধারণ করা হবে এ বিষয়ে চূড়ান্ত প্রতিবেদনে সুনির্দিষ্ট তথ্য থাকা আবশ্যক বলে সভায়	৩.৪। ফেনী নদীর পানি ব্যবহার করে SWTP Phase-II স্থাপনের যে সুপারিশ করা হয়েছে এর স্থান নির্ধারণ করাসহ ভূ-গর্ভস্থ পানি উত্তোলনের জন্য সুপারিশকৃত ২৫ টি গভীর নলকূপ স্থাপনের স্থান সুনির্দিষ্ট করে এ সংক্রান্ত লে-আউট প্ল্যান চূড়ান্ত প্রতিবেদনে সংযোজন করতে হবে।

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অভিমত ব্যক্ত করা হয়।	
৩.৫। প্রতিবেদনে SWTP পরিচালনা ও রক্ষণাবেক্ষণে প্রস্তাবিত Operation & Maintenance (O & M) এর জন্য সাংগঠনিক কাঠামোতে বর্ণিত জনবলের প্রতিটি পদের বিপরীতে সংখ্যা উল্লেখ করা বাঞ্ছনীয় বলে সভায় মত প্রকাশ করা হয়।	৩.৫। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানি সরবরাহের বিষয়ে SWTP পরিচালনা ও রক্ষণাবেক্ষণে প্রস্তাবিত Operation & Maintenance (O & M) সংক্রান্ত জনবল কাঠামোতে প্রতিটি পদের বিপরীতে সংখ্যা উল্লেখ করে তা চূড়ান্ত প্রতিবেদনে অন্তর্ভূক্ত করতে হবে।
৩.৬। ছোট ফেনী নদী হতে সারাবছর 40 MLD পানি উত্তোলন করা যেতে পারে বলে প্রতিবেদনে উল্লেখ করা হয়েছে। পানি শোধনাগারের মাধ্যমে পানি শোধন করে তা বঙ্গবন্ধু শেখ মুজিব শিল্পনগরের ফেনী নদীর উত্তর-পশ্চিম দিকে অবস্থিত এলাকায় সরবরাহ করা যেতে পারে মর্মে আলোচনা হয় এবং এ বিষয়ে পরবর্তীতে সম্ভাব্যতা সমীক্ষা করার প্রয়োজনীয়তা আছে মর্মে সভায় অভিমত ব্যক্ত করা হয়।	৩.৬। ছোট ফেনী নদী হতে পানি উত্তোলন করে তা পরিশোধনের বিষয়ে সমীক্ষা করার উদ্যোগ গ্রহণ করতে হবে।

০৪। আর কোন আলোচ্য বিষয় না থাকায় সভাপতি সকলকে ধন্যবাদ জানিয়ে সভার সমাপ্তি ঘোষণা করেন।

০৯/২০২০

(পবন চৌধুরী)
নির্বাহী চেয়ারম্যান

Annex-5: Response to the Comments on Draft Final Report

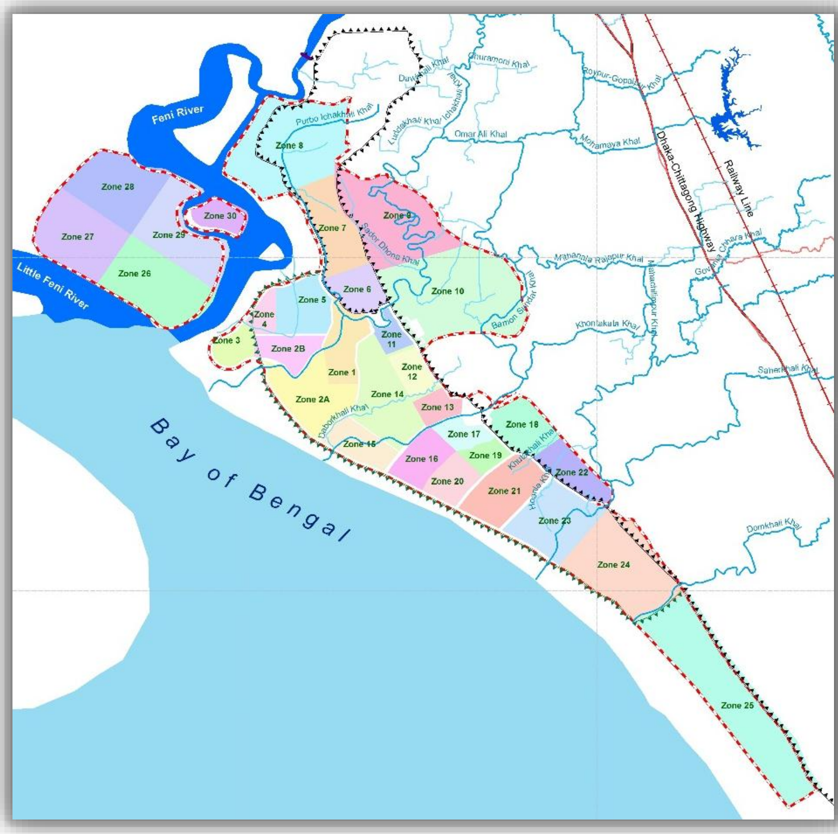
আলোচনা	সিদ্ধান্ত	পরামর্শক প্রতিষ্টান কর্তৃক গৃহীত কার্যক্রম
৩.১। ভবিষ্যতে বঙ্গবন্ধু শেখ মুজিব শিল্পনগর সংশ্লিষ্ট এলাকায় Township গড়ে উঠার বিষয়টি বিবেচনায় এনে পানির চাহিদা নিরূপণ করাসহ পানি সরবরাহের উৎস পরিষ্কারভাবে প্রতিবেদনে উল্লেখ করার বিষয়ে সভায় একমত পোষণ করা হয়।	৩.১। বঙ্গবন্ধু শেখ মুজিব শিল্পনগর এলাকায় যে সম্ভাব্য Township গড়ে উঠবে তা বিবেচনায় নিয়ে সে আলোকে পানির চাহিদা নিরূপণ এবং সরবরাহের উৎস প্রতিবেদনে স্পষ্টভাবে উল্লেখ করতে হবে।	৩.১। বঙ্গবন্ধু শেখ মুজিব শিল্পনগর এলাকায় যে সম্ভাব্য Township গড়ে উঠবে, সেই এলাকায় পানির চাহিদা এবং সম্ভাব্য উৎস Final Report (Volume-II) এর Section 3.6 এ সংযুক্ত করা হলো।
৩.২। ফেনী নদীর পানি যাতে অন্য কেও উত্তোলন করতে না পারে সে বিষয়ে বেজাকে প্রয়োজনীয় পদক্ষেপ নিতে হবে মর্মে IWM কর্তৃক অভিমত ব্যক্ত করার পাশাপাশি বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে ফেনী নদী হতে পানি সরবরাহের উদ্দেশ্যে পানি উন্নয়ন বোর্ডের সাথে একটি সমঝোতা স্মারক স্বাক্ষরের প্রয়োজনীয়তা রয়েছে বলে পরামর্শ প্রদান করা হয়।	৩.২। ফেনী নদী হতে বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানি সরবরাহের উদ্দেশ্যে বিষয়টি পানি উন্নয়ন বোর্ডকে অবহিত করা যেতে পারে।	৩.২। IWM এই বিষয়ে একমত এবং বিষয়টি Final Report (Volume-II) এর Section 4.3.5 ও 15.2 এ ইতোমধ্যে সুপারিশ করা হয়েছে।
৩.৩। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানির প্রাপ্যতা নিশ্চিত করতে বাওয়া ছড়া ও কমলদহ লেকের পানি ফেনী নদীতে এনে তা পরিশোধন করা যায় কি-না এ বিষয়ে সভায় আলোচনা হয় এবং এ বিষয়ে IWM-কে উপযোগিতা যাচাইয়ের বিষয়ে সভায় পরামর্শ প্রদান করা হয়।	৩.৩। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানির প্রাপ্যতা নিশ্চিত করতে বাওয়া ছড়া ও কমলদহ লেকের পানি ফেনী নদীতে এনে তা পরিশোধন করা যায় কি-না তার উপযোগিতা যাচাই করে এ সংক্রান্ত একটি অনুচ্ছেদ প্রতিবেদনে সন্নিবেশ করতে হবে।	৩.৩। বাওয়া ছড়া ও কমলদহ লেক হতে পানির পরিমাণ বিশ্লেষণ করে দেখা যায় যে এই দুইটি লেক পানির কোন নির্ভরযোগ্য উৎস নয়। এ বিষয়ের উপর বিস্তারিত বিশ্লেষণ Final Report (Volume-II) এর Section 4.8 ও 4.9 এ ইতোমধ্যে উল্লেখ করা হয়েছে।
৩.৪। ভূ-গর্ভস্থ পানি উত্তোলনের জন্য প্রতিবেদনে যে ২৫ টি গভীর নলকূপ স্থাপনের সুপারিশ করা হয়েছে এর জায়গাসমূহ সুনির্দিষ্ট করার পাশাপাশি Surface Water Treatment Plant (SWTP) Phase-II	৩.৪। ফেনী নদীর পানি ব্যবহার করে SWTP Phase-II স্থাপনের যে সুপারিশ করা হয়েছে এর স্থান নির্ধারণ করাসহ ভূ-গর্ভস্থ পানি উত্তোলনের জন্য সুপারিশকৃত ২৫ টি গভীর নলকূপ স্থাপনের স্থান	৩.৪.১। Zone 2A, 2B, 3,4 এবং 5 এ পানি সরবরাহের জন্য SWTP Phase-I এবং উপরোক্ত জোনসমূহে ২৫ টি গভীর নলকূপ বিবেচনায় এনে Distribution Network এর Outline design করা

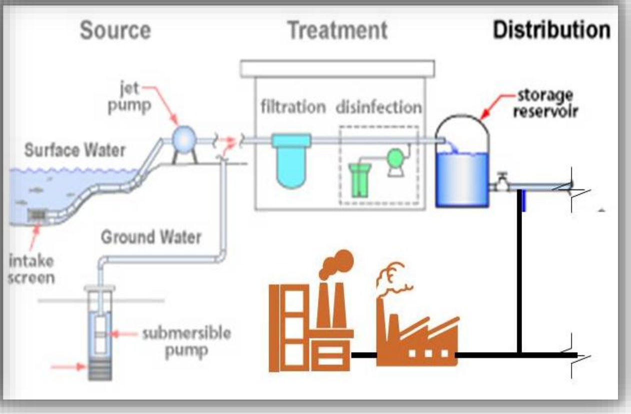
আলোচনা	সিদ্ধান্ত	পরামর্শক প্রতিষ্টান কর্তৃক গৃহীত কার্যক্রম
এর জন্য কোথায় জায়গা নির্ধারণ করা হবে এ বিষয়ে চূড়ান্ত প্রতিবেদনে সুনির্দিষ্ট তথ্য থাকা আবশ্যক বলে সভায় অভিমত ব্যক্ত করা হয়।	সুনির্দিষ্ট করে এ সংক্রান্ত লে-আউট প্ল্যান চূড়ান্ত প্রতিবেদনে সংযোজন করতে হবে।	হয়েছে। এছাড়া উক্ত ২৫ টি নলকূপ স্থাপনের জন্য BEZA, জনস্বাস্থ্য প্রকৌশল অধিদপ্তরকে দায়িত্ব প্রদান করেছে এবং জায়গাসমূহ ইতোমধ্যে সুনির্দিষ্ট করা হয়েছে। কাজেই SWTP Phase-II এর সাথে উক্ত ২৫ টি গভীর নলকূপের কোনো সংশ্লিষ্টতা নাই। সিদ্ধান্তমতে উক্ত ২৫ টি গভীর নলকূপের অবস্থান চিহ্নিত করে একটি নকশা Final Report (Volume-II) এর Section 9.2 এ সংযুক্ত করা হলো। ৩.৪.২। SWTP Phase-II এর পানি, উপরোক্ত জোনসমূহ বাদে 2^{nd} Priority জোনে সরবরাহ করা হবে। এখানে উল্লেখ্য যে SWTP Phase-I এর অবস্থান ইতোমধ্যে নির্ধারণ করা হয়েছে। SWTP Phase-II এর অবস্থান Phase-I এর কাছাকাছি নির্বাচন করা যেতে পারে। এতে করে পানি শোধনাগার দুটি অপেক্ষাকৃত কম জনবল দ্বারা এবং নতুন কোন অফিস স্থাপন ব্যতিরেকে পরিচালনা ও রক্ষণাবেক্ষণ করা সহজতর হবে।
৩.৫। প্রতিবাদনে SWTP পরিচালনা ও রক্ষণাবেক্ষণে প্রস্তাবিত Operation & Maintenance (O & M) এর জন্য সাংগঠনিক কাঠামোতে বর্ণিত জনবলের	৩.৫। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানি সরবরাহের বিষয়ে SWTP পরিচালনা ও রক্ষণাবেক্ষণে প্রস্তাবিত Operation & Maintenance (O & M) সংক্রান্ত জনবল কাঠামোতে প্রতিটি পদের বিপরীতে সংখ্যা	৩.৫। বঙ্গবন্ধু শেখ মুজিব শিল্পনগরে পানি সরবরাহের বিষয়ে SWTP পরিচালনা ও রক্ষণাবেক্ষণে প্রস্তাবিত Operation & Maintenance (O & M) সংক্রান্ত জনবল কাঠামোতে প্রতিটি পদের বিপরীতে সংখ্যা

আলোচনা	সিদ্ধান্ত	পরামর্শক প্রতিষ্টান কর্তৃক গৃহীত কার্যক্রম
প্রতিটি পদের বিপরীতে সংখ্যা উল্লেখ করা বাঞ্ছনীয় বলে সভায় মত প্রকাশ করা হয়।	উল্লেখ করে তা চূড়ান্ত প্রতিবেদনে অন্তর্ভূক্ত করতে হবে।	উল্লেখ করে তা Final Report (Volume-II) এর Section 10.2 এ সংযুক্ত করা হলো।
৩.৬। ছোট ফেনী নদী হতে সারাবছর 40 MLD পানি উত্তোলন করা যেতে পারে বলে প্রতিবেদনে উল্লেখ করা হয়েছে। পানি শোধনাগারের মাধ্যমে পানি শোধন করে তা বঙ্গবন্ধু শেখ মুজিব শিল্পনগরের ফেনী নদীর উত্তর-পশ্চিম দিকে অবস্থিত এলাকায় সরবরাহ করা যেতে পারে মর্মে আলোচনা হয় এবং এ বিষয়ে পরবর্তীতে সম্ভাব্যতা সমীক্ষা করার প্রয়োজনীয়তা আছে মর্মে সভায় অভিমত ব্যক্ত করা হয়।	৩.৬। ছোট ফেনী নদী হতে পানি উত্তোলন করে তা পরিশোধনের বিষয়ে সমীক্ষা করার উদ্যোগ গ্রহণ করতে হবে।	৩.৬। IWM এ বিষয়ে একমত পোষণ করে এবং এ বিষয়ে Final Report (Volume-II) এর Section 4.4.5 ও 15.2 এ ইতোমধ্যে সুপারিশ করা হয়েছে।

Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR





Final Report

Volume V: Sub-soil Investigation Report

February, 2020

INSTITUTE OF WATER MODELLING

Bangladesh Economic Zones Authority
Prime Minister's Office

DETAIL STUDY ON TOTAL WATER DEMAND AND WATER AVAILABILITY ASSESSMENT FOR BANGABANDHU SHEIKH MUJIB SHILPANAGAR

Final Report

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INSTITUTE OF WATER MODELLING

Contents of Final Report

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REPORT

1.0 INTRODUCTION :

This report presents the results of soil mechanics tests and field investigation carried out on the sub-surface soil samples collected from Proposed Intake Site at Osmanpur, Water Treatment Plant Site Near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram

Delta Soil Engineers was entrusted with the investigation works and all the factual information together with comments and recommendation have been included in this report. The purpose of investigation is for safe and economic design for the proposed foundation of the structure at the site.

2.0 OBJECTIVE OF WORKS :

The main scope of this investigation works are :

(a) Execution of exploratory borings, recording of sub-soil stratification and position of ground water level.

(b) Execution of standard penetration test (SPT) at an interval of 1.5m (5ft.) depth with collection of disturbed soil samples upto the final depth of exploration of each boring.

(c) Collection of undisturbed soil samples by thin walled shelby tubes from each hole.

(d) Execution of laboratory tests on soil samples to determine the physical and mechanical characteristics of the underlying soil deposit.

(e) Preparation of final report with all works including bearing capacity and skin friction values of sub-soil.

3.0 FIELD INVESTIGATION WORKS :

The field investigation was carried out by Delta Soil Engineers, Dhaka on 29-01-2019 to 08-02-2019 and execution of a total of twenty six borings upto the maximum depth of about 23.0 m from the existing ground surface. The executed Bore Holes were mentioned in the Bore Logs of Attachment-II. The holes were made by driving the casing of 10 cm (4") diameter upto 1.83m (6'-0") depth. The disturbed samples were collected by driving split spoon sampler of 3.15 cm (1-3/8") inner diameter with a hammer of 63.5 kg (140 lbs.) weight falling freely a height of about 76.2 cm (30") in average and the number of blows required to drive the sampler for every 0.15m (6") penetration over 0.45m (1.5 ft.) depth was recorded to measure the standard penetration resistance-N per 0.30m (foot.). Disturbed samples were collected at an interval of 1.5m (5 ft.) depth. The undisturbed samples were collected in 7.62 cm (3") diameter shelby tubes. Ground water table was recorded 24 hours after completion of each hole.

4.0 LABORATORY TESTINGS :

The disturbed samples collected in polythene bags and undisturbed samples in Shellby Tubes and were brought to soil mechanics Laboratory for testings. All the samples were visually examined and all undisturbed and representative disturbed samples were selected for necessary testings. The following tests were performed on the selected samples.

Natural Moisture Content	68 Nos.
Liquid & Plastic Limit	28 Nos.
Specific Gravity	45 Nos.
Grain Size Analysis	64 Nos.
Wet & Dry Density	26 Nos.
Unconfined Compression Test	26 Nos.
Consolidation Test	7 Nos.
Direct Shear Test	14 Nos.

5.0 DISCUSSION ON TEST RESULTS :

5.0 Soil Profile :

The stratification of materials around the holes at the site consists of an upper cohesive deposit of very soft to stiff silty CLAY and clayey SILT mixed with varying amount of fine sand upto the maximum depth of about 9.5 m from the existing ground surface. The deposit below upto the depth of exploration consists of noncohesive deposit of loose to very dense sandy SILT and silty FINE SAND mixed with trace amount of mica.

The standard penetration test (SPT) results have been shown in the respective boring log and the results vary between 1 and 11 in cohesive deposit and 6 and >50 in the non-cohesive deposit. The detailed information on stratification have been shown in the laboratory boring logs of attachment-II.

5.1 Range of Values of Test Results :

Name of Tests/Parameters	**Range of Values**
Natural Moisture Content (%)	24.1 - 36.6
Liquid Limit (%)	29 - 45
Plastic Limit (%)	21 - 28
Specific Gravity	2.648 - 2.675
Wet Density (kN/m^3)	18.12 - 18.52
Dry Density (kN/m^3)	13.39 - 14.72
Unconfined Compressive Strength (kN/m^2)	25.6 - 98.3
Compression Index, C_c	0.145 - 0.305
Void Ratio, e_o	0.771 - 0.927
Angle of Internal Friction, ϕ (degree)	32.0 - 40.0
Cohesion, C (kN/m^2)	0.0 - 0.0

6.0 BEARING CAPACITY FOR SHALLOW & DEEP FOUNDATION :

6.1 BEARING CAPACITY FOR SHALLOW FOUNDATION :

The allowable bearing capacities in kN/m^2 of sub-soil for square and strip footing for shallow foundation have been calculated with F.S.3 and is shown in Table-1 below :

TABLE – 1

ALLOWABLE BEARING CAPACITIES IN kN/m^2 WITH F.S.3

Bore Hole No.	Depth in (m)	Allowable bearing capacities for	
		Sq. Footing	Strip Footing
BH-1	1.5	0.32	0.27
	3.0	0.44	0.38
	4.5	0.44	0.38
BH-2	1.5	0.32	0.27
	3.0	0.38	0.32
	4.5	0.61	0.55
BH-3	1.5	0.32	0.27
	3.0	0.38	0.32
	4.5	0.61	0.55
BH-4	1.5	0.32	0.27
	3.0	0.56	0.45
	4.5	0.75	0.60
BH-5	1.5	0.32	0.27
	3.0	0.55	0.45
	4.5	0.75	0.60
BH-6	1.5	0.37	0.27
	3.0	0.56	0.45
	4.5	0.91	0.75
BH-7	1.5	0.37	0.27
	3.0	0.56	0.45
	4.5	0.91	0.75
BH-8	1.5	0.25	0.20
	3.0	0.25	0.20
	4.5	0.44	0.38
BH-9	1.5	0.38	0.32
	3.0	0.38	0.32
	4.5	0.44	0.38
BH-10	1.5	0.25	0.20
	3.0	0.25	0.30
	4.5	0.44	0.38
BH-11	1.5	0.38	0.32
	3.0	0.38	0.32
	4.5	0.60	0.55
BH-12	1.5	0.32	0.27
	3.0	0.38	0.32
	4.5	0.60	0.55

TABLE – 1

ALLOWABLE BEARING CAPACITIES IN kN/m^2 WITH F.S.3

Bore Hole No.	Depth in (m)	Allowable bearing capacities for	
		Sq. Footing	Strip Footing
BH-13	1.5	0.32	0.27
	3.0	0.55	0.45
	4.5	0.75	0.65
BH-14	1.5	0.25	0.20
	3.0	0.25	0.20
	4.5	0.44	0.38
BH-15	1.5	0.32	0.27
	3.0	0.55	0.45
	4.5	0.75	0.65
BH-16	1.5	0.20	0.15
	3.0	0.38	0.32
	4.5	0.60	0.55
BH-17	1.5	0.32	0.27
	3.0	0.55	0.45
	4.5	0.91	0.75
BH-18	1.5	0.25	0.20
	3.0	0.25	0.20
	4.5	1.23	0.98
BH-19	1.5	0.32	0.27
	3.0	0.44	0.38
	4.5	0.44	0.38
BH-20	1.5	0.32	0.27
	3.0	0.44	0.38
	4.5	0.44	0.38
BH-21	1.5	0.20	0.15
	3.0	0.38	0.32
	4.5	2.63	2.40
BH-22	1.5	0.32	0.27
	3.0	0.38	0.32
	4.5	0.75	0.65
BH-23	1.5	0.38	0.32
	3.0	0.38	0.32
	4.5	0.60	0.50
BH-24	1.5	0.32	0.27
	3.0	0.55	0.45
	4.5	0.91	0.75
BH-25	1.5	0.20	0.15
	3.0	0.38	0.32
	4.5	0.75	0.65
BH-26	1.5	0.25	0.20
	3.0	0.25	0.20
	4.5	0.44	0.38

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-1

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	2	2	2.356	12.263	13.00	21.670	45.51	67.18	22.39	26.87
6.0	s	8	8	2.356		18.85	188.496	64.36	252.85	84.28	101.14
7.5	s	10	10	2.356		23.56	235.620	87.92	323.54	107.85	129.42
9.0	s	18	16.5	2.356		38.88	388.773	126.79	515.57	171.86	206.23
10.5	s	30	22.5	2.356		53.01	530.145	179.81	709.95	236.65	283.98
12.0	s	40	27.5	2.356		64.80	647.955	244.60	892.56	297.52	357.02
13.5	s	50	32.5	2.356		76.58	765.765	321.18	1086.95	362.32	434.78
15.0	s	50	32.5	2.356		76.58	765.765	397.76	1163.52	387.84	465.41
16.5	s	50	32.5	2.356		76.58	765.765	474.33	1240.10	413.37	496.04
18.0	s	50	32.5	2.356		76.58	765.765	550.91	1316.67	438.89	526.67
20.0	s	50	32.5	2.356		76.58	765.765	627.49	1393.25	464.42	557.30

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-2

Pile diameter D= 0.5 m   Cross Sectional Area, A_c = 0.19635 m²   F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	2	2	2.356	12.263	13.00	21.670	26.00	47.67	15.89	19.07
4.5	c	3	3	2.356	18.394	19.50	32.505	45.51	78.01	26.00	31.20
6.0	s	6	6	2.356		14.14	141.372	59.64	201.02	67.01	80.41
7.5	s	8	8	2.356		18.85	188.496	78.49	266.99	89.00	106.80
9.0	s	17	16.0	2.356		37.70	376.992	116.19	493.18	164.39	197.27
10.5	s	32	23.5	2.356		55.37	553.707	171.56	725.27	241.76	290.11
12.0	s	38	26.5	2.356		62.44	624.393	234.00	858.39	286.13	343.36
13.5	s	42	28.5	2.356		67.15	671.517	301.15	972.67	324.22	389.07
15.0	s	50	32.5	2.356		76.58	765.765	377.73	1143.49	381.16	457.40
16.5	s	50	32.5	2.356		76.58	765.765	454.31	1220.07	406.69	488.03
18.0	s	50	32.5	2.356		76.58	765.765	530.88	1296.65	432.22	518.66
20.0	s	50	32.5	2.356		76.58	765.765	607.46	1373.22	457.74	549.29

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-3

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	2	2	2.356	12.263	13.00	21.670	26.00	47.67	15.89	19.07
4.5	c	3	3	2.356	18.394	19.50	32.505	45.51	78.01	26.00	31.20
6.0	s	19	17.0	2.356		40.06	400.554	85.56	486.12	162.04	194.45
7.5	s	20	17.5	2.356		41.23	412.335	126.79	539.13	179.71	215.65
9.0	s	32	23.5	2.356		55.37	553.707	182.17	735.87	245.29	294.35
10.5	s	40	27.5	2.356		64.80	647.955	246.96	894.92	298.31	357.97
12.0	s	35	25.0	2.356		58.90	589.050	305.87	894.92	298.31	357.97
13.5	s	43	29.0	2.356		68.33	683.298	374.20	1057.49	352.50	423.00
15.0	s	50	32.5	2.356		76.58	765.765	450.77	1216.54	405.51	486.61
16.5	s	50	32.5	2.356		76.58	765.765	527.35	1293.11	431.04	517.25
18.0	s	50	32.5	2.356		76.58	765.765	603.92	1369.69	456.56	547.88
20.0	s	50	32.5	2.356		76.58	765.765	680.50	1446.27	482.09	578.51

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-4

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	4	4	2.356	24.525	26.00	43.339	58.51	101.85	33.95	40.74
6.0	c	4	4	2.356	24.525	26.00	43.339	84.51	127.85	42.62	51.14
7.5	c	7	7	2.356	42.919	45.51	75.844	130.02	205.86	68.62	82.34
9.0	s	40	27.5	2.356		64.80	647.955	194.81	842.77	280.92	337.11
10.5	s	42	28.5	2.356		67.15	671.517	261.96	933.48	311.16	373.39
12.0	s	50	32.5	2.356		76.58	765.765	338.54	1104.31	368.10	441.72
13.5	s	50	32.5	2.356		76.58	765.765	415.12	1180.88	393.63	472.35
15.0	s	50	32.5	2.356		76.58	765.765	491.69	1257.46	419.15	502.98
16.5	s	50	32.5	2.356		76.58	765.765	568.27	1334.03	444.68	533.61
18.0	s	50	32.5	2.356		76.58	765.765	644.85	1410.61	470.20	564.24
20.0	s	50	32.5	2.356		76.58	765.765	721.42	1487.19	495.73	594.88

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-5

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	4	4	2.356	24.525	26.00	43.339	58.51	101.85	33.95	40.74
6.0	c	5	5	2.356	30.656	32.50	54.174	91.01	145.19	48.40	58.07
7.5	s	18	16.5	2.356		38.88	388.773	129.89	518.66	172.89	207.47
9.0	s	22	18.5	2.356		43.59	435.897	173.48	609.38	203.13	243.75
10.5	s	35	25.0	2.356		58.90	589.050	232.38	821.43	273.81	328.57
12.0	s	50	32.5	2.356		76.58	765.765	308.96	1074.73	358.24	429.89
13.5	s	35	25.0	2.356		58.90	589.050	367.87	956.92	318.97	382.77
15.0	s	38	26.5	2.356		62.44	624.393	430.30	1054.70	351.57	421.88
16.5	s	45	30.0	2.356		70.69	706.860	500.99	1207.85	402.62	483.14
18.0	s	45	30.0	2.356		70.69	706.860	571.68	1278.54	426.18	511.41
20.0	s	50	32.5	2.356		76.58	765.765	648.25	1414.02	471.34	565.61

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-6

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	5	5	2.356	30.656	32.50	54.174	65.01	119.18	39.73	47.67
6.0	s	18	16.5	2.356		38.88	388.773	103.89	492.66	164.22	197.06
7.5	s	30	22.5	2.356		53.01	530.145	156.90	687.05	229.02	274.82
9.0	s	40	27.5	2.356		64.80	647.955	221.70	869.65	289.88	347.86
10.5	s	42	28.5	2.356		67.15	671.517	288.85	960.36	320.12	384.15
12.0	s	50	32.5	2.356		76.58	765.765	365.42	1131.19	377.06	452.48
13.5	s	50	32.5	2.356		76.58	765.765	442.00	1207.76	402.59	483.11
15.0	s	50	32.5	2.356		76.58	765.765	518.58	1284.34	428.11	513.74
16.5	s	50	32.5	2.356		76.58	765.765	595.15	1360.92	453.64	544.37
18.0	s	50	32.5	2.356		76.58	765.765	671.73	1437.49	479.16	575.00
20.0	s	50	32.5	2.356		76.58	765.765	748.31	1514.07	504.69	605.63

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-7

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	5	5	2.356	30.656	32.50	54.174	65.01	119.18	39.73	47.67
6.0	c	6	6	2.356	36.788	39.01	65.009	104.01	169.02	56.34	67.61
7.5	s	15	15	2.356		35.34	353.430	139.36	492.79	164.26	197.11
9.0	s	42	28.5	2.356		67.15	671.517	206.51	878.03	292.68	351.21
10.5	s	43	29.0	2.356		68.33	683.298	274.84	958.14	319.38	383.25
12.0	s	50	32.5	2.356		76.58	765.765	351.41	1117.18	372.39	446.87
13.5	s	50	32.5	2.356		76.58	765.765	427.99	1193.76	397.92	477.50
15.0	s	50	32.5	2.356		76.58	765.765	504.57	1270.33	423.44	508.13
16.5	s	50	32.5	2.356		76.58	765.765	581.14	1346.91	448.97	538.76
18.0	s	50	32.5	2.356		76.58	765.765	657.72	1423.48	474.49	569.39
20.0	s	50	32.5	2.356		76.58	765.765	734.30	1500.06	500.02	600.02

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-8

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area, A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	3	3	2.356	18.394	19.50	32.505	19.50	52.01	17.34	20.80
3.0	c	1	1	2.356	6.131	6.50	10.835	26.00	36.84	12.28	14.74
4.5	c	2	2	2.356	12.263	13.00	21.670	39.01	60.68	20.23	24.27
6.0	c	8	8	2.356	49.050	52.01	86.679	91.01	177.69	59.23	71.08
7.5	s	16	15.5	2.356		36.52	365.211	127.53	492.74	164.25	197.10
9.0	s	28	21.5	2.356		50.66	506.583	178.19	684.77	228.26	273.91
10.5	s	43	29.0	2.356		68.33	683.298	246.52	929.82	309.94	371.93
12.0	s	45	30.0	2.356		70.69	706.860	317.21	1024.07	341.36	409.63
13.5	s	50	32.5	2.356		76.58	765.765	393.78	1159.55	386.52	463.82
15.0	s	40	27.5	2.356		64.80	647.955	458.58	1106.53	368.84	442.61
16.5	s	50	32.5	2.356		76.58	765.765	535.16	1300.92	433.64	520.37
18.0	s	50	32.5	2.356		76.58	765.765	611.73	1377.50	459.17	551.00
20.0	s	50	32.5	2.356		76.58	765.765	688.31	1454.07	484.69	581.63

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-9

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	3	3	2.356	18.394	19.50	32.505	19.50	52.01	17.34	20.80
3.0	c	2	2	2.356	12.263	13.00	21.670	32.50	54.17	18.06	21.67
4.5	c	2	2	2.356	12.263	13.00	21.670	45.51	67.18	22.39	26.87
6.0	c	7	7	2.356	42.919	45.51	75.844	91.01	166.86	55.62	66.74
7.5	s	13	13	2.356		30.63	306.306	121.64	427.95	142.65	171.18
9.0	s	24	19.5	2.356		45.95	459.459	167.59	627.05	209.02	250.82
10.5	s	30	22.5	2.356		53.01	530.145	220.60	750.75	250.25	300.30
12.0	s	35	25.0	2.356		58.90	589.050	279.51	868.56	289.52	347.42
13.5	s	42	28.5	2.356		67.15	671.517	346.66	1018.18	339.39	407.27
15.0	s	48	31.5	2.356		74.22	742.203	420.88	1163.08	387.69	465.23
16.5	s	50	32.5	2.356		76.58	765.765	497.46	1263.22	421.07	505.29
18.0	s	50	32.5	2.356		76.58	765.765	574.03	1339.80	446.60	535.92
20.0	s	50	32.5	2.356		76.58	765.765	650.61	1416.37	472.12	566.55

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-10

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area, A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	1	1	2.356	6.131	6.50	10.835	19.50	30.34	10.11	12.14
4.5	c	2	2	2.356	12.263	13.00	21.670	32.50	54.17	18.06	21.67
6.0	s	10	10	2.356		23.56	235.620	56.07	291.69	97.23	116.67
7.5	s	17	16.0	2.356		37.70	376.992	93.77	470.76	156.92	188.30
9.0	s	40	27.5	2.356		64.80	647.955	158.56	806.52	268.84	322.61
10.5	s	35	25.0	2.356		58.90	589.050	217.47	806.52	268.84	322.61
12.0	s	45	30.0	2.356		70.69	706.860	288.15	995.01	331.67	398.00
13.5	s	49	32.0	2.356		75.40	753.984	363.55	1117.53	372.51	447.01
15.0	s	50	32.5	2.356		76.58	765.765	440.13	1205.89	401.96	482.36
16.5	s	50	32.5	2.356		76.58	765.765	516.70	1282.47	427.49	512.99
18.0	s	50	32.5	2.356		76.58	765.765	593.28	1359.04	453.01	543.62
20.0	s	50	32.5	2.356		76.58	765.765	669.86	1435.62	478.54	574.25

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-11

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	3	3	2.356	18.394	19.50	32.505	19.50	52.01	17.34	20.80
3.0	c	2	2	2.356	12.263	13.00	21.670	32.50	54.17	18.06	21.67
4.5	c	3	3	2.356	18.394	19.50	32.505	52.01	84.51	28.17	33.80
6.0	s	13	13	2.356		30.63	306.306	82.64	388.94	129.65	155.58
7.5	s	17	16.0	2.356		37.70	376.992	120.34	497.33	165.78	198.93
9.0	s	25	20.0	2.356		47.12	471.240	167.46	638.70	212.90	255.48
10.5	s	37	26.0	2.356		61.26	612.612	228.72	841.33	280.44	336.53
12.0	s	43	29.0	2.356		68.33	683.298	297.05	980.35	326.78	392.14
13.5	s	48	31.5	2.356		74.22	742.203	371.27	1113.47	371.16	445.39
15.0	s	36	25.5	2.356		60.08	600.831	431.35	1032.19	344.06	412.87
16.5	s	50	32.5	2.356		76.58	765.765	507.93	1273.70	424.57	509.48
18.0	s	50	32.5	2.356		76.58	765.765	584.51	1350.27	450.09	540.11
20.0	s	50	32.5	2.356		76.58	765.765	661.08	1426.85	475.62	570.74

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-12

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	2	2	2.356	12.263	13.00	21.670	26.00	47.67	15.89	19.07
4.5	c	3	3	2.356	18.394	19.50	32.505	45.51	78.01	26.00	31.20
6.0	s	25	20.0	2.356		47.12	471.240	92.63	563.87	187.96	225.55
7.5	s	30	22.5	2.356		53.01	530.145	145.64	675.79	225.26	270.32
9.0	s	27	21.0	2.356		49.48	494.802	195.12	689.93	229.98	275.97
10.5	s	35	25.0	2.356		58.90	589.050	254.03	843.08	281.03	337.23
12.0	s	47	31.0	2.356		73.04	730.422	327.07	1057.49	352.50	423.00
13.5	s	46	30.5	2.356		71.86	718.641	398.94	1117.58	372.53	447.03
15.0	s	50	32.5	2.356		76.58	765.765	475.51	1241.28	413.76	496.51
16.5	s	44	29.5	2.356		69.51	695.079	545.02	1240.10	413.37	496.04
18.0	s	50	32.5	2.356		76.58	765.765	621.60	1387.36	462.45	554.94
20.0	s	50	32.5	2.356		76.58	765.765	698.17	1463.94	487.98	585.57

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-13

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	4	4	2.356	24.525	26.00	43.339	58.51	101.85	33.95	40.74
6.0	s	22	18.5	2.356		43.59	435.897	102.10	537.99	179.33	215.20
7.5	s	36	25.5	2.356		60.08	600.831	162.18	763.01	254.34	305.20
9.0	s	40	27.5	2.356		64.80	647.955	226.98	874.93	291.64	349.97
10.5	s	42	28.5	2.356		67.15	671.517	294.13	965.64	321.88	386.26
12.0	s	35	25.0	2.356		58.90	589.050	353.03	942.08	314.03	376.83
13.5	s	40	27.5	2.356		64.80	647.955	417.83	1065.78	355.26	426.31
15.0	s	50	32.5	2.356		76.58	765.765	494.40	1260.17	420.06	504.07
16.5	s	50	32.5	2.356		76.58	765.765	570.98	1336.75	445.58	534.70
18.0	s	50	32.5	2.356		76.58	765.765	647.56	1413.32	471.11	565.33
20.0	s	50	32.5	2.356		76.58	765.765	724.13	1489.90	496.63	595.96

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-14

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m $Qs=0.45*Cu*A_S$ (Clay),$1.0*N'*A_S$ (sand) kN	Ultimate End Bearing $Qe=9*Cu*A_c$ (Clay),$120*N'*A_c$ (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	1	1	2.356	6.131	6.50	10.835	19.50	30.34	10.11	12.14
4.5	c	2	2	2.356	12.263	13.00	21.670	32.50	54.17	18.06	21.67
6.0	s	24	19.5	2.356		45.95	459.459	78.45	537.91	179.30	215.16
7.5	s	27	21.0	2.356		49.48	494.802	127.93	622.73	207.58	249.09
9.0	s	35	25.0	2.356		58.90	589.050	186.84	775.89	258.63	310.35
10.5	s	40	27.5	2.356		64.80	647.955	251.63	899.59	299.86	359.83
12.0	s	43	29.0	2.356		68.33	683.298	319.96	1003.26	334.42	401.30
13.5	s	50	32.5	2.356		76.58	765.765	396.54	1162.30	387.43	464.92
15.0	s	40	27.5	2.356		64.80	647.955	461.33	1109.29	369.76	443.71
16.5	s	50	32.5	2.356		76.58	765.765	537.91	1303.67	434.56	521.47
18.0	s	21	18.0	2.356		42.41	424.116	580.32	1004.44	334.81	401.77
20.0	s	50	32.5	2.356		76.58	765.765	656.90	1422.66	474.22	569.06

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-15

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	11	11	2.356	67.444	71.51	119.183	104.01	223.20	74.40	89.28
6.0	c	18	16.5	2.356	101.166	107.26	178.775	211.28	390.05	130.02	156.02
7.5	s	30	22.5	2.356		53.01	530.145	264.29	794.44	264.81	317.78
9.0	s	38	26.5	2.356		62.44	624.393	326.73	951.13	317.04	380.45
10.5	s	50	32.5	2.356		76.58	765.765	403.31	1169.07	389.69	467.63
12.0	s	50	32.5	2.356		76.58	765.765	479.89	1245.65	415.22	498.26
13.5	s	50	32.5	2.356		76.58	765.765	556.46	1322.23	440.74	528.89
15.0	s	50	32.5	2.356		76.58	765.765	633.04	1398.80	466.27	559.52
16.5	s	50	32.5	2.356		76.58	765.765	709.61	1475.38	491.79	590.15
18.0	s	50	32.5	2.356		76.58	765.765	786.19	1551.96	517.32	620.78
20.0	s	50	32.5	2.356		76.58	765.765	862.77	1628.53	542.84	651.41

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-16

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	1	1	2.356	6.131	6.50	10.835	6.50	17.34	5.78	6.93
3.0	c	2	2	2.356	12.263	13.00	21.670	19.50	41.17	13.72	16.47
4.5	c	3	3	2.356	18.394	19.50	32.505	39.01	71.51	23.84	28.60
6.0	s	17	16.0	2.356		37.70	376.992	76.70	453.70	151.23	181.48
7.5	s	30	22.5	2.356		53.01	530.145	129.72	659.86	219.95	263.95
9.0	s	40	27.5	2.356		64.80	647.955	194.51	842.47	280.82	336.99
10.5	s	48	31.5	2.356		74.22	742.203	268.73	1010.94	336.98	404.37
12.0	s	40	27.5	2.356		64.80	647.955	333.53	981.48	327.16	392.59
13.5	s	50	32.5	2.356		76.58	765.765	410.11	1175.87	391.96	470.35
15.0	s	32	23.5	2.356		55.37	553.707	465.48	1019.18	339.73	407.67
16.5	s	50	32.5	2.356		76.58	765.765	542.05	1307.82	435.94	523.13
18.0	s	50	32.5	2.356		76.58	765.765	618.63	1384.39	461.46	553.76
20.0	s	50	32.5	2.356		76.58	765.765	695.21	1460.97	486.99	584.39

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-17

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	5	5	2.356	30.656	32.50	54.174	65.01	119.18	39.73	47.67
6.0	s	15	15	2.356		35.34	353.430	100.35	453.78	151.26	181.51
7.5	s	18	16.5	2.356		38.88	388.773	139.23	528.00	176.00	211.20
9.0	s	38	26.5	2.356		62.44	624.393	201.67	826.06	275.35	330.42
10.5	s	42	28.5	2.356		67.15	671.517	268.82	940.34	313.45	376.13
12.0	s	50	32.5	2.356		76.58	765.765	345.40	1111.16	370.39	444.46
13.5	s	50	32.5	2.356		76.58	765.765	421.97	1187.74	395.91	475.09
15.0	s	50	32.5	2.356		76.58	765.765	498.55	1264.31	421.44	505.73
16.5	s	50	32.5	2.356		76.58	765.765	575.12	1340.89	446.96	536.36
18.0	s	50	32.5	2.356		76.58	765.765	651.70	1417.47	472.49	566.99
20.0	s	50	32.5	2.356		76.58	765.765	728.28	1494.04	498.01	597.62

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-18

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D=		0.5 m		Cross Sectional Area,A_c =		0.19635 m²		F. Safety = 3.0			
Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	3	3	2.356	18.394	19.50	32.505	19.50	52.01	17.34	20.80
3.0	c	1	1	2.356	6.131	6.50	10.835	26.00	36.84	12.28	14.74
4.5	c	7	7	2.356	42.919	45.51	75.844	71.51	147.35	49.12	58.94
6.0	c	5	5	2.356	30.656	32.50	54.174	104.01	158.19	52.73	63.28
7.5	s	10	10	2.356		23.56	235.620	127.58	363.20	121.07	145.28
9.0	s	33	24.0	2.356		56.55	565.488	184.12	749.61	249.87	299.85
10.5	s	36	25.5	2.356		60.08	600.831	244.21	845.04	281.68	338.02
12.0	s	35	25.0	2.356		58.90	589.050	303.11	892.16	297.39	356.87
13.5	s	50	32.5	2.356		76.58	765.765	379.69	1145.45	381.82	458.18
15.0	s	50	32.5	2.356		76.58	765.765	456.27	1222.03	407.34	488.81
16.5	s	50	32.5	2.356		76.58	765.765	532.84	1298.61	432.87	519.44
18.0	s	50	32.5	2.356		76.58	765.765	609.42	1375.18	458.39	550.07
20.0	s	50	32.5	2.356		76.58	765.765	685.99	1451.76	483.92	580.70

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-19

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	2	2	2.356	12.263	13.00	21.670	45.51	67.18	22.39	26.87
6.0	c	6	6	2.356	36.788	39.01	65.009	84.51	149.52	49.84	59.81
7.5	s	14	14	2.356		32.99	329.868	117.50	447.37	149.12	178.95
9.0	s	20	17.5	2.356		41.23	412.335	158.73	571.07	190.36	228.43
10.5	s	25	20.0	2.356		47.12	471.240	205.86	677.10	225.70	270.84
12.0	s	19	17.0	2.356		40.06	400.554	245.91	646.46	215.49	258.59
13.5	s	26	20.5	2.356		48.30	483.021	294.21	777.23	259.08	310.89
15.0	s	36	25.5	2.356		60.08	600.831	354.30	955.13	318.38	382.05
16.5	s	21	18.0	2.356		42.41	424.116	396.71	820.82	273.61	328.33
18.0	s	14	14.5	2.356		34.16	341.649	430.87	772.52	257.51	309.01
19.5	s	40	27.5	2.356		64.80	647.955	495.67	1143.62	381.21	457.45
21.0	s	50	32.5	2.356		76.58	765.765	572.24	1338.01	446.00	535.20
23.0	s	50	32.5	2.356		76.58	765.765	648.82	1414.59	471.53	565.83

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-20

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m $Qs=0.45*Cu*A_S$ (Clay),$1.0*N'*A_S$ (sand) kN	Ultimate End Bearing $Qe=9*Cu*A_c$ (Clay),$120*N'*A_c$ (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	4	4	2.356	24.525	26.00	43.339	39.01	82.34	27.45	32.94
4.5	c	5	5	2.356	30.656	32.50	54.174	71.51	125.68	41.89	50.27
6.0	s	15	15	2.356		35.34	353.430	106.85	460.28	153.43	184.11
7.5	s	22	18.5	2.356		43.59	435.897	150.44	586.34	195.45	234.54
9.0	s	38	26.5	2.356		62.44	624.393	212.88	837.27	279.09	334.91
10.5	s	42	28.5	2.356		67.15	671.517	280.03	951.55	317.18	380.62
12.0	s	43	29.0	2.356		68.33	683.298	348.36	1031.66	343.89	412.66
13.5	s	50	32.5	2.356		76.58	765.765	424.94	1190.70	396.90	476.28
15.0	s	47	31.0	2.356		73.04	730.422	497.98	1228.40	409.47	491.36
16.5	s	50	32.5	2.356		76.58	765.765	574.56	1340.32	446.77	536.13
18.0	s	50	32.5	2.356		76.58	765.765	651.13	1416.90	472.30	566.76
20.0	s	50	32.5	2.356		76.58	765.765	727.71	1493.47	497.82	597.39

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-21

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D=		0.5 m		Cross Sectional Area, A_c =		0.19635 m²		F. Safety = 3.0			
Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	1	1	2.356	6.131	6.50	10.835	6.50	17.34	5.78	6.93
3.0	c	2	2	2.356	12.263	13.00	21.670	19.50	41.17	13.72	16.47
4.5	s	18	16.5	2.356		38.88	388.773	58.38	447.15	149.05	178.86
6.0	s	21	18.0	2.356		42.41	424.116	100.79	524.91	174.97	209.96
7.5	s	27	21.0	2.356		49.48	494.802	150.27	645.07	215.02	258.03
9.0	s	30	22.5	2.356		53.01	530.145	203.29	733.43	244.48	293.37
10.5	s	42	28.5	2.356		67.15	671.517	270.44	941.95	313.98	376.78
12.0	s	50	32.5	2.356		76.58	765.765	347.01	1112.78	370.93	445.11
13.5	s	50	32.5	2.356		76.58	765.765	423.59	1189.36	396.45	475.74
15.0	s	37	26.0	2.356		61.26	612.612	484.85	1097.46	365.82	438.99
16.5	s	50	32.5	2.356		76.58	765.765	561.43	1327.19	442.40	530.88
18.0	s	50	32.5	2.356		76.58	765.765	638.00	1403.77	467.92	561.51
20.0	s	50	32.5	2.356		76.58	765.765	714.58	1480.35	493.45	592.14

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-23

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	3	3	2.356	18.394	19.50	32.505	19.50	52.01	17.34	20.80
3.0	c	2	2	2.356	12.263	13.00	21.670	32.50	54.17	18.06	21.67
4.5	c	3	3	2.356	18.394	19.50	32.505	52.01	84.51	28.17	33.80
6.0	s	16	15.5	2.356		36.52	365.211	88.53	453.74	151.25	181.50
7.5	s	23	19.0	2.356		44.77	447.678	133.30	580.97	193.66	232.39
9.0	s	30	22.5	2.356		53.01	530.145	186.31	716.46	238.82	286.58
10.5	s	35	25.0	2.356		58.90	589.050	245.22	834.27	278.09	333.71
12.0	s	44	29.5	2.356		69.51	695.079	314.72	1009.80	336.60	403.92
13.5	s	50	32.5	2.356		76.58	765.765	391.30	1157.06	385.69	462.83
15.0	s	50	32.5	2.356		76.58	765.765	467.88	1233.64	411.21	493.46
16.5	s	39	27.0	2.356		63.62	636.174	531.49	1167.67	389.22	467.07
18.0	s	50	32.5	2.356		76.58	765.765	608.07	1373.83	457.94	549.53
20.0	s	50	32.5	2.356		76.58	765.765	684.65	1450.41	483.47	580.16

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-22

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	2	2	2.356	12.263	13.00	21.670	26.00	47.67	15.89	19.07
4.5	c	4	4	2.356	24.525	26.00	43.339	52.01	95.35	31.78	38.14
6.0	s	17	16.0	2.356		37.70	376.992	89.71	466.70	155.57	186.68
7.5	s	27	21.0	2.356		49.48	494.802	139.19	633.99	211.33	253.60
9.0	s	35	25.0	2.356		58.90	589.050	198.09	787.14	262.38	314.86
10.5	s	40	27.5	2.356		64.80	647.955	262.89	910.84	303.61	364.34
12.0	s	50	32.5	2.356		76.58	765.765	339.46	1105.23	368.41	442.09
13.5	s	40	27.5	2.356		64.80	647.955	404.26	1052.21	350.74	420.89
15.0	s	45	30.0	2.356		70.69	706.860	474.94	1181.80	393.93	472.72
16.5	s	40	27.5	2.356		64.80	647.955	539.74	1187.69	395.90	475.08
18.0	s	50	32.5	2.356		76.58	765.765	616.32	1382.08	460.69	552.83
20.0	s	50	32.5	2.356		76.58	765.765	692.89	1458.66	486.22	583.46

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 800 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-25

Pile diameter D= 0.8 m   Cross Sectional Area,A_c = 0.50266 m²   F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	1	1	3.770	6.131	10.40	27.737	10.40	38.14	12.71	15.26
3.0	c	2	2	3.770	12.263	20.80	55.474	31.20	86.68	28.89	34.67
4.5	c	4	4	3.770	24.525	41.61	110.949	72.81	183.76	61.25	73.50
6.0	s	18	16.5	3.770		62.20	995.259	135.01	1130.27	376.76	452.11
7.5	s	25	20.0	3.770		75.40	1206.374	210.41	1416.79	472.26	566.71
9.0	s	10	12.5	3.770		47.12	753.984	257.54	1011.52	337.17	404.61
10.5	s	13	13	3.770		49.01	784.143	306.54	1090.69	363.56	436.28
12.0	s	9	9	3.770		33.93	542.868	340.47	883.34	294.45	353.34
13.5	s	42	28.5	3.770		107.44	1719.084	447.92	2167.00	722.33	866.80
15.0	s	50	32.5	3.770		122.52	1960.358	570.44	2530.80	843.60	1012.32
16.5	s	50	32.5	3.770		122.52	1960.358	692.96	2653.32	884.44	1061.33
18.0	s	50	32.5	3.770		122.52	1960.358	815.48	2775.84	925.28	1110.34
20.0	s	50	32.5	3.770		122.52	1960.358	938.00	2898.36	966.12	1159.35

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 500 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-24

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.5 m Cross Sectional Area,A_c = 0.19635 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	2.356	12.263	13.00	21.670	13.00	34.67	11.56	13.87
3.0	c	3	3	2.356	18.394	19.50	32.505	32.50	65.01	21.67	26.00
4.5	c	5	5	2.356	30.656	32.50	54.174	65.01	119.18	39.73	47.67
6.0	s	8	8	2.356		18.85	188.496	83.86	272.35	90.78	108.94
7.5	s	22	18.5	2.356		43.59	435.897	127.45	563.35	187.78	225.34
9.0	s	42	28.5	2.356		67.15	671.517	194.60	866.12	288.71	346.45
10.5	s	38	26.5	2.356		62.44	624.393	257.04	881.43	293.81	352.57
12.0	s	40	27.5	2.356		64.80	647.955	321.83	969.79	323.26	387.92
13.5	s	50	32.5	2.356		76.58	765.765	398.41	1164.18	388.06	465.67
15.0	s	50	32.5	2.356		76.58	765.765	474.99	1240.75	413.58	496.30
16.5	s	50	32.5	2.356		76.58	765.765	551.56	1317.33	439.11	526.93
18.0	s	50	32.5	2.356		76.58	765.765	628.14	1393.90	464.63	557.56
20.0	s	50	32.5	2.356		76.58	765.765	704.72	1470.48	490.16	588.19

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 800 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-26

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 0.8 m Cross Sectional Area,A_c = 0.50266 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m $Qs=0.45*Cu*A_S$ (Clay),$1.0*N'*A_S$ (sand) kN	Ultimate End Bearing $Qe=9*Cu*A_c$ (Clay),$120*N'*A_c$ (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	3.770	12.263	20.80	55.474	20.80	76.28	25.43	30.51
3.0	c	1	1	3.770	6.131	10.40	27.737	31.20	58.94	19.65	23.58
4.5	c	2	2	3.770	12.263	20.80	55.474	52.01	107.48	35.83	42.99
6.0	s	14	14	3.770		52.78	844.462	104.79	949.25	316.42	379.70
7.5	s	21	18.0	3.770		67.86	1085.737	172.64	1258.38	419.46	503.35
9.0	c	6	6	3.770	36.788	62.41	166.423	235.05	401.48	133.83	160.59
10.5	s	8	8	3.770		30.16	482.550	265.21	747.76	249.25	299.10
12.0	s	6	6	3.770		22.62	361.912	287.83	649.74	216.58	259.90
13.5	s	40	27.5	3.770		103.67	1658.765	391.50	2050.27	683.42	820.11
15.0	s	50	32.5	3.770		122.52	1960.358	514.03	2474.38	824.79	989.75
16.5	s	50	32.5	3.770		122.52	1960.358	636.55	2596.91	865.64	1038.76
18.0	s	50	32.5	3.770		122.52	1960.358	759.07	2719.43	906.48	1087.77
20.0	s	50	32.5	3.770		122.52	1960.358	881.59	2841.95	947.32	1136.78

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 1000 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

BH-25

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Pile diameter D= 1 m Cross Sectional Area,A_c = 0.78540 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	1	1	4.712	6.131	13.00	43.339	13.00	56.34	18.78	22.54
3.0	c	2	2	4.712	12.263	26.00	86.679	39.01	125.68	41.89	50.27
4.5	c	4	4	4.712	24.525	52.01	173.357	91.01	264.37	88.12	105.75
6.0	s	18	16.5	4.712		77.75	1555.092	168.77	1723.86	574.62	689.54
7.5	s	25	20.0	4.712		94.25	1884.960	263.01	2147.97	715.99	859.19
9.0	s	10	12.5	4.712		58.90	1178.100	321.92	1500.02	500.01	600.01
10.5	s	13	13	4.712		61.26	1225.224	383.18	1608.40	536.13	643.36
12.0	s	9	9	4.712		42.41	848.232	425.59	1273.82	424.61	509.53
13.5	s	42	28.5	4.712		134.30	2686.068	559.90	3245.96	1081.99	1298.39
15.0	s	50	32.5	4.712		153.15	3063.060	713.05	3776.11	1258.70	1510.44
16.5	s	50	32.5	4.712		153.15	3063.060	866.20	3929.26	1309.75	1571.70
18.0	s	50	32.5	4.712		153.15	3063.060	1019.35	4082.41	1360.80	1632.97
20.0	s	50	32.5	4.712		153.15	3063.060	1172.51	4235.57	1411.86	1694.23

5.2 INDIVIDUAL CAST IN-SITU PILE CAPACITY FOR DEEP FOUNDATION

TABLE - 2

CHART FOR SKIN FRICTION & END BEARING CAPACITY OF CAST IN-SITU PILE IN kN & ALLOWABLE WORKING LOAD

FOR 1000 mm DIA PILE

Project : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

Location : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BH-26

Pile diameter D= 1 m Cross Sectional Area,A_c = 0.78540 m² F. Safety = 3.0

Depth in m	Type of Sample	Field SPT N	Corrected SPT N'=N,N<15 N'=15+(N-15)/2,N>15	Surface area for 1.5m segment m² A_S	Undrained Cohesion for Cohesive Soil, Cu=6.13125*N' kN	Ultimate skin friction for 1.5m Qs=0.45*Cu*A_S (Clay),1.0*N'*A_S (sand) kN	Ultimate End Bearing Qe=9*Cu*A_c (Clay),120*N'*A_c (sand) kN	Total Cumulitve Ultimate Skin Friction kN	Total Ultimate Load Capacity kN	Allowable Load Capacity with FS 3.0 kN	Allowable Load Capacity with FS 2.5 kN
1.5	c	2	2	4.712	12.263	26.00	86.679	26.00	112.68	37.56	45.07
3.0	c	1	1	4.712	6.131	13.00	43.339	39.01	82.34	27.45	32.94
4.5	c	2	2	4.712	12.263	26.00	86.679	65.01	151.69	50.56	60.68
6.0	s	14	14	4.712		65.97	1319.472	130.98	1450.45	483.48	580.18
7.5	s	21	18.0	4.712		84.82	1696.464	215.81	1912.27	637.42	764.91
9.0	c	6	6	4.712	36.788	78.01	260.036	293.82	553.85	184.62	221.54
10.5	s	8	8	4.712		37.70	753.984	331.52	1085.50	361.83	434.20
12.0	s	6	6	4.712		28.27	565.488	359.79	925.28	308.43	370.11
13.5	s	40	27.5	4.712		129.59	2591.820	489.38	3081.20	1027.07	1232.48
15.0	s	50	32.5	4.712		153.15	3063.060	642.53	3705.59	1235.20	1482.24
16.5	s	50	32.5	4.712		153.15	3063.060	795.69	3858.75	1286.25	1543.50
18.0	s	50	32.5	4.712		153.15	3063.060	948.84	4011.90	1337.30	1604.76
20.0	s	50	32.5	4.712		153.15	3063.060	1101.99	4165.05	1388.35	1666.02

7.0 CONCLUSION & RECOMMNDATION :

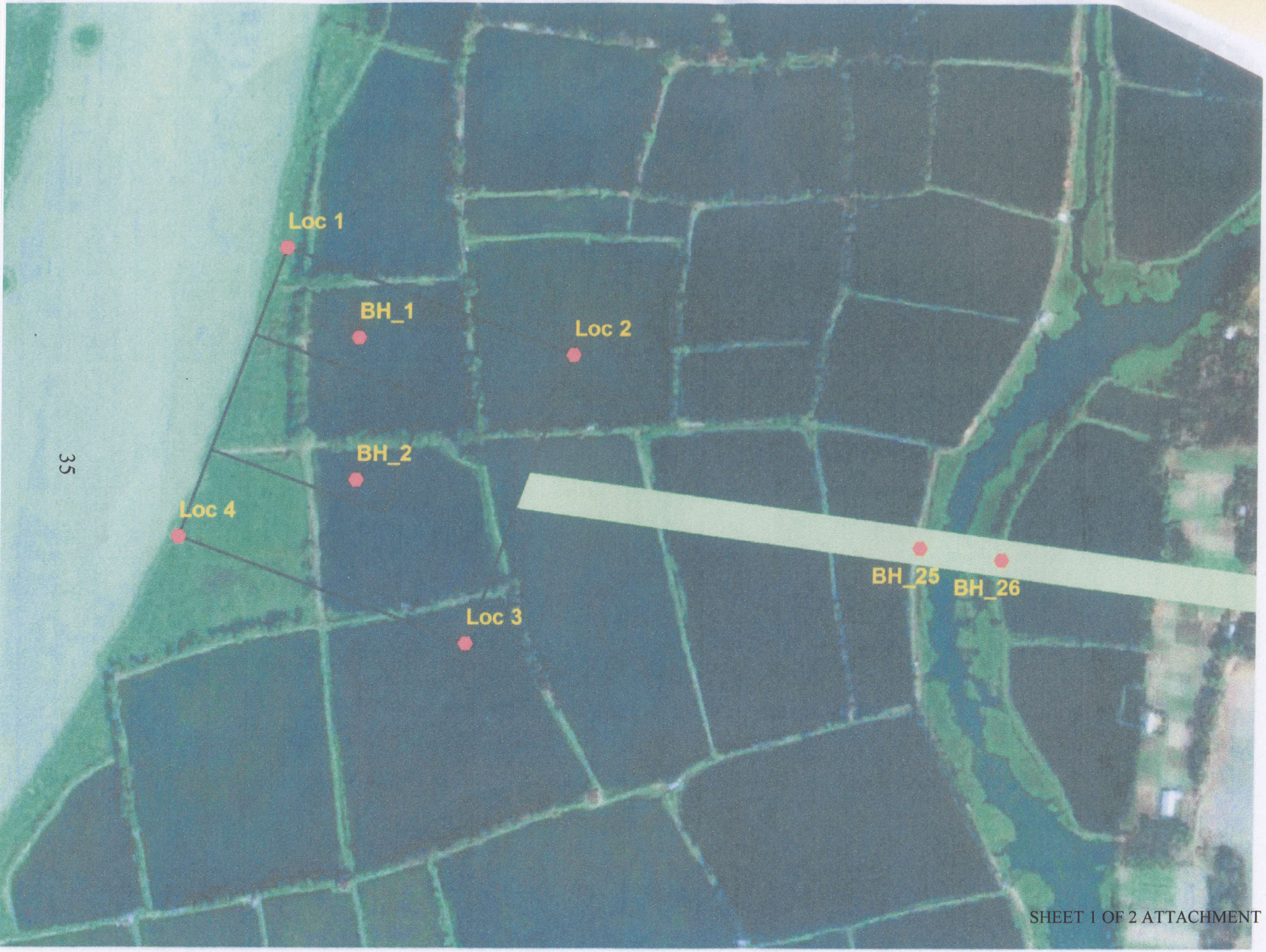
In the light of field and laboratory investigations it is concluded that the deposit encountered at the site consists of cohesive materials of cohesive deposit of very soft to stiff silty CLAY and clayey SILT mixed with varying amount of fine sand upto the maximum depth of about 9.5 m from the existing ground surface. The deposit below upto the depth of exploration consists of noncohesive deposit of loose to very dense sandy SILT and silty FINE SAND mixed with trace amount of mica.

The allowable bearing capacities at 1.5 m, 3.0 m and 4.5 m depths have been shown in Table-1 at page No. 4 to 5 and skin friction, end bearing and individual cast in-situ pile capacities of 500 mm diameter for Intake & Water Treatment Plant Site and 800 and 1000 mm diameter have been shown for Construction of of Bridge of River Crossing site have been shown in Table-2 at page no. 6 to 33.

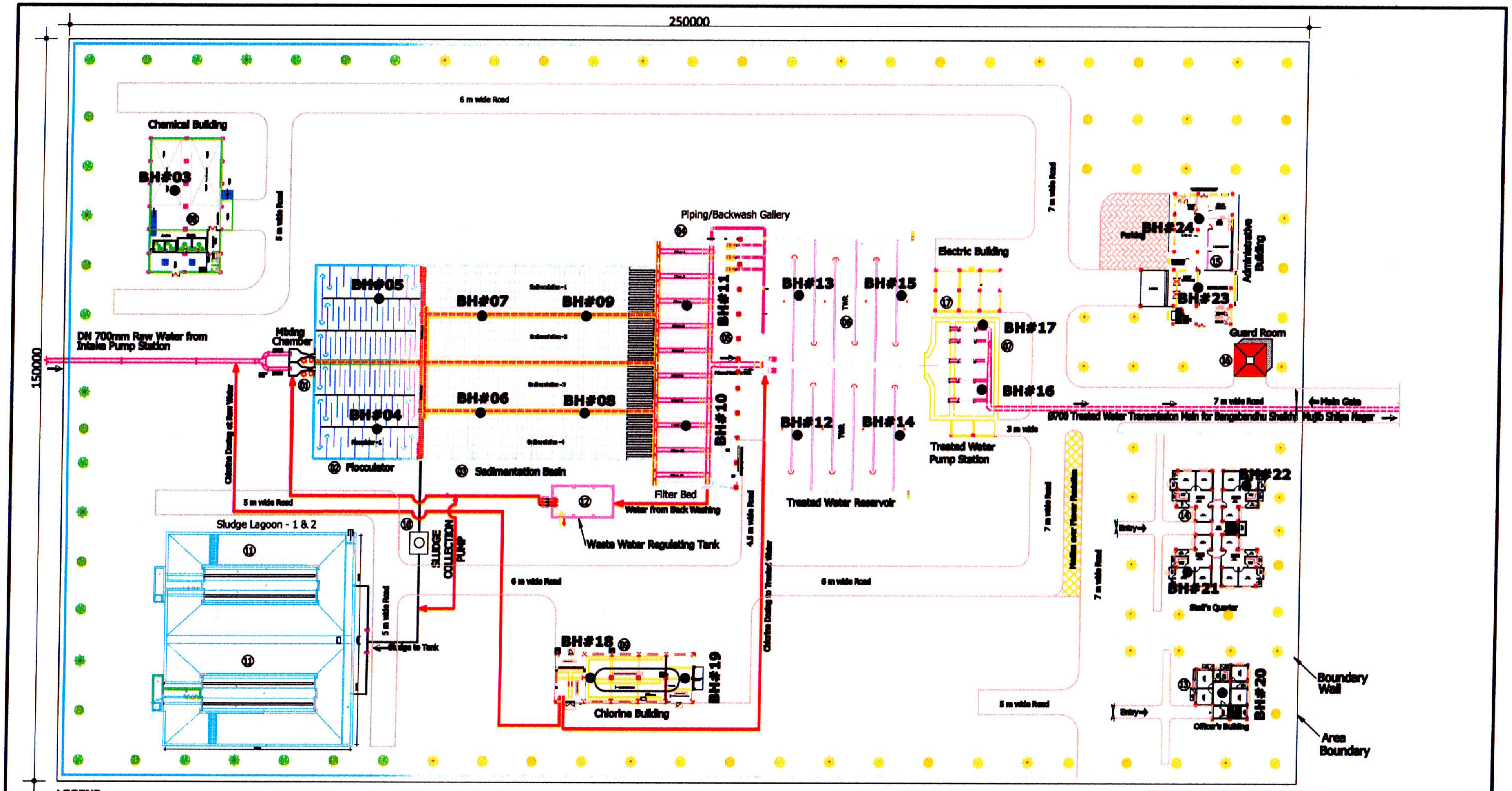
The Design Engineer shall choose suitable and appropriate type of foundation considering the overall structural load, loading pattern etc. of the proposed Intake and Water Treatment Plant and River Crossing at the site.

24-02-2019

Engr. Abul Hashim Sikder
B.Sc. Engg. (Civil), FIEB Fellow No. 8027
Senior Engineer
DELTA SOIL ENGINEERS



SHEET 1 OF 2 ATTACHMENT - I



LEGEND:

- 01. Mixing Chamber
- 02. Flocculation Basin
- 03. Sedimentation Basin
- 04. Filter Bed
- 05. Backwash/Piping Gallery
- 06. Treated Water Reservoir
- 07. Treated Water Pump House
- 08. Chemical Building
- 09. Chlorine Building
- 10. Sludge Collection Pump
- 11. Sludge Lagoon (2 nos.)
- 12. Waste Water Regulating Tank
- 13. Administrative Building
- 14. Officer's Quarter
- 15. Staff's Quarter
- 16. Guard Room
- 17. Electric Building
- 🟩 Plantation

Site Layout Plan of Water Treatment Plant near Takerhat Bazar (Bore Hole Map)

Rev	Description	Drawn	Checked	Approved	Date

CLIENT
Bangladesh Economic Zones Authority
Prime Minister's Office, Dhaka, Bangladesh

CONSULTANT
Institute of Water Modelling
House - 496, Road - 32, Mohakhali DOHS,
Dhaka-1206, Bangladesh

Notes:
All dimensions are in millimetres & all levels are in m PWD unless otherwise mentioned in drawing.

Original Drawing Size
A3 = 420x297

Scale - 1:750

Drawing No.
BSMSN-WTP-GS-C-01

Bangladesh Economic Zones Authority
Prime Minister's Office

Detail Study on Total Water Demand and Water Availability Assessment for Bangabandhu Sheikh Mujib Shilpa Nagar

Bore Hole
Site Layout Plan of Water Treatment Plant near Takerhat Bazar (Bore Hole Map)

Drawn	Design	Checked	Recommended	Approved
Fahim Uddin	Abdur Rahman	Md. Serajuddin	Team Leader	Md. Abdus Salam Mandal Executive Engineer (Attch.), BEZA

SHEET 2 OF 2 ATTACHMENT - I

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Intake Site at Osmanpur.

BORE HOLE NO. 1 22°51'25.038"N, 91°28'18.904"E

GROUND LEVEL R.L.: : 5.060 m

GROUND WATER LEVEL: : 3.536 m

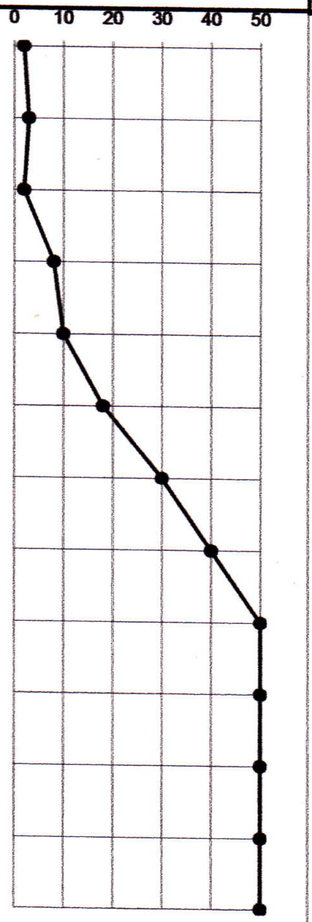
DATE : 07-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
06-02-2019	D-1	▨						1	1	1	2	1.5
	U-1	■		5.0	Grey soft silty CLAY trace fine sand medium plastic.							
	D-2	▨						1	1	2	3	3.0
	D-3	▨	5.0					1	1	1	2	4.5
	D-4	▨		3.0	Grey loose silty FINE SAND trace mica			2	3	5	8	6.0
	D-5	▨	8.0					3	4	6	10	7.5
	D-6	▨						4	8	10	18	9.0
	D-7	▨					100mm	5	14	16	30	10.5
	D-8	▨						8	18	22	40	12.0
	D-9	▨		12.0	Grey medium dense to very dense silty FINE SAND trace mica			10	22	28	50	13.5
	D-10	▨						12	23	27	50	15.0
	D-11	▨						14	24	26	50	16.5
	D-12	▨						15	30	20	50	18.0
	D-13	▨	20.0					17	35	15	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 1 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Intake Site at Osmanpur.

BORE HOLE NO. 2 22°51'21.282"N, 91°28'18.824"E

GROUND LEVEL R.L.: : 4.940 m

GROUND WATER LEVEL: : 3.416 m

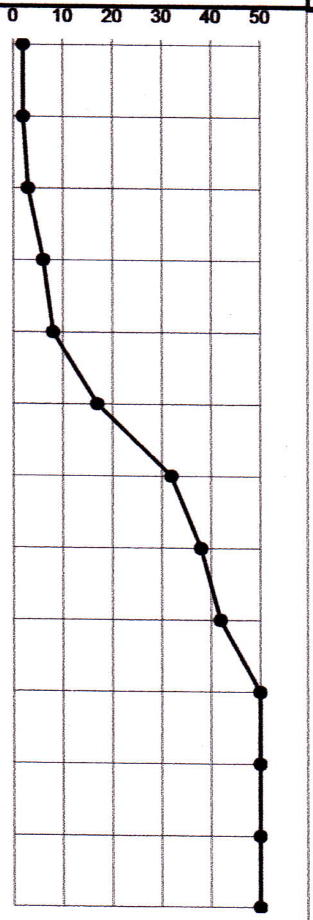
DATE : 08-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
07-02-2019	D-1	▨	2.0	2.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	U-1 D-2	■ ▨		3.0	Grey soft clayey SILT with fine sand low compress.			1	1	1	2	3.0
	D-3	▨	5.0					1	1	2	3	4.5
	D-4	▨		3.0	Grey loose silty FINE SAND trace mica			2	2	4	6	6.0
	D-5	▨	8.0					3	3	5	8	7.5
	D-6	▨						5	8	9	17	9.0
	D-7	▨						6	15	17	32	10.5
	D-8	▨						8	18	20	38	12.0
	D-9	▨		12.0	Grey medium dense to very dense silty FINE SAND trace mica			10	20	22	42	13.5
	D-10	▨						12	22	28	50	15.0
	D-11	▨						14	30	20	50	16.5
	D-12	▨						15	35	15	50	18.0
	D-13	▨	20.0					17	22	28	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 2 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 3 22°47'36.167"N, 91°27'19.296"E

GROUND LEVEL R.L.: : 3.686 m

GROUND WATER LEVEL: : 1.247 m

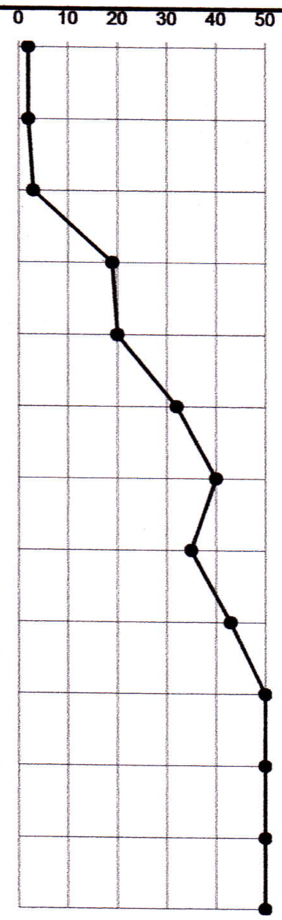
DATE : 02-02-2019

STANDARD PENETRATION RESISTANCE (FIELD S P T)

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	15cm	15cm	15cm	SPT	BH DEPTH (m)
01-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	1	2	3.0
	U-1 D-3	■ ▨	5.0					1	1	2	3	4.5
	D-4	▨	6.5	1.5	Grey medium dense sandy SILT trace mica			3	6	13	19	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			5	8	12	20	7.5
	D-6	▨						7	12	20	32	9.0
	D-7	▨						8	18	22	40	10.5
	D-8	▨						10	15	20	35	12.0
	D-9	▨						11	20	23	43	13.5
	D-10	▨						14	22	28	50	15.0
	D-11	▨						15	30	20	50	16.5
	D-12	▨						17	35	15	50	18.0
	D-13	▨	20.0					19	40	10	50	19.5



Drawn by : Checked by : Sheet 3 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 4 22⁰47'33.987"N, 91⁰27'17.638"E

GROUND LEVEL R.L.: : 3.752 m

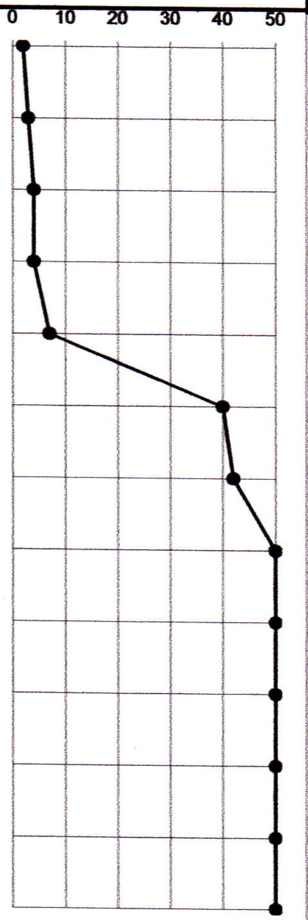
GROUND WATER LEVEL: : 1.313 m

DATE : 31-01-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRATION RESISTANCE (FIELD S P T)	BH DEPTH (m)
30-01-2019	D-1	▨	2.0	2.0	Grey soft silty CLAY trace fine sand medium plastic.	▥	100mm	1	1	1	2		1.5
	D-2	▨		6.0	Grey soft clayey SILT with fine sand med compress.	▦		1	1	2	3		3.0
	U-1 D-3	■ ▨						1	2	2	4		4.5
	D-4	▨						1	2	2	4		6.0
	D-5	▨	8.0					2	3	4	7		7.5
	D-6	▨		12.0	Grey dense to very dense silty FINE SAND trace mica	⁙		8	18	22	40		9.0
	D-7	▨						10	20	22	42		10.5
	D-8	▨						12	22	28	50		12.0
	D-9	▨						10	15	35	50		13.5
	D-10	▨						12	30	20	50		15.0
	D-11	▨						14	30	20	50		16.5
	D-12	▨						8	15	35	50		18.0
	D-13	▨	20.0					12	20	30	50		19.5



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Sheet 4 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 5 22°47'34.322"N, 91°27'18.827"E

GROUND LEVEL R.L.: : 3.697 m

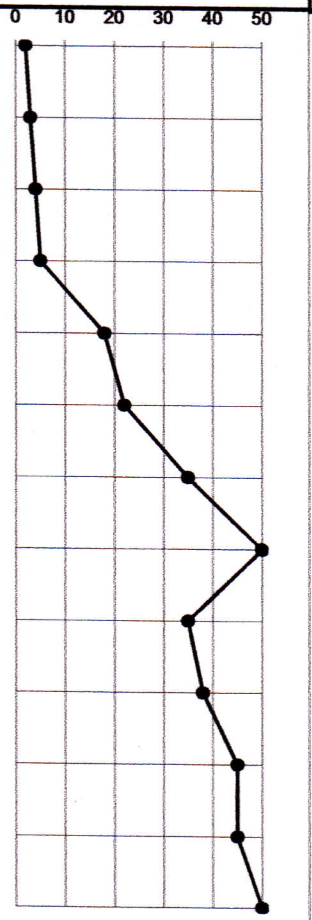
GROUND WATER LEVEL: : 1.258 m

DATE : 01-02-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
31-02-2019	D-1	▨		6.5	Grey soft to medium stiff silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	U-1 D-2	■ ▨						1	1	2	3	3.0
	D-3	▨						1	2	2	4	4.5
	D-4	▨	6.5					2	2	3	5	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			5	8	10	18	7.5
	D-6	▨						6	10	12	22	9.0
	D-7	▨						7	15	20	35	10.5
	D-8	▨						10	20	30	50	12.0
	D-9	▨						8	15	20	35	13.5
	D-10	▨						9	18	20	38	15.0
	D-11	▨						10	20	25	45	16.5
	D-12	▨						12	22	23	45	18.0
	D-13	▨	20.0					26	33	17	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 5 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 6 22°47'33.242"N, 91°27'18.051"E

GROUND LEVEL R.L.: : 3.963 m

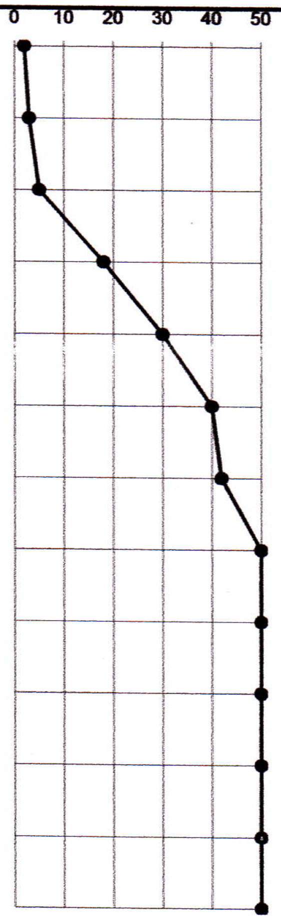
GROUND WATER LEVEL: : 1.524 m

DATE : 31-01-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				BH DEPTH (m)
								15cm	15cm	15cm	SPT	
30-01-2019	D-1	▨		3.5	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨	3.5					1	1	2	3	3.0
	U-1 D-3	■ ▨	5.0	1.5	Grey med stiff clayey SILT with fine sand med compress.			1	2	3	5	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			5	8	10	18	6.0
	D-5	▨						6	14	16	30	7.5
	D-6	▨						8	18	22	40	9.0
	D-7	▨						10	20	22	42	10.5
	D-8	▨						12	22	28	50	12.0
	D-9	▨						14	23	27	50	13.5
	D-10	▨						15	24	26	50	15.0
	D-11	▨						16	30	20	50	16.5
	D-12	▨						18	32	18	50	18.0
	D-13	▨	20.0					20	30	20	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 6 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 7 22°47'33.497"N, 91°27'18.937"E

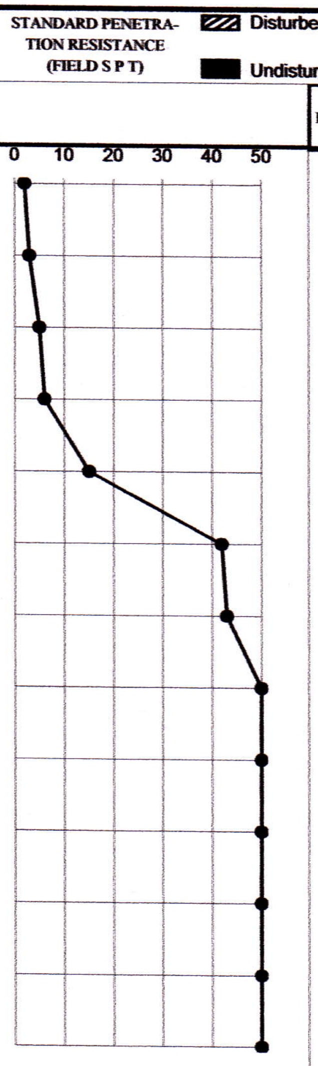
GROUND LEVEL R.L.: : 3.816 m

GROUND WATER LEVEL: : 1.377 m

DATE : 03-02-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
02-02-2019	D-1	▨		6.5	Grey soft to medium stiff silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	2	3	3.0
	U-1 D-3	■ ▨						2	2	3	5	4.5
	D-4	▨	6.5					2	3	3	6	6.0
	D-5	▨	8.0	3.0	Grey medium dense sandy SILT trace mica			5	7	8	15	7.5
	D-6	▨		12.0	Grey medium dense to very dense silty FINE SAND trace mica			7	20	22	42	9.0
	D-7	▨						8	20	23	43	10.5
	D-8	▨						10	22	28	50	12.0
	D-9	▨						12	30	20	50	13.5
	D-10	▨						14	32	18	50	15.0
	D-11	▨						15	22	28	50	16.5
	D-12	▨						17	30	20	50	18.0
	D-13	▨	20.0					18	32	18	50	19.5



Drawn by : Checked by : Sheet 7 of 26 Attachment II

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 8 22°47'32.453"N, 91°27'18.308"E

GROUND LEVEL R.L.: : 4.132 m

GROUND WATER LEVEL: : 1.998 m

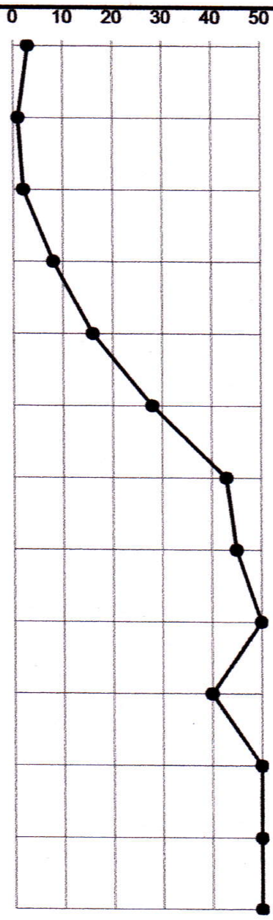
DATE : 03-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				BH DEPTH (m)
								15cm	15cm	15cm	SPT	
02-02-2019	D-1	▨		5.0	Grey very soft to soft silty CLAY trace fine sand medium plastic.		100mm	1	1	2	3	1.5
	D-2	▨						1	0	1	1	3.0
	D-3	▨	5.0					1	1	1	2	4.5
	U-1 D-4	■ ▨	6.5	1.5	Grey med stiff clayey SILT with fine sand med compress.			1	3	5	8	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			2	6	10	16	7.5
	D-6	▨						4	10	18	28	9.0
	D-7	▨						6	18	25	43	10.5
	D-8	▨						7	20	25	45	12.0
	D-9	▨						8	25	25	50	13.5
	D-10	▨						9	16	24	40	15.0
	D-11	▨						7	23	27	50	16.5
	D-12	▨						8	25	25	50	18.0
	D-13	▨	20.0					10	28	22	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 8 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 9 22°47'32.707"N, 91°278'19.198"E

GROUND LEVEL R.L.: : 3.962 m

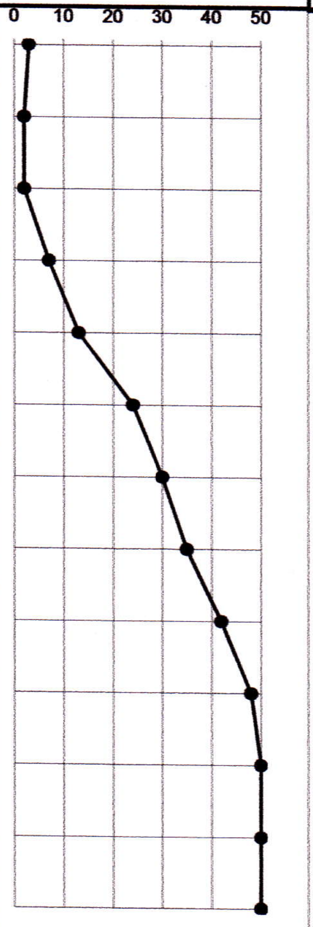
GROUND WATER LEVEL: : 1.218 m

DATE : 02-02-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
01-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	2	3	1.5
	U-1	■										
	D-2	▨						1	1	1	2	3.0
	D-3	▨	5.0					1	1	1	2	4.5
	D-4	▨	6.5	1.5	Grey med stiff clayey SILT with fine sand med compress.			2	3	4	7	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			3	5	8	13	7.5
	D-6	▨						5	9	15	24	9.0
	D-7	▨						7	13	17	30	10.5
	D-8	▨						8	15	20	35	12.0
	D-9	▨						9	18	24	42	13.5
	D-10	▨						10	21	27	48	15.0
	D-11	▨						11	25	25	50	16.5
	D-12	▨						10	26	24	50	18.0
	D-13	▨	20.0					11	28	22	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

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Sheet 9 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 10 22°47'31.653"N, 91°27'18.453"E

GROUND LEVEL R.L.: : 4.361 m

GROUND WATER LEVEL: : 1.922 m

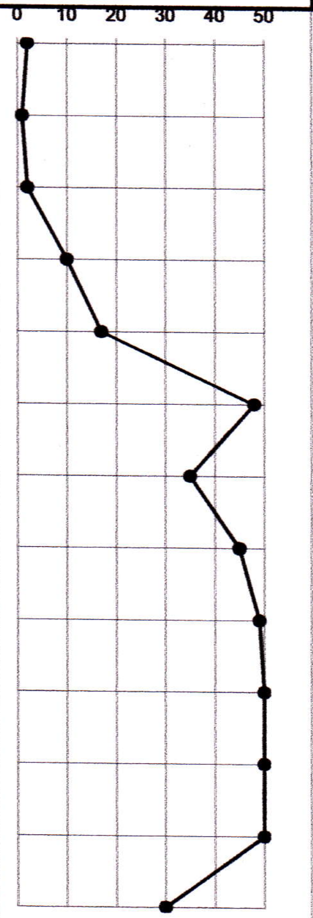
DATE : 01-02-2019

STANDARD PENETRATION RESISTANCE (FIELD S P T)

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
31-01-2019	D-1	▨		5.0	Grey very soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	0	1	1	3.0
	U-1	■										
	D-3	▨	5.0					1	1	1	2	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			3	4	6	10	6.0
	D-5	▨						4	7	10	17	7.5
	D-6	▨						8	20	28	48	9.0
	D-7	▨						8	15	20	35	10.5
	D-8	▨						8	20	25	45	12.0
	D-9	▨						9	21	28	49	13.5
	D-10	▨						10	25	25	50	15.0
	D-11	▨						12	33	17	50	16.5
	D-12	▨						13	38	12	50	18.0
	D-13	▨	20.0					10	20	10	30	19.5



Drawn by : Checked by : Sheet 10 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 11 22°47'31.972"N, 91°27'19.550"E

GROUND LEVEL R.L.: : 4.084 m

GROUND WATER LEVEL: : 1.950 m

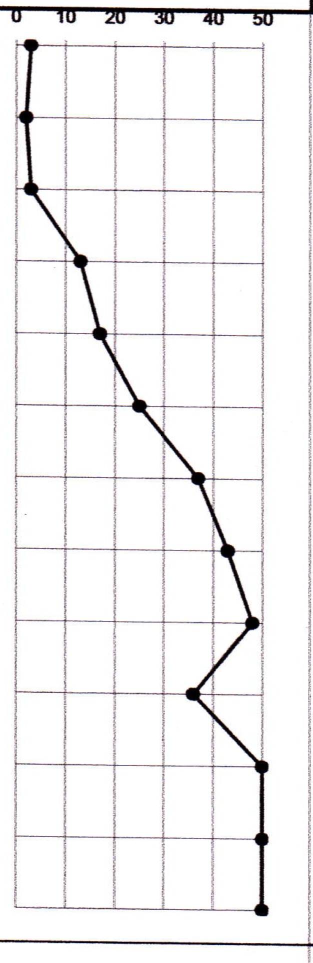
DATE : 02-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
01-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.	▥	100mm	1	1	2	3	1.5
	U-1	■										
	D-2	▨						1	1	1	2	3.0
	D-3	▨	5.0					1	1	2	3	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica	░		3	5	8	13	6.0
	D-5	▨						5	7	10	17	7.5
	D-6	▨						6	10	15	25	9.0
	D-7	▨						7	15	22	37	10.5
	D-8	▨						9	18	25	43	12.0
	D-9	▨						8	20	28	48	13.5
	D-10	▨						9	19	17	36	15.0
	D-11	▨						10	26	24	50	16.5
	D-12	▨						9	35	15	50	18.0
	D-13	▨	20.0					10	38	12	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 11 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 12 22°47'30.782"N, 91°27'18.647"E

GROUND LEVEL R.L.: : 4.695 m

GROUND WATER LEVEL: : 2.256 m

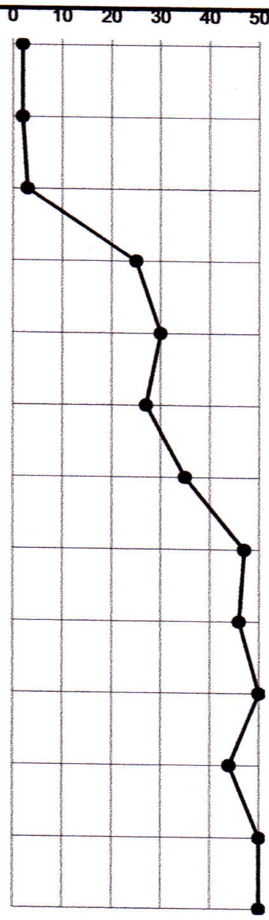
DATE : 03-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
02-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	1	2	3.0
	U-1	■										
	D-3	▨	5.0					1	1	2	3	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			6	10	15	25	6.0
	D-5	▨						7	13	17	30	7.5
	D-6	▨						5	12	15	27	9.0
	D-7	▨						6	15	20	35	10.5
	D-8	▨						8	20	27	47	12.0
	D-9	▨						9	22	24	46	13.5
	D-10	▨						10	25	25	50	15.0
	D-11	▨						9	18	26	44	16.5
	D-12	▨						9	23	27	50	18.0
	D-13	▨	20.0					10	26	24	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 12 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**

LOCATION : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.**

BORE HOLE NO. **13** 22°47'31.149"N, 91°27'19.927"E

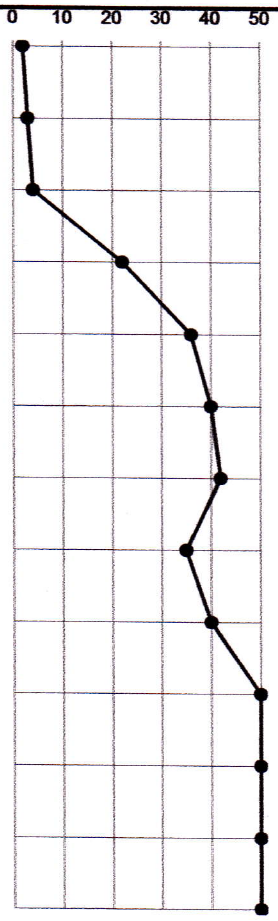
GROUND LEVEL R.L.: : **4.287 m**

GROUND WATER LEVEL: : **1.543 m**

DATE : **03-02-2019**

▨ Disturbed

■ Undisturbed



DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
02-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	2	3	3.0
	U-1	■										
	D-3	▨	5.0					1	2	2	4	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			5	10	12	22	6.0
	D-5	▨						7	16	20	36	7.5
	D-6	▨						8	20	20	40	9.0
	D-7	▨						10	20	22	42	10.5
	D-8	▨						8	15	20	35	12.0
	D-9	▨						10	18	22	40	13.5
	D-10	▨						14	20	30	50	15.0
	D-11	▨						15	22	28	50	16.5
	D-12	▨						17	30	20	50	18.0
	D-13	▨	20.0					18	40	10	50	19.5

Drawn by : Checked by : Sheet 13 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 14 $22^0 47' 30.003'' N, 91^0 27' 18.906'' E$

GROUND LEVEL R.L.: : 4.769 m

GROUND WATER LEVEL: : 2.330 m

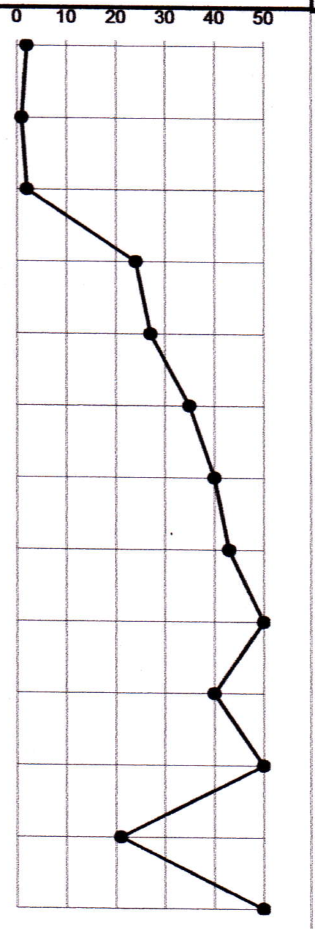
DATE : 04-02-2019

STANDARD PENETRATION RESISTANCE (FIELD S P T)

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				BH DEPTH (m)
								15cm	15cm	15cm	SPT	
03-02-2019	D-1	▨		5.0	Grey very soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	0	1	1	3.0
	U-1 D-3	■ ▨	5.0					1	1	1	2	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			6	10	14	24	6.0
	D-5	▨						7	12	15	27	7.5
	D-6	▨						13	15	20	35	9.0
	D-7	▨						9	18	22	40	10.5
	D-8	▨						7	20	23	43	12.0
	D-9	▨						8	23	27	50	13.5
	D-10	▨						6	18	22	40	15.0
	D-11	▨						7	22	28	50	16.5
	D-12	▨						7	9	12	21	18.0
	D-13	▨	20.0					9	19	31	50	19.5



Drawn by :

Checked by :

Sheet 14 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 15 $22^0 47' 30.373''$N, $91^0 27' 20.184''$E

GROUND LEVEL R.L.: : 4.308 m

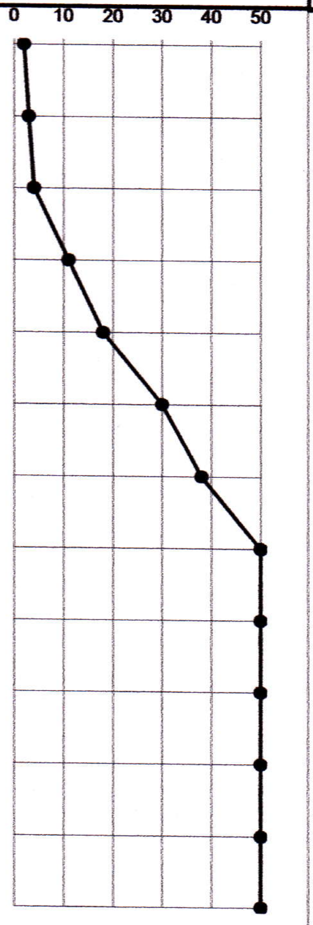
GROUND WATER LEVEL: : 2.174 m

DATE : 04-02-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
03-02-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	2	3	3.0
	U-1	■										
	D-3	▨	5.0					2	2	2	4	4.5
	D-4	▨	6.5	1.5	Grey stiff clayey SILT with fine sand med compress.			3	4	7	11	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			4	8	10	18	7.5
	D-6	▨						6	14	16	30	9.0
	D-7	▨						8	18	20	38	10.5
	D-8	▨						14	20	30	50	12.0
	D-9	▨						15	30	20	50	13.5
	D-10	▨						16	35	15	50	15.0
	D-11	▨						10	20	30	50	16.5
	D-12	▨						14	22	28	50	18.0
	D-13	▨	20.0					20	40	10	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 15 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 16 22°47'29.506"N, 91°27'19.531"E

GROUND LEVEL R.L.: : 4.577 m

GROUND WATER LEVEL: : 2.138 m

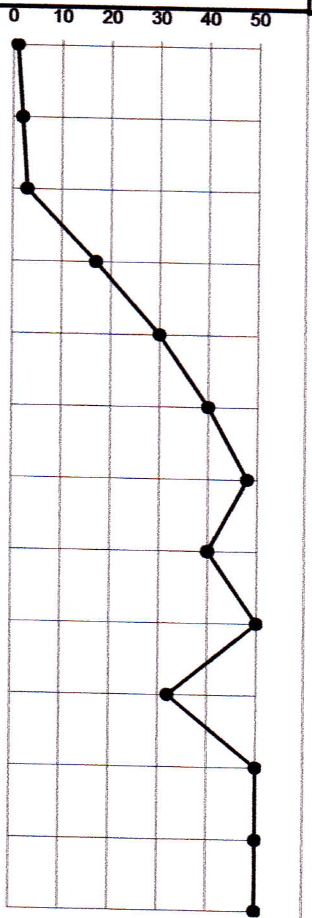
DATE : 04-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
03-02-2019	D-1	▨		3.5	Grey very soft silty CLAY trace fine sand medium plastic.	100mm	1	0	1	1	1.5
	D-2	▨	3.5				1	1	1	2	3.0
	U-1	■		1.5	Grey soft clayey SILT with fine sand med compress.						
	D-3	▨	5.0				1	1	2	3	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica		4	7	10	17	6.0
	D-5	▨					5	13	17	30	7.5
	D-6	▨					7	18	22	40	9.0
	D-7	▨					10	20	28	48	10.5
	D-8	▨					8	17	23	40	12.0
	D-9	▨					9	23	27	50	13.5
	D-10	▨					7	12	20	32	15.0
	D-11	▨					8	25	25	50	16.5
	D-12	▨					10	28	22	50	18.0
	D-13	▨	20.0				7	20	30	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 16 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 17 22°47'29.674"N, 91°27'20.128"E

GROUND LEVEL R.L.: : 4.396 m

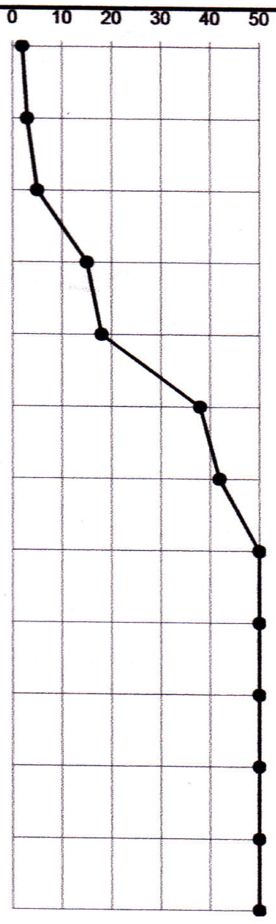
GROUND WATER LEVEL: : 2.262 m

DATE : 04-02-2019

▨ Disturbed ■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
03-02-2019	D-1	▨		5.0	Grey soft to medium stiff silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	2	3	3.0
	U-1 D-3	■ ▨	5.0					2	2	3	5	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			4	7	8	15	6.0
	D-5	▨						6	8	10	18	7.5
	D-6	▨						7	18	20	38	9.0
	D-7	▨						8	20	22	42	10.5
	D-8	▨						10	22	28	50	12.0
	D-9	▨						14	30	20	50	13.5
	D-10	▨						15	20	30	50	15.0
	D-11	▨						16	22	28	50	16.5
	D-12	▨						18	35	15	50	18.0
	D-13	▨	20.0					20	40	10	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



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Sheet 17 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 18 22°47'31.683"N, 91°27'15.913"E

GROUND LEVEL R.L.: : 4.074 m

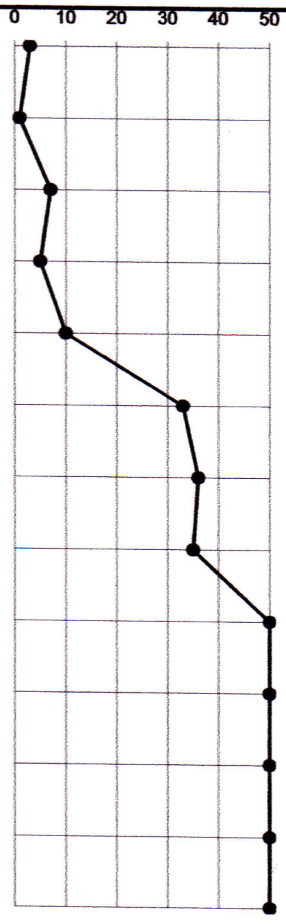
GROUND WATER LEVEL: : 2.245 m

DATE : 31-01-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRATION RESISTANCE (FIELD S P T)	BH DEPTH (m)
30-01-2019	D-1	▨					100mm	1	1	2	3		1.5
	D-2	▨		6.5	Grey very soft to medium stiff silty CLAY trace fine sand medium plastic.			1	0	1	1		3.0
	U-1	■											
	D-3	▨						1	4	3	7		4.5
	D-4	▨	6.5					2	2	3	5		6.0
	D-5	▨						3	4	6	10		7.5
	D-6	▨						5	15	18	33		9.0
	D-7	▨						6	16	20	36		10.5
	D-8	▨						7	17	18	35		12.0
	D-9	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			14	33	17	50		13.5
	D-10	▨						12	40	10	50		15.0
	D-11	▨						8	44	6	50		16.5
	D-12	▨						10	30	20	50		18.0
	D-13	▨	20.0					15	35	15	50		19.5



Drawn by :

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Sheet 18 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 19 $22^0 47' 30.963'' N, 91^0 27' 16.153'' E$

GROUND LEVEL R.L.: : 4.382 m

GROUND WATER LEVEL: : 1.943 m

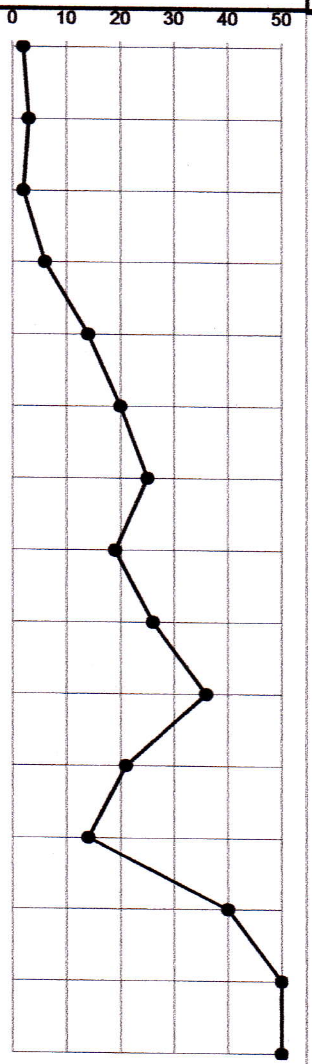
DATE : 30-01-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
29-01-2019	D-1	▨		5.0	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	U-1	■										
	D-2	▨						1	1	2	3	3.0
	D-3	▨	5.0					1	1	1	2	4.5
	D-4	▨	6.5	1.5	Grey med. stiff clayey SILT with fine sand med compress.			2	3	3	6	6.0
	D-5	▨		16.5	Grey medium dense to very dense silty FINE SAND trace mica			3	5	9	14	7.5
	D-6	▨						4	7	13	20	9.0
	D-7	▨						5	10	15	25	10.5
	D-8	▨						3	8	11	19	12.0
	D-9	▨						8	11	15	26	13.5
	D-10	▨						11	17	19	36	15.0
	D-11	▨						9	13	8	21	16.5
	D-12	▨						7	6	8	14	18.0
	D-13	▨						3	12	28	40	19.5
	D-14	▨						8	33	17	50	21.0
	D-15	▨	23.0					10	40	10	50	22.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

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Sheet 19 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 20 22°47'26.853"N, 91°27'17.381"E

GROUND LEVEL R.L.: : 4.971 m

GROUND WATER LEVEL: : 2.227 m

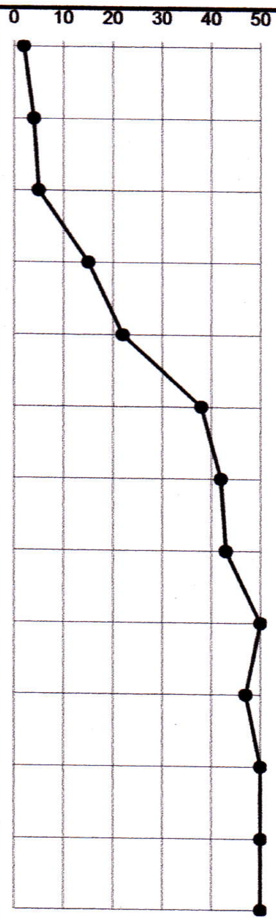
DATE : 05-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
04-02-2019	D-1	▨		5.0	Grey soft to medium stiff silty CLAY trace fine sand medium plastic.			1	1	1	2	1.5
	U-1 D-2	■ ▨						1	2	2	4	3.0
	D-3	▨	5.0					1	2	3	5	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica		100mm	3	7	8	15	6.0
	D-5	▨						5	10	12	22	7.5
	D-6	▨						7	18	20	38	9.0
	D-7	▨						8	20	22	42	10.5
	D-8	▨						10	21	22	43	12.0
	D-9	▨						12	22	28	50	13.5
	D-10	▨						14	23	24	47	15.0
	D-11	▨						15	30	20	50	16.5
	D-12	▨						18	35	15	50	18.0
	D-13	▨	20.0					20	40	10	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 20 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 21 22°47'27.450"N, 91°27'18.395"E

GROUND LEVEL R.L.: : 4.783 m

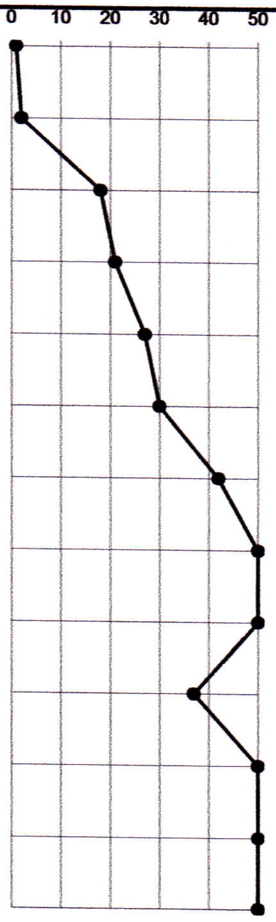
GROUND WATER LEVEL: : 3.563 m (in water)

DATE : 06-02-2019

▨ Disturbed
■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
05-02-2019	D-1	▨		3.5	Grey very soft silty CLAY trace fine sand medium plastic.		100mm	1	0	1	1	1.5
	U-1	■										
	D-2	▨	3.5					1	1	1	2	3.0
	D-3	▨	5.0	1.5	Grey medium dense sandy SILT trace mica.			5	8	10	18	4.5
	D-4	▨			Grey medium dense to very dense silty FINE SAND trace mica			5	9	12	21	6.0
	D-5	▨						6	12	15	27	7.5
	D-6	▨						7	13	17	30	9.0
	D-7	▨						9	18	24	42	10.5
	D-8	▨		15.0				10	25	25	50	12.0
	D-9	▨						8	30	20	50	13.5
	D-10	▨						7	15	22	37	15.0
	D-11	▨						8	20	30	50	16.5
	D-12	▨						10	23	27	50	18.0
	D-13	▨	20.0					11	26	24	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 21 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

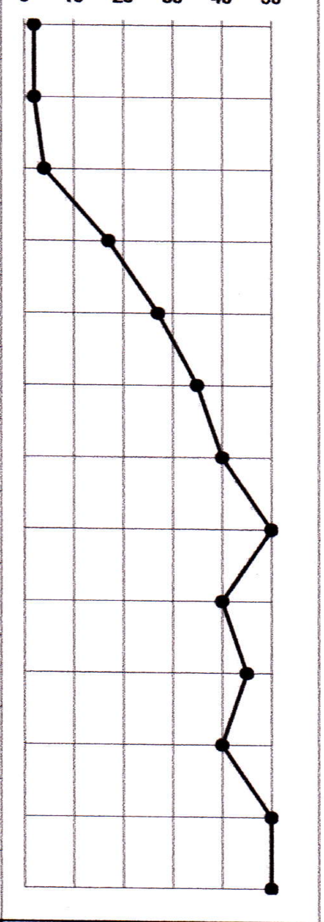
LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 22 22°47'27.239"N, 91°27'19.330"E

GROUND LEVEL R.L.: : 4.504 m

GROUND WATER LEVEL: : 1.760 m

DATE : 05-02-2019

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRATION RESISTANCE (FIELD S P T) ▨ Disturbed ■ Undisturbed	BH DEPTH (m)
04-02-2019	D-1	▨		3.5	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2		1.5
	D-2	▨	3.5					1	1	1	2		3.0
	U-1 D-3	■ ▨	5.0	1.5	Grey med. stiff clayey SILT with fine sand med compress.			1	2	2	4		4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			3	7	10	17		6.0
	D-5	▨						5	10	17	27		7.5
	D-6	▨						6	15	20	35		9.0
	D-7	▨						7	18	22	40		10.5
	D-8	▨						8	21	29	50		12.0
	D-9	▨						6	18	22	40		13.5
	D-10	▨						7	20	25	45		15.0
	D-11	▨						8	17	23	40		16.5
	D-12	▨						10	24	26	50		18.0
	D-13	▨	20.0					11	26	24	50		19.5

Drawn by : Checked by : Sheet 22 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 23 22°47'28.147"N, 91°27'21.007"E

GROUND LEVEL R.L.: : 4.266 m

GROUND WATER LEVEL: : 1.827 m

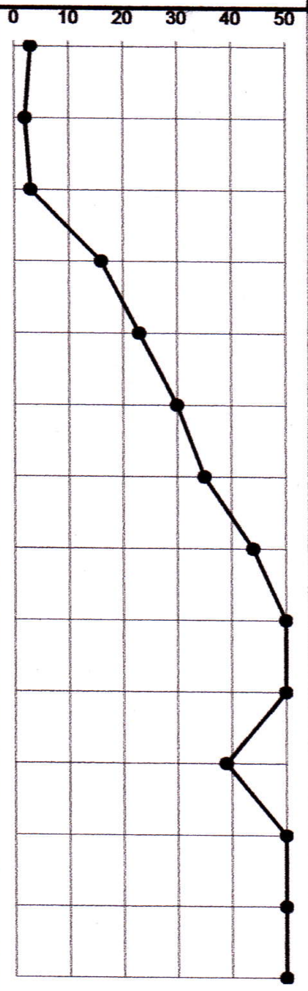
DATE : 05-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
04-02-2019	D-1	▨		3.5	Grey soft silty CLAY trace fine sand medium plastic.		100mm	1	1	2	3	1.5
	D-2	▨	3.5					1	1	1	2	3.0
	U-1 D-3	■ ▨	5.0	1.5	Grey soft clayey SILT with fine sand med compress.			1	1	2	3	4.5
	D-4	▨		15.0	Grey medium dense to very dense silty FINE SAND trace mica			3	7	9	16	6.0
	D-5	▨						5	10	13	23	7.5
	D-6	▨						5	13	17	30	9.0
	D-7	▨						5	15	20	35	10.5
	D-8	▨						9	19	25	44	12.0
	D-9	▨						8	22	28	50	13.5
	D-10	▨						9	24	26	50	15.0
	D-11	▨						10	15	24	39	16.5
	D-12	▨						8	18	32	50	18.0
	D-13	▨	20.0					9	21	29	50	19.5
	D-14	▨						10	24	26	50	21.0

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 23 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

BORE HOLE NO. 24 22°47'28.327"N, 91°27'31.636"E

GROUND LEVEL R.L.: : 4.119 m

GROUND WATER LEVEL: : 1.985 m

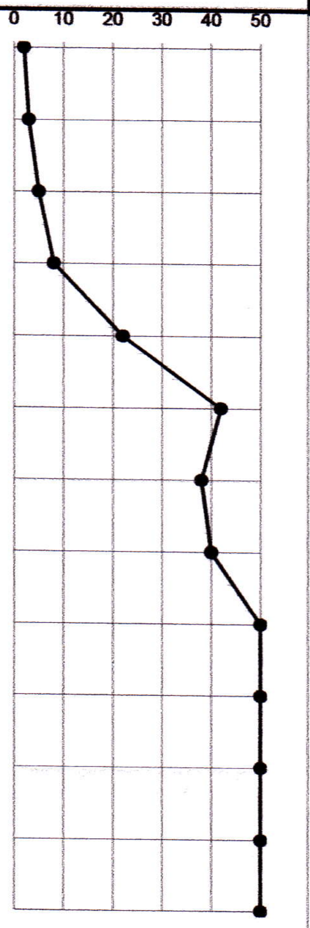
DATE : 05-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
04-02-2019	D-1	▨		5.0	Grey soft to medium stiff silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	1	2	3	3.0
	U-1	■										
	D-3	▨	5.0					2	2	3	5	4.5
	D-4	▨	6.5	1.5	Grey loose silty FINE SAND trace mica			3	3	5	8	6.0
	D-5	▨		13.5	Grey medium dense to very dense silty FINE SAND trace mica			5	10	12	22	7.5
	D-6	▨						8	20	22	42	9.0
	D-7	▨						10	18	20	38	10.5
	D-8	▨						10	20	20	40	12.0
	D-9	▨						14	22	28	50	13.5
	D-10	▨						15	23	27	50	15.0
	D-11	▨						16	30	20	50	16.5
	D-12	▨						17	30	20	50	18.0
	D-13	▨	20.0					18	40	10	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by : Checked by : Sheet 24 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Construction of Bridge.

LOCATION : Proposed Bridge at Azompur Khal Crossing.

BORE HOLE NO. **25** 22°51'19.347"N, 91°28'34.960"E

GROUND LEVEL R.L.: : -0.934 m

GROUND WATER LEVEL: : -2.763 m

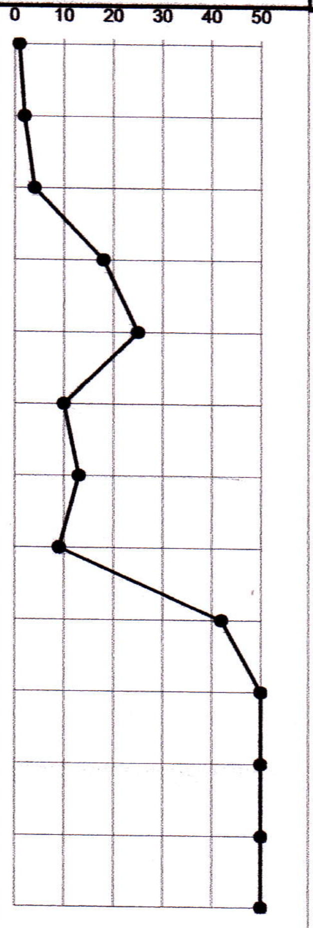
DATE : 07-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
06-02-2019	D-1	▨		5.0	Grey very soft to soft silty CLAY trace fine sand medium plastic.		100mm	1	0	1	1	1.5
	D-2	▨						1	1	1	2	3.0
	U-1	■										
	D-3	▨	5.0					1	2	2	4	4.5
	D-4	▨		6.0	Grey medium dense silty FINE SAND trace mica			3	8	10	18	6.0
	D-5	▨						5	10	15	25	7.5
	D-6	▨						3	4	6	10	9.0
	D-7	▨	11.0					3	5	8	13	10.5
	D-8	▨	12.5	1.5	Grey loose silty FINE SAND trace mica			3	4	5	9	12.0
	D-9	▨		7.5	Grey dense to very dense silty FINE SAND trace mica			9	18	24	42	13.5
	D-10	▨						10	31	19	50	15.0
	D-11	▨						8	22	28	50	16.5
	D-12	▨						10	24	26	50	18.0
	D-13	▨	20.0					11	29	21	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



Drawn by :

Checked by :

Sheet 25 of 26 Attachment II

DELTA SOIL ENGINEERS

BORING LOG

PROJECT : Sub-Soil Investigation for Construction of Bridge.

LOCATION : Proposed Bridge at Azompur Khal Crossing.

BORE HOLE NO. 26 22°51'19.027"N, 91°28'37.290"E

GROUND LEVEL R.L.: : 0.913 m

GROUND WATER LEVEL: : -1.221 m

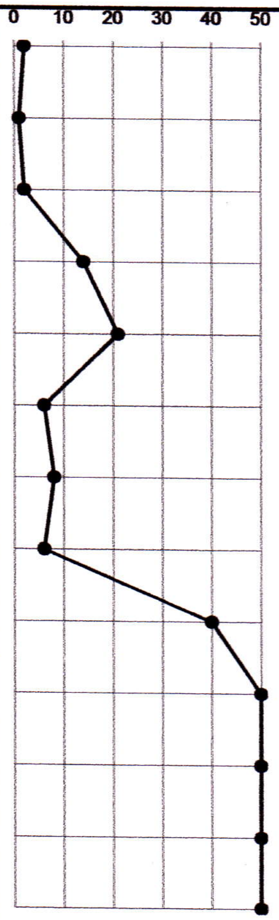
DATE : 06-02-2019

▨ Disturbed

■ Undisturbed

DATE	SAMPLE NO.	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	BH DEPTH (m)
06-02-2019	D-1	▨		5.0	Grey very soft silty CLAY trace fine sand medium plastic.		100mm	1	1	1	2	1.5
	D-2	▨						1	0	1	1	3.0
	U-1	■										
	D-3	▨	5.0					1	1	1	2	4.5
	D-4	▨		3.0	Grey medium dense silty FINE SAND trace mica			4	6	8	14	6.0
	D-5	▨	8.0					5	9	12	21	7.5
	D-6	▨	9.5	1.5	Grey med. stiff clayey SILT with fine sand low compress.			2	2	4	6	9.0
	D-7	▨		3.0	Grey loose silty FINE SAND trace mica			2	3	5	8	10.5
	D-8	▨	12.5					2	3	3	6	12.0
	D-9	▨		7.5	Grey dense to very dense silty FINE SAND trace mica			8	15	25	40	13.5
	D-10	▨						17	30	20	50	15.0
	D-11	▨						12	25	25	50	16.5
	D-12	▨						10	27	23	50	18.0
	D-13	▨	20.0					13	28	22	50	19.5

STANDARD PENETRATION RESISTANCE (FIELD S P T)



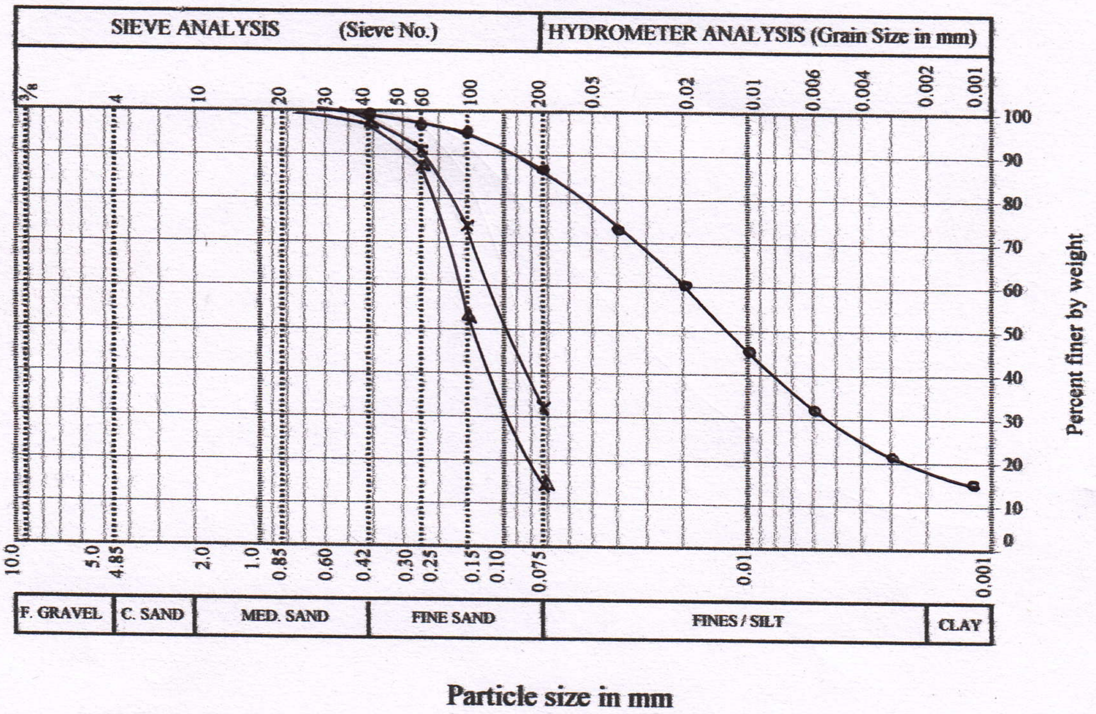
Drawn by :

Checked by :

Sheet 26 of 26 Attachment II

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Water Intake site.**

GRADATION CURVE



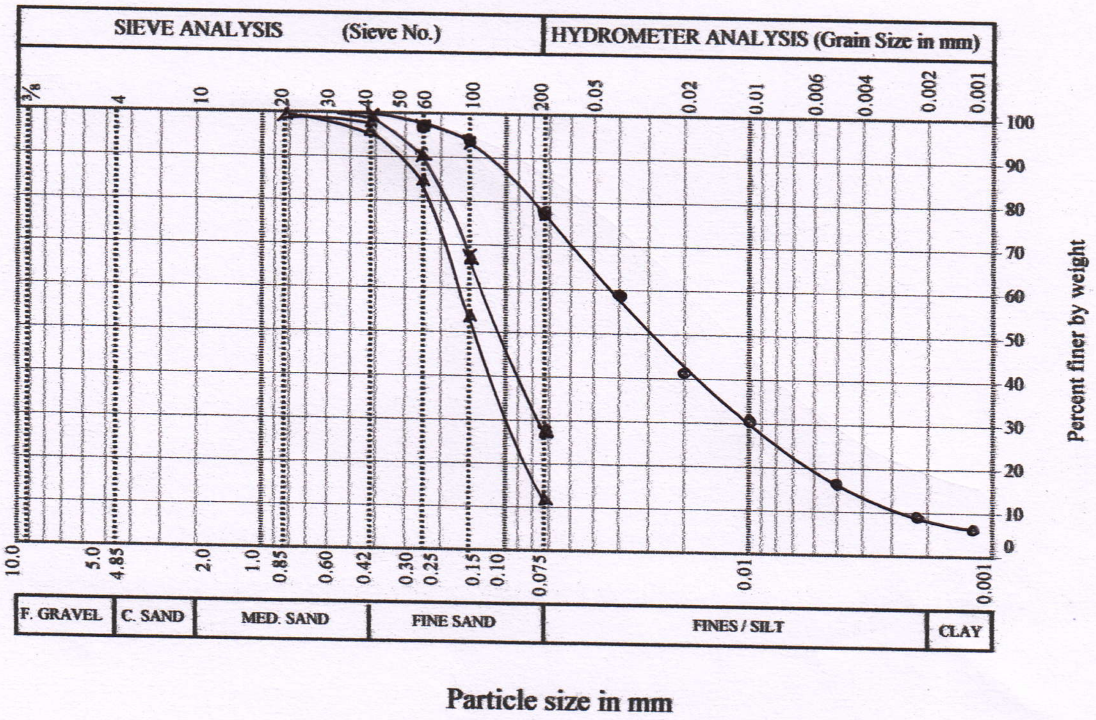
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 1	●—●—●	D - 1	1.5	12	70	18	–	31.5	41	26	Silty CLAY
BH - 1	★★★	D - 4	6.0	68	32	0	–	–	–	–	Silty FINE SAND
BH - 1	▲—▲—▲	D - 8	12.0	85	15	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by : SHEET 1 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS	**GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed water Intake site.**

GRADATION CURVE

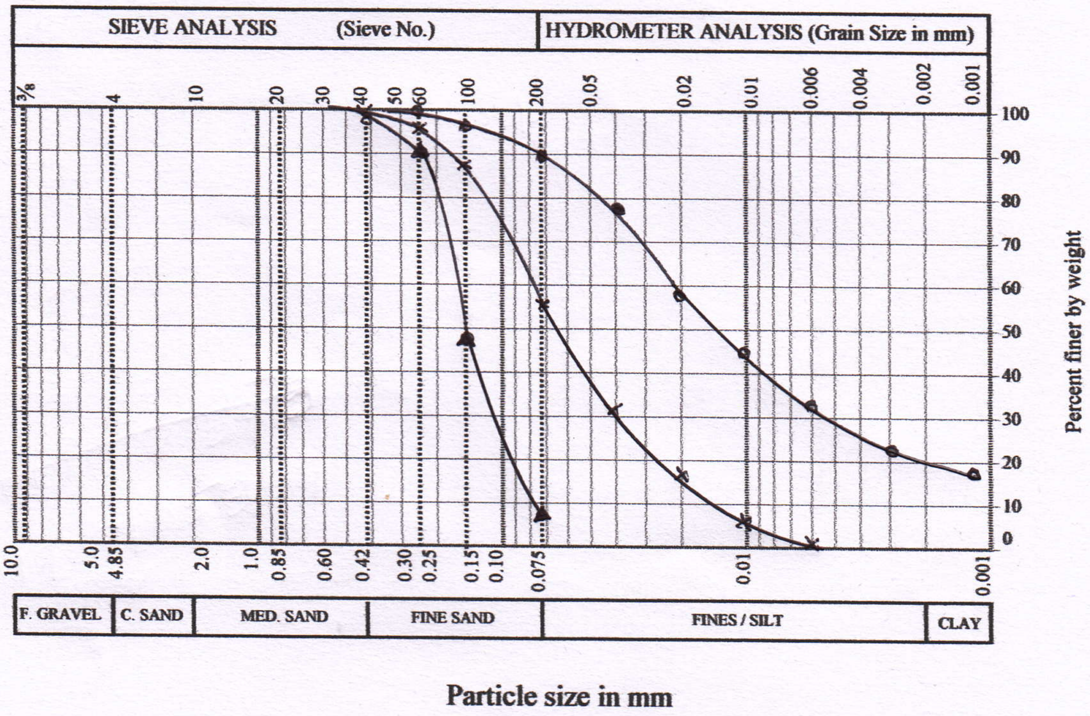


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 2	●—●—●	D - 3	4.5	22	72	6	–	29.2	30	26	Clayey SILT
BH - 2	★—★—★	D - 5	7.5	72	28	0	–	–	–	–	Silty FINE SAND
BH - 2	▲—▲—▲	D - 10	15.0	88	12	0	–	–	–	–	Silty FINE SAND

Tested by : Phosh Checked by : SHEET 2 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

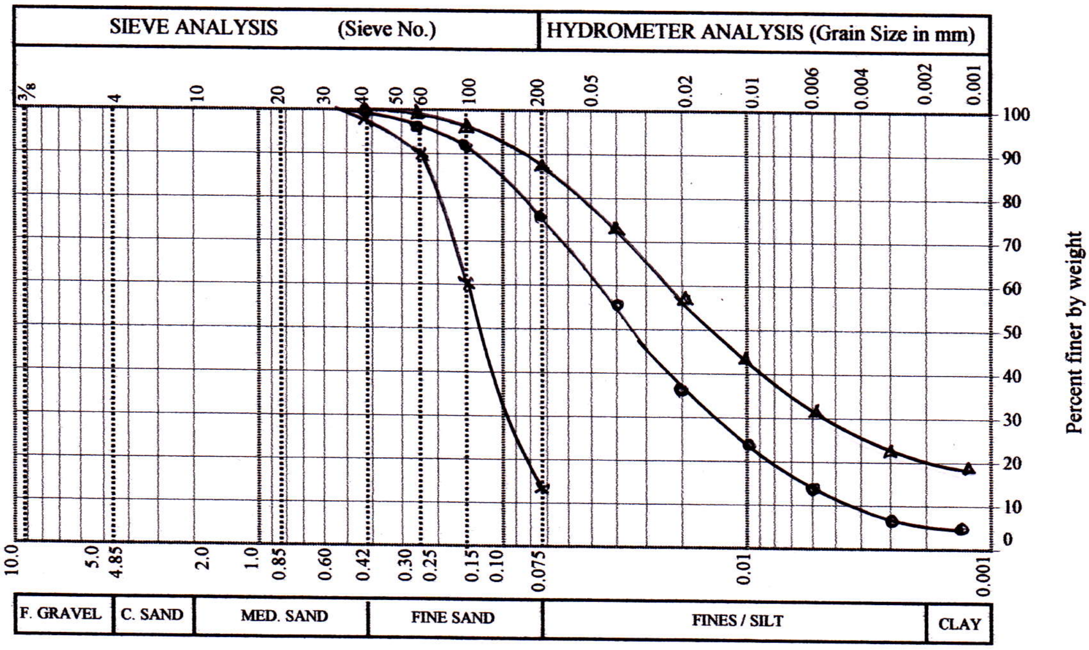


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 3	●—●—●	D - 2	3.0	10	70	20	–	30.7	42	23	Silty CLAY
BH - 3	★—★—★	D - 4	6.0	44	56	0	–	–	–	–	Sandy SILT
BH - 3	▲—▲—▲	D - 12	18.0	92	8	0	–	–	–	–	Silty FINE SAND

Tested by : Ptosh Checked by :

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



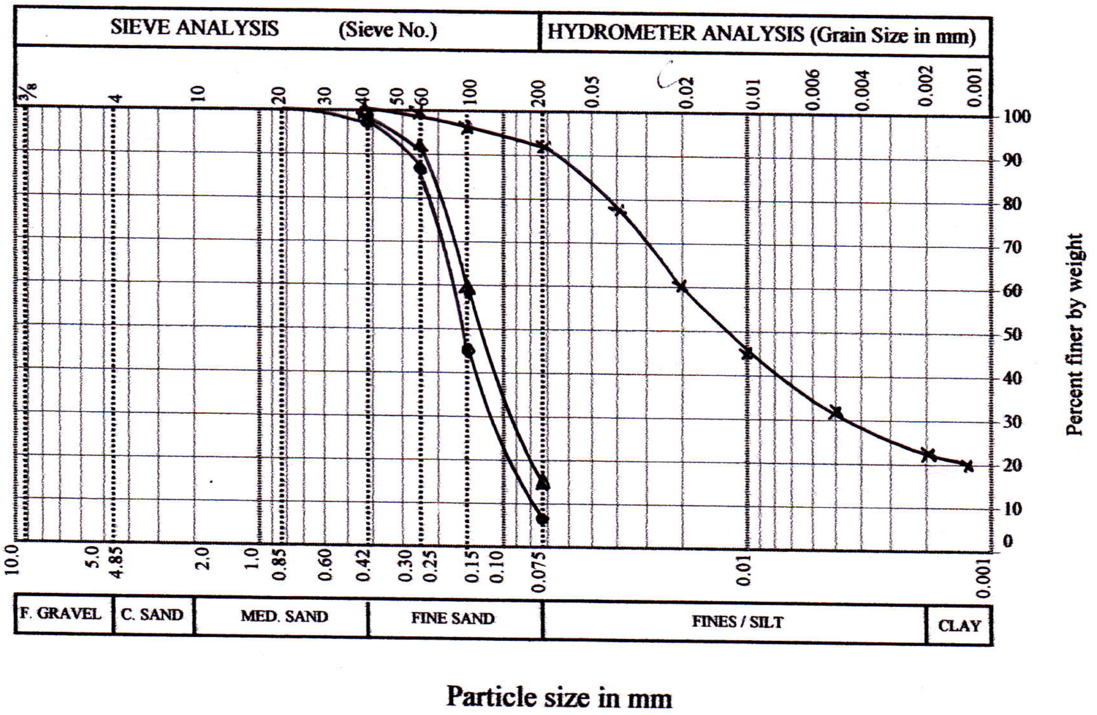
Particle size in mm

BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 4	●—●—●	D - 4	6.0	23	72	5	–	28.3	29	25	Clayey SILT
BH - 4	★★★	D - 10	15.0	87	13	0	–	–	–	–	Silty FINE SAND
BH - 5	▲—▲—▲	D - 3	4.5	12	68	20	–	27.4	41	25	Silty CLAY

Tested by : Pdooh Checked by :

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



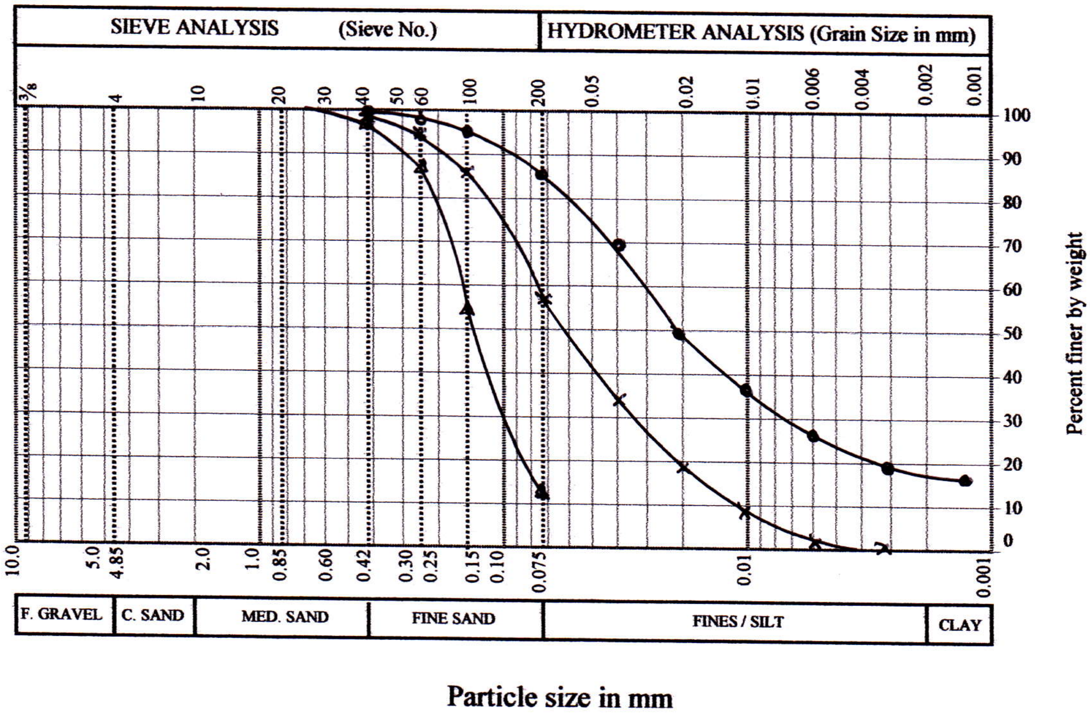
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 5	●—●—●	D - 11	16.5	93	7	0	–	–	–	–	Silty FINE SAND
BH - 6	★★★	D - 2	3.0	8	71	21	–	29.4	43	22	Silty CLAY
BH - 6	▲—▲—▲	D - 6	9.0	85	15	0	–	–	–	–	Silty FINE SAND

Tested by : Pdosh Checked by :

SHEET 5 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



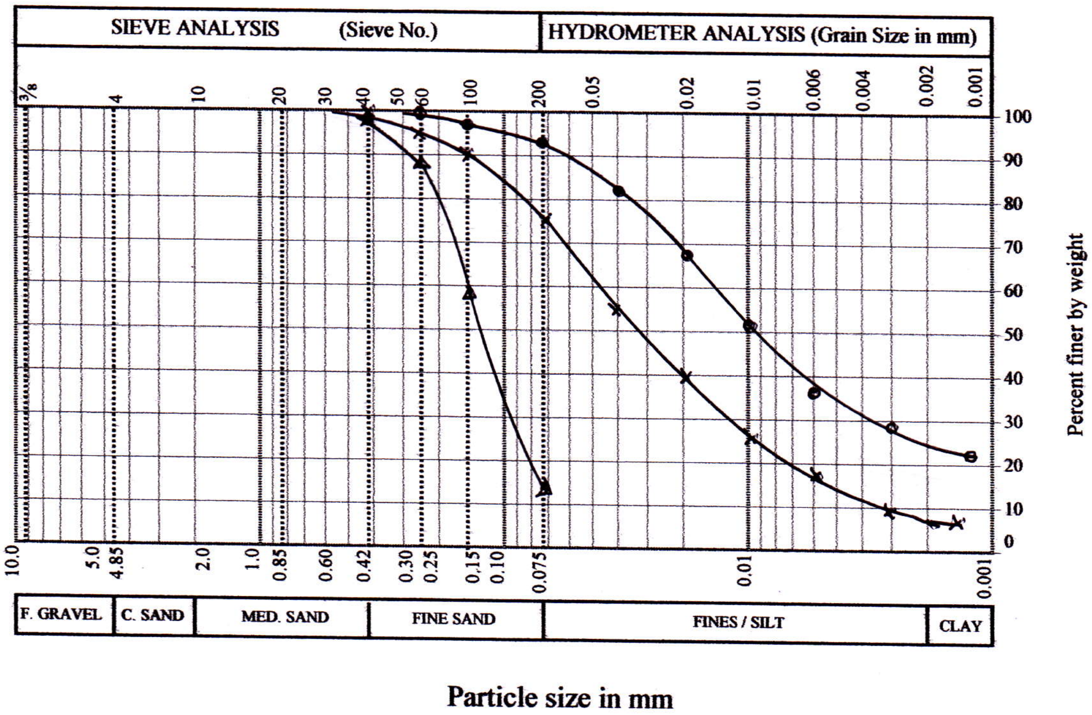
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 7	●—●—●	D - 1	1.5	14	69	17	–	30.4	40	23	Silty CLAY
BH - 7	★—★—★	D - 5	7.5	42	58	0	–	–	–	–	Sandy SILT
BH - 7	▲—▲—▲	D - 8	12.0	88	12	0	–	–	–	–	Silty FINE SAND

Tested by : PJosh Checked by :

SHEET 6 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 8	●—●—●	D - 3	4.5	7	70	23	–	31.4	42	25	Silty CLAY
BH - 8	★★★	D - 4	6.0	23	70	7	–	25.5	35	28	Sandy SILT
BH - 8	▲—▲—▲	D - 10	15.0	86	14	0	–	–	–	–	Silty FINE SAND

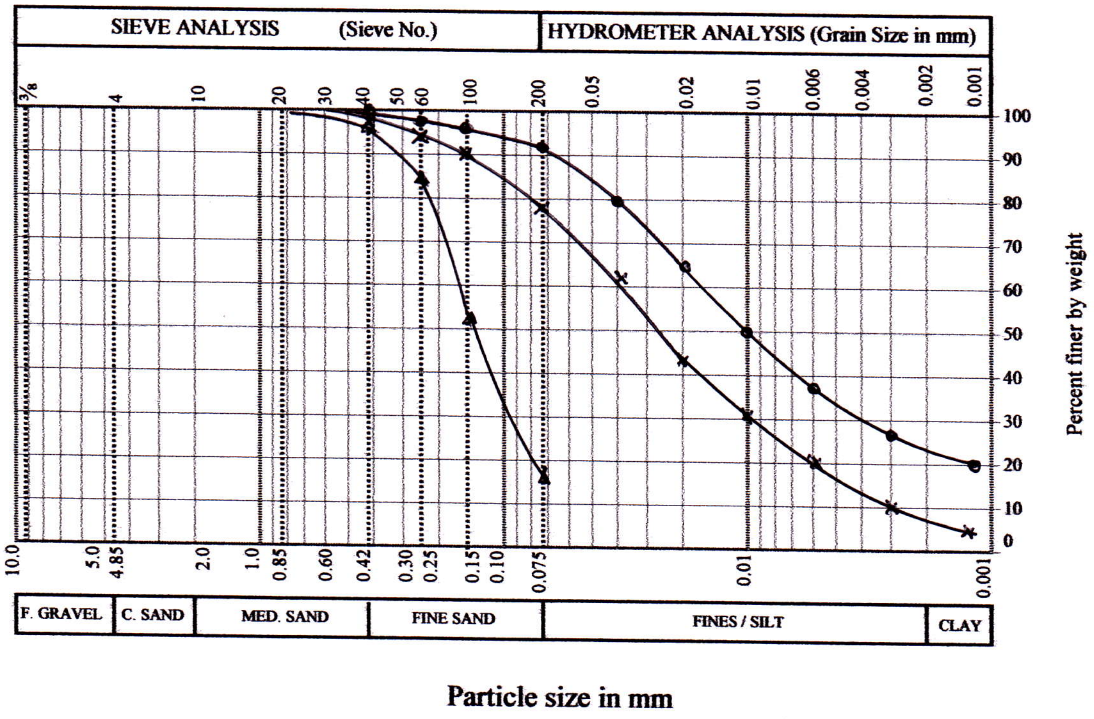
Tested by : Checked by :

SHEET 7 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS | **GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



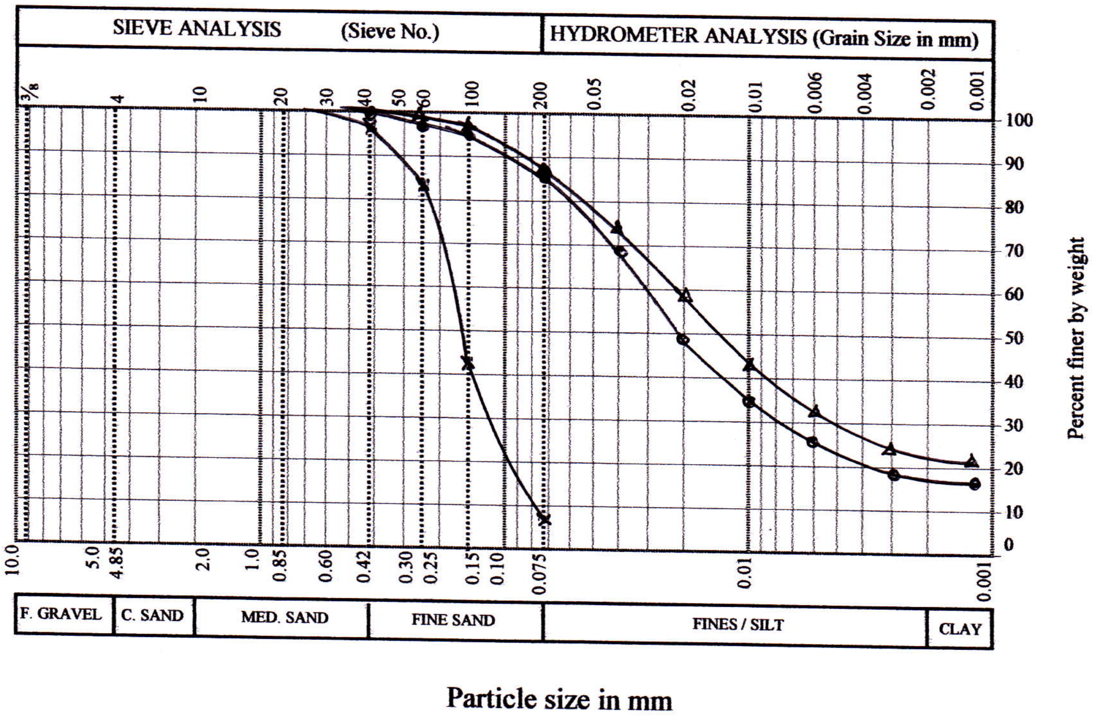
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 9	—●—●—●—	D - 1	1.5	8	70	22	–	28.4	45	26	Silty CLAY
BH - 9	★★★	D - 4	6.0	21	72	7	–	26.5	34	25	Sandy SILT
BH - 9	—▲—▲—▲—	D - 7	10.5	83	17	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by : SHEET 8 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS | **GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

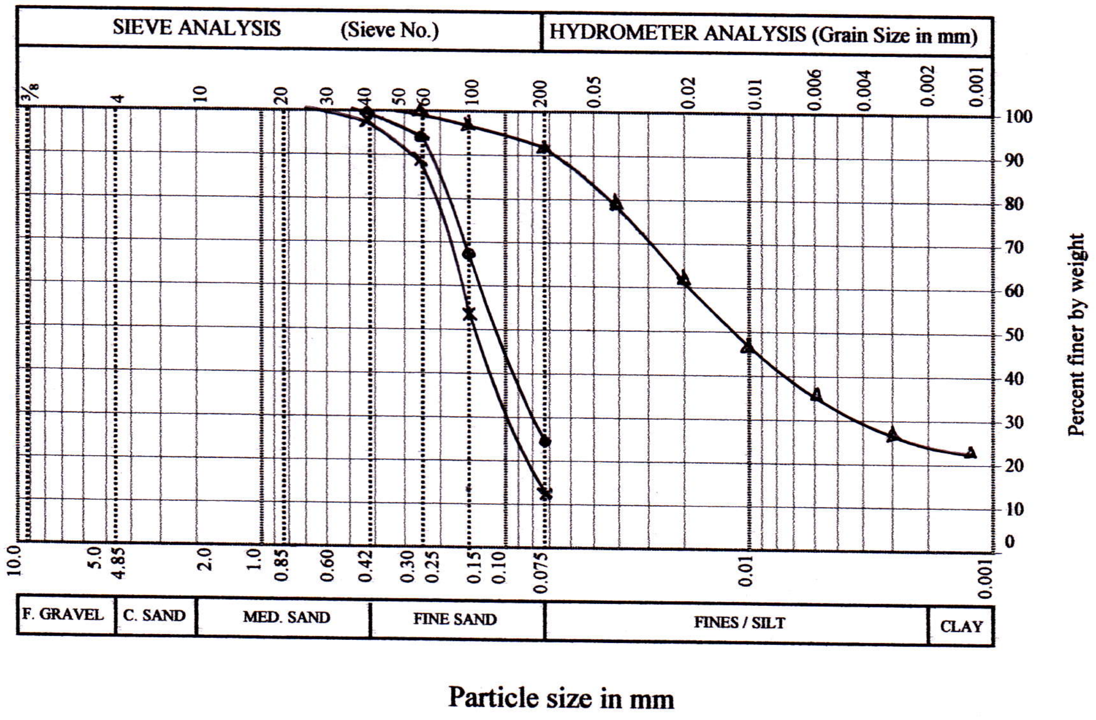


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 10	●—●—●	D - 3	4.5	14	69	17	–	30.5	40	21	Silty CLAY
BH - 10	★★★	D - 12	18.0	92	8	0	–	–	–	–	Silty FINE SAND
BH - 11	▲—▲—▲	D - 1	1.5	12	67	21	–	28.2	43	24	Silty CLAY

Tested by : Checked by : SHEET 9 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



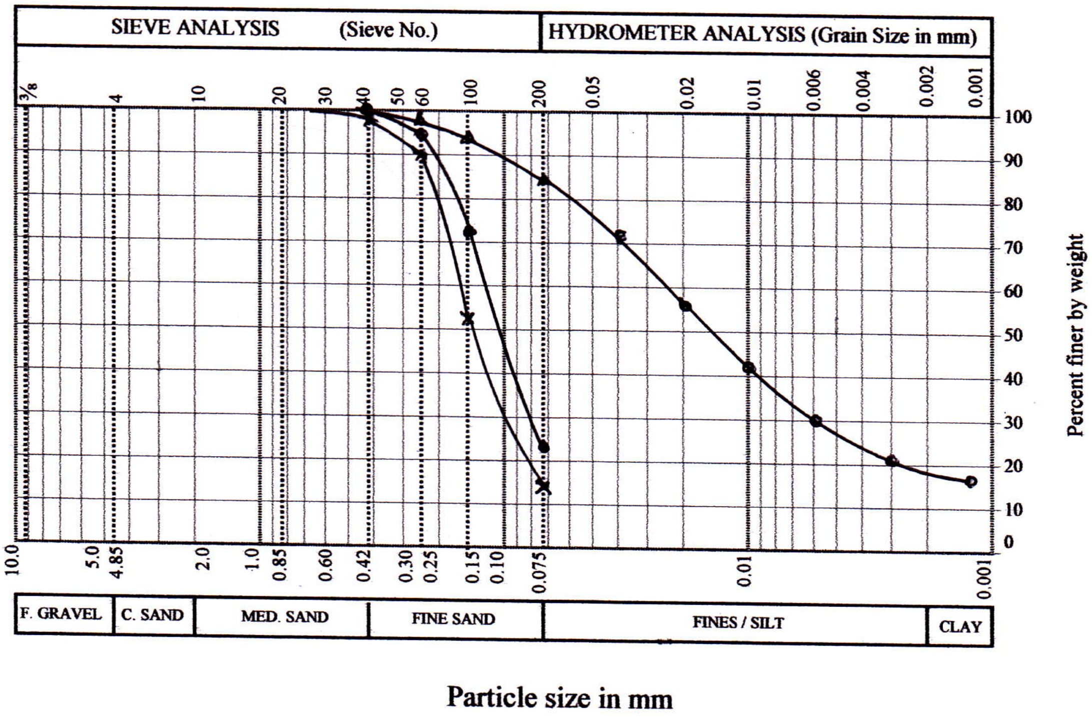
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 11	●—●—●	D - 6	9.0	75	25	0	–	–	–	–	Silty FINE SAND
BH - 11	★—★—★	D - 10	15.0	88	12	0	–	–	–	–	Silty FINE SAND
BH - 12	▲—▲—▲	D - 2	3.0	8	69	23	–	31.7	44	25	Silty CLAY

Tested by : Checked by : SHEET 10 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS	**GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

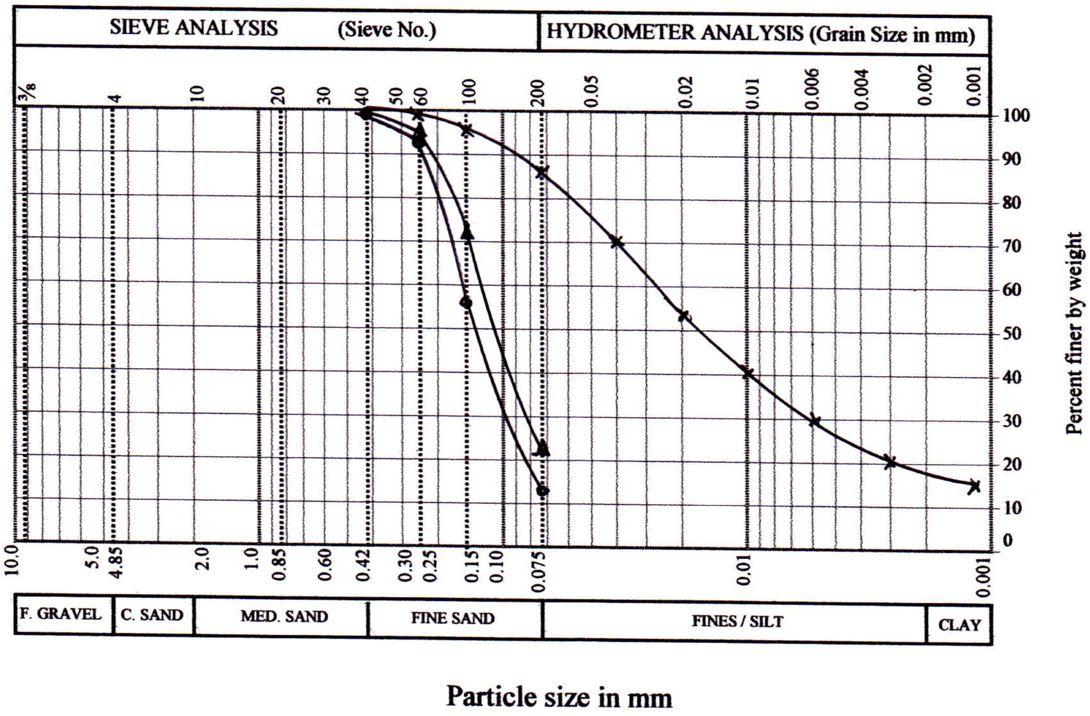


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 12	●—●—●	D - 4	6.0	78	22	0	–	–	–	–	Silty FINE SAND
BH - 12	★★★	D - 8	12.0	85	15	0	–	–	–	–	Silty FINE SAND
BH - 13	▲—▲—▲	D - 3	4.5	15	67	18	–	28.4	42	23	Silty CLAY

Tested by : Checked by : SHEET 11 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

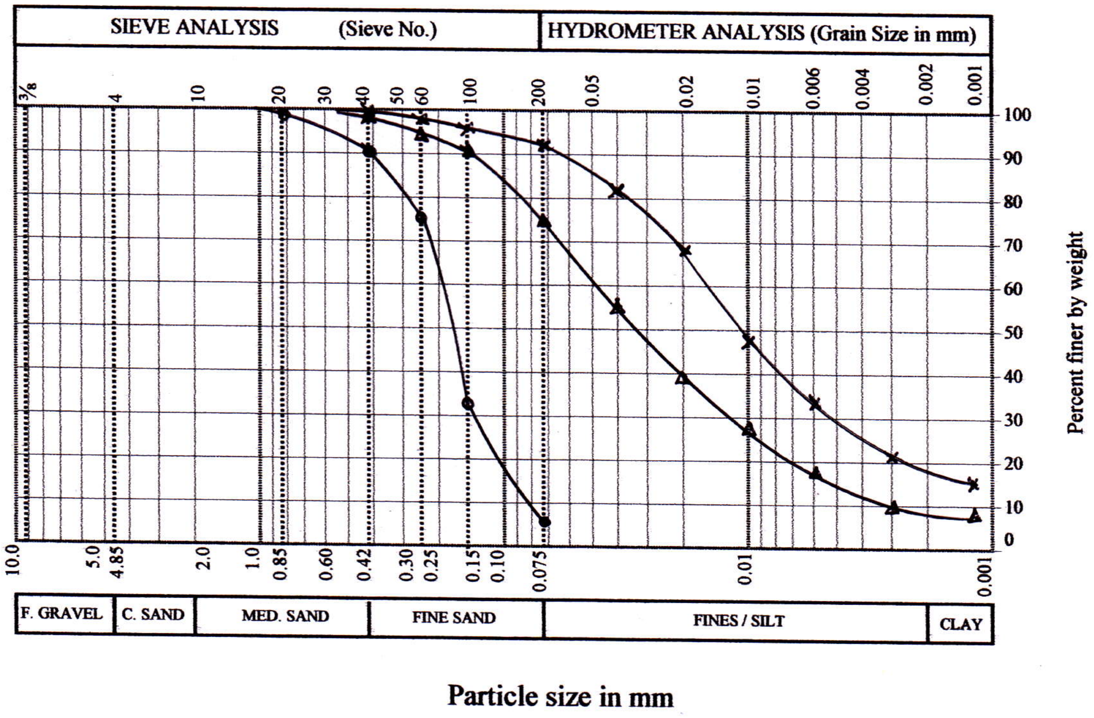


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 13	●—●—●	D - 11	16.5	87	13	0	–	–	–	–	Silty FINE SAND
BH - 14	★—★—★	D - 2	3.0	13	69	18	–	35.3	42	24	Silty CLAY
BH - 14	▲—▲—▲	D - 6	9.0	77	23	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by :

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

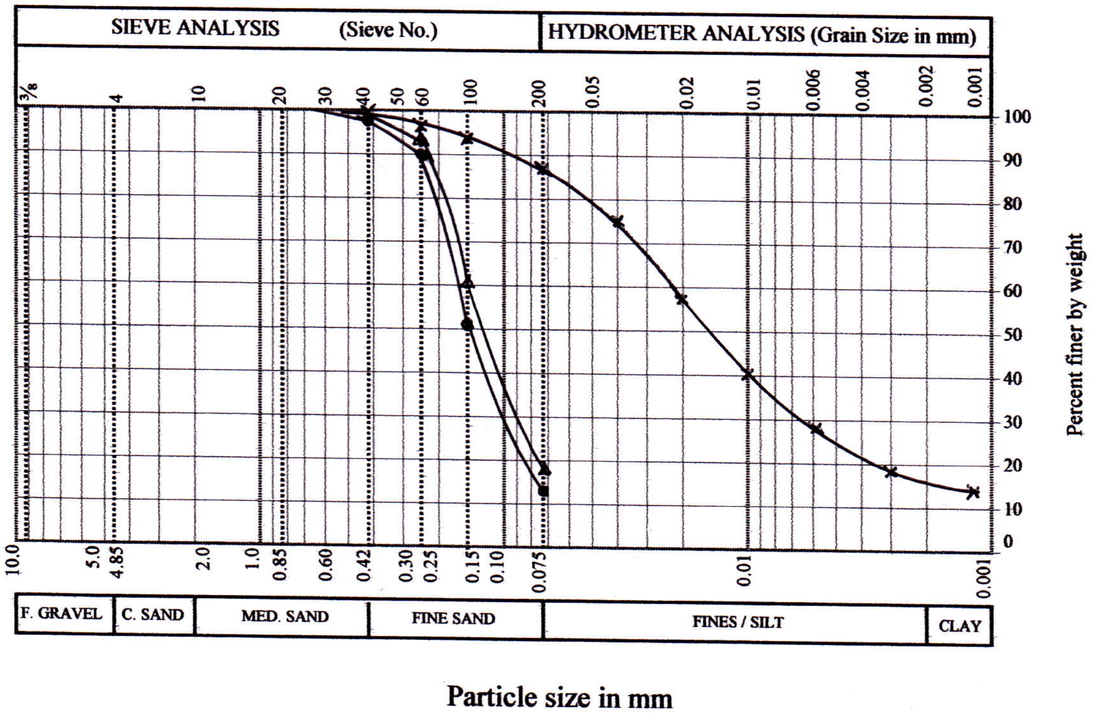


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 14	●—●—●	D - 13	19.5	94	6	0	–	–	–	–	Silty FINE SAND
BH - 15	★★★	D - 1	1.5	8	73	19	–	23.8	43	25	Silty CLAY
BH - 15	▲—▲—▲	D - 4	6.0	25	70	5	–	24.1	32	27	Clayey SILT

Tested by : Checked by : SHEET 13 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

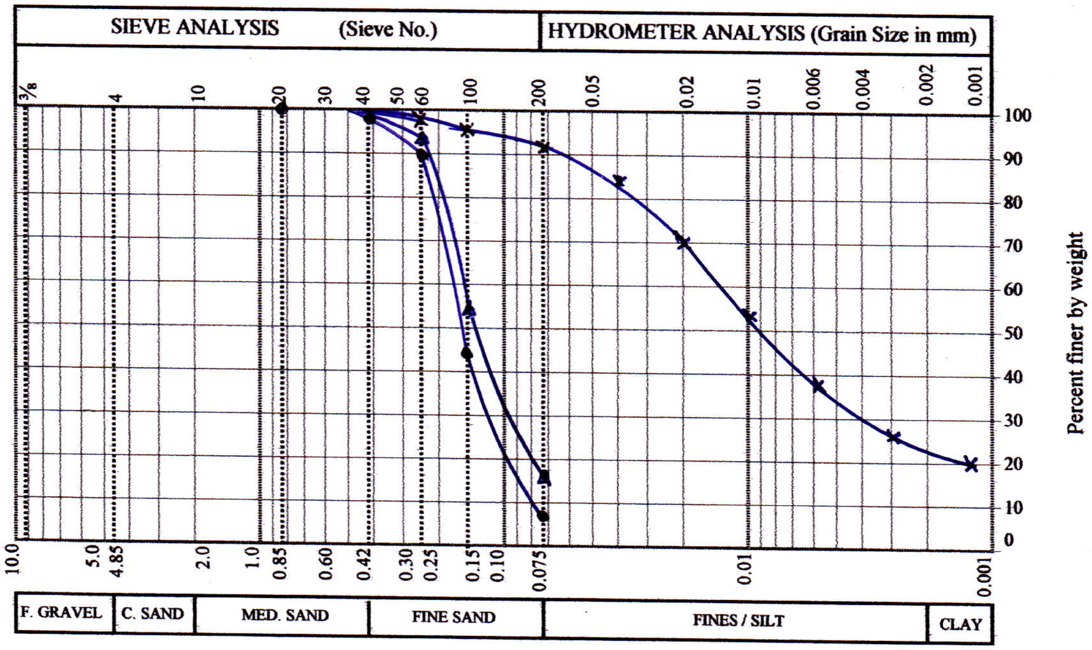


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 15	●—●—●	D - 10	15.0	86	14	0	–	–	–	–	Silty FINE SAND
BH - 16	★—★—★	D - 2	3.0	12	72	16	–	31.4	38	21	Clayey SILT
BH - 16	▲—▲—▲	D - 4	6.0	82	18	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by :

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



Particle size in mm

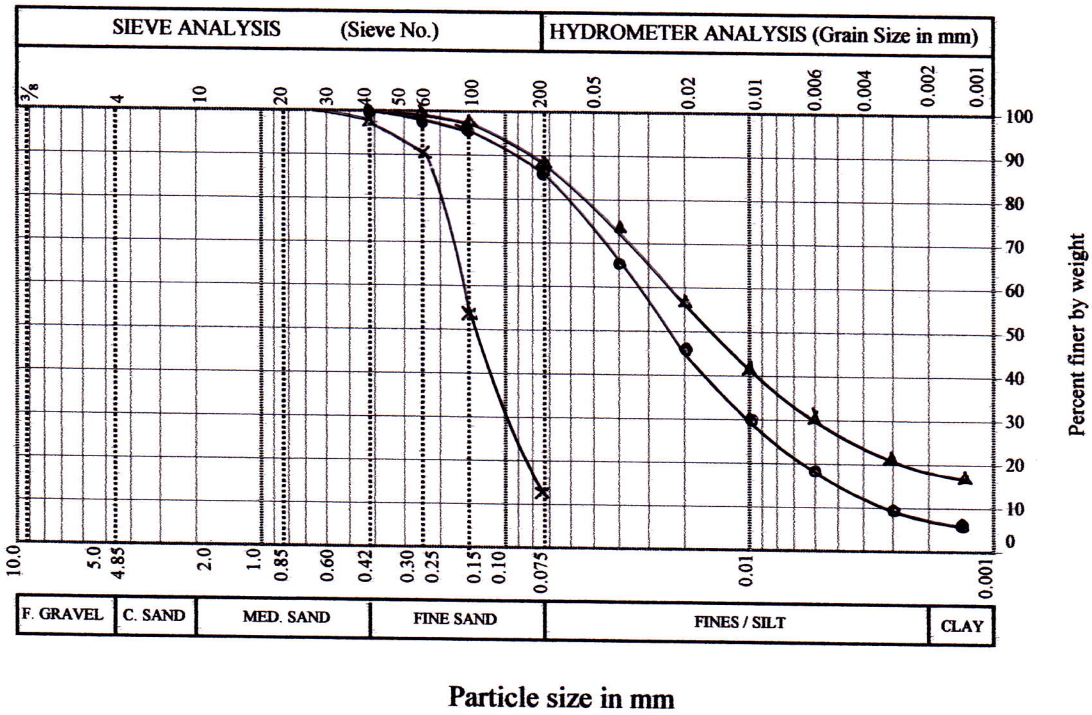
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 16	●—●—●	D - 12	18.0	92	8	0	–	–	–	–	Silty FINE SAND
BH - 17	★—★—★	D - 1	1.5	8	70	22	–	30.4	43	26	Silty CLAY
BH - 17	▲—▲—▲	D - 8	12.0	84	16	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by :

DELTA SOIL ENGINEERS | **GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 18	●—●—●	D - 4	6.0	13	69	18	–	27.4	41	25	Silty CLAY
BH - 18	★★★	D - 12	18.0	88	12	0	–	–	–	–	Silty FINE SAND
BH - 19	▲—▲—▲	D - 3	4.5	11	72	7	–	31.4	40	26	Silty CLAY

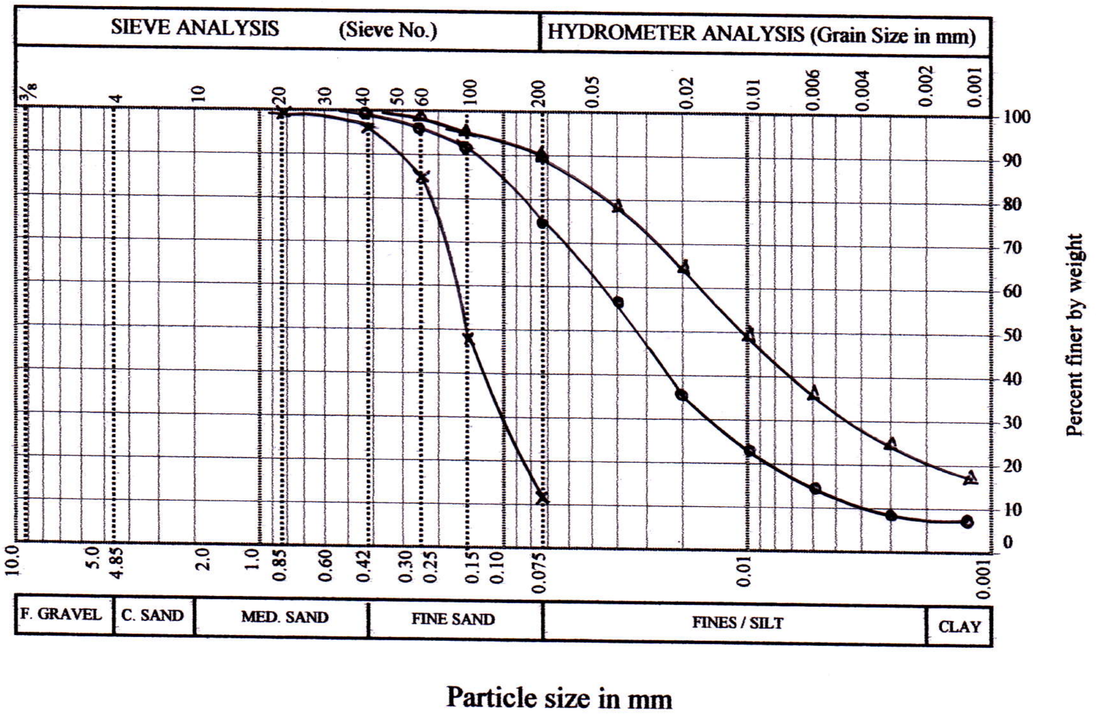
Tested by : Ploh Checked by :

SHEET 16 OF 23 ATTACHMENT - III

GRAIN SIZE TEST

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



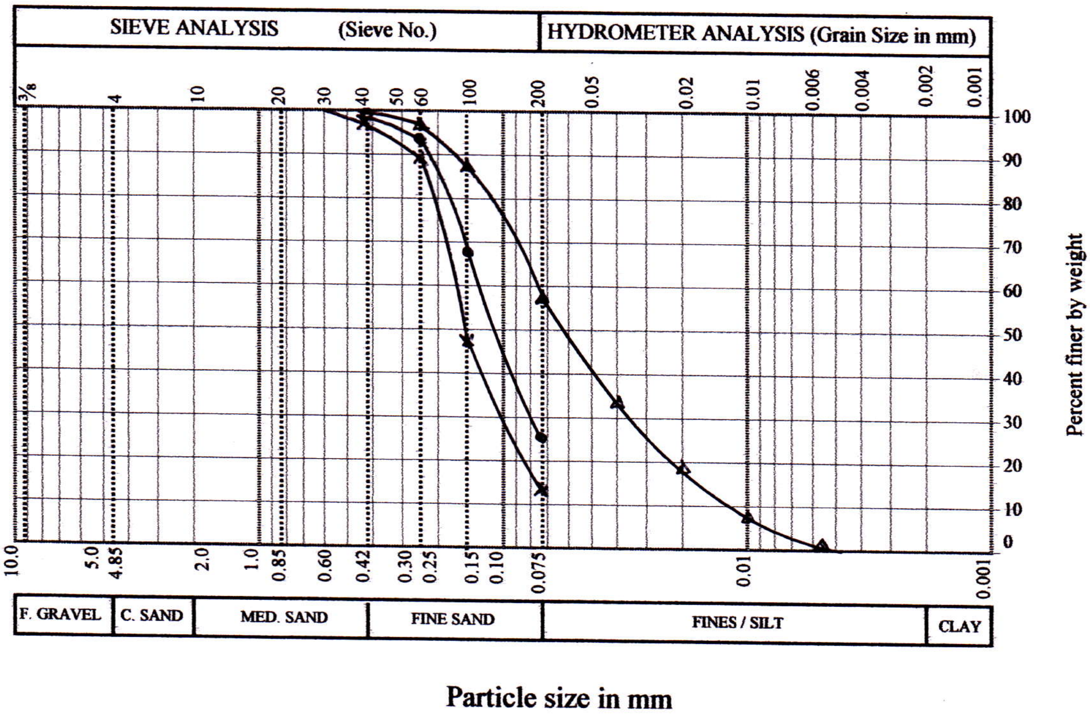
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 19	●—●—●	D - 4	6.0	24	70	6	–	26.6	33	37	Clayey SILT
BH - 19	★—★—★	D - 14	21.0	89	11	0	–	–	–	–	Silty FINE SAND
BH - 20	▲—▲—▲	D - 1	1.5	10	70	20	–	28.3	42	24	Silty CLAY

Tested by :
Checked by :
SHEET 17 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS | **GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

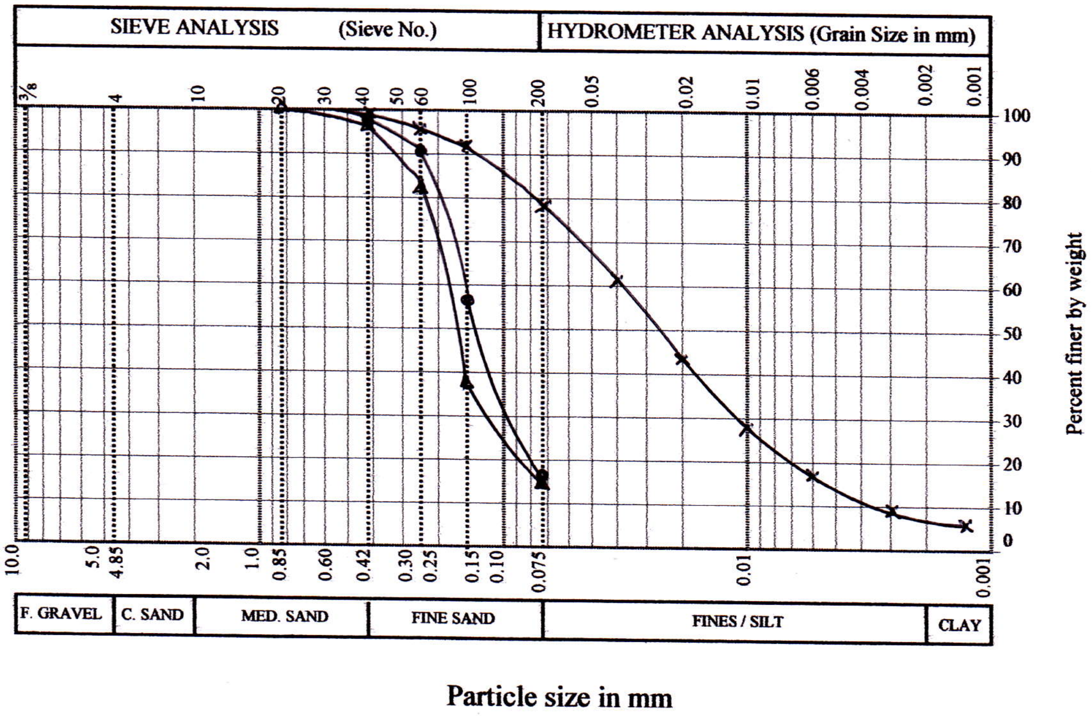


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 20	●—●—●	D - 5	7.5	74	26	0	–	–	–	–	Silty FINE SAND
BH - 20	★—★—★	D - 12	18.0	87	13	0	–	–	–	–	Silty FINE SAND
BH - 21	▲—▲—▲	D - 3	4.5	42	58	0	–	–	–	–	Sandy SILT

Tested by : Checked by : SHEET 18 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

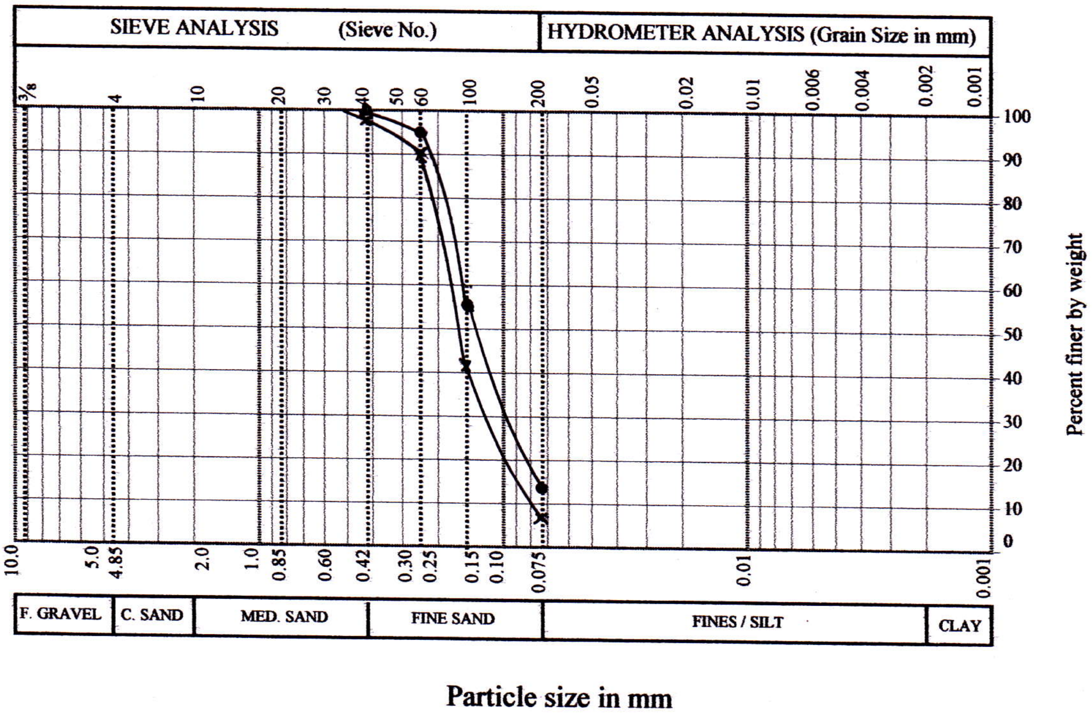


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 21	●—●—●	D - 10	15.0	83	17	0	–	–	–	–	Silty FINE SAND
BH - 22	★—★—★	D - 3	4.5	21	73	6	–	27.4	32	27	Clayey SILT
BH - 22	▲—▲—▲	D - 8	12.0	85	15	0	–	–	–	–	Silty FINE SAND

Tested by : Checked by : SHEET 19 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE

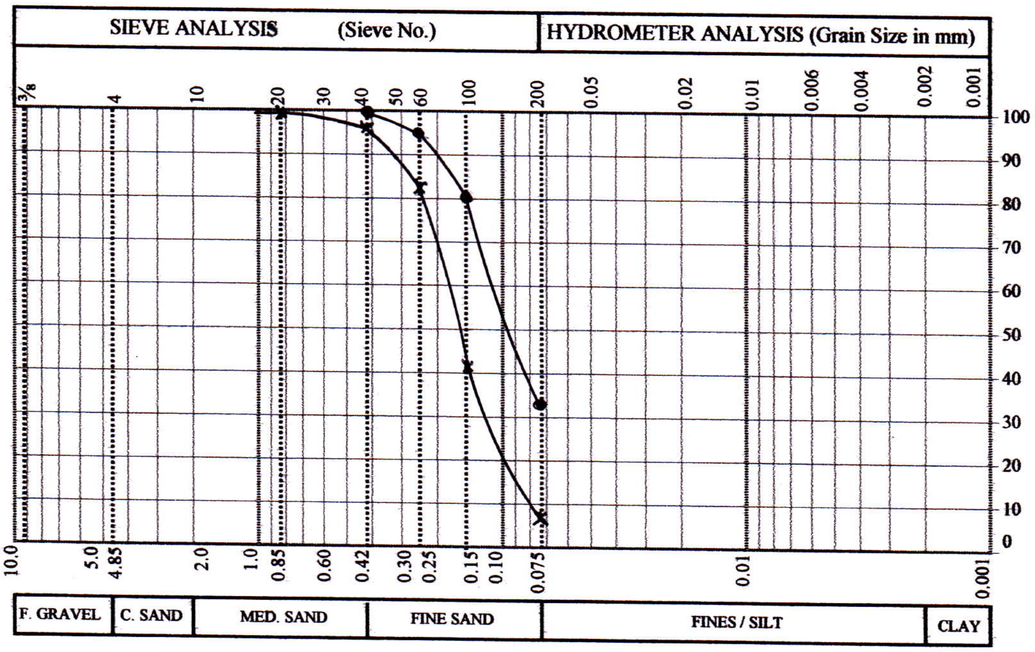


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 23	●—●—●	D - 11	16.5	86	14	0	–	–	–	–	Silty FINE SAND
BH - 24	★★★	D - 2	3.0	7	71	22	–	28.4	43	25	Silty CLAY

Tested by : Checked by : SHEET 20 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,**
Mirsarai, Chittagong.

GRADATION CURVE



Percent finer by weight

Particle size in mm

BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 24	●—●—●	D - 4	6.0	67	33	0	–	–	–	–	Silty FINE SAND
BH - 24	★★★	D - 8	12.0	92	8	0	–	–	–	–	Silty FINE SAND

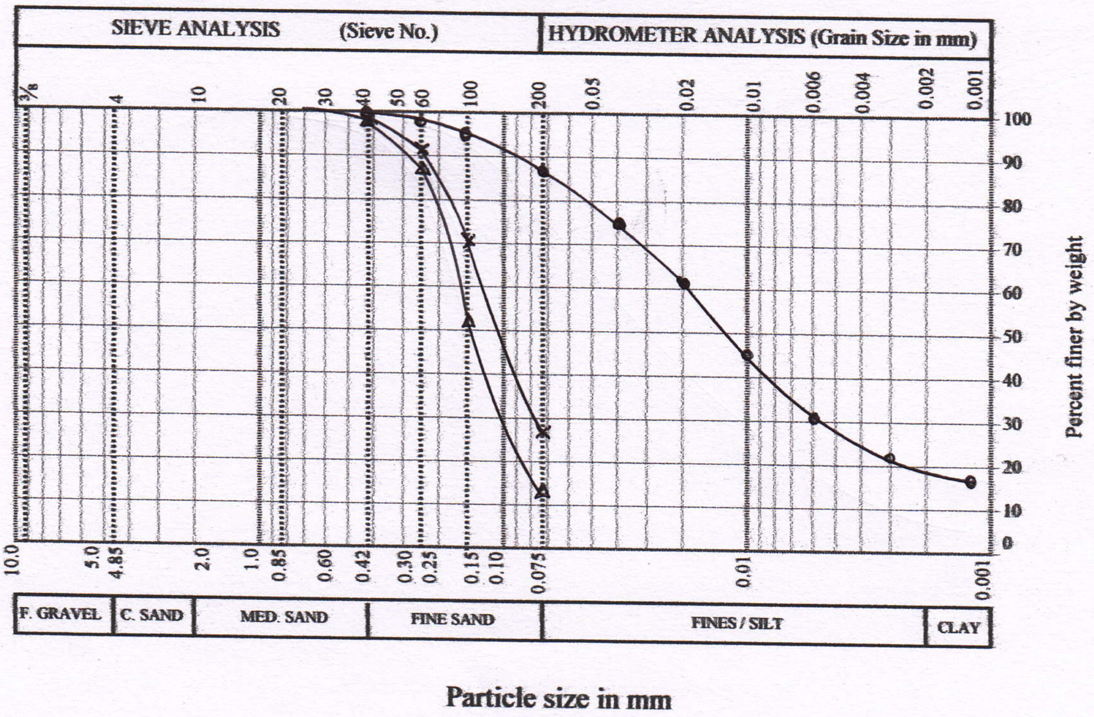
Tested by : Pkoh Checked by :

SHEET 21 OF 23 ATTACHMENT - III

DELTA SOIL ENGINEERS | **GRAIN SIZE TEST**

PROJECT : **Sub-Soil Investigation for Bridge Construction.**
SITE : **Azompur River Crossing site.**

GRADATION CURVE

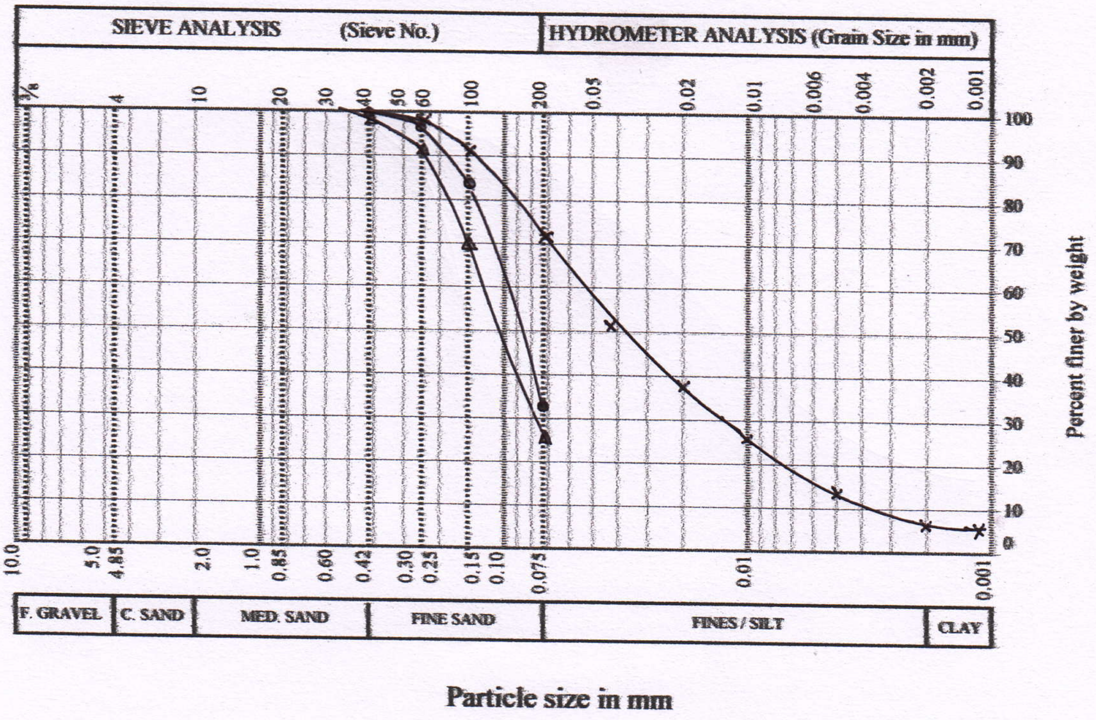


BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 25	●—●—●	D - 3	4.5	12	70	18	–	27.6	40	22	Silty CLAY
BH - 25	★★★	D - 6	9.0	72	28	0	–	–	–	–	Silty FINE SAND
BH - 25	▲▲▲	D - 12	18.0	87	13	0	–	–	–	–	Silty FINE SAND

Tested by : Ptoh Checked by : SHEET 22 OF 23 ATTACHMENT - III

PROJECT : **Sub-Soil Investigation for Bridge Construction.**
SITE : **Azompur River Crossing site.**

GRADATION CURVE



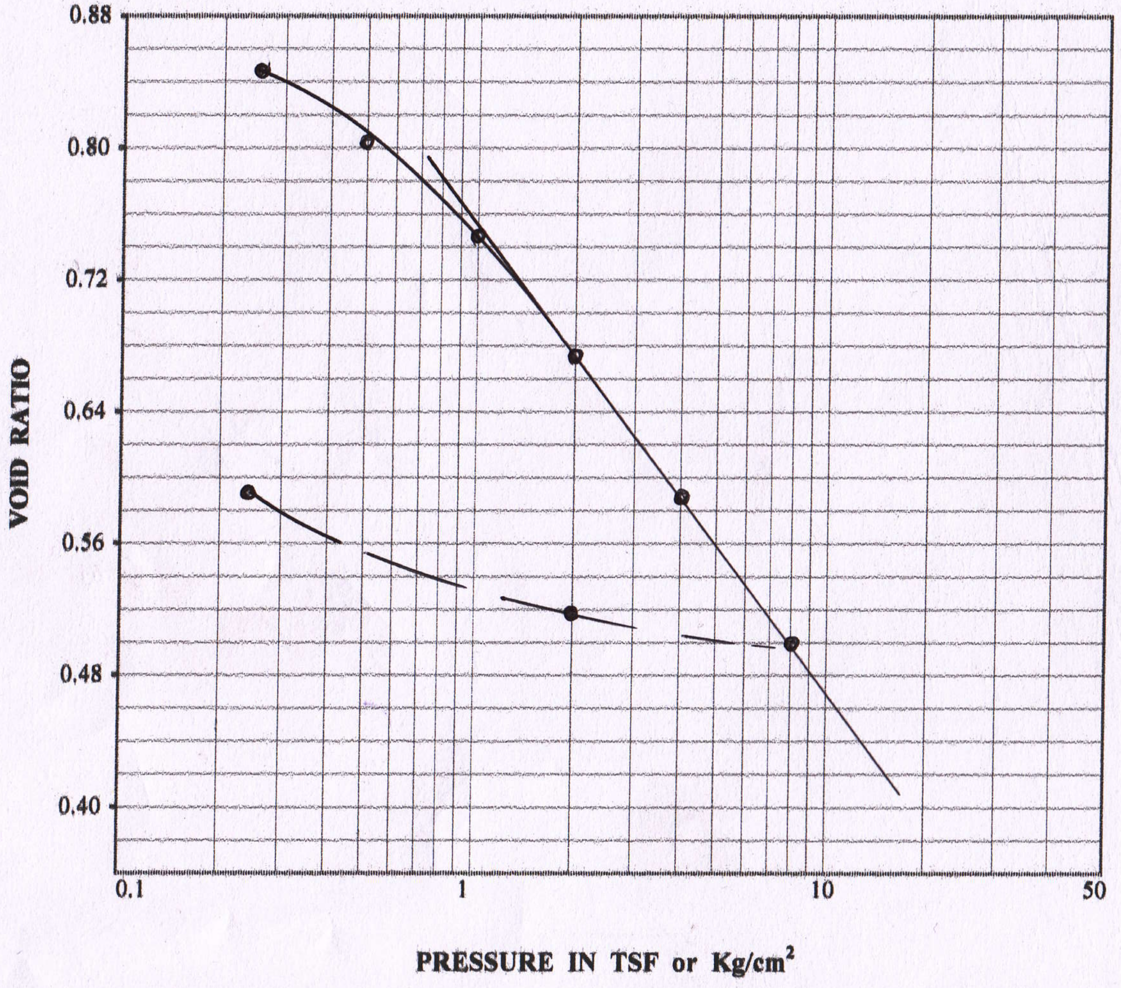
BH No.	Legend	Sample	Depth (m)	Sand	Silt	Clay	Sp. Gr.	MC%	LL%	PL%	Type of Soil
BH - 26	●—●—●	D - 4	6.0	67	33	0	–	–	–	–	Silty FINE SAND
BH - 26	★—★—★	D - 6	9.0	28	67	5	–	26.8	29	26	Clayey SILT
BH - 26	▲—▲—▲	D - 10	15.0	84	16	0	–	–	–	–	Silty FINE SAND

Tested by : Ptosh Checked by :

DELTA SOIL ENGINEERS

CONSOLIDATION TEST
VOID RATIO-LOG PRESSURE CURVE

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.**
SITE : **Proposed Water Intake site.**



BORING NO. : 1
SAMPLE NO. : U - 1
SAMPLE DEPTH (m.) : 2.55 to 3.0
DESCRIPTION : silty CLAY
DIAMETER : 6.35 cm
INITIAL HEIGHT : 2.54 cm
SOLID HEIGHT : 1.353 cm
INITIAL M.C. : 30.6%
DRY DENSITY (kN/m^3) : 13.94
INITIAL VOID RATIO (e_0) : 0.877
SPECIFIC GRAVITY : 2.673
COMPRESSION INDEX (Cc) : 0.250

Tested by : Checked by : SHEET 1 OF 7 ATTACHMENT - IV

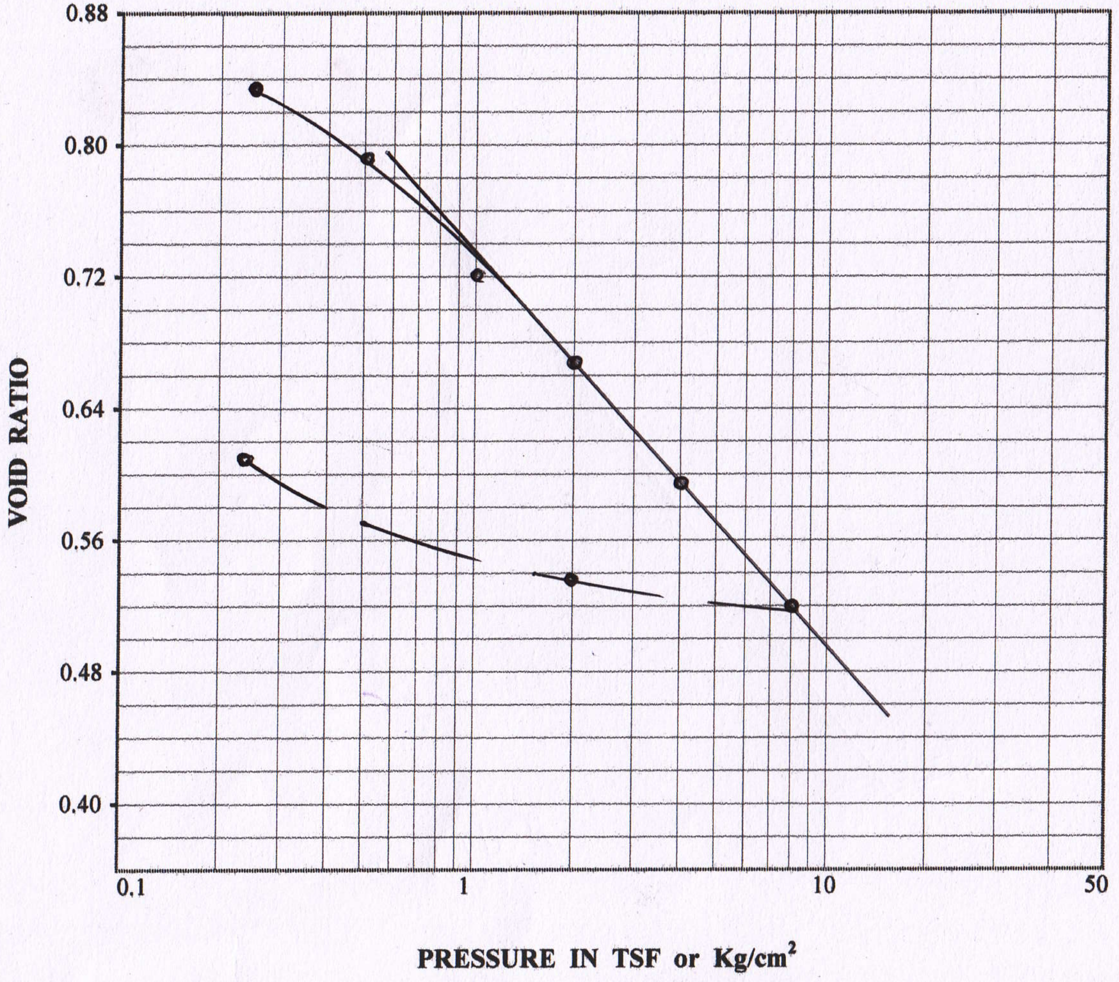
DELTA SOIL ENGINEERS

CONSOLIDATION TEST

VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-soil Investigationfor Const. Of Proposed Water Treatment Plant.

SITE :Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.



BORING NO. : 3

SAMPLE NO. : U - 1

SAMPLE DEPTH (m.) : 4.05 to 4.5

DESCRIPTION : silty CLAY

DIAMETER : 6.35 cm

INITIAL HEIGHT : 2.54 cm

SOLID HEIGHT : 1.357 cm

INITIAL M.C. : 30.3%

DRY DENSITY (kN/m^3) : 13.98

INITIAL VOID RATIO (e_0) : 0.872

SPECIFIC GRAVITY : 2.675

COMPRESSION INDEX (Cc) : 0.240

Tested by :

Checked by :

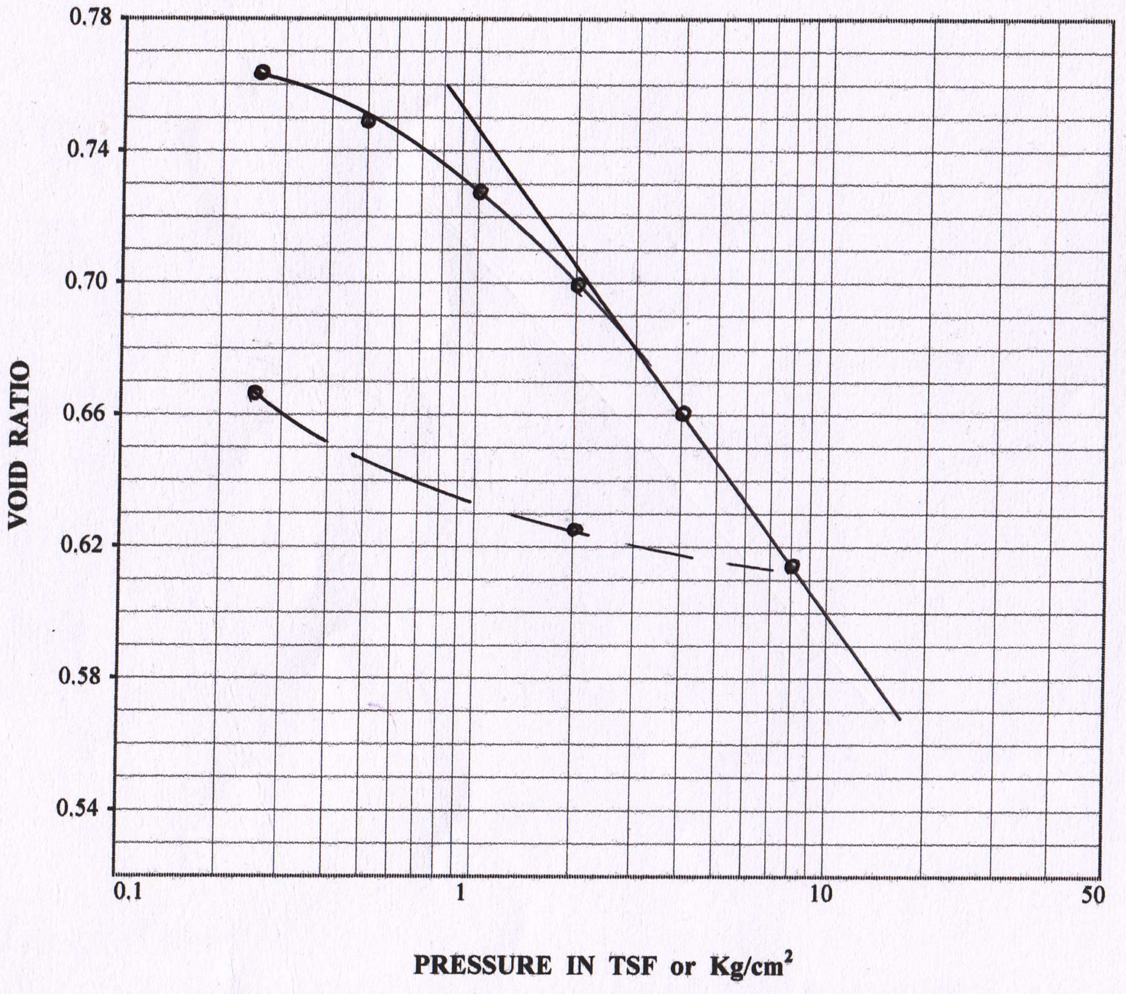
SHEET 2 OF 7 ATTACHMENT - IV

DELTA SOIL ENGINEERS

CONSOLIDATION TEST

VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-soil Investigationfor Const. Of Proposed Water Treatment Plant.
SITE :Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.



BORING NO. :	8
SAMPLE NO. :	U - 1
SAMPLE DEPTH (m.) :	5.55 to 6.0
DESCRIPTION :	silty CLAY
DIAMETER :	6.35 cm
INITIAL HEIGHT :	2.54 cm
SOLID HEIGHT :	1.434 cm
INITIAL M.C. :	25.8%
DRY DENSITY (kN/m^3) :	14.72
INITIAL VOID RATIO (e_0) :	0.771
SPECIFIC GRAVITY :	2.668
COMPRESSION INDEX (Cc) :	0.145

Tested by :

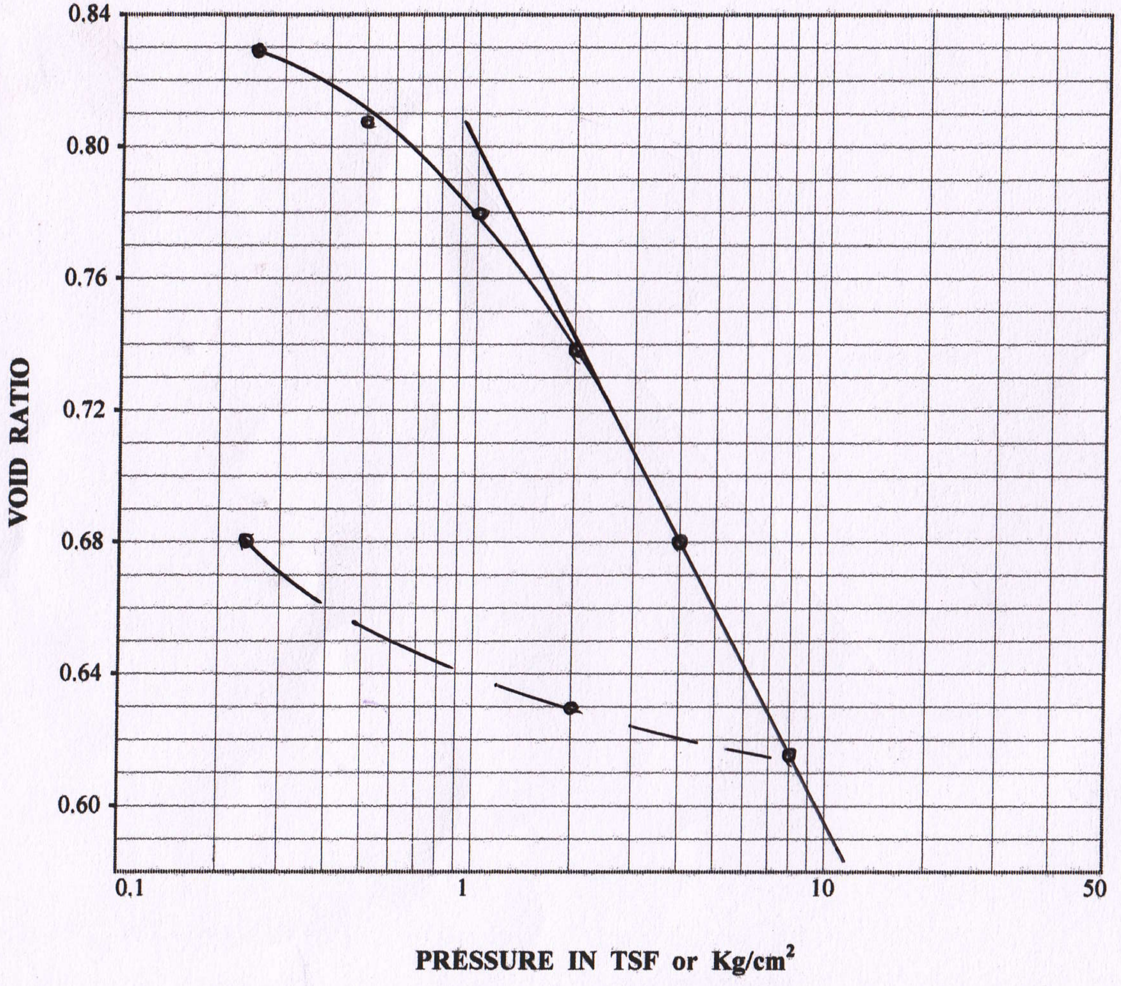
Checked by :

SHEET 3 OF 7 ATTACHMENT - IV

DELTA SOIL ENGINEERS

CONSOLIDATION TEST
VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-soil Investigationfor Const. Of Proposed Water Treatment Plant.
SITE :Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.



BORING NO. :	15
SAMPLE NO. :	U - 1
SAMPLE DEPTH (m.) :	4.05 to 4.5
DESCRIPTION :	silty CLAY
DIAMETER :	6.35 cm
INITIAL HEIGHT :	2.54 cm
SOLID HEIGHT :	1.382 cm
INITIAL M.C. :	28.6%
DRY DENSITY (kN/m^3) :	14.26
INITIAL VOID RATIO (e_0) :	0.838
SPECIFIC GRAVITY :	2.674
COMPRESSION INDEX (Cc) :	0.205

Tested by :

Checked by :

SHEET 4 OF 7 ATTACHMENT - IV

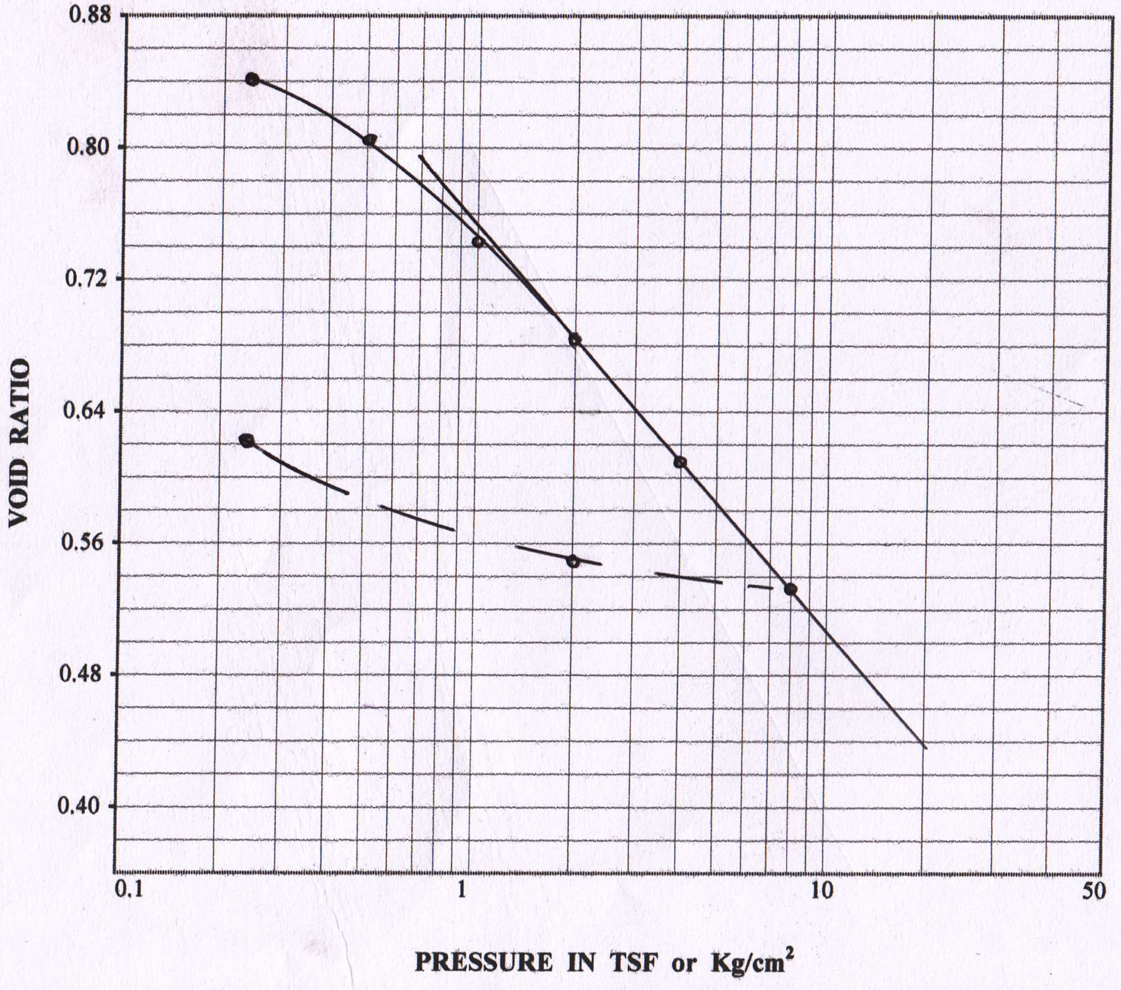
DELTA SOIL ENGINEERS

CONSOLIDATION TEST

VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-soil Investigationfor Const. Of Proposed Water Treatment Plant.

SITE :Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.



BORING NO. : 19

SAMPLE NO. : U - 1

SAMPLE DEPTH (m.) : 2.55 to 3.0

DESCRIPTION : silty CLAY

DIAMETER : 6.35 cm

INITIAL HEIGHT : 2.54 cm

SOLID HEIGHT : 1.353 cm

INITIAL M.C. : 30.8%

DRY DENSITY (kN/m^3) : 13.93

INITIAL VOID RATIO (e_0) : 0.877

SPECIFIC GRAVITY : 2.673

COMPRESSION INDEX (Cc) : 0.245

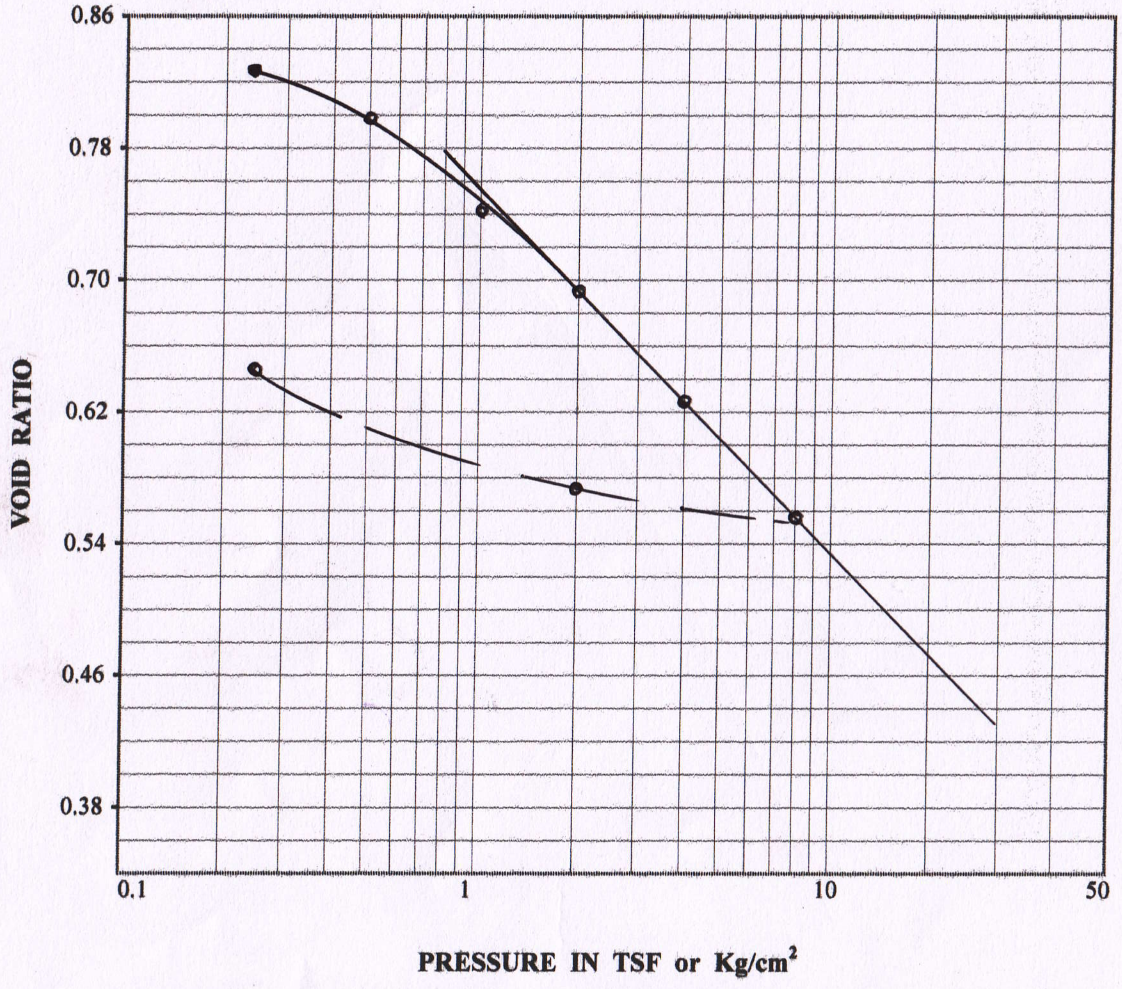
Tested by : Checked by : SHEET 5 OF 7 ATTACHMENT - IV

DELTA SOIL ENGINEERS

CONSOLIDATION TEST

VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-soil Investigationfor Const. Of Proposed Water Treatment Plant.
SITE :Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.



BORING NO. :	22
SAMPLE NO. :	U - 1
SAMPLE DEPTH (m.) :	4.05 to 4.5
DESCRIPTION :	silty CLAY
DIAMETER :	6.35 cm
INITIAL HEIGHT :	2.54 cm
SOLID HEIGHT :	1.377 cm
INITIAL M.C. :	28.8%
DRY DENSITY (kN/m^3) :	14.21
INITIAL VOID RATIO (e_0) :	0.845
SPECIFIC GRAVITY :	2.672
COMPRESSION INDEX (Cc) :	0.220

Tested by : Phoh Checked by :

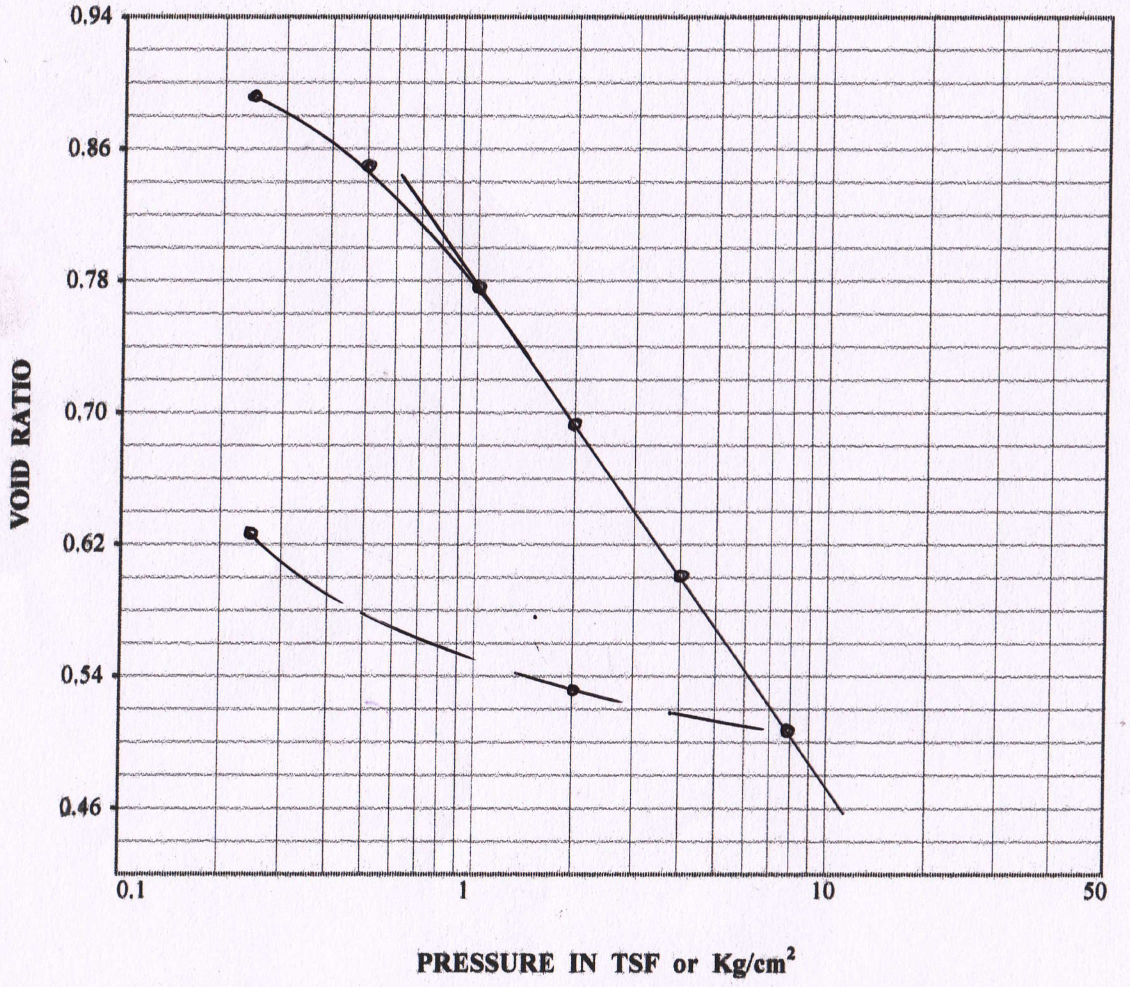
SHEET 6 OF 7 ATTACHMENT - IV

DELTA SOIL ENGINEERS

CONSOLIDATION TEST

VOID RATIO-LOG PRESSURE CURVE

PROJECT : Sub-Soil Investigation for Bridge Construction.
SITE : Azompur River Crossing Site.



BORING NO. :	26
SAMPLE NO. :	U - 1
SAMPLE DEPTH (m.) :	4.05 to 4.5
DESCRIPTION :	silty CLAY
DIAMETER :	6.35 cm
INITIAL HEIGHT :	2.54 cm
SOLID HEIGHT :	1.318 cm
INITIAL M.C. :	33.8%
DRY DENSITY (kN/m^3) :	13.57
INITIAL VOID RATIO (e_0) :	0.927
SPECIFIC GRAVITY :	2.667
COMPRESSION INDEX (Cc) :	0.305

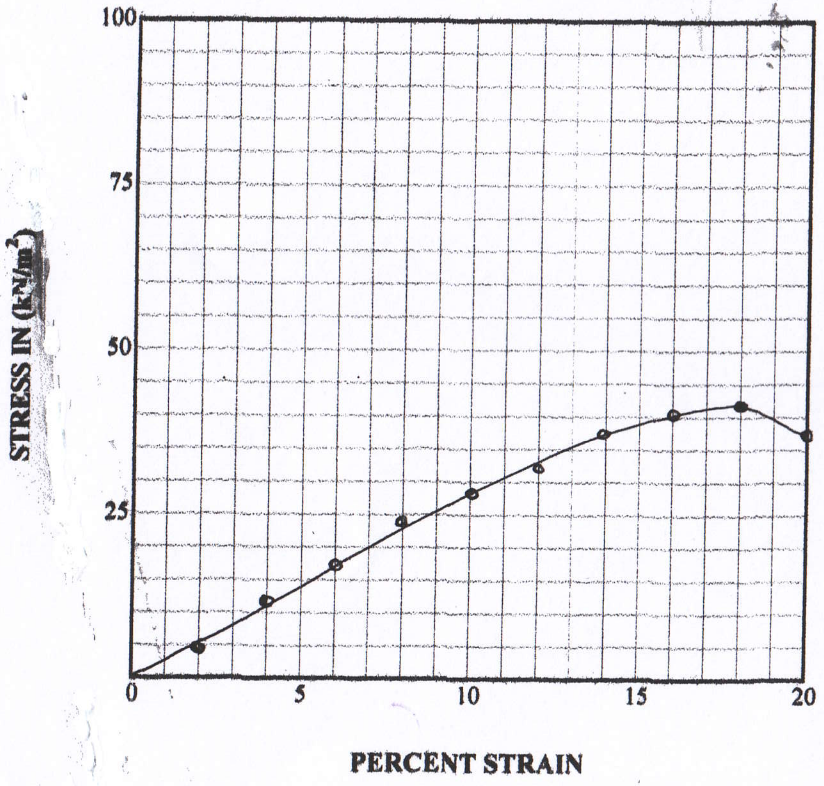
Tested by :

Checked by :

SHEET 7 OF 7 ATTACHMENT - IV

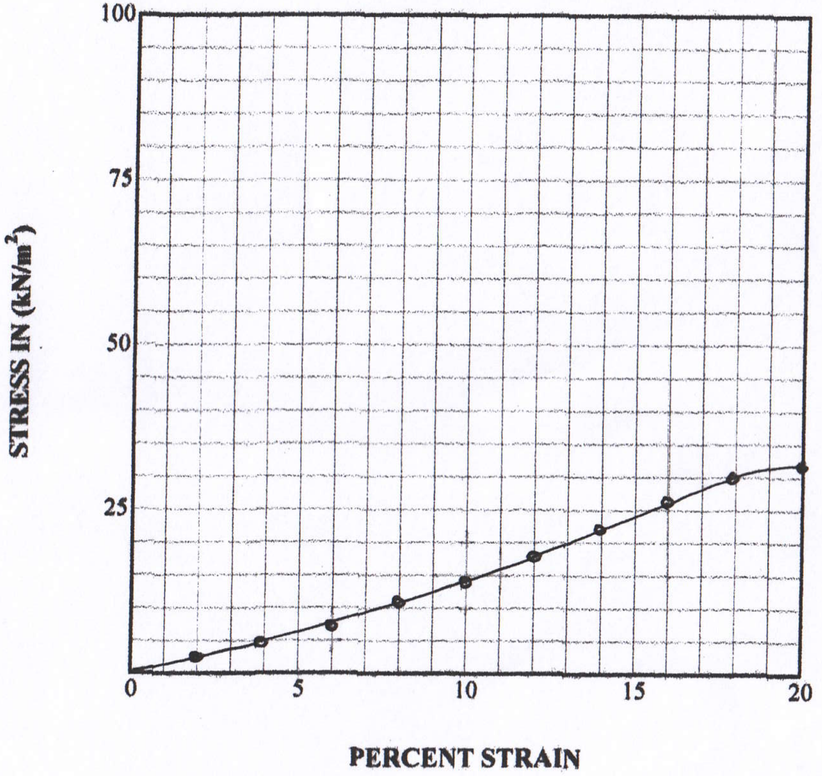
DELTA SOIL ENGINEERS	**UNCONFINED COMPRESSION TEST**	**PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.** **SITE : Proposed Water Intake site.**

Bore Hole No. 1 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m²)	41.6
Percent Strain at Failure	18.0
Moisture Content (%)	30.6
Wet Density (kN/m³)	18.20
Dry Density (kN/m³)	13.94

Bore Hole No. 2 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m²)	31.7
Percent Strain at Failure	20.0
Moisture Content (%)	31.7
Wet Density (kN/m³)	18.14
Dry Density (kN/m³)	13.77

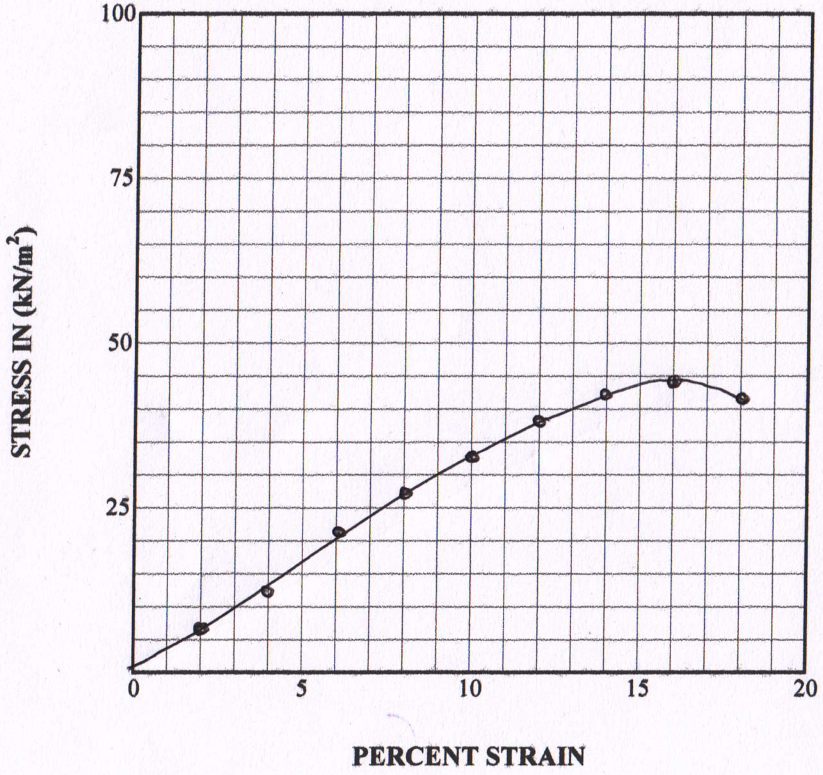
Tested by : Checked by : SHEET 1 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

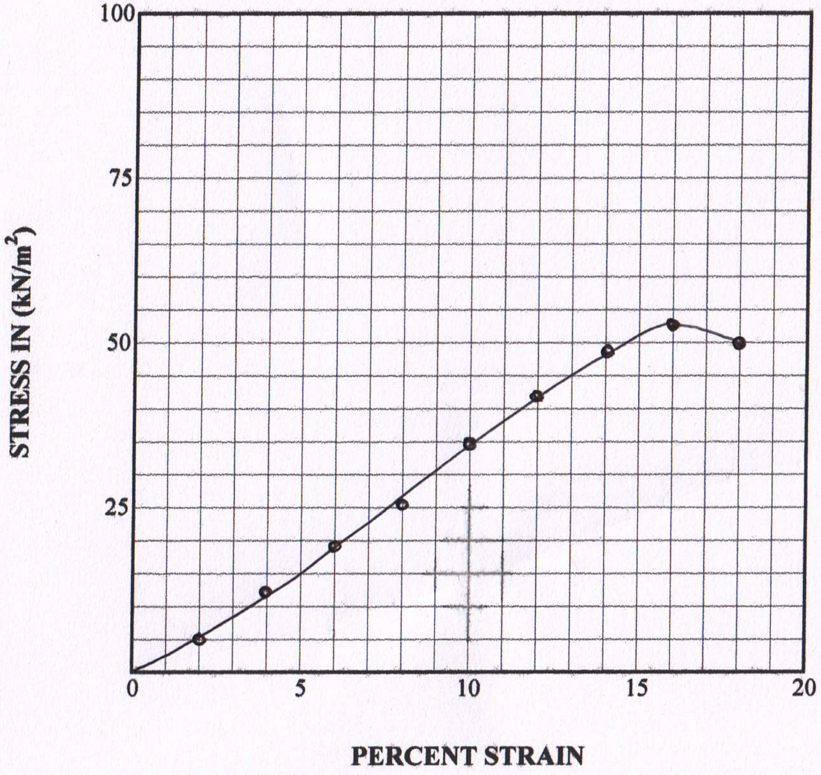
PROJECT : Sub-Soil Investigation for Const. of
Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,
Mirsarai, Chittagong.

Bore Hole No. 3 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	44.7
Percent Strain at Failure	16.0
Moisture Content (%)	30.3
Wet Density (kN/m^3)	18.22
Dry Density (kN/m^3)	13.98

Bore Hole No. 4 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	52.8
Percent Strain at Failure	16.0
Moisture Content (%)	28.8
Wet Density (kN/m^3)	18.30
Dry Density (kN/m^3)	14.21

Tested by : Checked by :

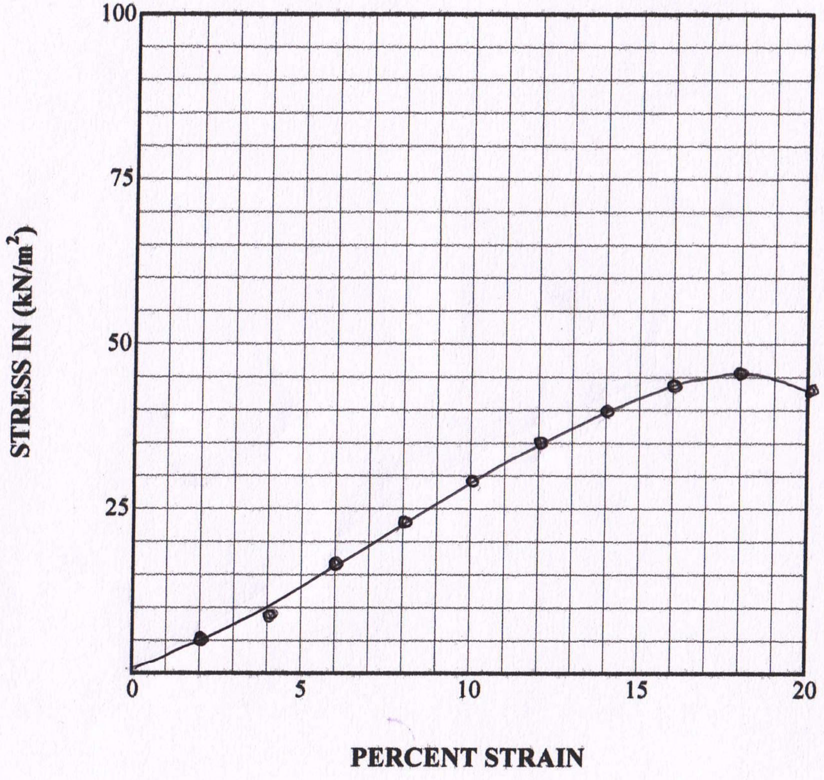
SHEET 2 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

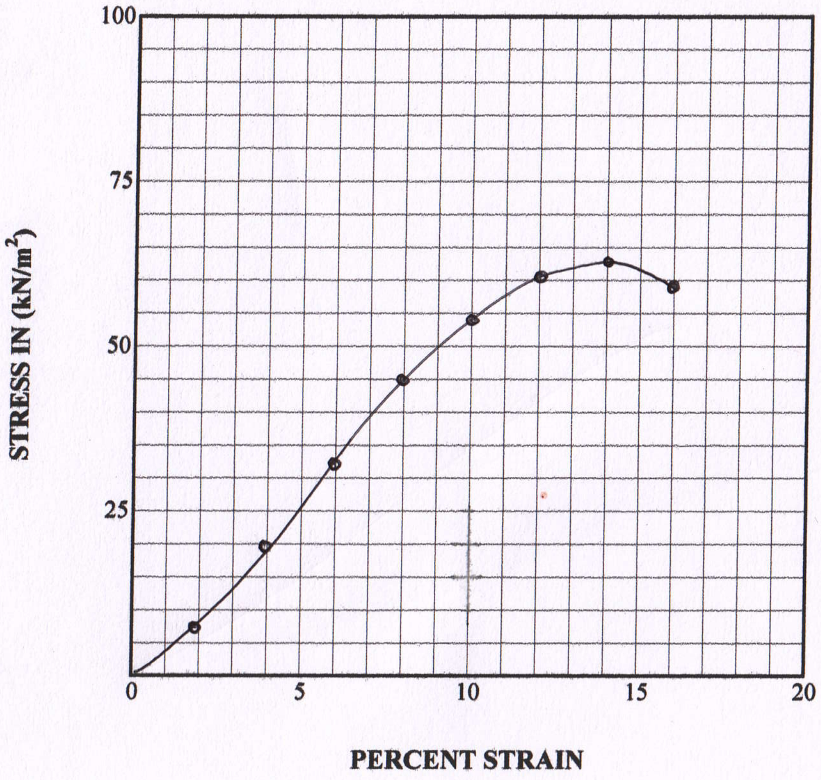
PROJECT : Sub-Soil Investigation for Const. of
Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar,
Mirsarai, Chittagong.

Bore Hole No. 5 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m^2)	45.4
Percent Strain at Failure	18.0
Moisture Content (%)	32.4
Wet Density (kN/m^3)	18.23
Dry Density (kN/m^3)	13.77

Bore Hole No. 6 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	67.8
Percent Strain at Failure	14.0
Moisture Content (%)	27.5
Wet Density (kN/m^3)	18.36
Dry Density (kN/m^3)	14.40

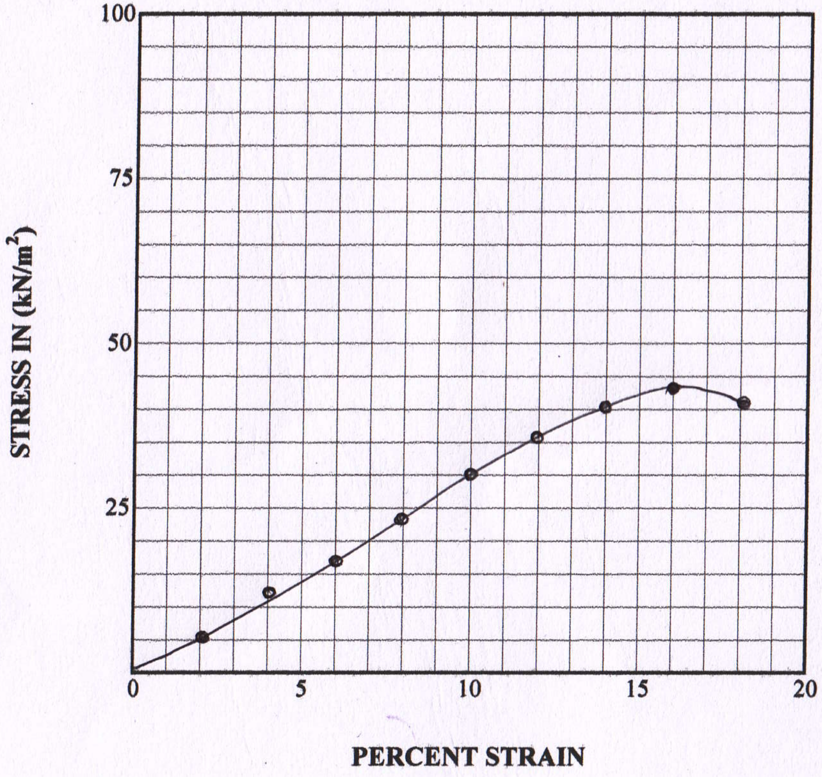
Tested by : Checked by : SHEET 3 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

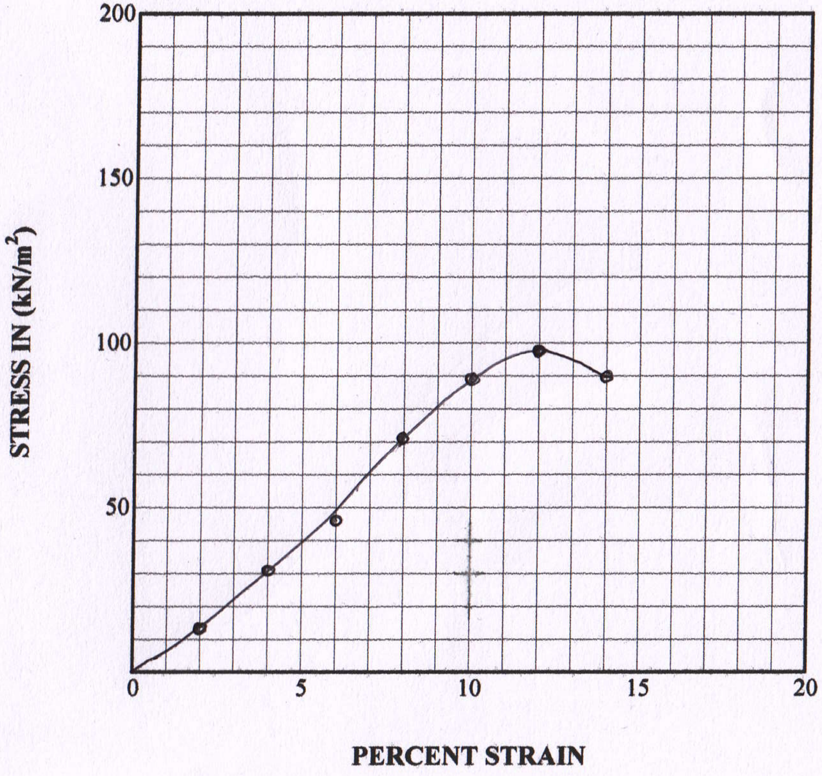
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 7 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	43.2
Percent Strain at Failure	16.0
Moisture Content (%)	31.5
Wet Density (kN/m^3)	18.24
Dry Density (kN/m^3)	13.77

Bore Hole No. 8 Sample No. U-1 Sample Depth 5.55 to 6.00 m



Unconfined Compressive Strength (kN/m^2)	98.3
Percent Strain at Failure	12.0
Moisture Content (%)	25.8
Wet Density (kN/m^3)	18.52
Dry Density (kN/m^3)	14.72

Tested by : Checked by :

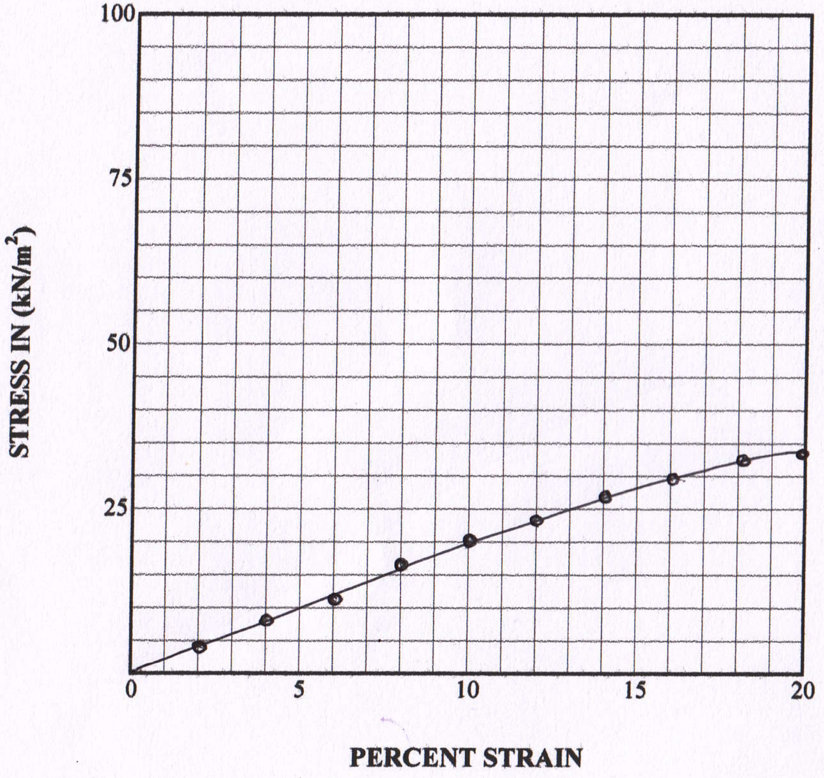
SHEET 4 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

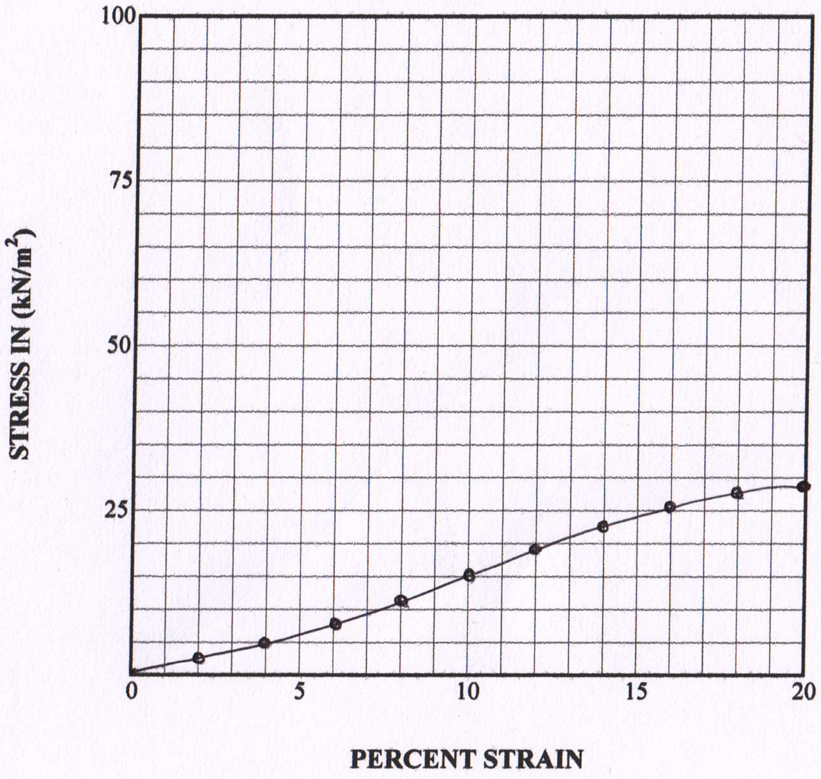
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 9 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m^2)	34.8
Percent Strain at Failure	20.0
Moisture Content (%)	31.7
Wet Density (kN/m^3)	18.20
Dry Density (kN/m^3)	13.82

Bore Hole No. 10 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	28.7
Percent Strain at Failure	20.0
Moisture Content (%)	33.5
Wet Density (kN/m^3)	18.18
Dry Density (kN/m^3)	13.62

Tested by :

Checked by :

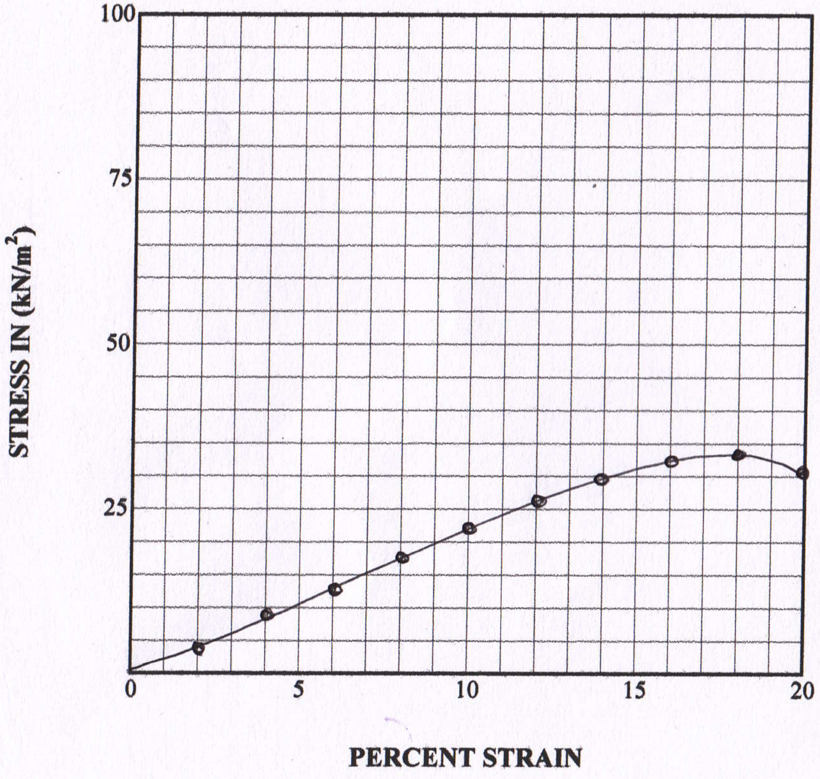
SHEET 5 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

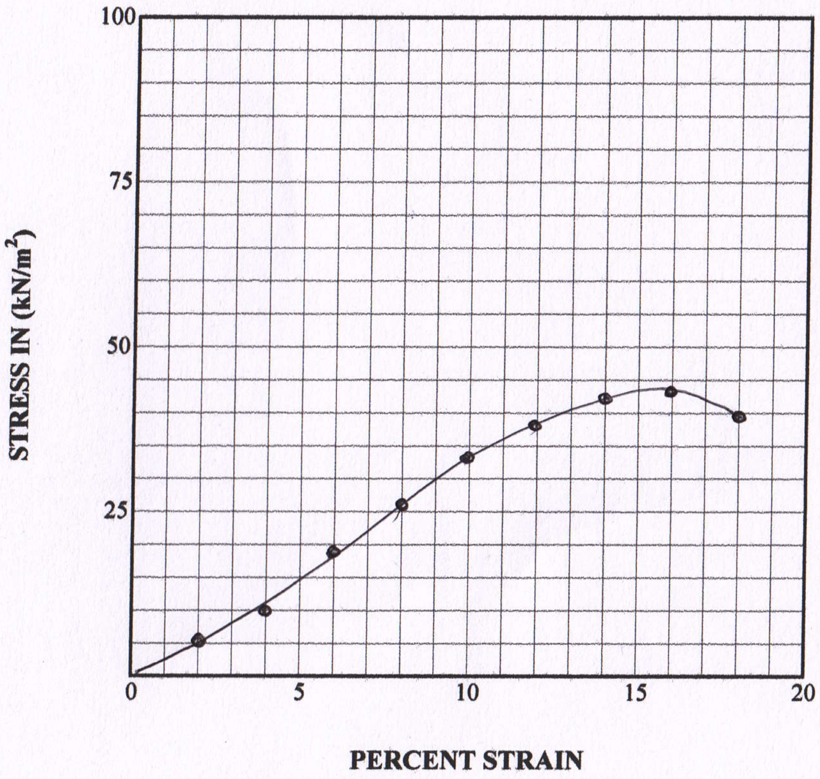
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 11 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m^2)	33.6
Percent Strain at Failure	18.0
Moisture Content (%)	31.2
Wet Density (kN/m^3)	18.15
Dry Density (kN/m^3)	13.83

Bore Hole No. 12 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	43.5
Percent Strain at Failure	16.0
Moisture Content (%)	31.5
Wet Density (kN/m^3)	18.22
Dry Density (kN/m^3)	13.86

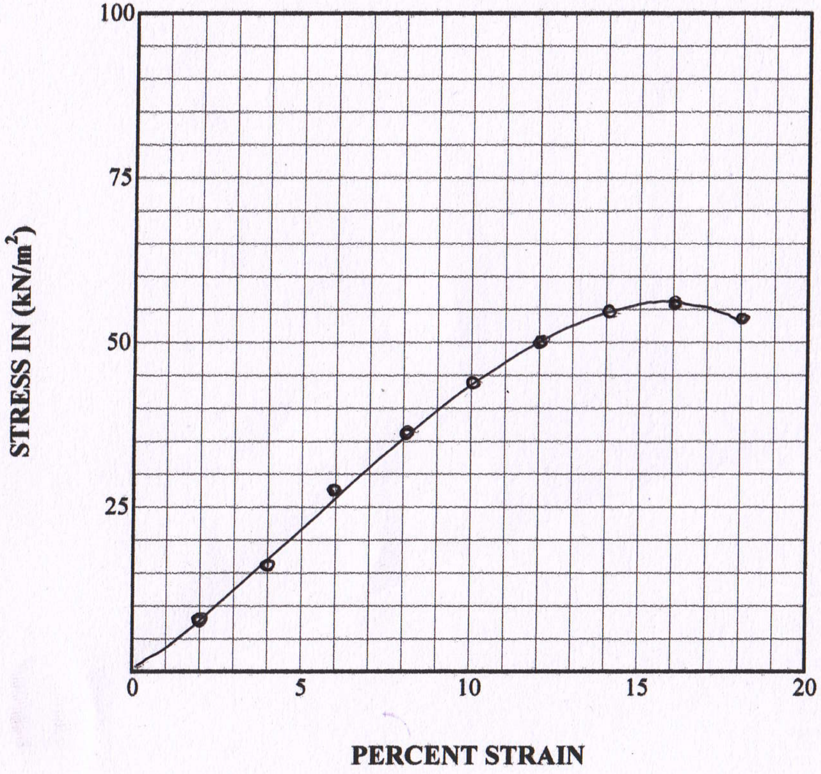
Tested by : Checked by : SHEET 6 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

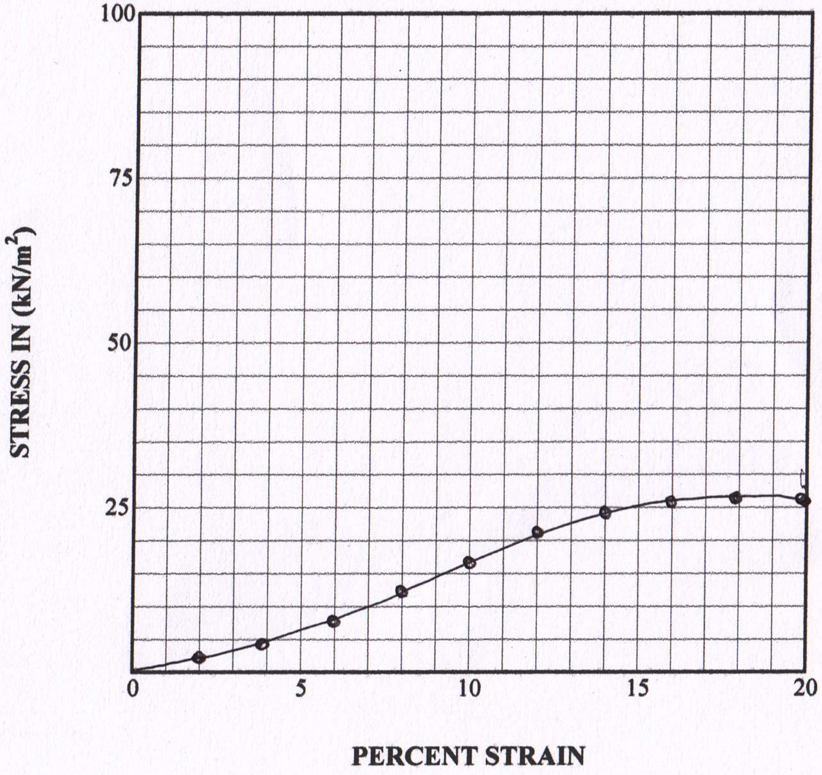
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 13 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	55.6
Percent Strain at Failure	16.0
Moisture Content (%)	29.2
Wet Density (kN/m^3)	18.33
Dry Density (kN/m^3)	14.19

Bore Hole No. 14 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	26.2
Percent Strain at Failure	20.0
Moisture Content (%)	34.6
Wet Density (kN/m^3)	18.15
Dry Density (kN/m^3)	13.48

Tested by : Phoh Checked by :

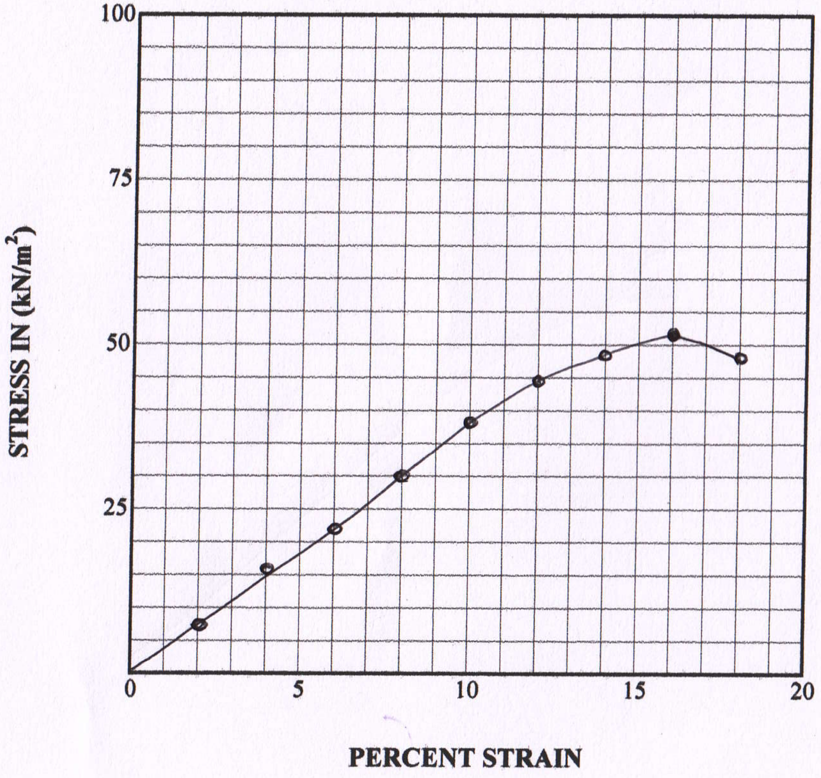
SHEET 7 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

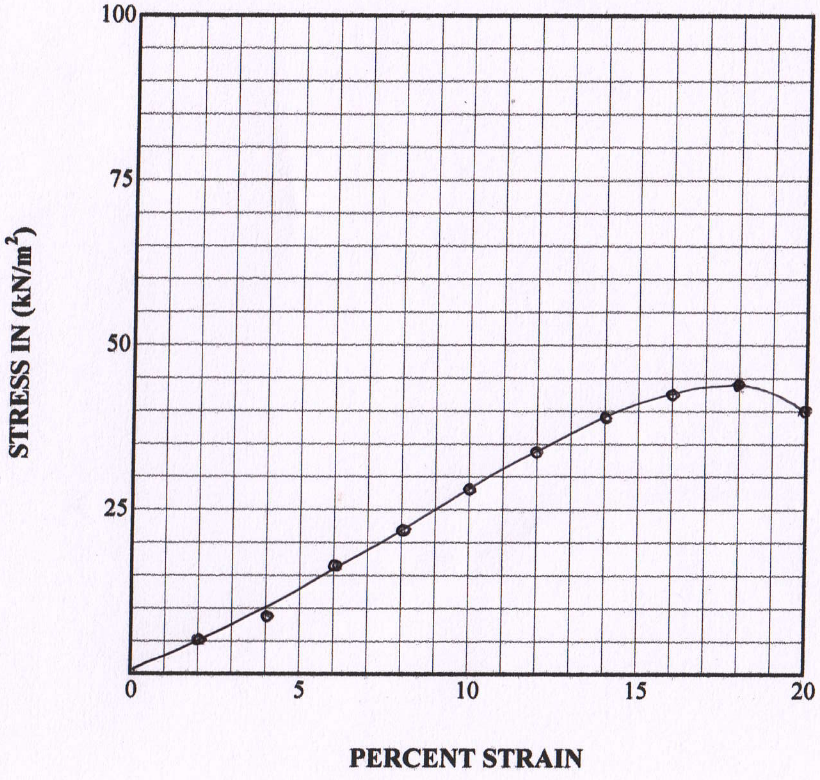
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 15 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	51.5
Percent Strain at Failure	16.0
Moisture Content (%)	28.6
Wet Density (kN/m^3)	18.34
Dry Density (kN/m^3)	14.26

Bore Hole No. 16 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	44.3
Percent Strain at Failure	18.0
Moisture Content (%)	31.8
Wet Density (kN/m^3)	18.25
Dry Density (kN/m^3)	13.85

Tested by :

Checked by :

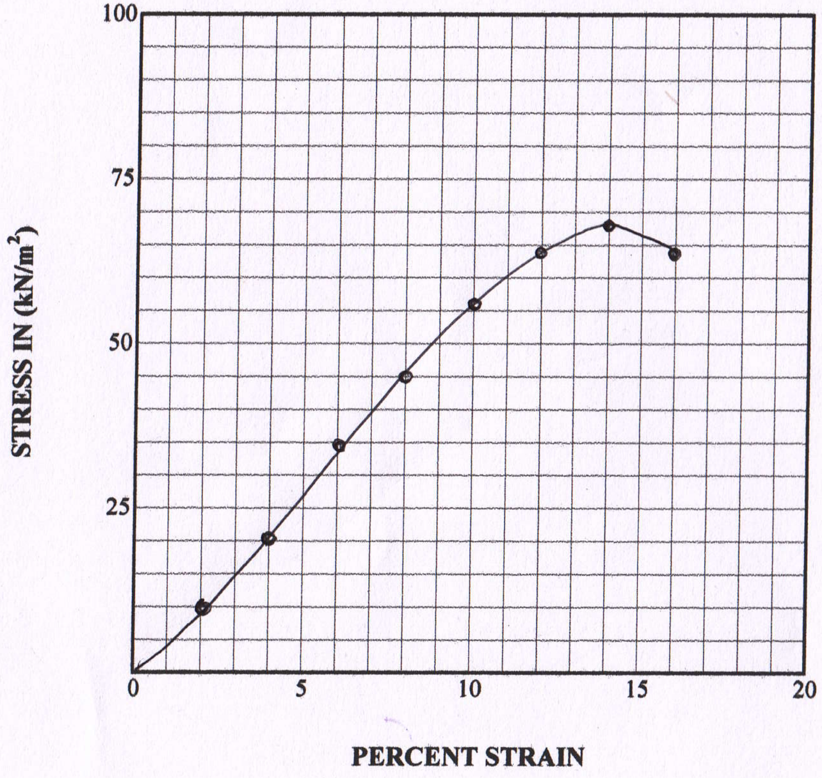
SHEET 8 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

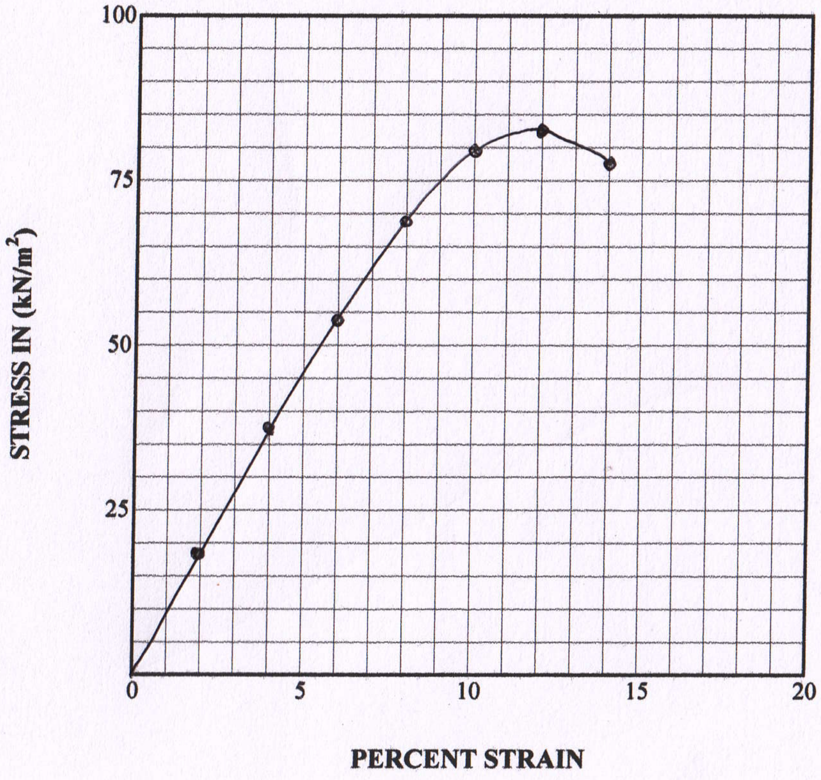
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 17 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	68.2
Percent Strain at Failure	14.0
Moisture Content (%)	27.6
Wet Density (kN/m^3)	18.41
Dry Density (kN/m^3)	14.43

Bore Hole No. 18 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	82.3
Percent Strain at Failure	12.0
Moisture Content (%)	26.8
Wet Density (kN/m^3)	18.50
Dry Density (kN/m^3)	14.59

Tested by : Checked by :

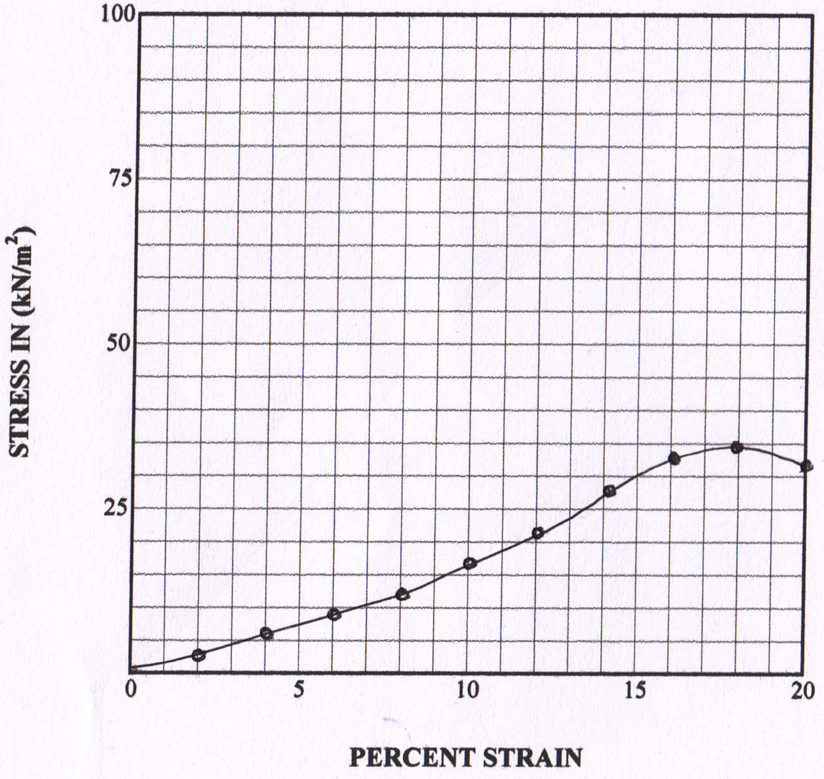
SHEET 9 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

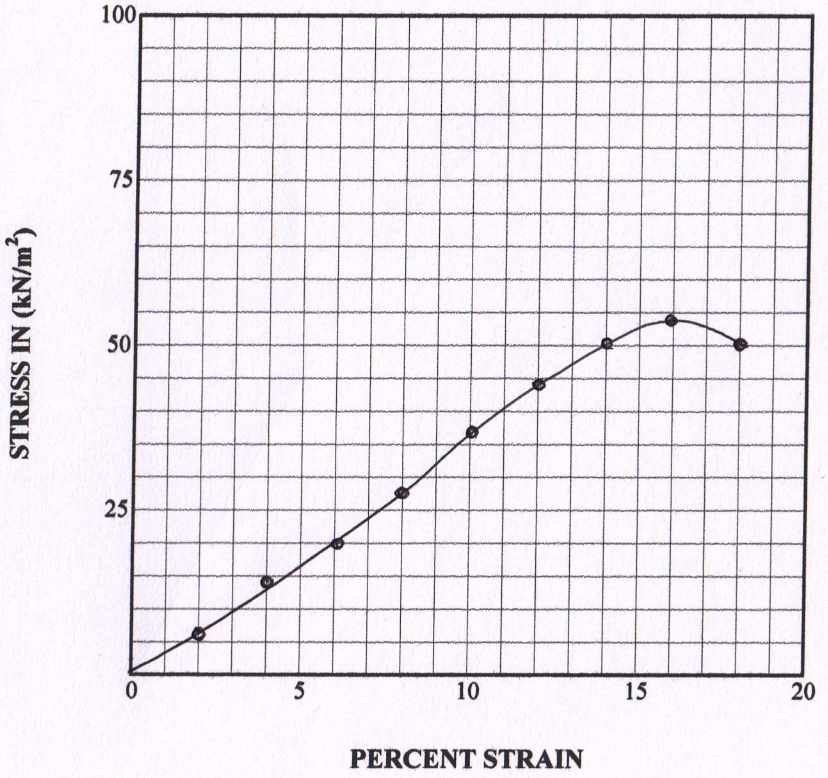
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 19 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m^2)	34.6
Percent Strain at Failure	18.0
Moisture Content (%)	30.8
Wet Density (kN/m^3)	18.22
Dry Density (kN/m^3)	13.93

Bore Hole No. 20 Sample No. U-1 Sample Depth 2.55 to 3.00 m



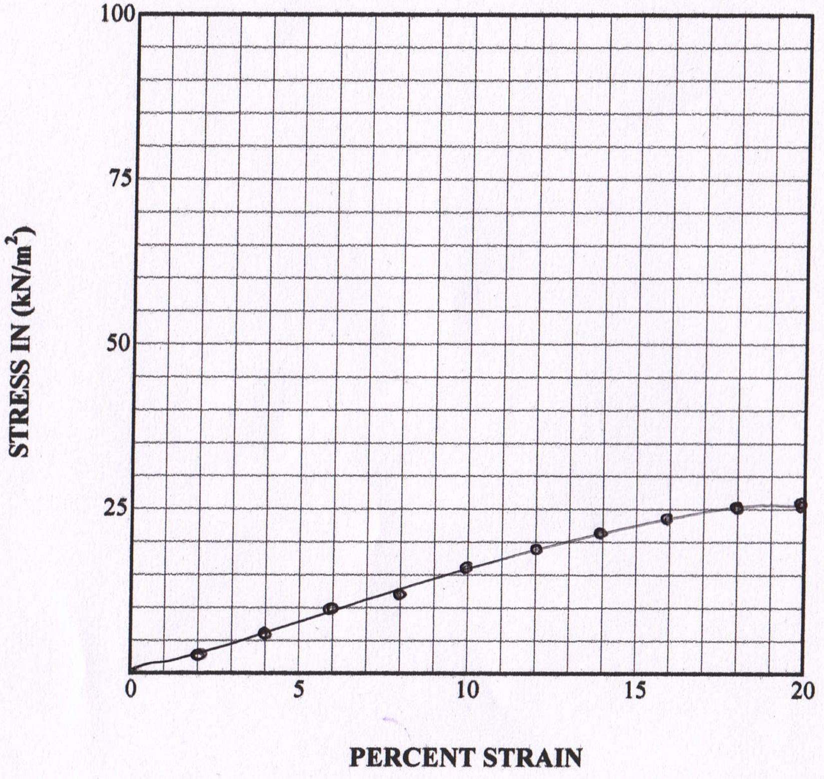
Unconfined Compressive Strength (kN/m^2)	54.2
Percent Strain at Failure	16.0
Moisture Content (%)	28.4
Wet Density (kN/m^3)	18.32
Dry Density (kN/m^3)	14.27

Tested by : Checked by :

SHEET 10 OF 13 ATTACHMENT - V

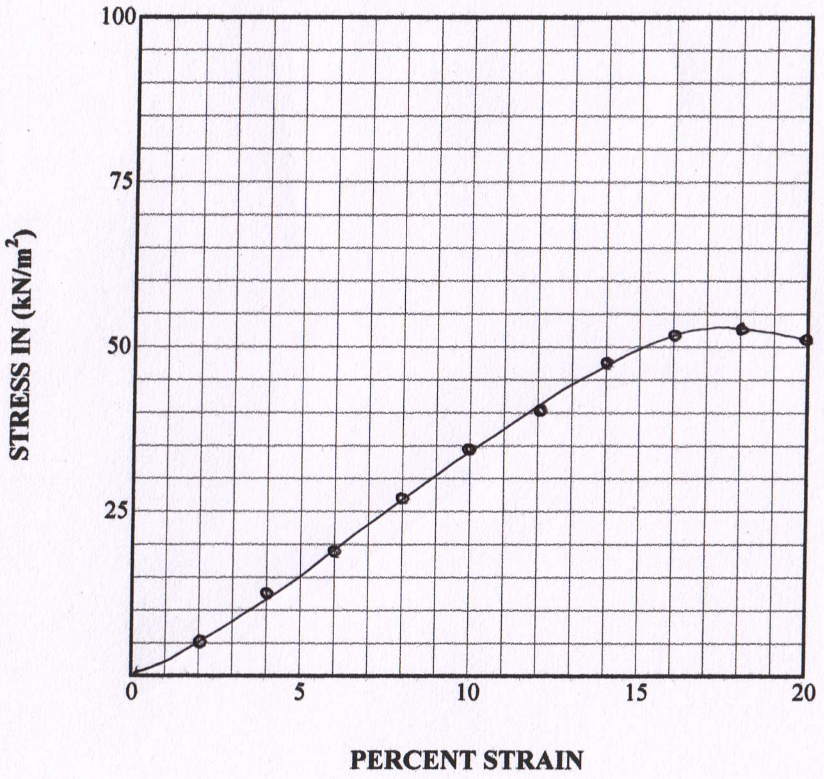
DELTA SOIL ENGINEERS	**UNCONFINED COMPRESSION TEST**	**PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.** **SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.**

Bore Hole No. 21 Sample No. U-1 Sample Depth 2.55 to 3.00 m



Unconfined Compressive Strength (kN/m^2)	25.6
Percent Strain at Failure	20.0
Moisture Content (%)	35.3
Wet Density (kN/m^3)	18.12
Dry Density (kN/m^3)	13.39

Bore Hole No. 22 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	52.5
Percent Strain at Failure	18.0
Moisture Content (%)	28.8
Wet Density (kN/m^3)	18.30
Dry Density (kN/m^3)	14.21

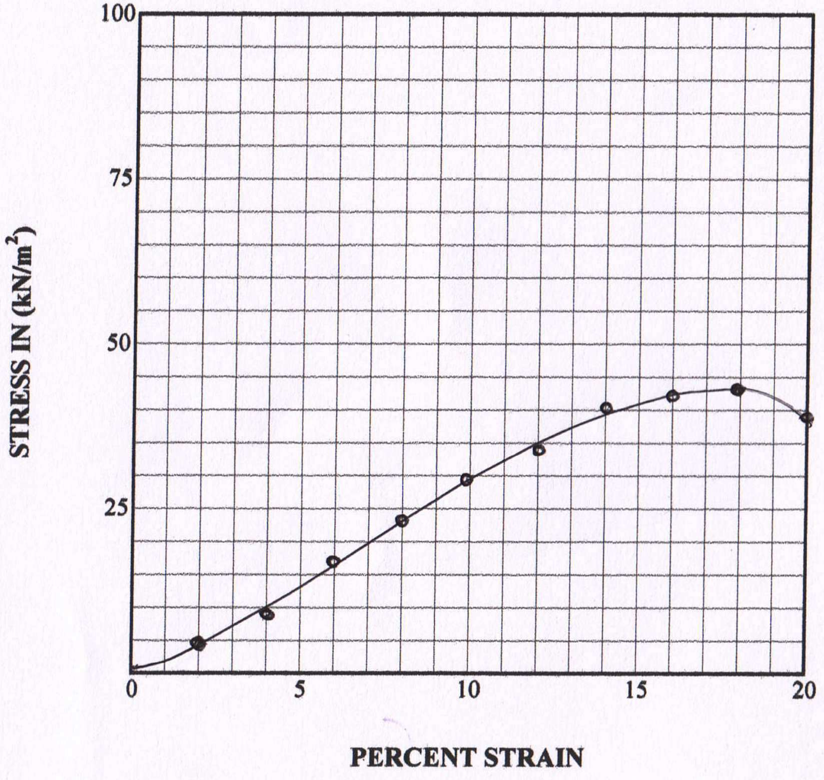
Tested by : Checked by : SHEET 11 OF 13 ATTACHMENT - V

DELTA SOIL ENGINEERS

UNCONFINED COMPRESSION TEST

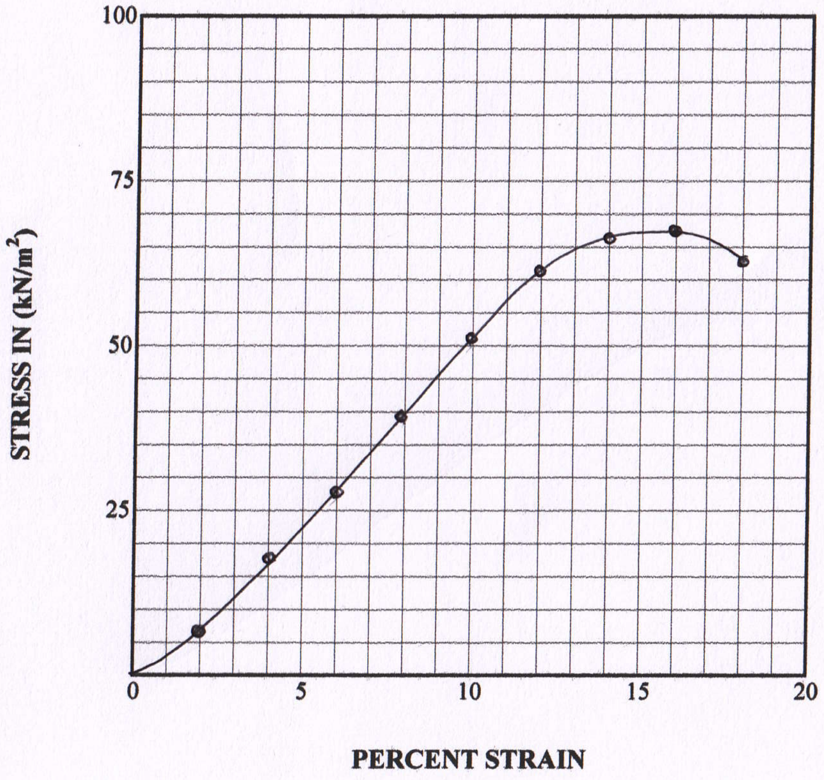
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 23 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	43.5
Percent Strain at Failure	18.0
Moisture Content (%)	30.5
Wet Density (kN/m^3)	18.24
Dry Density (kN/m^3)	13.98

Bore Hole No. 24 Sample No. U-1 Sample Depth 4.05 to 4.50 m

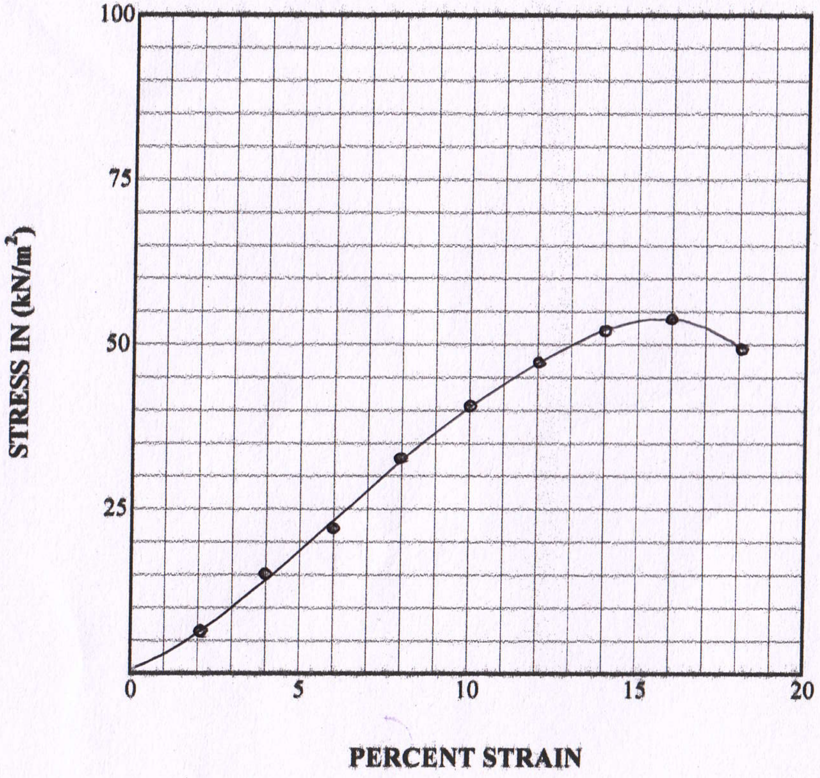


Unconfined Compressive Strength (kN/m^2)	67.6
Percent Strain at Failure	16.0
Moisture Content (%)	27.4
Wet Density (kN/m^3)	18.35
Dry Density (kN/m^3)	14.40

Tested by : Checked by : SHEET 12 OF 13 ATTACHMENT - V

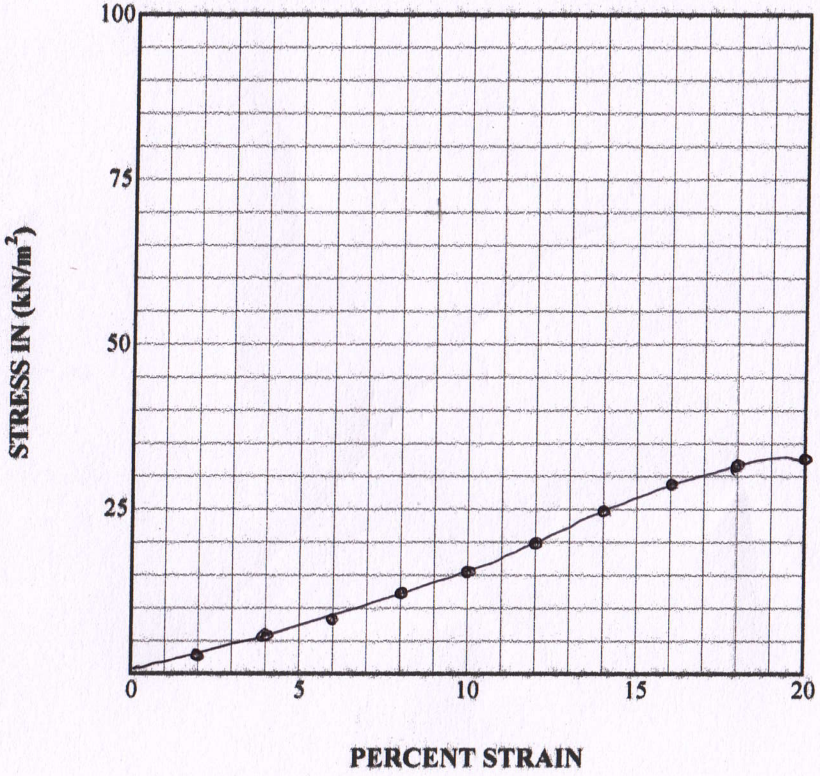
DELTA SOIL ENGINEERS	**UNCONFINED COMPRESSION TEST**	**PROJECT : Sub-Soil Investigation for Bridge Construction.** **SITE : Azompur River Crossing Site.**

Bore Hole No. 25 Sample No. U-1 Sample Depth 4.05 to 4.50 m



Unconfined Compressive Strength (kN/m^2)	54.2
Percent Strain at Failure	16.0
Moisture Content (%)	28.7
Wet Density (kN/m^3)	18.31
Dry Density (kN/m^3)	14.23

Bore Hole No. 26 Sample No. U-1 Sample Depth 4.05 to 4.50 m

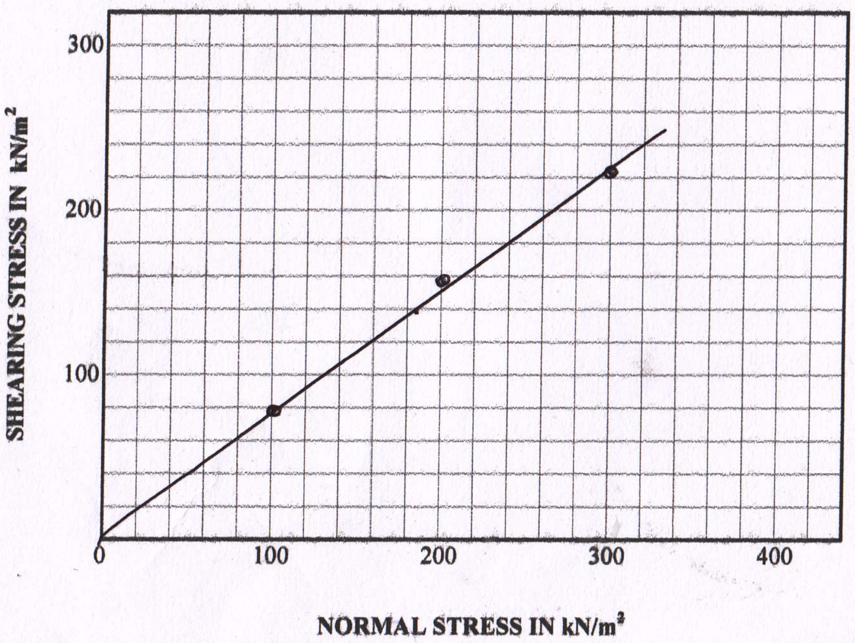


Unconfined Compressive Strength (kN/m^2)	32.6
Percent Strain at Failure	20.0
Moisture Content (%)	33.8
Wet Density (kN/m^3)	18.15
Dry Density (kN/m^3)	13.57

Tested by : Checked by : SHEET 13 OF 13 ATTACHMENT - V

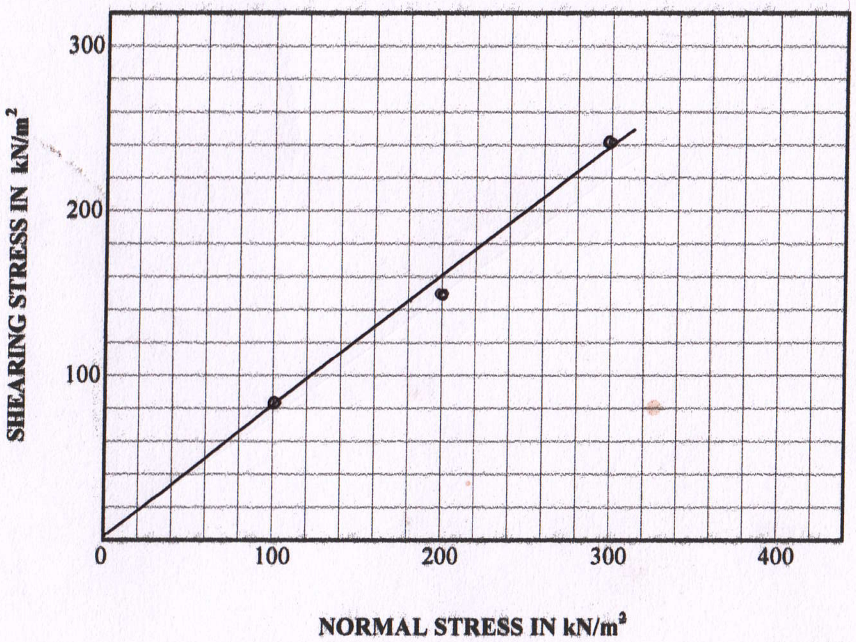
DELTA SOIL ENGINEERS	**DIRECT SHEAR TEST**	**PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.** **SITE : Proposed Water Intake site.**

Bore Hole No. 1 Sample No. D - 8 Sample Depth 12.00 to 12.45 m



SHEARING ANGLE, φ (Degree)	36.0
COHESION, C (kN/m²)	0.0

Bore Hole No. 2 Sample No. D - 10 Sample Depth 15.00 to 15.45 m

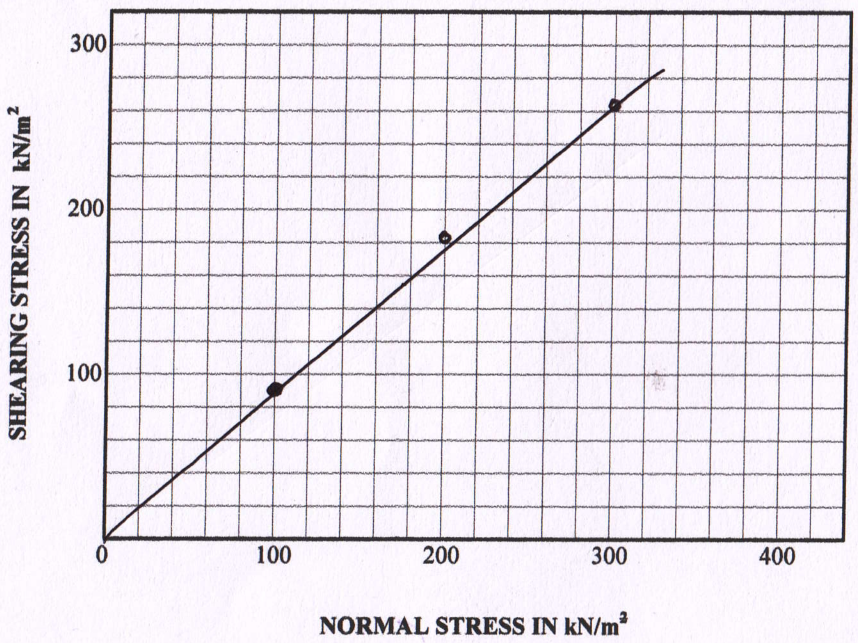


SHEARING ANGLE, φ (Degree)	38.0
COHESION, C (kN/m²)	0.0

Tested by : Checked by : SHEET 1 OF 3 ATTACHMENT - VI

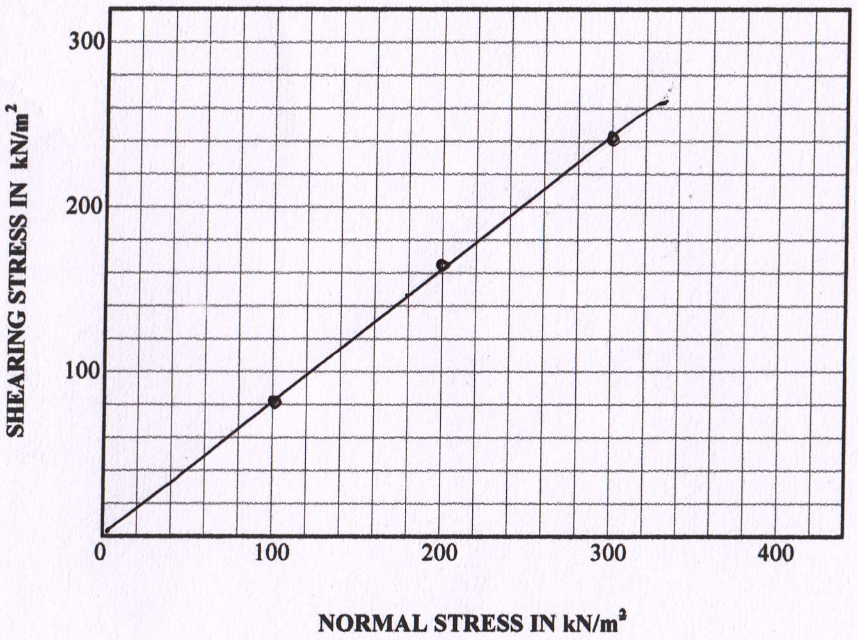
DELTA SOIL ENGINEERS	**DIRECT SHEAR TEST**	**PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.** **SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.**

Bore Hole No. 3 Sample No. D - 12 Sample Depth 18.00 to 18.45 m



SHEARING ANGLE, ϕ (Degree)	40.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 5 Sample No. D - 11 Sample Depth 16.5 to 16.95 m



SHEARING ANGLE, ϕ (Degree)	38.0
COHESION, C (kN/m^2)	0.0

Tested by : Checked by :

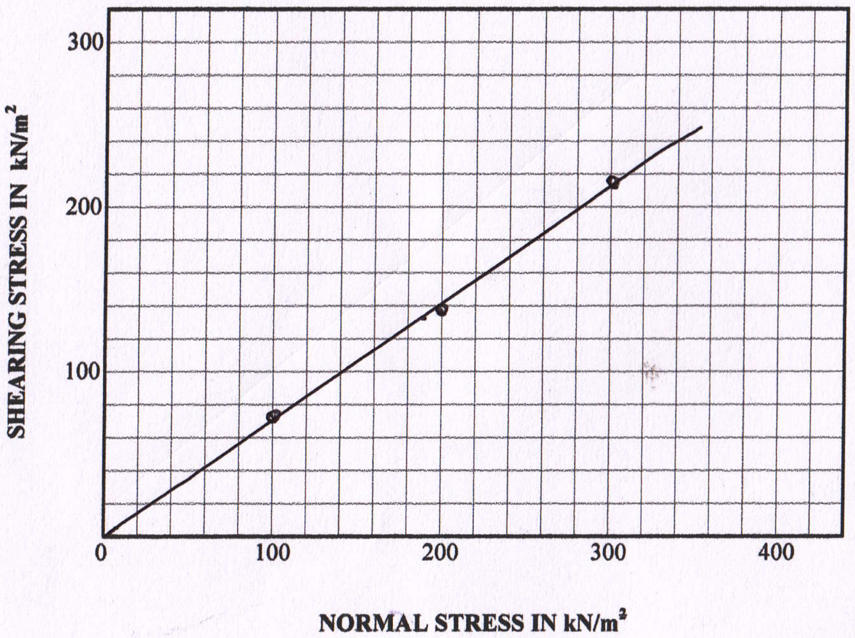
SHEET 2 OF 7 ATTACHMENT - VI

DELTA SOIL ENGINEERS

DIRECT SHEAR TEST

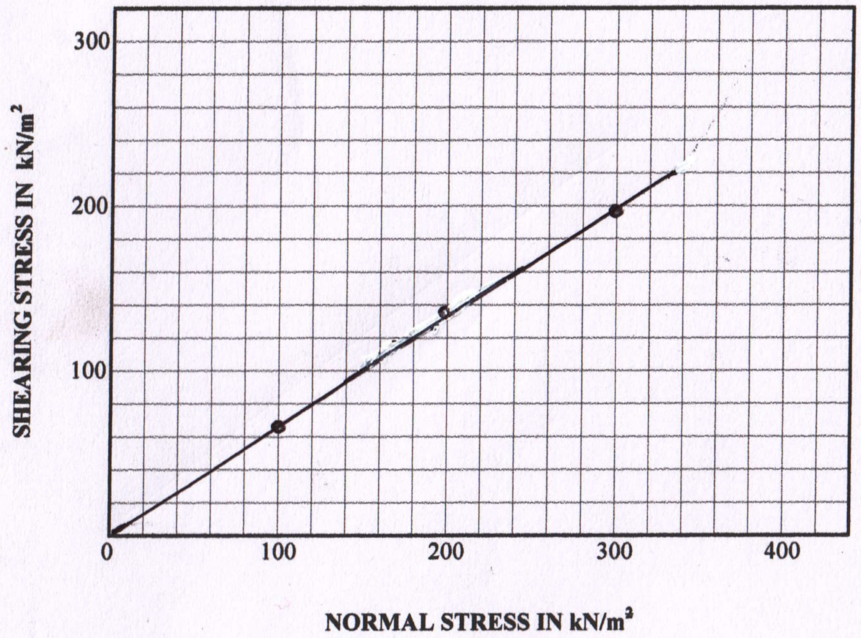
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 7 Sample No. D - 8 Sample Depth 12.00 to 12.95 m



SHEARING ANGLE, ϕ (Degree)	34.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 9 Sample No. D - 7 Sample Depth 10.5 to 10.95 m



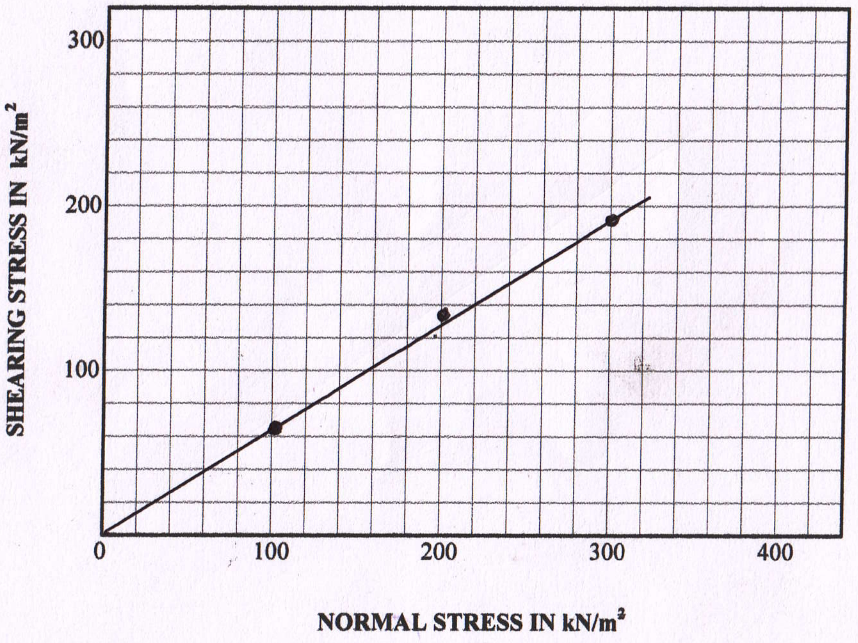
SHEARING ANGLE, ϕ (Degree)	32.0
COHESION, C (kN/m^2)	0.0

Tested by : Checked by :

SHEET 3 OF 7 ATTACHMENT - VI

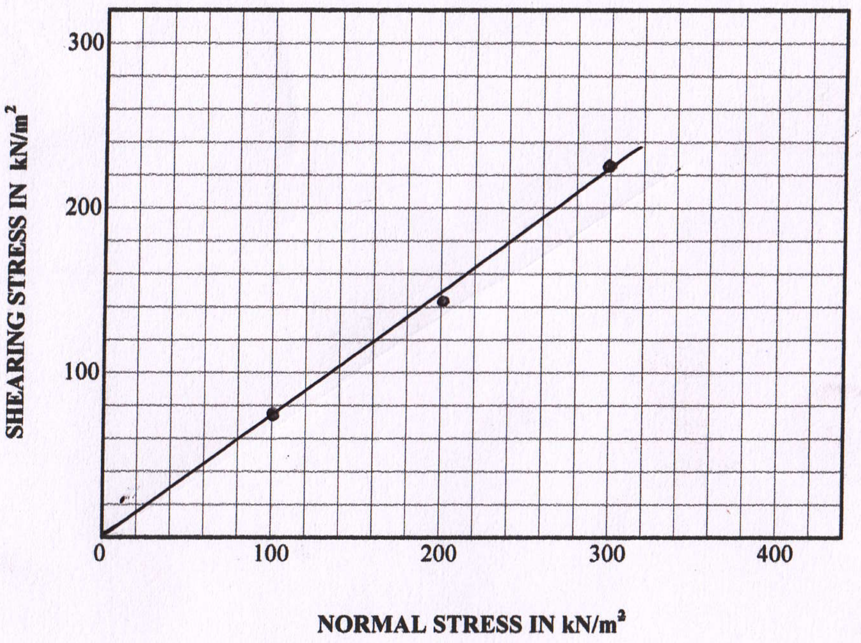
DELTA SOIL ENGINEERS	**DIRECT SHEAR TEST**	**PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.** **SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.**

Bore Hole No. 11 Sample No. D - 6 Sample Depth 9.00 to 9.45 m



SHEARING ANGLE, ϕ (Degree)	32.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 13 Sample No. D - 11 Sample Depth 16.5 to 16.95 m



SHEARING ANGLE, ϕ (Degree)	36.0
COHESION, C (kN/m^2)	0.0

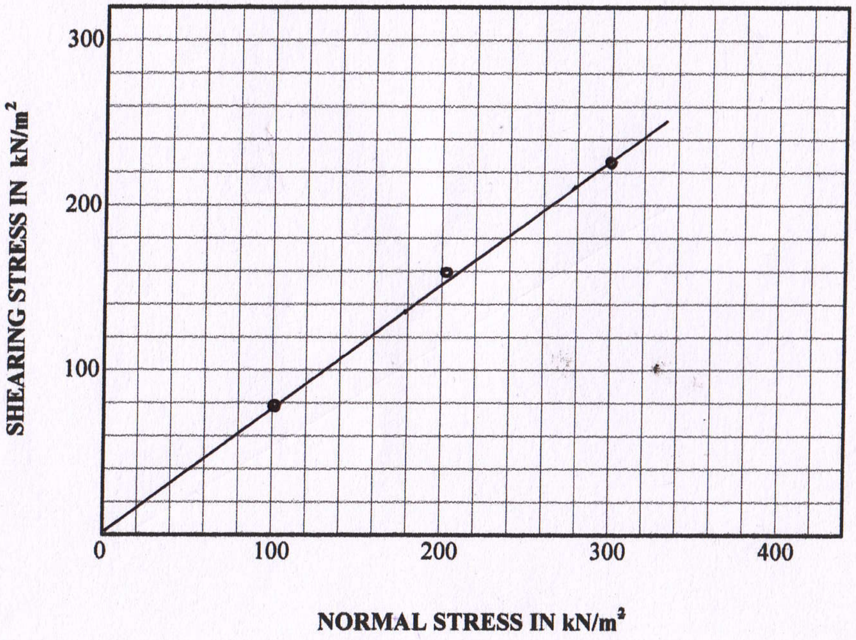
Tested by : Checked by : SHEET 4 OF 7 ATTACHMENT - VI

DELTA SOIL ENGINEERS

DIRECT SHEAR TEST

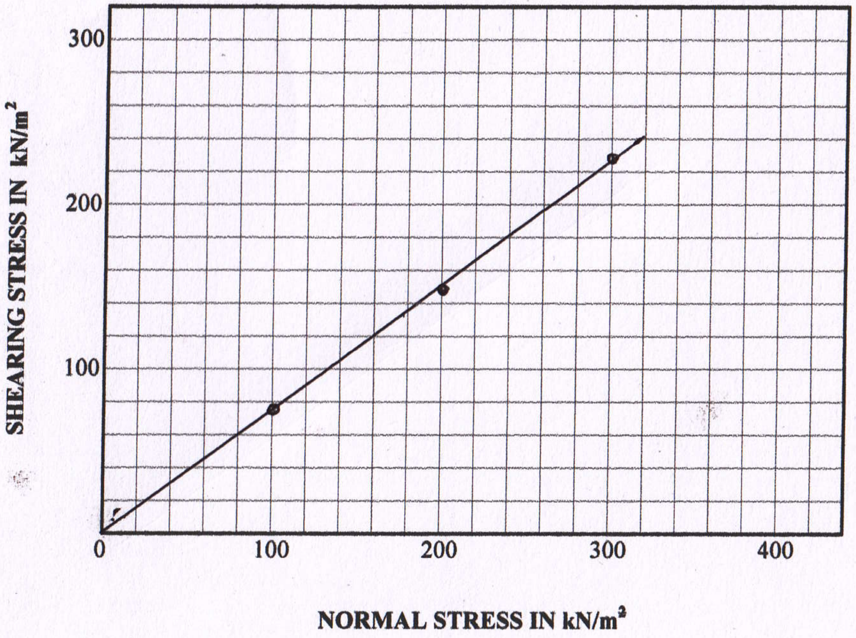
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 15 Sample No. D - 10 Sample Depth 15.00 to 15.45 m



SHEARING ANGLE, ϕ (Degree)	37.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 17 Sample No. D - 8 Sample Depth 12.00 to 12.45 m



SHEARING ANGLE, ϕ (Degree)	36.0
COHESION, C (kN/m^2)	0.0

Tested by :

Checked by :

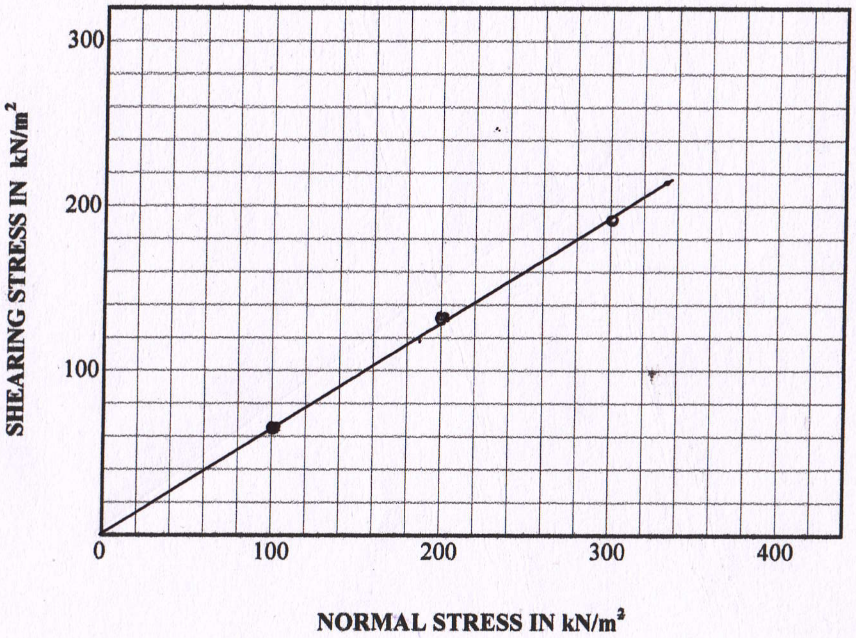
SHEET 5 OF 7 ATTACHMENT - VI

DELTA SOIL ENGINEERS

DIRECT SHEAR TEST

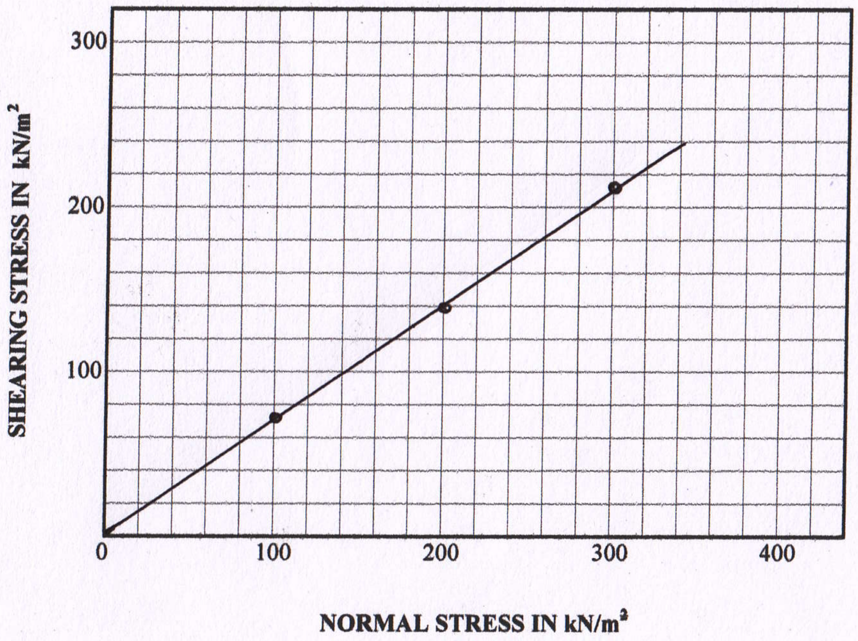
PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Bore Hole No. 20 Sample No. D - 12 Sample Depth 18.00 to 18.45 m



SHEARING ANGLE, ϕ (Degree)	32.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 23 Sample No. D - 11 Sample Depth 16.50 to 16.95 m

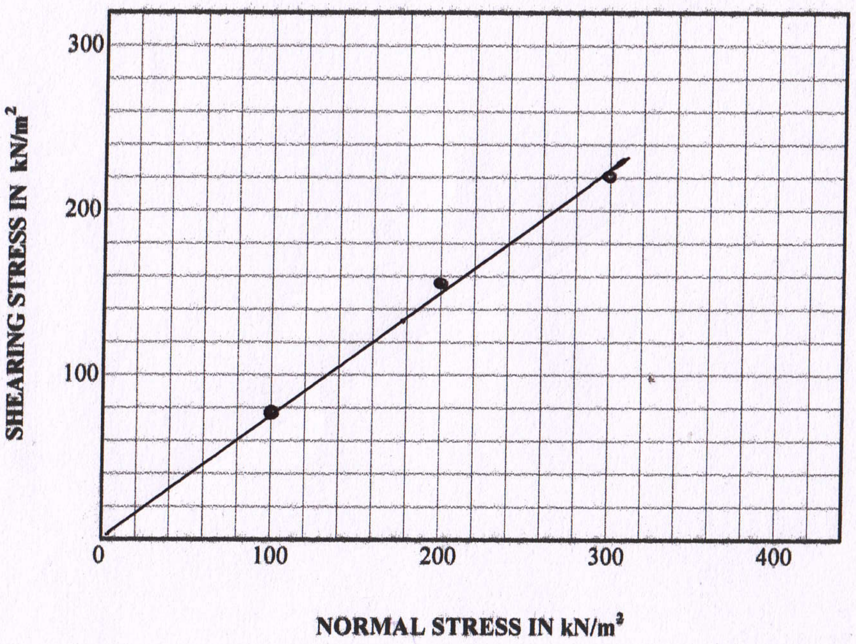


SHEARING ANGLE, ϕ (Degree)	35.0
COHESION, C (kN/m^2)	0.0

Tested by : Checked by : SHEET 6 OF 7 ATTACHMENT - VI

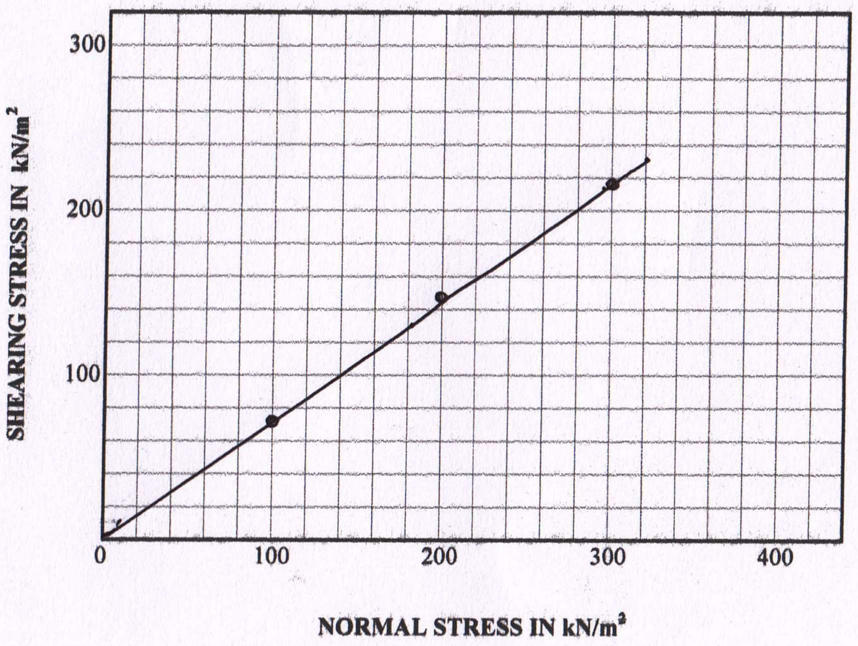
DELTA SOIL ENGINEERS	**DIRECT SHEAR TEST**	**PROJECT : Sub-Soil Investigation for Bridge Construction.** **SITE : Azompur River Crossing Site.**

Bore Hole No. 25 Sample No. D - 12 Sample Depth 18.00 to 18.45 m



SHEARING ANGLE, ϕ (Degree)	37.0
COHESION, C (kN/m^2)	0.0

Bore Hole No. 26 Sample No. D - 10 Sample Depth 15.00 to 15.45 m



SHEARING ANGLE, ϕ (Degree)	35.0
COHESION, C (kN/m^2)	0.0

Tested by :

Checked by :

SHEET 7 OF 7 ATTACHMENT - VI

DELTA SOIL ENGINEERS	**SUMMARY OF LABORATORY TEST RESULTS**	PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant. SITE : Proposed Water Intake site.

Location.																
Bore Hole No.		BH - 1				BH - 2										
Sample No.		D - 1	U - 1	D - 4	D - 8	D - 1	U - 1	D - 3	D - 5	D - 10						
Depth in Meter		1.5 to 1.95	2.55 to 3.0	6.0 to 6.45	12.0 to 12.45	1.5 to 1.95	2.55 to 3.0	4.5 to 4.95	7.5 to 7.95	15.0 to 15.45						
Natural Moisture Content (%)		31.5	30.6			30.4	31.7	29.2								
Specific Gravity			2.673		2.655		2.648		2.652							
Atterberg Limits	Liquid Limit, LL	41						30								
	Plastic Limit, PL	26						26								
Bulk Density	Wet (kN/m^3)		18.20				18.14									
	Dry (kN/m^3)		13.94				13.77									
Grain Size Analysis	Sand (%)	12		68	85			22	72	88						
	Silt (%)	70		32	15			72	28	12						
	Clay (%)	18		0	0			6	0	0						
Consolidation Tests	Natural Void Ratio, e_0		0.877													
	Compression Index, C_c		0.250													
Unconfined Compression Tests	Strain at failure (%)		18.0				20.0									
	Stress Undist. (kN/m^2)		41.6				31.7									
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)				36.0					38.0						
	C (kN/m^2)				0.0					0.0						

Conversion : 1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 1 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS

SUMMARY OF LABORATORY TEST RESULTS

PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		BH - 3					BH - 4				BH - 5					
Sample No.		D - 1	D - 2	U - 1	D - 4	D - 12	D - 1	U - 1	D - 4	D - 10	D - 1	U - 1	D - 3	D - 11		
Depth in Meter		1.5 to 1.95	3.0 to 3.45	4.05 to 4.5	6.0 to 6.45	18.0 to 18.45	1.5 to 1.95	4.05 to 4.5	6.0 to 6.45	15.0 to 15.45	1.5 to 1.95	2.55 to 3.0	4.5 to 4.95	16.5 to 16.95		
Natural Moisture Content (%)		28.4	30.7	30.3			29.7	28.8	28.3		28.4	32.4	27.4			
Specific Gravity				2.675		2.656		2.650		2.660		2.672		2.660		
Atterberg Limits	Liquid Limit, LL		42						29				41			
	Plastic Limit, PL		23						25				25			
Bulk Density	Wet (kN/m^3)			18.22				18.30				18.23				
	Dry (kN/m^3)			13.98				14.21				13.77				
Grain Size Analysis	Sand (%)		10		44	92			23	87			12	93		
	Silt (%)		70		56	8			72	13			68	7		
	Clay (%)		20		0	0			5	0			20	0		
Consolidation Tests	Natural Void Ratio, e_0			0.872												
	Compression Index, C_c			0.240												
Unconfined Compression Tests	Strain at failure (%)			16.0				16.0				18.0				
	Stress Undist. (kN/m^2)			44.7				52.8				45.6				
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)					40.0								38.0		
	C (kN/m^2)					0.0								0.0		

Conversion :
1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by :　　Checked by :　　SHEET 2 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS	SUMMARY OF LABORATORY TEST RESULTS	PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant. SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		BH - 6				BH - 7				BH - 8						
Sample No.		D - 2	U - 1	D - 3	D - 6	D - 1	U - 1	D - 5	D - 8	D - 3	U - 1	D - 4	D - 10			
Depth in Meter		3.0 to 3.45	4.05 to 4.5	4.5 to 4.95	9.0 to 9.45	1.5 to 1.95	4.05 to 4.5	7.5 to 7.95	12.0 to 12.45	4.5 to 4.95	5.55 to 6.0	6.0 to 6.45	15.0 to 15.45			
Natural Moisture Content (%)		29.4	27.5	26.5		30.4	32.5			31.4	25.8	25.5				
Specific Gravity		2.670		2.650			2.656		2.660		2.668		2.665			
Atterberg Limits	Liquid Limit, LL	43				40				42		35				
	Plastic Limit, PL	22				23				25		28				
Bulk Density	Wet (kN/m^3)		18.36				18.24				18.52					
	Dry (kN/m^3)		14.40				13.77				14.72					
Grain Size Analysis	Sand (%)	8			85	14		42	88	7		23	86			
	Silt (%)	71			15	67		58	12	70		70	14			
	Clay (%)	21			0	17		0	0	23		7	0			
Consolidation Tests	Natural Void Ratio, e_0										0.771					
	Compression Index, C_c										0.145					
Unconfined Compression Tests	Strain at failure (%)		14.0				16.0				12.0					
	Stress Undist. (kN/m^2)		67.8				43.2				98.3					
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)								34.0							
	C (kN/m^2)								0.0							

Conversion : 1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 3 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS	**SUMMARY OF LABORATORY TEST RESULTS**	PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant. SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		**BH - 9**				**BH - 10**				**BH - 11**						
Sample No.		D - 1	U - 1	D - 4	D - 7	D - 2	U - 1	D - 3	D - 12	D - 1	U - 1	D - 6	D - 10			
Depth in Meter		1.5 to 1.95	2.55 to 3.0	6.0 to 6.45	10.5 to 10.95	3.0 to 3.45	4.05 to 4.5	4.5 to 4.95	18.0 to 18.45	1.5 to 1.95	2.55 to 3.0	9.0 to 9.45	15.0 to 15.45			
Natural Moisture Content (%)		28.4	31.7	26.5		36.5	33.5	30.5		28.2	31.2					
Specific Gravity			2.670		2.665		2.665		2.660		2.672		2.660			
Atterberg Limits	Liquid Limit, LL	45		34				40		43						
	Plastic Limit, PL	26		28				21		24						
Bulk Density	Wet (kN/m^3)		18.20				18.18				18.15					
	Dry (kN/m^3)		13.82				13.62				13.83					
Grain Size Analysis	Sand (%)	8		21	83			14	92	12		75	88			
	Silt (%)	70		72	17			69	8	67		25	12			
	Clay (%)	22		7	0			17	0	21		0	0			
Consolidation Tests	Natural Void Ratio, e_0															
	Compression Index, C_c															
Unconfined Compression Tests	Strain at failure (%)		20.0				20.0				18.0					
	Stress Undist. (kN/m^2)		34.8				28.7				33.6					
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)				32.0							32.0				
	C (kN/m^2)				0.0							0.0				

Conversion :
1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 4 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS

SUMMARY OF LABORATORY TEST RESULTS

PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		BH - 12				BH - 13				BH - 14						
Sample No.		D - 1	U - 1	D - 4	D - 8	D - 1	U - 1	D - 3	D - 11	D - 2	U - 1	D - 6	D - 13			
Depth in Meter		1.5 to 1.95	4.05 to 4.5	6.0 to 6.45	12.0 to 12.45	1.5 to 1.95	4.05 to 4.5	4.5 to 4.95	16.5 to 16.95	3.0 to 3.45	4.05 to 4.5	9.0 to 9.45	19.5 to 19.95			
Natural Moisture Content (%)		31.7	31.5			30.1	29.2	28.4		35.3	34.6					
Specific Gravity			2.675		2.655		2.665		2.660		2.672		2.660			
Atterberg Limits	Liquid Limit, LL	44						42		42						
	Plastic Limit, PL	25						23		24						
Bulk Density	Wet (kN/m^3)		18.22				18.33				18.15					
	Dry (kN/m^3)		13.86				14.19				13.48					
Grain Size Analysis	Sand (%)	8		78	85			15	87	13		77	94			
	Silt (%)	69		22	15			67	13	69		23	6			
	Clay (%)	23		0	0			18	0	18		0	0			
Consolidation Tests	Natural Void Ratio, e_0															
	Compression Index, C_c															
Unconfined Compression Tests	Strain at failure (%)		16.0				16.0				20.0					
	Stress Undist. (kN/m^2)		43.5				55.6				26.2					
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)								36.0							
	C (kN/m^2)								0.0							

Conversion :
1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 5 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS

SUMMARY OF LABORATORY TEST RESULTS

PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant.
SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		BH - 15				BH - 16				BH - 17			BH - 18			
Sample No.		D - 1	U - 1	D - 4	D - 10	D - 2	U - 1	D - 4	D - 12	D - 1	U - 1	D - 8	D - 2	U - 1	D - 4	D - 12
Depth in Meter		1.5 to 1.95	4.05 to 4.5	6.0 to 6.45	15.0 to 15.45	3.0 to 3.45	4.05 to 4.5	6.0 to 6.45	18.0 to 18.45	1.5 to 1.95	4.05 to 4.5	12.0 to 12.45	3.0 to 3.45	4.05 to 4.5	6.0 to 6.45	18.0 to 18.45
Natural Moisture Content (%)		28.8	28.6	24.1		31.4	31.8			30.4	27.6		35.5	26.8	27.4	
Specific Gravity			2.674	2.655			2.670		2.662		2.656	2.658				
Atterberg Limits	Liquid Limit, LL	43		32		38				43					41	
	Plastic Limit, PL	25		27		21				26					25	
Bulk Density	Wet (kN/m^3)		18.34				18.25				18.41			18.50		
	Dry (kN/m^3)		14.26				13.85				14.43			14.59		
Grain Size Analysis	Sand (%)	8		25	86	12		82	92	8		84			13	88
	Silt (%)	73		70	14	72		18	8	70		16			69	12
	Clay (%)	19		5	0	16		0	0	22		0			18	0
Consolidation Tests	Natural Void Ratio, e_0		0.838													
	Compression Index, C_c		0.205													
Unconfined Compression Tests	Strain at failure (%)		16.0				18.0				14.0			12.0		
	Stress Undist. (kN/m^2)		51.5				44.3				66.2			82.3		
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)				37.0							36.0				
	C (kN/m^2)				0.0							0.0				

Conversion : 1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 6 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS	**SUMMARY OF LABORATORY TEST RESULTS**	PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant. SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		**BH - 19**					**BH - 20**				**BH - 21**					
Sample No.		D - 1	U - 1	D - 3	D - 4	D - 14	D - 1	U - 1	D - 5	D - 12	D - 1	U - 1	D - 3	D - 10		
Depth in Meter		1.5 to 1.95	2.55 to 3.0	4.5 to 4.95	6.0 to 6.45	21.0 to 21.45	1.5 to 1.95	2.55 to 3.0	7.5 to 7.95	18.0 to 18.45	1.5 to 1.95	2.55 to 3.0	4.5 to 4.95	15.0 to 15.45		
Natural Moisture Content (%)		29.2	30.8	31.4	26.6		28.3	28.4			36.6	35.3				
Specific Gravity			2.673		2.658			2.670		2.656		2.645				
Atterberg Limits	Liquid Limit, LL			40	33		42									
	Plastic Limit, PL			26	27		24									
Bulk Density	Wet (kN/m^3)		18.22					18.32				18.12				
	Dry (kN/m^3)		13.93					14.27				13.39				
Grain Size Analysis	Sand (%)			11	24	89	10		74	87			42	83		
	Silt (%)			72	70	11	70		26	13			58	17		
	Clay (%)			17	6	0	20		0	0			0	0		
Consolidation Tests	Natural Void Ratio, e_0		0.877													
	Compression Index, C_c		0.245													
Unconfined Compression Tests	Strain at failure (%)		18.0					16.0				20.0				
	Stress Undist. (kN/m^2)		34.6					54.2				25.6				
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)									32.0						
	C (kN/m^2)									0.0						

Conversion :
1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 7 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS	**SUMMARY OF LABORATORY TEST RESULTS**	PROJECT : Sub-soil Investigation for Const. Of Proposed Water Treatment Plant. SITE : Proposed Bangabandhu Sheikh Mujib Shilpo Nagar, Mirsarai, Chittagong.

Location.																
Bore Hole No.		**BH - 22**				**BH - 23**			**BH - 24**							
Sample No.		D - 2	U - 1	D - 3	D - 8	D - 2	U - 1	D - 11	D - 2	U - 1	D - 4	D - 8				
Depth in Meter		3.0 to 3.45	4.05 to 4.5	4.5 to 4.95	12.0 to 12.45	3.0 to 3.45	4.05 to 4.5	16.5 to 16.95	3.0 to 3.45	4.05 to 4.5	6.0 to 6.45	12.0 to 12.45				
Natural Moisture Content (%)		30.2	28.4	27.4		31.5	30.5		28.4	27.4						
Specific Gravity				2.667			2.670					2.654				
Atterberg Limits	Liquid Limit, LL			32					43							
	Plastic Limit, PL			27					25							
Bulk Density	Wet (kN/m^3)		18.30				18.24			18.35						
	Dry (kN/m^3)		14.21				13.98			14.40						
Grain Size Analysis	Sand (%)			21	85			86	7		67	92				
	Silt (%)			73	15			14	71		33	8				
	Clay (%)			6	0			0	22		0	0				
Consolidation Tests	Natural Void Ratio, e_0		0.845													
	Compression Index, C_c		0.220													
Unconfined Compression Tests	Strain at failure (%)		18.0				18.0			16.0						
	Stress Undist. (kN/m^2)		52.5				43.5			67.6						
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)							35.0								
	C (kN/m^2)							0.0								

Conversion : 1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 8 OF 9 ATTACHMENT - VI

DELTA SOIL ENGINEERS

SUMMARY OF LABORATORY TEST RESULTS

PROJECT : Sub-Soil Investigation for Bridge Construction.
SITE : Azompur River Crossing Site.

Location.																
Bore Hole No.		**BH - 25**					**BH - 26**									
Sample No.		D - 1	U - 1	D - 3	D - 6	D - 12	D - 2	U - 1	D - 4	D - 6	D - 10					
Depth in Meter		1.5 to 1.95	4.05 to 4.5	4.5 to 4.95	9.0 to 9.45	18.0 to 18.45	3.0 to 3.45	4.05 to 4.5	6.0 to 6.45	9.0 to 9.45	15.0 to 15.45					
Natural Moisture Content (%)		36.6	28.7	27.6			35.8	33.8		26.8						
Specific Gravity			2.674					2.667		2.665						
Atterberg Limits	Liquid Limit, LL			40						29						
	Plastic Limit, PL			22						26						
Bulk Density	Wet (kN/m^3)		18.31					18.15								
	Dry (kN/m^3)		14.23					13.57								
Grain Size Analysis	Sand (%)			12	72	87			67	28	84					
	Silt (%)			70	28	13			33	67	16					
	Clay (%)			18	0	0			0	5	0					
Consolidation Tests	Natural Void Ratio, e_0							0.927								
	Compression Index, C_c							0.305								
Unconfined Compression Tests	Strain at failure (%)		14.0					20.0								
	Stress Undist. (kN/m^2)		54.2					32.6								
	Stress Remould (kN/m^2)															
	Sensivity															
Direct Shear Tests	ϕ (Degree)					37.0					35.0					
	C (kN/m^2)					0.0					0.0					

Conversion :
1 PCF = 0.1571 kN/m^3
1 PSI = 6.895 kN/m^2
1 TSF = 14.20 PSI = 98.05 kN/m^2

Comptd. by : Checked by : SHEET 9 OF 9 ATTACHMENT - VI

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed Water Intake site

BORE HOLE NO. 1

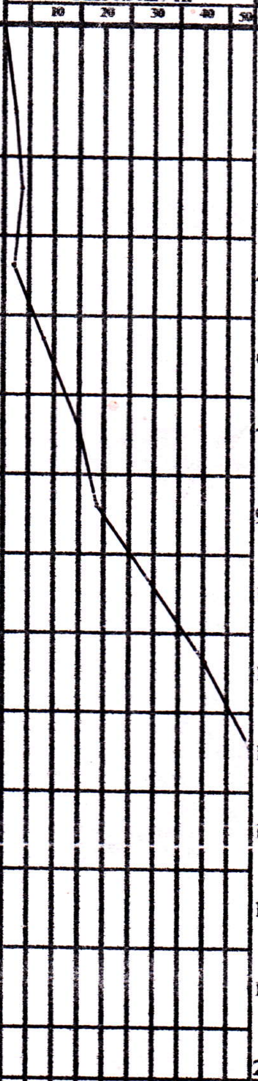
GROUND LEVEL R.L. : 5.060 m

GROUND WATER LEVEL : 3.536 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft	INDEX ▨ DISTURBED ■ NDISTURBED REMARKS
								15cm	15cm	15cm	SPT	10 20 30 40 50	
6-2-2019	D-1	▨		5.0	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2		1.5m
	U-1	■											
	D-2	▨						1	1	2	3		3.0m
	D-3	▨	5.0					1	1	1	2		4.5m
	D-4	▨		3.0	Grey silty FINE SAND trac mica.			2	3	5	8		6.0m
	D-5	▨	8.0					3	4	6	10		7.5m
	D-6	▨		12.0	Grey silty FINE SAND trace mica.			4	8	10	18		9.0m
	D-7	▨						5	14	16	30		10.5m
	D-8	▨						8	18	22	40		12.0m
	D-9	▨						10	22	28	50		13.5m
	D-10	▨						12	23	27	50		15.0m
	D-11	▨						14	24	26	50		16.5m
	D-12	▨						15	30	20	50		18.0m
	D-13	▨	20.0					17	35	15	50		20.0m



Client/Consultant

Sheet 1 of 26 Attachment VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

dt. 7/2/19

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed water Intake site.

BORE HOLE NO. 2

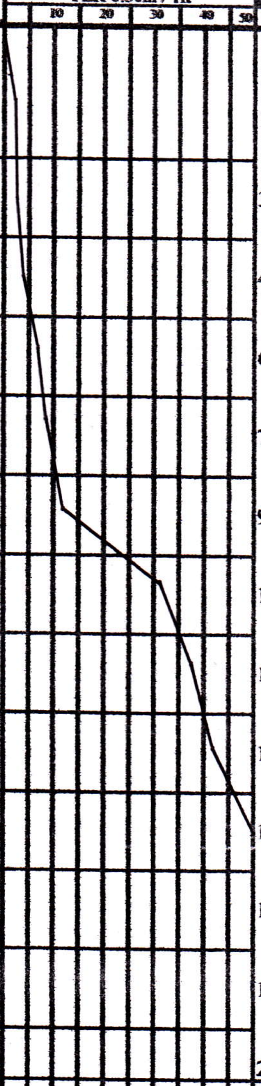
GROUND LEVEL R.L. : 4.940 m

GROUND WATER LEVEL : 3.416 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
								15cm	15cm	15cm	SPT	10 20 30 40 50	
7-2-2019	D-1	▨	2.0	2.0	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2		1.5m
	V-1 D-2	■ ▨		3.0	Grey clayey SILT compress			1	1	1	2		3.0m
	D-3	▨	5.0					1	1	2	3		4.5m
	D-4	▨		3.0	Grey silty FINE SAND trace mica			2	2	4	6		6.0m
	D-5	▨	8.0					3	3	5	8		7.5m
	D-6	▨						5	8	9	17		9.0m
	D-7	▨						6	15	17	32		10.5m
	D-8	▨			Grey silty FINE SAND trace mica			8	18	20	38		12.0m
	D-9	▨		12.0				10	20	22	42		13.5m
	D-10	▨						12	22	28	50		15.0m
	D-11	▨						14	30	20	50		16.5m
	D-12	▨						15	35	15	50		18.0m
	D-13	▨	20.0					7	22	28	50		20.0m



Client/Consultant

sheet 2 of 26 Attachment VIII

Field Supervisor

Driller

BH-3
dt. 1-2-2019

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed Bangabandhu Sheikh Mujib Shilpa Nagar, Mirsari Chattogram

BORE HOLE NO. 03

GROUND LEVEL R.L. : 3.686 m

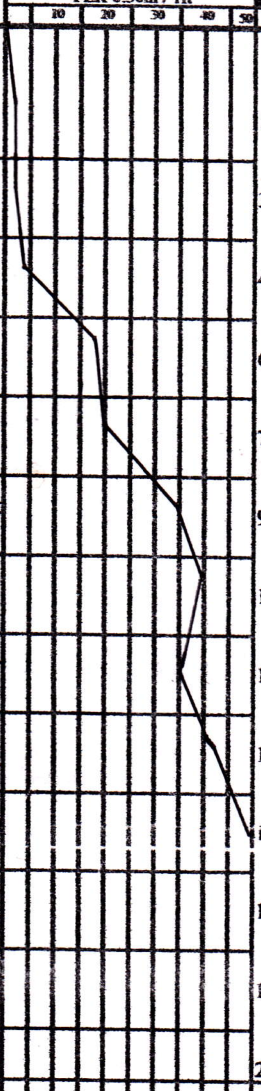
GROUND WATER LEVEL : 1.247 m

DATE : 30-1-2019 **TIME : 09:00 am**

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
4-2-2019	D-1	▨		5.0	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨						1	1	1	2	3.0m
	V-1 D-3	■ ▨	5.0					1	1	2	3	4.5m
	D-4	▨	6.5	1.5	Grey sandy SILT trace mica			3	6	13	19	6.0m
	D-5	▨		13.5	Grey silty FINE SAND trace mica.			5	8	12	20	7.5m
	D-6	▨						7	15	20	35	9.0m
	D-7	▨						8	18	22	40	10.5m
	D-8	▨						10	15	20	35	12.0m
	D-9	▨						11	20	23	42	13.5m
	D-10	▨						14	22	28	50	15.0m
	D-11	▨						15	30	20	50	16.5m
	D-12	▨						17	35	15	50	18.0m
	D-13	▨	20.0					19	40	10	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

Sheet 3 of 26 Attachment-VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

BH-4
dt. 30-01-2019

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai, Chattogram.

BORE HOLE NO. 4

GROUND LEVEL R.L. : 3.752 m

GROUND WATER LEVEL : 1.313 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
30-2-2019	D-1	▨	2.0	2.0	Grey silty CLAY medium plastic	▥	100 mm (4") φ	1	1	1	2	1.5m
	D-2	▨		6.0	Grey clayey SILT med compress	▨		1	1	2	3	3.0m
	U-1 D-3	■ ▨						1	2	2	4	4.5m
	D-4	▨						1	2	2	4	6.0m
	D-5	▨	8.0					2	3	4	7	7.5m
30-1-2019	D-6	▨		12.0	Grey silty FINE SAND trace mica.	░		8	18	22	40	9.0m
	D-7	▨						10	20	22	42	10.5m
	D-8	▨						12	22	28	50	12.0m
	D-9	▨						10	15	35	50	13.5m
	D-10	▨						12	30	20	50	15.0m
	D-11	▨						14	30	20	50	16.5m
	D-12	▨						8	15	35	50	18.0m
	D-13	▨	20.0					12	20	30	50	20.0m

Client/Consultant

Sheet 4 of 26 Attachment-VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram.

BORE HOLE NO. 05

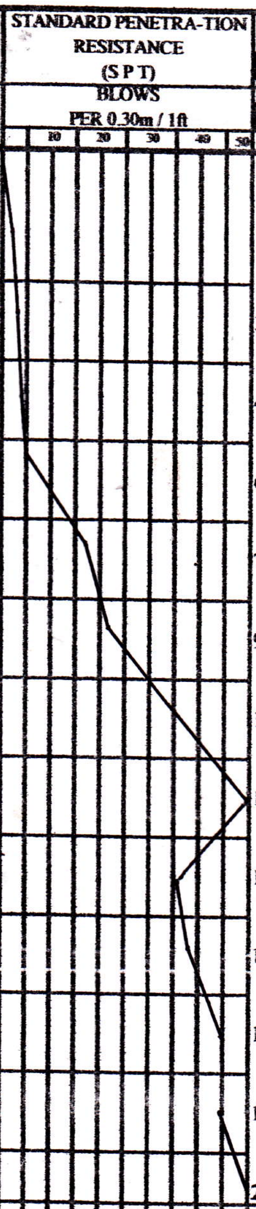
GROUND LEVEL R.L. : 3.697 m

GROUND WATER LEVEL : 1.358 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
31-1-2019	D-1	▨			Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2	1.5m
	V-1	■										
	D-2	▨		6.5				1	1	2	3	3.0m
	D-3	▨						1	2	2	4	4.5m
	D-4	▨	6.5					2	2	3	5	6.0m
	D-5	▨			Grey silty FINE SAND trace mica-			5	8	10	18	7.5m
	D-6	▨						6	10	12	22	9.0m
	D-7	▨						7	15	20	35	10.5m
	D-8	▨						10	20	30	50	12.0m
	D-9	▨		13.5				8	15	20	35	13.5m
	D-10	▨						9	18	20	38	15.0m
	D-11	▨						10	20	25	45	16.5m
	D-12	▨						12	22	23	45	18.0m
	D-13	▨	20.0					36	33	17	50	20.0m



Client/Consultant

Sheet 5 of 26 Attachment-VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION: Proposed BSMSN, Mirsarai Chattogram.

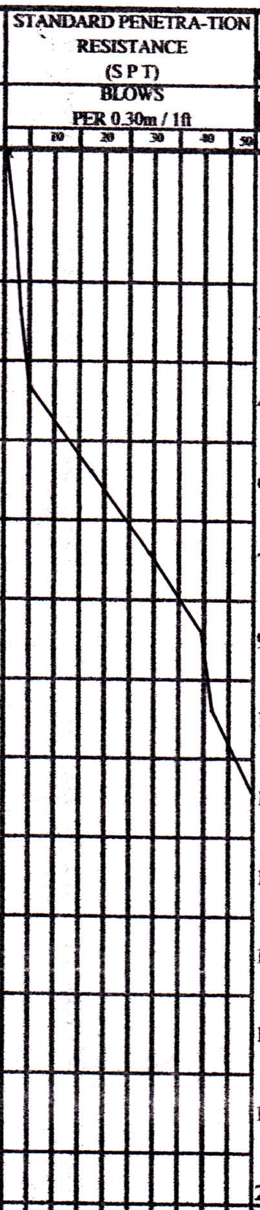
BORE HOLE NO. 6

GROUND LEVEL R.L. : 3.963 m

GROUND WATER LEVEL : 1.524 m

DATE :

TIME : 09:00 am



DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
30-1-2019	D-1	▨		3.5	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨	3.5					1	1	2	3	3.0m
	U-1	■		1.5	Grey clayey SILT med compress							
	D-3	▨	5.0					2	2	3	5	4.5m
	D-4	▨		15.0	Grey silty FINE SAND trace mica.			5	8	10	18	6.0m
	D-5	▨						6	14	16	30	7.5m
	D-6	▨						8	18	22	40	9.0m
	D-7	▨						10	20	22	42	10.5m
	D-8	▨						12	22	28	50	12.0m
	D-9	▨						14	23	27	50	13.5m
	D-10	▨						15	24	26	50	15.0m
	D-11	▨						16	30	20	50	16.5m
	D-12	▨						18	32	18	50	18.0m
	D-13	▨	20.0					20	30	20	50	20.0m

Client/Consultant

Sheet 6 of 26 Attachment-VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chittagong.

BORE HOLE NO. 7

GROUND LEVEL R.L. : 3.816 m

GROUND WATER LEVEL : 1.377 m

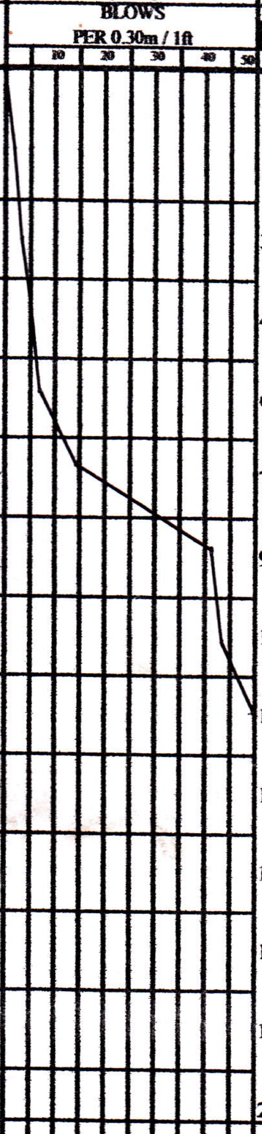
DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
2-2-2019	D-1	▨		6.5	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨						1	1	2	3	3.0m
	V-1	■										
	D-3	▨						2	2	3	5	4.5m
	D-4	▨	6.5					2	3	3	6	6.0m
	D-5	▨	8.0	1.5	Grey sandy SILT trace mica			5	7	8	15	7.5m
	D-6	▨		12.0	Grey silty FINE SAND trace mica			7	20	22	42	9.0m
	D-7	▨						8	20	23	43	10.5m
	D-8	▨						10	22	28	50	12.0m
	D-9	▨						12	30	20	50	13.5m
	D-10	▨						14	32	18	50	15.0m
	D-11	▨						15	22	28	50	16.5m
	D-12	▨						17	30	20	50	18.0m
	D-13	▨	20.0					18	32	18	50	20.0m

INDEX: ▨ DISTURBED ■ UNDISTURBED

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

Field Supervisor

Driller

Sheet 7 of 26 Attachment-VIII

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai Chattogram

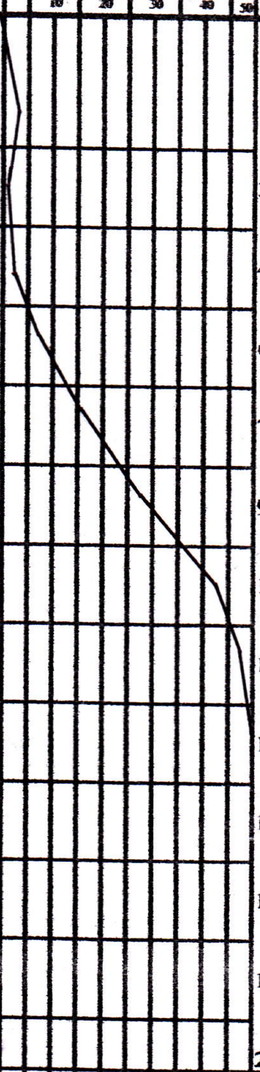
BORE HOLE NO. 08

GROUND LEVEL R.L. : 4.132 m

GROUND WATER LEVEL : 1.998 m

DATE : 2-2-2019 **TIME : 09:00 am**

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ NDISTURBED REMARKS
	D-1	▨		5.0	Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	2	3		1.5m
	D-2	▨						1	0	1	1		3.0m
	D-3	▨	5.0					1	1	1	2		4.5m
	U-1	■		1-5	Grey clayed SILT med compress.								
	D-4	▨	6.5					1	3	5	8		6.0m
	D-5	▨		13.5	Grey silty FINE SAND trace mica.			2	6	10	16		7.5m
	D-6	▨						4	10	18	28		9.0m
	D-7	▨						6	18	25	43		10.5m
	D-8	▨						7	20	28	48		12.0m
	D-9	▨						8	24	26	50		13.5m
	D-10	▨						9	26	24	50		15.0m
	D-11	▨						7	23	27	50		16.5m
	D-12	▨						9	25	25	50		18.0m
	D-13	▨	20.0					10	28	22	50		20.0m



Client/Consultant **Field Supervisor** **Driller**

Sheet 8 of 26 Attachment-XIV

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposd BSMSN, Mirsarai chattogram

BORE HOLE NO. 09

GROUND LEVEL R.L. : 3.962 m

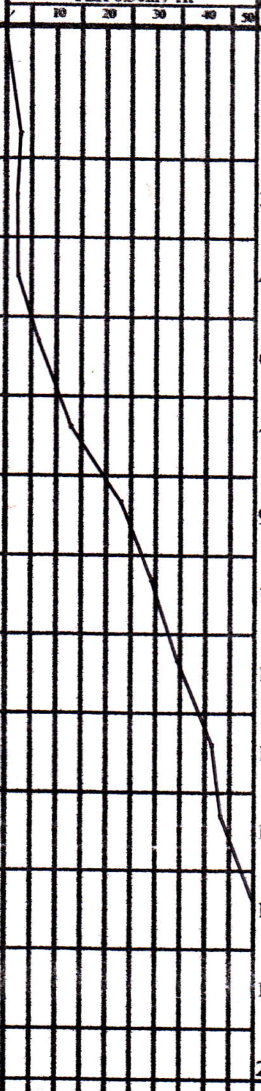
GROUND WATER LEVEL : 1.218 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
11-2-2017	D-1	▨			Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	2	3	1.5m
	U-1	■										
	D-2	▨						1	1	1	2	3.0m
	D-3	▨	5.0					1	1	1	2	4.5m
	D-4	▨	6.5		Grey clayey SILT med compress			3	3	4	7	6.0m
	D-5	▨		13.5	Grey silty FINE SAND trace mica.			3	5	8	13	7.5m
	D-6	▨						5	9	15	24	9.0m
	D-7	▨						7	13	17	30	10.5m
	D-8	▨						8	15	20	35	12.0m
	D-9	▨						9	18	24	42	13.5m
	D-10	▨						10	21	27	48	15.0m
	D-11	▨						11	25	25	50	16.5m
	D-12	▨						12	26	24	50	18.0m
	D-13	▨	20.0					11	28	22	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



INDEX

▨ DISTURBED

■ UNDISTURBED

REMARKS

Client/Consultant

Field Supervisor

Driller

Sheet 9 of 26 Attachment-VIII

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

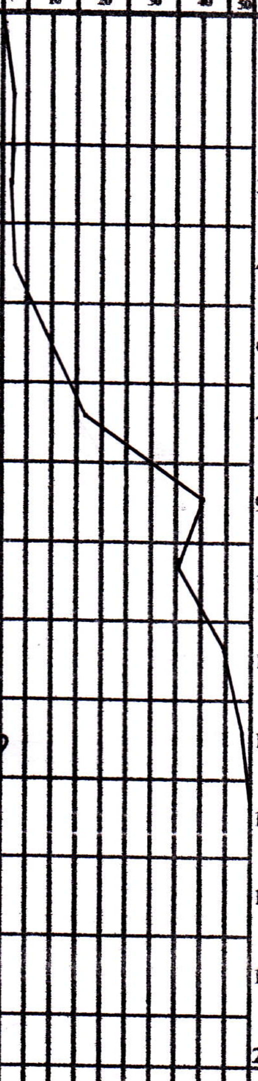
BORE HOLE NO. 10

GROUND LEVEL R.L. : 4.361 m

GROUND WATER LEVEL : 1.922 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
30-7-2017	D-1	▨			Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	1	2		1.5m
	D-2	▨		5.0				1	0	1	1		3.0m
	V-1	■											
	D-3	▨	5.0					1	1	1	2		4.5m
	D-4	▨			Grey silty FINE SAND trace mica.			3	4	6	10		6.0m
	D-5	▨						4	7	10	17		7.5m
	D-6	▨						8	20	28	48		9.0m
	D-7	▨						9	15	20	35		10.5m
	D-8	▨		15.0				8	20	25	45		12.0m
	D-9	▨						9	22	28	49		13.5m
	D-10	▨						10	25	25	50		15.0m
	D-11	▨						12	33	17	50		16.5m
	D-12	▨						13	38	12	50		18.0m
	D-13	▨	20.0					10	40	10	50		20.0m

Client/Consultant

Sheet 10 of 26 Attachment-VII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

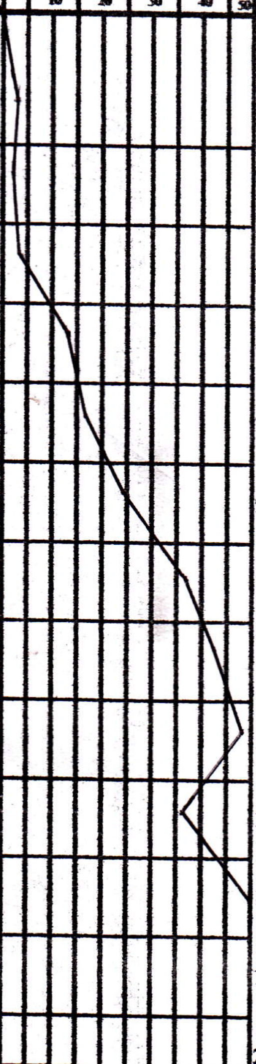
LOCATION: Proposed BSMSN, Mirsarai Chattagram

BORE HOLE NO. 11

GROUND LEVEL R.L. : 4.084 m

GROUND WATER LEVEL : 1.950 m

DATE : 1-2-2019 **TIME : 09:00 am**

DATE	NUMBER OF SAMPLE	TYPE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
1-2-2019	D-1	▨			Grey silty CLAY medium plastic		100 mm (4") ϕ	1	1	2	3		1.5m
	U-1	■		5.0									
	D-2	▨						1	1	1	2		3.0m
	D-3	▨	5.0					1	1	2	3		4.5m
	D-4	▨			Grey silty FINE SAND trace mica.			3	5	8	13		6.0m
	D-5	▨						5	7	10	17		7.5m
	D-6	▨						6	10	15	25		9.0m
	D-7	▨						7	15	22	37		10.5m
	D-8	▨		15.0				9	18	25	43		12.0m
	D-9	▨						8	20	28	48		13.5m
	D-10	▨						9	19	17	36		15.0m
	D-11	▨						10	26	24	50		16.5m
	D-12	▨						9	35	18	58		18.0m
	D-13	▨	20.0					10	38	12	50		20.0m

Client/Consultant

Field Supervisor

Driller

Sheet 11 of 26 Attachment-VIII

FIELD BORE LOG

DELTA SOIL ENGINEERS

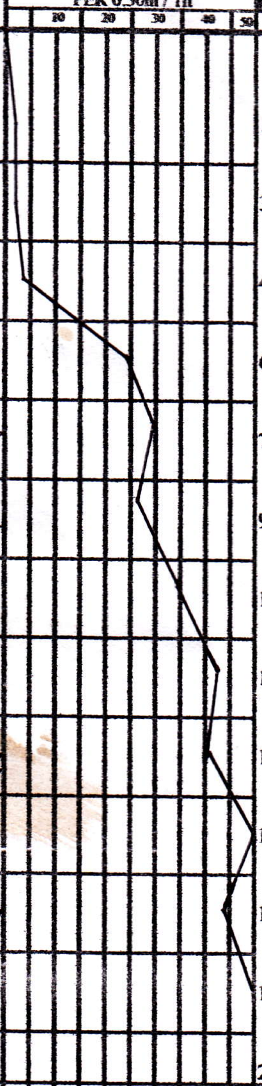
871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)	**GROUND LEVEL R.L.** : 4.695 m
LOCATION : Proposed BSMSN, Mirsarai chattogram	**GROUND WATER LEVEL** : 2.256 m
BORE HOLE NO. 12	**DATE** : **TIME** : 09:00 am

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
	D-1	▨			Grey silty CLAY			1	1	1	2	1.5m
	D-2	▨		5.0	medium plastic			1	1	1	2	3.0m
	U-1	■										
	D-3	▨	5.0					1	1	2	3	4.5m
	D-4	▨						6	10	15	25	6.0m
	D-5	▨						7	13	17	30	7.5m
	D-6	▨					100 mm (4") ϕ	5	12	15	27	9.0m
2-2-2019	D-7	▨			Grey silty FINE			6	15	20	35	10.5m
	D-8	▨		15.0	SAND trace mica.			8	20	27	47	12.0m
	D-9	▨						9	22	28	46	13.5m
	D-10	▨						10	25	25	50	15.0m
	D-11	▨						9	19	26	44	16.5m
	D-12	▨						9	33	27	50	18.0m
	D-13	▨	20.0					10	26	24	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

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Field Supervisor

Driller

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FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattagram

BORE HOLE NO. 13

GROUND LEVEL R.L. : 4.287 m

GROUND WATER LEVEL : 1.543 m

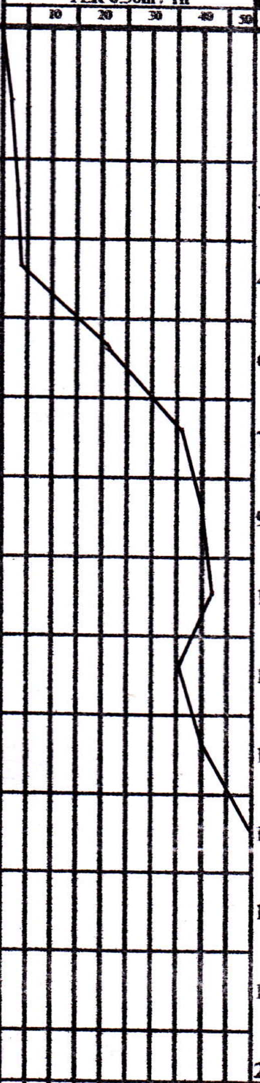
DATE :

TIME : 09:00 am

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
2-2-2019	D-1	▨			Grey silty CLAY medium plastic		100 mm (4") φ	1	1	1	2	1.5m
	D-2	▨		5.0				1	1	2	3	3.0m
	U-1	■										
	D-3	▨	5.0					1	2	2	4	4.5m
	D-4	▨			Grey silty FINE SAND trace mica.			5	10	12	22	6.0m
	D-5	▨						7	16	20	36	7.5m
	D-6	▨						8	20	20	40	9.0m
	D-7	▨						10	20	22	42	10.5m
	D-8	▨		15.0				8	15	20	35	12.0m
	D-9	▨						10	18	22	40	13.5m
	D-10	▨						14	20	30	50	15.0m
	D-11	▨						15	22	28	50	16.5m
	D-12	▨						17	30	20	50	18.0m
	D-13	▨	20.0					18	40	10	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

Field Supervisor

Driller

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FIELD BORE LOG
DELTA SOIL ENGINEERS
871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai Chattogram

BORE HOLE NO. 14

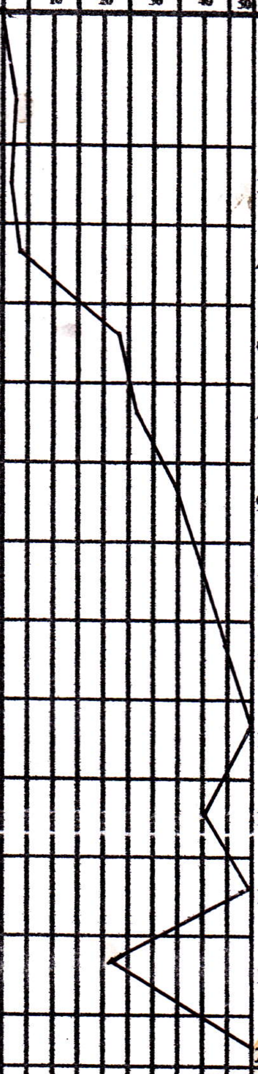
GROUND LEVEL R.L. : 4.769 m

GROUND WATER LEVEL : 2.350 m

DATE :

TIME : 09:00 am

INDEX: ▨ DISTURBED, ■ UNDISTURBED



DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
3-1-2019	D-1	▨			Grey silty CLAY		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨		5.0	med plastic			1	0	1	1	3.0m
	U-1	■										
	D-3	▨	5.0					1	1	2	3	4.5m
	D-4	▨						6	10	14	24	6.0m
	D-5	▨						7	12	15	27	7.5m
	D-6	▨						13	15	20	35	9.0m
	D-7	▨			Grey silty FINE			9	18	22	40	10.5m
	D-8	▨		15.0	SAND trace mica.			7	20	23	43	12.0m
	D-9	▨						8	23	27	50	13.5m
	D-10	▨						6	18	22	40	15.0m
	D-11	▨						7	22	28	50	16.5m
	D-12	▨						7	9	12	21	18.0m
	D-13	▨	20.0					9	19	31	50	20.0m

Client/Consultant

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Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

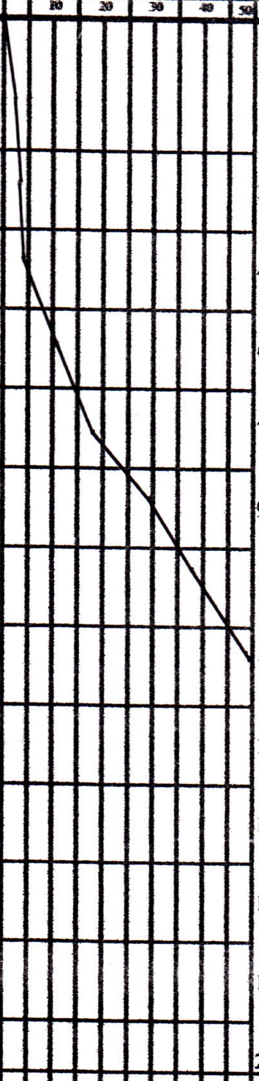
BORE HOLE NO. 15

GROUND LEVEL R.L. : 4.308 m

GROUND WATER LEVEL : 2.174 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ NDISTURBED REMARKS
3-2-2019	D-1	▨		5.0	Grey silty CLAY med plastic		100 mm (4") φ	1	1	1	2		1.5m
	D-2	▨						1	1	2	3		3.0m
	V-1 D-3	■ ▨	5.0					2	2	2	4		4.5m
	D-4	▨	6.5	1.5	Grey clayey SILT med compress			3	4	7	11		6.0m
	D-5	▨		13.5	Grey silty FINE SAND trace mica.			4	8	10	18		7.5m
	D-6	▨						6	14	16	30		9.0m
	D-7	▨						8	18	20	38		10.5m
	D-8	▨						14	20	30	50		12.0m
	D-9	▨						15	30	20	50		13.5m
	D-10	▨						16	35	15	50		15.0m
	D-11	▨						10	20	30	50		16.5m
	D-12	▨						14	22	28	50		18.0m
	D-13	▨	20.0					20	40	10	50		20.0m

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Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

BORE HOLE NO. 16

GROUND LEVEL R.L. : 4.577 m

GROUND WATER LEVEL : 2.138 m

DATE :

TIME : 09:00 am

INDEX
▨ DISTURBED
■ NDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	REMARKS
3-2-2019	D-1	▨		3.5	Grey silty CLAY med plastic		100 mm (4") ϕ	1	0	1	1		1.5m
	D-2	▨	3.5					1	1	1	2		3.0m
	V-1	■		1.5	Grey clayey SILT med compress								
	D-3	▨	5.0					1	1	2	3		4.5m
	D-4	▨		15.0	Grey silty FINE SAND trace mica.			4	7	10	17		6.0m
	D-5	▨						5	13	17	30		7.5m
	D-6	▨						7	18	22	40		9.0m
	D-7	▨						10	20	28	48		10.5m
	D-8	▨						8	17	25	42		12.0m
	D-9	▨						9	23	27	50		13.5m
	D-10	▨						7	12	20	32		15.0m
	D-11	▨						9	25	25	50		16.5m
	D-12	▨						10	28	22	50		18.0m
	D-13	▨	20.0					7	20	30	50		20.0m

Client/Consultant

Field Supervisor

Driller

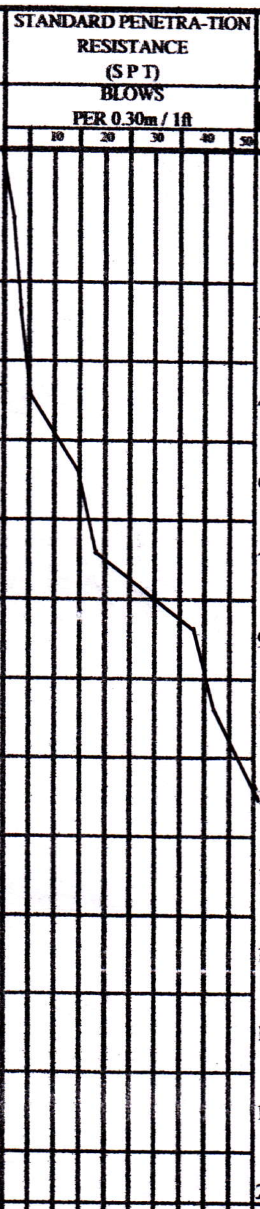
Sheet 16 of 26 Attachment-VIII

FIELD BORE LOG
DELTA SOIL ENGINEERS
871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)	**GROUND LEVEL R.L.** : 1.396 m
LOCATION : Proposed BSMSN, Mirsarai, chattogram	**GROUND WATER LEVEL** : 2.262 m
BORE HOLE NO. 17	**DATE** : **TIME : 09:00 am**

INDEX
▨ DISTURBED
■ NDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
3-2-2019	D-1	▨		5.0	Grey silty CLAY med plastic		100 mm (4") φ	1	1	1	2	1.5m
	D-2	▨						1	1	2	3	3.0m
	C-1	■										
	D-3	▨	5.0					2	2	3	5	4.5m
	D-4	▨		15.0	Grey silty FINE SAND trace mica.			4	7	8	15	6.0m
	D-5	▨						6	8	10	18	7.5m
	D-6	▨						7	18	20	38	9.0m
	D-7	▨						8	20	22	42	10.5m
	D-8	▨						10	22	28	50	12.0m
	D-9	▨						14	30	20	50	13.5m
	D-10	▨						15	20	30	50	15.0m
	D-11	▨						16	22	28	50	16.5m
	D-12	▨						18	35	15	50	18.0m
	D-13	▨	20.0					20	40	10	50	20.0m



Client/Consultant

Field Supervisor

Driller

Sheet 17 of 26 Attachment ~~VIII~~

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

BORE HOLE NO. 18

GROUND LEVEL R.L. : 4.074 m

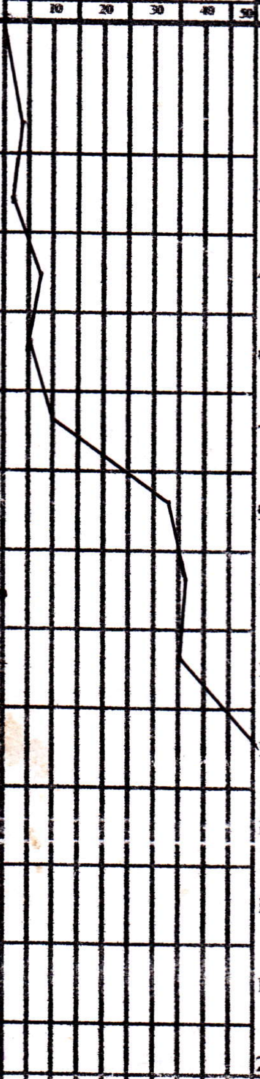
GROUND WATER LEVEL : 2.245 m

DATE : 30-1-2019 **TIME : 09:00 am**

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
	D-1	▨		6.5	Grey silty CLAY Med plastic		100 mm (4") φ	1	1	2	3	1.5m
	D-2	▨						1	0	1	2	3.0m
	U-1	■										
	D-3	▨						1	4	3	7	4.5m
	D-4	▨	6.5					2	2	3	5	6.0m
	D-5	▨			Grey silty FINE SAND trace mica.			3	4	6	10	7.5m
	D-6	▨						5	15	18	33	9.0m
	D-7	▨						6	16	20	36	10.5m
	D-8	▨						7	17	18	35	12.0m
	D-9	▨						14	33	17	50	13.5m 3rd
	D-10	▨						12	40	10	50	4th 15.0m
	D-11	▨						8	44	6	50	16.5m 5th
	D-12	▨						10	30	20	50	18.0m
	D-13	▨	20.0									20.0m

STANDARD PENETRATION RESISTANCE (SPT) BLOWS PER 0.30m / 1ft



Client/Consultant

Sheet 18 of 26 Attachment VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

GROUND LEVEL R.L. : 4.382 m

LOCATION : Proposed BSMSN, Mirsarai Chattogram

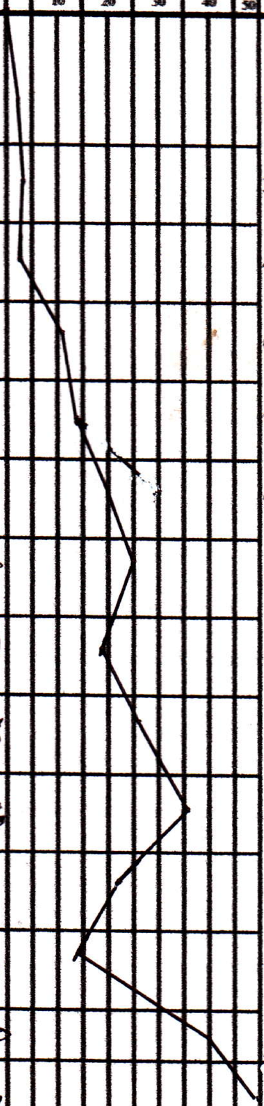
GROUND WATER LEVEL : 1.943 m

BORE HOLE NO. 19

DATE 30-1-2018 **TIME : 09:00 am**

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
30-1-2019	D-1	▨		5.0	Grey silty CLAY med plastic		100 mm (4") φ	1	1	1	2	1.5m
	U-1	■										
	D-2	▨						1	1	2	3	3.0m
	D-3	▨	5.0					1	1	1	2	4.5m
	D-4	▨	6.5	1.5	Grey clayey SILT med compress			2	3	3	6	6.0m
	D-5	▨		16.5	Grey silty FINE SAND trace mica.			3	5	9	14	7.5m
	D-6	▨						4	7	13	20	9.0m
	D-7	▨						5	10	15	25	10.5m
	D-8	▨						3	8	11	19	12.0m
	D-9	▨						4	11	15	26	13.5m
	D-10	▨						11	17	19	36	15.0m
	D-11	▨						9	13	8	21	16.5m
	D-12	▨						7	6	8	14	18.0m
	D-13	▨						3	12	28	40	20.0m
	D-14	▨						8	33	17	50	3" 21.5m
	D-15	▨	23.0					10	40	10	50	4" 23.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

Field Supervisor

Driller

Sheet 19 of 26 Attachment VIII

FIELD BORE LOG
DELTA SOIL ENGINEERS
871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)**

LOCATION : Proposed BSMSN, Mirsarai Chattogram

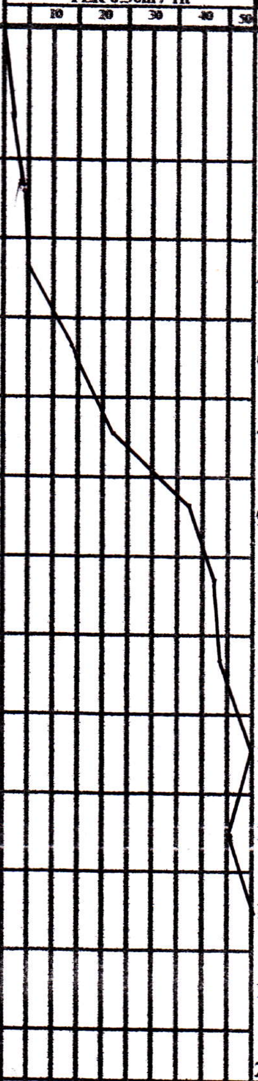
BORE HOLE NO. 20

GROUND LEVEL R.L. : 4.971 m

GROUND WATER LEVEL : 2.227 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
4-2-2019	D-1	▨			Grey silty CLAY med plastic		100 mm (4") ϕ	1	1	1	2		1.5m
	U-1	■		5.0									
	D-2	▨						1	2	2	4		3.0m
	D-3	▨	5.0					1	2	3	5		4.5m
	D-4	▨						3	7	8	15		6.0m
	D-5	▨						5	10	12	22		7.5m
	D-6	▨						7	18	20	38		9.0m
	D-7	▨			Grey silty FINE SAND trace mica			8	20	22	42		10.5m
	D-8	▨		15.0				10	21	22	43		12.0m
	D-9	▨						12	22	28	50		13.5m
	D-10	▨						14	23	24	45		15.0m
	D-11	▨						15	30	20	50		16.5m
	D-12	▨						18	35	15	50		18.0m
	D-13	▨	20.0					20	40	10	50		20.0m

Client/Consultant

Sheet 20 of 26 Attachment-VIII

Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

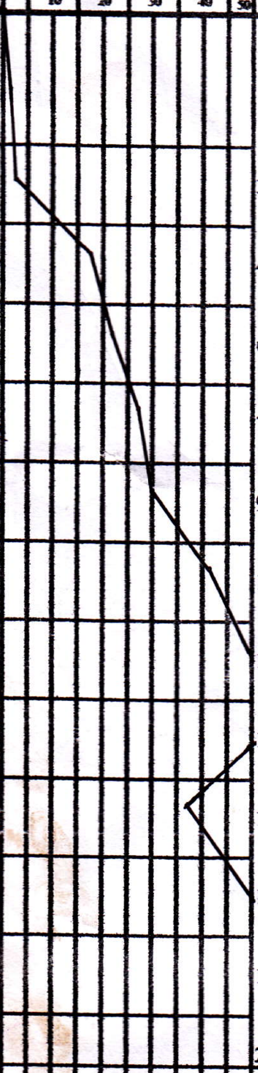
BORE HOLE NO. 21

GROUND LEVEL R.L. : 4.783 m

GROUND WATER LEVEL : 3.563 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
5-2-2019	D-1	▨		3.5	Grey silty CLAY med. plastic.		100 mm (4") ϕ	1	0	1	1		1.5m
	U-1	■											
	D-2	▨	3.5					1	1	1	2		3.0m
	D-3	▨	5.0	1.5	Grey sandy SILT			5	8	10	18		4.5m
	D-4	▨		15.0	Grey silty FINE SAND			5	9	12	21		6.0m
	D-5	▨						6	12	15	27		7.5m
	D-6	▨						7	13	17	30		9.0m
	D-7	▨						9	18	24	42		10.5m
	D-8	▨						10	25	25	50		12.0m
	D-9	▨						8	30	20	50		13.5m
	D-10	▨						7	15	22	37		15.0m
	D-11	▨						8	20	30	50		16.5m
	D-12	▨						6	23	27	50		18.0m
	D-13	▨	20.0					11	26	24	50		20.0m

Client/Consultant

Field Supervisor

Driller

Sheet 21 of 26 Attachment-VIII

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai chattogram

BORE HOLE NO. 22

GROUND LEVEL R.L. : 4.504 m

GROUND WATER LEVEL : 1.760 m

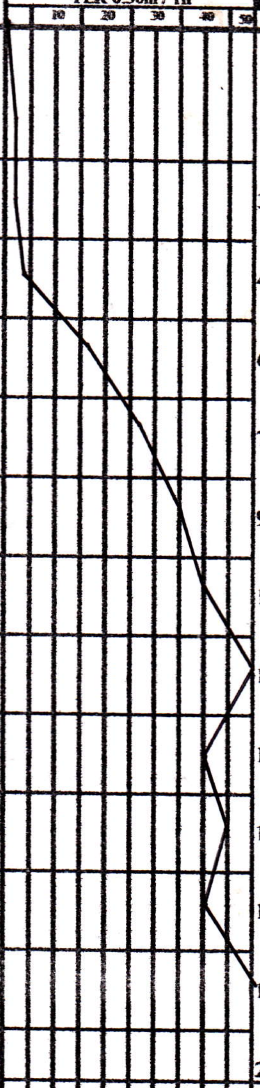
DATE :

TIME : 09:00 am

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
4-2-2017	D-1	▨		3.5	Grey silty CLAY med. plastic.		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨	3.5					1	1	1	2	3.0m
	U-1 D-3	■ ▨	5.0	1.5	Grey clayey SILT med. compress.			1	2	2	4	4.5m
	D-4	▨		15.0	Grey silty FINE SAND.			3	7	10	17	6.0m
	D-5	▨						5	10	17	27	7.5m
	D-6	▨						6	15	20	35	9.0m
	D-7	▨						7	18	22	40	10.5m
	D-8	▨						8	21	29	50	12.0m
	D-9	▨						6	18	22	40	13.5m
	D-10	▨						7	20	25	45	15.0m
	D-11	▨						8	17	23	40	16.5m
	D-12	▨						10	24	26	50	18.0m
	D-13	▨	20.0					11	26	24	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

Field Supervisor

Driller

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FIELD BORE LOG
DELTA SOIL ENGINEERS
871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Construction of Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai Chattogram

BORE HOLE NO. 23

GROUND LEVEL R.L. : 4.266 m

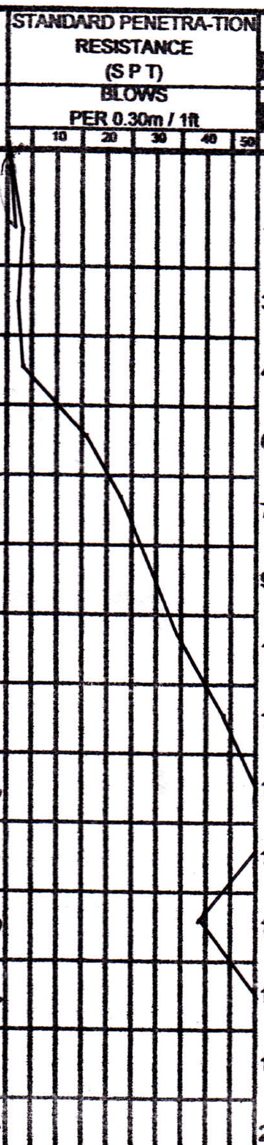
GROUND WATER LEVEL : 1.827 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 6" PENETRATION 6"	6"	6"	SPT	REMARKS
4-2-2017	D-1	▨		3.5	Grey silty CLAY med. plastic.		100 mm (4") ϕ	1	1	2	3	1.5m
	D-2	▨	3.5					1	1	1	2	3.0m
	U-1	■										
	D-3	▨	5.0	1.5	Grey clayey SILT med. compress.			1	1	2	3	4.5m
	D-4	▨		15.0	Grey silty FINE SAND.			3	7	9	16	6.0m
	D-5	▨						5	10	13	23	7.5m
	D-6	▨						5	13	17	30	9.0m
	D-7	▨						5	15	20	35	10.5m
	D-8	▨						9	19	25	44	12.0m
	D-9	▨						8	22	28	30	13.5m
	D-10	▨						9	24	26	50	15.0m
	D-11	▨						10	15	24	39	16.5m
	D-12	▨						8	18	32	50	18.0m
	D-13	▨						9	21	29	50	19.5m
	D-14	▨	20.0					10	24	26	50	21.0m
	D-15	▨										22.5m
	D-16	▨										24.0m
	D-17	▨										25.5m
	D-18	▨										27.0m
	D-19	▨										28.5m
	D-20	▨										30.0m

INDEX: ▨ DISTURBED ■ UNDISTURBED



Client/Consultant

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Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)

LOCATION : Proposed BSMSN, Mirsarai, chattogram

BORE HOLE NO. 24

GROUND LEVEL R.L. : 4.119 m

GROUND WATER LEVEL : 1.985 m

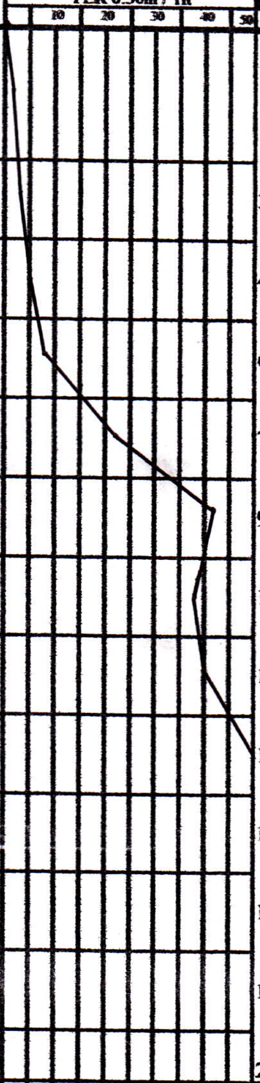
DATE :

TIME : 09:00 am

INDEX: ▨ DISTURBED ■ UNDISTURBED

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	REMARKS
4-2-2019	D-1	▨			Grey silty CLAY		100 mm (4") ϕ	1	1	1	2	1.5m
	D-2	▨		5.0	medi plastic.			1	1	2	3	3.0m
	U-1 D-3	■ ▨	5.0					2	2	3	5	4.5m
	D-4	▨						3	3	5	8	6.0m
	D-5	▨						5	10	12	22	7.5m
	D-6	▨						8	20	22	42	9.0m
	D-7	▨						10	18	20	38	10.5m
	D-8	▨			Grey silty FINE			10	20	20	40	12.0m
	D-9	▨		15.0	SAND.			14	22	28	50	13.5m
	D-10	▨						15	23	27	50	15.0m
	D-11	▨						16	30	20	50	16.5m
	D-12	▨						17	30	20	50	18.0m
	D-13	▨	20.0					18	40	10	50	20.0m

STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft



Client/Consultant

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Field Supervisor

Driller

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)**

LOCATION : Azompur River crossing site,

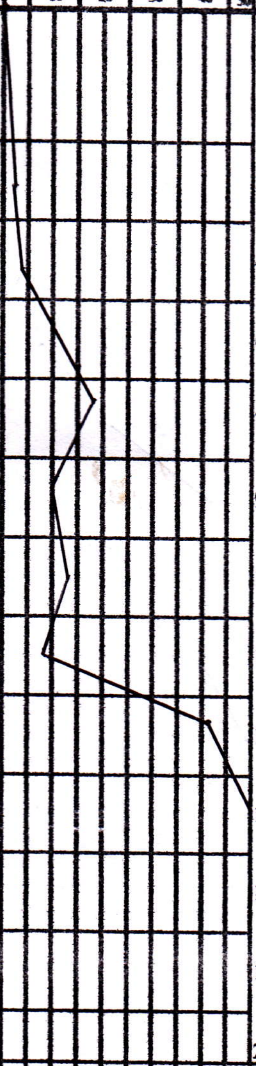
BORE HOLE NO. 25

GROUND LEVEL R.L. : -0.934 m

GROUND WATER LEVEL : -2.763 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION 15cm	15cm	15cm	SPT	STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft 10 20 30 40 50	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
6-2-2012	D-1	▨			Grey silty CLAY		100 mm (4") ϕ	1	0	1	1		1.5m
	D-2	▨		5.0	med. plastic.			1	1	1	2		3.0m
	U-1	■											
	D-3	▨	5.0					1	2	2	4		4.5m
	D-4	▨						3	8	10	18		6.0m
	D-5	▨		6.0	Grey silty FINE SAND.			5	10	15	25		7.5m
	D-6	▨						3	4	6	10		9.0m
	D-7	▨	11.0					3	5	8	13		10.5m
	D-8	▨	12.5	1.5	Grey silty FINE SAND.			3	4	5	9		12.0m
	D-9	▨						9	18	24	42		13.5m
	D-10	▨			Grey silty			10	31	17	50		15.0m
	D-11	▨		7.5	FINE SAND.			8	22	28	50		16.5m
	D-12	▨						10	24	26	50		18.0m
	D-13	▨	20.0					11	29	21	50		20.0m

Client/Consultant

Field Supervisor

Driller

Sheet 25 of 26 Attachment-VIII

FIELD BORE LOG

DELTA SOIL ENGINEERS

871, Rokeya Sarani, Mirpur, Dhaka

PROJECT : **Sub-Soil Investigation for Const. of Proposed Water Treatment Plant (WTP)**

LOCATION : Azompur River crossing site.

BORE HOLE NO. 26

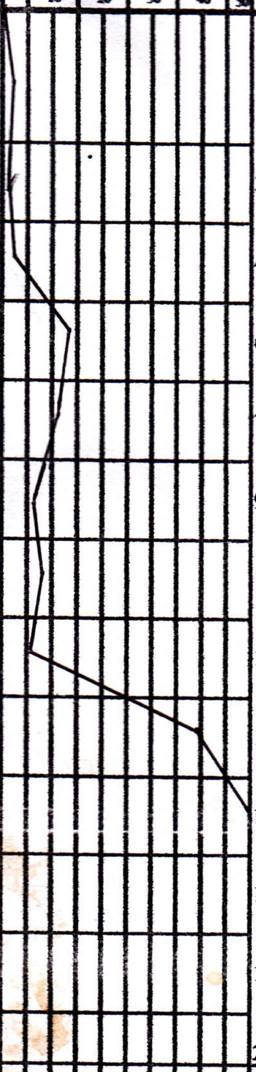
GROUND LEVEL R.L. : 0.913 m

GROUND WATER LEVEL : -1.221 m

DATE :

TIME : 09:00 am

DATE	NUMBER OF SAMPLE	TYPE OF SAMPLE	DEPTH (m)	THICKNESS (m)	DESCRIPTION OF MATERIALS	LOG	DIAMETER OF BORING	BLOWS ON SPOON PER 15cm PENETRATION				STANDARD PENETRA-TION RESISTANCE (S P T) BLOWS PER 0.30m / 1ft	INDEX ▨ DISTURBED ■ UNDISTURBED REMARKS
								15cm	15cm	15cm	SPT	10 20 30 40 50	
6-2-2019	D-1	▨			Grey silty CLAY med. plastic.		100 mm (4") ϕ	1	1	1	2		1.5m
	D-2	▨		5.0				1	0	1	1		3.0m
	D-3	▨	5.0					1	1	1	2		4.5m
	D-4	▨		3.0	Grey silty FINE SAND.			4	6	8	14		6.0m
	D-5	▨	8.0					5	9	12	21		7.5m
	D-6	▨	9.5	1.5	Grey clayey SILT med. compress.			2	2	4	6		9.0m
	D-7	▨		3.0	Grey silty FINE SAND.			2	3	5	8		10.5m
	D-8	▨	12.5					2	3	3	6		12.0m
	D-9	▨			Grey silty FINE SAND.			8	15	25	40		13.5m
	D-10	▨						17	30	20	50		15.0m
	D-11	▨		7.5				12	25	25	50		16.5m
	D-12	▨						10	27	23	50		18.0m
	D-13	▨	20.0					13	28	22	50		20.0m



Client/Consultant

Sheet 26 of 26 Attachment-VIII

Field Supervisor

Driller

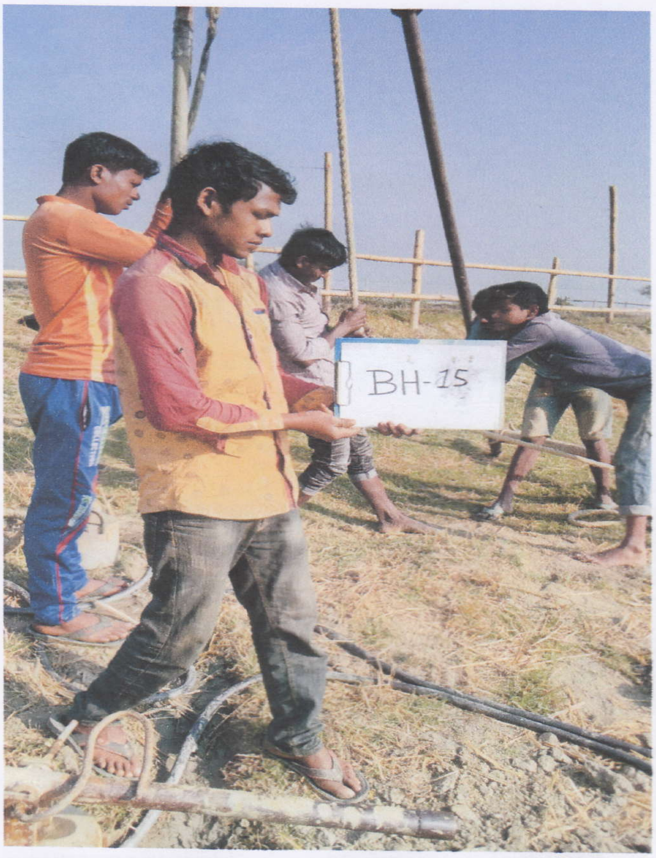
SITE PHOTOGRAPH

Project: **Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.**

Sheet 1 of 7 Attachment-IX

SITE PHOTOGRAPH

Project: **Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.**



SITE PHOTOGRAPH

Project: **Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.**

SITE PHOTOGRAPH

Project: **Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.**

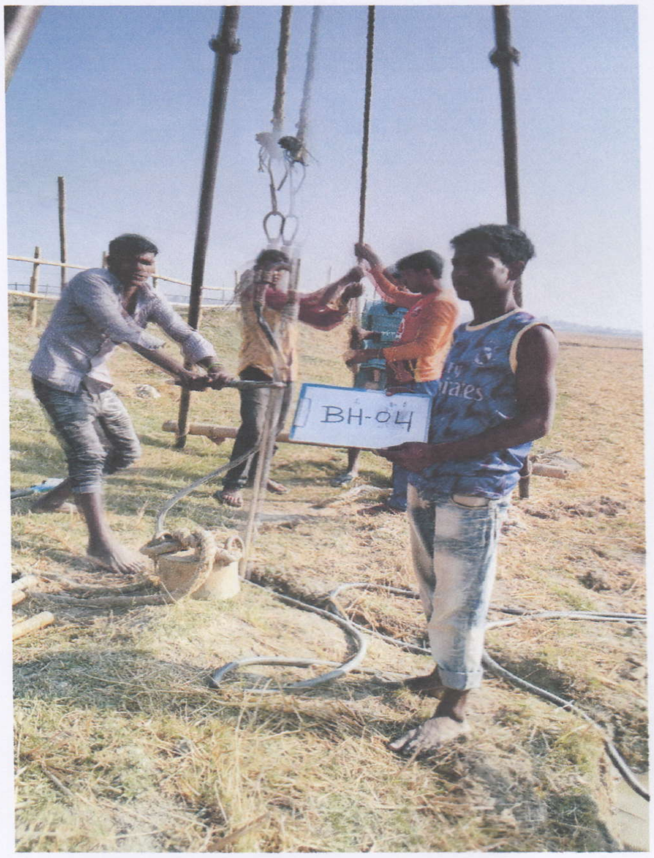
SITE PHOTOGRAPH

Project: **Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.**

Sheet 5 of 7 Attachment-IX

SITE PHOTOGRAPH

Project: Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.



SITE PHOTOGRAPH

Project: Sub-Soil Investigation of Proposed Intake Site at Osmanpur, Water Treatment Plant Site near Tekerhat Bazar and Azompur Khal Crossing at Mirsarai, Chottagram.