CHENNAI METROPOLITAN WATER SUPPLY & SEWERAGE BOARD
(CMWSSB)

PMC FOR CHENNAI PERUR 400 MLD DESALINATION PLANT AND ALLIED WORKS

Concept Design Report for 400 MLD Desalination Plant (CP1) at Perur

Reference No. Loan ID-P267
Contract No.: CNT/ CON/DESAL /ICB/GoI/016/2018-19

Submitted on 23 April 2021

VOLUME I
REPORT

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IMPORTANT NOTICE

This report is confidential and is provided solely for the purposes of briefing the Client on the planned activities to be undertaken by the Project Management Consultant ("PMC") during the course of the Consulting Services under the Chennai 400 MLD Desalination Plant project]. This report is provided pursuant to a Consultancy Agreement between PMC consisting of SMEC International Pty Ltd ("SMEC"), as lead consultant with Joint venture partners, consisting of TATA Consulting Engineers Ltd. (TCE), NJS Engineers India Pvt. Ltd. (NJSEI) and SMEC (India) Private Limited and CMWSSB, under which PMC undertook to perform a specific and limited task for CMWSSB.

This report is strictly limited to the matters stated in it and subject to the various assumptions, qualifications and limitations in it and does not apply by implication to other matters. SMEC makes no representation that the scope, assumptions, qualifications and exclusions set out in this report will be suitable or sufficient for other purposes nor that the content of the report covers all matters which you may regard as material for your purposes.

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Introduction

Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) is responsible for providing water supply and sewerage facilities to Chennai Metropolitan Area. The boundary of Chennai City Corporation has been expanded from 176 sq.km. to 426 sq.km by annexing the 42 adjacent local bodies which includes 9 Municipalities,8 Town Panchayat and 25 Village Panchayats. The Population of Chennai City Corporation was 6.7 million in 2011 and is projected as 7.6 million in the year 2020, 9 million in the year 2035 and 10.90 million in the year 2050.

The rest of the Chennai Metropolitan Area (CMA) comprises of 7 Municipalities, 12 Town Panchayats and 189 Village Panchayats. As per 2011 census the population in Rest of CMA was 2.3 Million and is expected to reach 3.6 million in the year 2020, 6.3 million in the year 2035 and 9.7 million in year 2050.The total jurisdiction of entire Chennai Metropolitan Area (CMA) is 1189 Sq.km, and the projected population is about 11.20 million for the year 2020, 15.48 million for the year 2035 and 20.68 million for the year 2050.

Rapid urbanization and migration to the Chennai Metropolitan Area from other parts of the State has resulted in significant increase in the population leading to substantial increase in the demand for water supply and other infrastructures. The growing needs which are a dynamic call for prudent utilization of the existing sources of water supply and the urgent need to improve/ augment the existing sources. The other infrastructures like road, sewerage facilities, etc are summarily inadequate to meet the present level of population and the increase in the coming years would definitely pose a mammoth problem to be tackled. To annihilate the despondency, proper planning and a road map to guide the future course of action is essential to the agency vested with the responsibility of implementing and maintaining the respective systems, viz. CMWSSB in respect of water supply and sewerage disposal and the Corporation of Chennai and other local bodies in respect of roads and other facilities.

Government of Tamil Nadu through CMWSSB is committed to provide adequate water supply and sewerage facilities to the entire area covered under Chennai City Corporation and Chennai Metropolitan Area by either improving the existing water supply and sewerage facilities or by providing new water supply and sewerage facilities. The need to improve the existing as well as to provide new infrastructural facilities commensurate to the growing needs of Water Supply and Wastewater Management for Chennai City and Chennai Metropolitan Area was engaging the attention of the planners and resultantly two Master Plans, one in the year 1978 and the other in the year 1991 were prepared. The present Master Plan has been prepared considering the works carried out based on the recommendations of the previous Master plans and outlines the detailed actions to be taken in respect of water supply and sewerage sectors in entire Chennai metropolitan area for the future requirement in the context of the expanded boundary of the Chennai City Corporation and the Chennai Metropolitan Area.

Although CMA is facing chronic and sever water shortage, surface water and groundwater are not only sufficient to satisfy the growing water demand from population and economic growths, but also are vulnerable to drought. Therefore, in order to secure additional water supply from safe and reliable water source, consideration of seawater desalination plant is necessary. This will envisage not only the safe and reliable, but also provides an opportunity towards improvement of revenue by introducing metering policy for sustainability of the project.

In this regard, CMWSSB through GoTN and GoI, has approached JICA for funding the 400 Mld Seawater Desalination Plant at Perur, Chennai and allied works to improve the transmission and water distribution system of the City including service reservoirs. JICA has concurred the sanction of loan for the following components of the project:

- CP1 - 400 MLD Seawater Reverse Osmosis (SWRO) Desalination Plant at Perur
- CP2 - Pumping Stations & Reservoirs at Perur and Porur
- CP3 - Product Water Conveyance Main for about 65Km length from Perur to Porur
- CP4 - Improvements to Existing Distribution System in the core area of Chennai City
- CP5 - Installation of external dedicated transmission line

CMWSSB has called the appointment of Project Management Consultant (PMC) for implementation of the above mentioned project components. M/s SMEC International and its consortium (M/s SMEC (I), M/s NJS & M/s TCE Ltd) has been selected through the competitive process by the CMWSSB to assist the PIU for implementation of the Project and signed the consultancy agreement on 9th January 2020. The Project Management Consultant (PMC), working closely with the Project Implementation Unit (PIU) of CMWSSB. The scope of work under Contract Package-1 (CP1) includes the preparation of a concept design report for a cost-effective process selection and smooth operation of the 400 MLD Perur desalination plant. CMWSSB has provided to PMC the information on the previous studies conducted by two agencies, i.e. the DPR consultant, M/s AECOM and financial loan provider, JICA. PMC team has also collected raw water quality data, visited the existing plant sites to understand the functional performance of various units and gathered operational issues prior to COVID-19 lockdown. PMC has collated and analysed the information to draw inferences on critical parameters for the conceptual process design of the 400 MLD Perur desalination plant. Under the current lockdown situation, the PMC team, in a very coordinated manner, planned and completed this study. The study information already presented in the Interim report and draft concept design report, which will be the basis for finalizing the Conceptual Design Report. The objective of this Report is:

- To present the inferences based on the available technical information/data.
- Identification of further study and investigations requirements
- Evaluation and providing observations on the past study reports
- Provide recommendations on each of the process units from offshore seawater intake to product water tank.
- Provide a platform to discuss and obtain early feedback from PIU to proceed further.

The Concept Design Report covers the major process issues of the concept design, which require early feedback from the PIU team to make significant progress towards the completion of the final concept design report depending on the post-COVID-19 lockdown situation.

The Key Areas focused on the report are:

Key Areas to Focus

- Intake structure and associate investigative works
- Desalination Plant site – protection and costs
- Seawater quality specifically TOC, SDI etc. to determine the pre-treatment requirements
- RO design configurations
- Post treatment with water stabilisation
- Finished water quality parameters to include Bacteria, Prozoa & Viruses
- Whole lifecycle costing (Capital & Operation)

Due to the current COVID-19 lockdown, several Webinar/Zoom net-meetings were organised with PIU to seek feedback on the actions presented in this report to continue to complete the preparation and submission of the final concept design report.

Site Conditions

Detailed investigation of site conditions has been done in DPR, and JICA reports. The planned site elevation is +6.5m above Mean Sea Level (MSL), which is a minimum elevation to protect the plant against the high tides and large waves, particularly during the stormy climate and the event of Tsunami. The site will be prepared with the required civil works for the different processes, including pretreatment, RO system and post-treatment and undertaking the hydraulics of the plant. The previous studies by DPR and JICA report lack investigation on the potential source of pollution to the sea. Pollution (river, sewage outlet, others) or marine activities (marine traffic, harbour) impacting raw water quality are required to be investigated and assessed in detail. A recent investigation 5 km coast in the Southern and Northern of the Perur site revealed one major sewage outputs ingress in the North of the Perur site between Perur site and Marina Beach.

Raw Seawater Assessment

There is a lack of available historical seawater chemistry data of the proposed intake site. The seawater analyses conducted by DPR and JICA report are for a short period. There is only a set of 5 years of data available from Nemmeli DSP, which can be considered as the main source of the seawater chemistry for the pretreatment and RO system design. However, some of the important seawater constituents such as total organic carbon (TOC), colour, Barium (Ba), Strontium (Sr) are missing from the analysis results. DPR and JICA reports have based their design on the average value of TSS (i.e., 75 mg/L), which is very much less compared to the frequently recorded values above 150 mg/l during monsoon season. Moreover, one of the important sources of fouling, i.e. the presence of total organic carbon (TOC) in seawater, has not been taken into consideration in the design – mainly the issue of while fibre presence in seawater that arose later in early 2019. The Nemmeli DSP has reported TOC content up to 250 mg/L during Feb 2019 till Feb 2020, which is highly unrealistic. The National Institute of Ocean Technology (NIOT) report addressed the TOC content in seawater and reported TOC value within 7 mg/L, which is quite reasonable. It is to be noted that pre-treatment for TOC removal is quite difficult and varies with the molecular type and source of TOC. Based on the available seawater analysis data from the Nemmeli desalination plant (DSP), the design envelopes for the major parameters adopted by PMC are given below.

Criteria Description	Unit	Minimum	Median	Maximum
pH		8.0	8.1	8.2
Temperature	°C	26	28.3	31.5
Total Dissolved Solids	mg/L	32000	36000	39000
TSS	mg/L	10	75	300
TOC*	mg/L	2	5	8
Boron	mg/L	3.2	3.5	3.8
Algae	cells/ml	100	500	30000
Jelly fish occurrence		NA	NA	yearly

* PMC conducted seawater analysis for TOC by at least 4 reputed agencies and found the TOC value in seawater within 5 mg/l/.

Intake/ outfall locations

DPR has proposed 3 pipes (2 intakes + 1 discharge) in 3 different profiles (routes), which is not a common practice since it implies significantly high dredging cost for the marine works. JICA has also proposed 3 pipes but all in the same trench, which is consistent with desalination practices. A minimum of 600 m between brine reject and intake locations usually applies for the extra-large plant to ensure TDS increase less than 1% at a 400 m radius around the brine diffusers during static sea condition. Even with such a margin, the brine dispersion model is always recommended for this size of plants. PMC has no information about the brine dispersion study performed during the preparation of DPR. With the approval of CMWSSB, PMC carried out a brine dispersion study and submitted a report on the study outcome. The study reveals that an outfall location at 1800 m and an Intake location at 1200 m from the seashore is the feasible positions for the brine dispersion and to avoid any adverse effect on the intake TDS concentration.

The details of the intake and outfall pipe length proposed by the DPR and JICA report and adopted by PMC are given below.

Studies by	Length of the pipeline	
	Intake	Outfall
DPR (AECOM)	1010 m	750 m
JICA report	1140 m	1690 m
PMC	1200 m	1800 m

The diameter of the intake pipeline should be 2500 mm, as recommended by AECOM.

Pretreatment Processes for RO Feed

The DPR and JICA Study reports have suggested implementing 3 pre-treatments technologies (i.e. Lamella + DAF + DMF), but they have not discussed much of the reasoning for the process selection.

PMC is satisfied with the implementation of three (3) processes for the recent seawater quality of the Perur site, particularly due to the expected algae bloom in seawater and plant operation at the baseload capacity and especially due to the recent white fibres issues. The optimum critical parameters for the design of the pretreatment processes are discussed in this report.

The expected TSS and TOC removal efficiency of the 3 processes are given below:

a) A coagulation/flocculation system. An appropriate dosing rate of $FeCl_3$ is needed for the required elimination of TSS and TOC. Jar tests are required to ascertain the optimum dose rate.
b) A Lamella settler is suitable to remove up to 80-90 % of TSS (heavy particles) and approx. 30% TOC with appropriate coagulant dose rate – jar/pilot tests are required to verify this.
c) A dissolved air flotation (DAF) can decrease up to 70-80% of remaining TSS (light particles), an additional 10-15% TOC – jar/pilot tests are required to verify this.
d) For the expected high level of TOC reaching this last stage of pretreatment, the GDMF is reputed to be the most efficient technology compared to UF (high OPEX) and pressure DMF (less efficient results). Deep media beds (1.0- 1.5 m/media thickness) and a low loading rate (7- 8 m/hr) will improve the filtrate water quality.

PMC conducted additional analyses of seawater to confirm the content of TOC in the seawater. The TOC value is found within 5 mg/l in seawater. In the case of the TOC content in raw seawater higher than 8mg/l in future, a significant change in the pre-treatment process might be considered. Considering the seawater's recent analysis results, the maximum TOC value in seawater has been kept at 8 mg/l to meet the eventuality.

RO System Design

RO system will be designed to operate at 46% recovery. However, in the case of the worst seawater quality, the intake system and pretreatment process have been proposed by DPR and JICA to be designed to treat the RO feed suitable for 42% RO recovery. During design and costing of the intake and pre-treatment system, it is found that the provision of operating RO system at a reduced recovery of 42% will incur an additional cost of about INR 130 crores for seldom need of RO system operation at reduced recovery. The provision of additional flow to the plant will increase the capital and operating cost too. PMC recommends eliminating the provision of reduced recovery or reducing it to 2% reduction instead of 4%, i.e., 46% to 44%. PMC suggested to the PIU team to consider and confirm.

The Perur desalination Project is based on a single RO pass system with a Boron requirement for product water <1 mg/l.

Two technical options are available and shall be economically compared:

- High rejection membranes shall be able to meet the boron target with no chemical injection (pH reduction) or a minimum injection in summer.
- Low energy membranes are more recently developed membranes aiming at reducing energy consumption. Operated in similar conditions as the high rejection membranes, pressure requirement may be reduced by 3-4 bars. However, it offers a lower boron rejection, and an increase in pH with a significant amount of sodium hydroxide addition is required to meet the necessary boron rejection.
- Some hybrid configurations (4 high rejection membranes + 4 low energy membranes) have also been adopted on several extra-large plants (Ashdod). A study on the hybrid membrane with cost analysis has been done and presented in this report. The study provisions are found suitable to be adopted in the Perur DSP.
- A cost-effective membrane selection shall be made, taking into consideration all capital and operating costs and the required TDS and boron rejection.

The DPR and JICA Study report have recommended a conventional train configuration (16 trains + 1 standby). This configuration commonly offers a plant availability of 94-95%. With one stand-by train, the availability can reach up to 96-97%. An alternative to this is a 3-Center design configuration which allows high availability (>97%) with acceptable flexibility. With this configuration, the RO Skids, the High-Pressure Pumps (HPP) and the Energy Recovery Devices (ERD) are no longer organized in individual RO trains but associated in “center”. The cost of the water per m^3 in 3-Centre design SWRO plants can be considerably reduced. The detailed pros and cons of the 3 center design are given below in this report.

The report has addressed only the major processes in the desalination plant that may pose issues in meeting the required quantity or quality of product water. A process flow diagram (Drawing no.7061563/PMC/400 MLD/CP1/P/PFD/001) is attached in the report, which indicates the major process units included in the plant.

Summary of Major Proposed components

The summary of major proposed components, including a number of units and Material of Construction, is furnished below.

Sl. No.	Component Name	No. of Unit	Material of Construction (MOC)
01	Intake Pumping Station	1	RCC Epoxy
02	Lamella Settlers	36	RCC Epoxy
03	Dissolved Air Flotation (DAF)	12	RCC Epoxy
04	Gravity Dual Media Filter (GDMF)	80	RCC Epoxy
05	RO Feed Tank	2	RCC Epoxy
06	RO Building	2	PEB Shed
07	Limestone Filter	28	RCC Epoxy
08	RO Permeate Tank	2	Metallic Tank/ RCC Epoxy
09	CO_2 Storage Area	2	-
10	Product Water Tanks (7.5 ML Each)	4	Metallic Tank/ RCC Epoxy
11	Clear Water Reservoir (9 ML)	1	RCC Epoxy
12	Sludge Balancing Tank	1	RCC Epoxy
13	Thickened Sludge Thickeners	2	RCC Epoxy
14	Sludge Holding Tank	1	RCC Epoxy
15	Belt Filter Press Building	1	RCC
16	Outfall Tank	1	RCC Epoxy
17	Chemical Building for RO	2	RCC with Chemical Resistant Lining
18	Chemical Building for Pre-Treatment	2	RCC With Chemical Resistant Lining
19	Power Receiving Station/Control Building	1	RCC
20	Electrical Building for Intake Pump Station & Pre-Treatment	2	RCC
21	Electrical Building for RO Building	2	RCC
22	Warehouse	1	PEB SHED
23	Workshop	1	PEB SHED
24	Package STP	1	-
25	Fire Fighting Station	1	RCC
26	Administration Building (Officer's Room/ Conference/ Canteen) (G+2 Floors)	1	RCC
27	Administration Building (Laboratory cum Meeting/ Training Room) (G+1 Floor)	1	RCC
27.a	Parking Area	1	PEB SHED
28	Security Room	1	RCC
29	Additional Security Room	1	RCC
29a	Lay Down Area	1	-
31	Lay Down Area	1	-
32	Landscape & Park Area	1	-
33	Watch Towers	2	-

Project Implementation and O&M Period

The implementation and Operation & Maintenance period for the project is listed below:

- Design-Build period : 36 months
- Trial run and commissioning period : 3 months
- Process proving period : 3 months
- Operation & Maintenance period : 20 Years including one year of Defect Liability Period

1 INTRODUCTION

1.1 Project Background

Chennai is currently experiencing a chronic water shortage due to the impacts of climate change and the failure of monsoons to deliver enough rainfall and associated stream flow to refill the existing water supply system's surface water sources.

To improve the current water supply situation, the Chennai Metropolitan Water Supply and Sewerage Board ("CMWSSB" or "the Client") has obtained a loan from the Japan International Cooperation Agency ("JICA") through the Tamil Nadu Government, to implement a 400 MLD Sea Water Reverse Osmosis Desalination plant at Perur.

CMWSSB has selected a Project Management Consultant ("PMC") through a competitive bidding process to support the CMWSSB Project Implementation Unit ("PIU") for implementation of the 400 MLD Seawater Desalination Plant and its components (collectively referred to as the "Project"). A Consultancy Contract agreement was signed dated January 09, 2020, for Consulting Services with the PMC for the Project.

The PMC is a Consortium comprising of SMEC International Pty Ltd., Australia as the lead member of the consortium, Tata Consulting Engineers Limited (TCE), NJS Engineers India Pvt. Ltd. (NJSEI) and SMEC (India) Private Limited, who are joint venture partners and jointly liable for the execution of the project.

After receipt of the Notice to Proceed issued by CMWSSB on January 13, 2020, the PMC team commenced services on January 20, 2020, with the initial mobilization of project personnel. Under the reporting obligations of the Contract, and as per the letter issued by CMWSSB, a Conceptual Design Report is to be submitted. PMC started its activities from the day of notice to proceed and continued its effort even in the undulating period of COVID-19 to meet the project schedule and to achieve overall project success. This report is based on the previous studies conducted by DPR and JICA on the design and implementation of the 400 MLD SWRO Perur desalination plant.

The TECH 8 work schedule for Contract Package-1 (CP1) as in the PMC contract document under Clause 4.5.3 specifies eight tasks to be completed in 9 months to prepare the bid documents for the 400 MLD Perur desalination plant.

- Task 1. Data and information collection
- Task 2. Review the technical information
- Task 3. Conducting surveys and investigations
- Task 4. Concept design of Perur DSP
- Task 5. Preparation and submission of concept design report
- Task 6. Preparation of technical specifications
- Task 7. Financial analysis
- Task 8. Preparation of O&M requirements for bid documentation

With the view of fulfilling Task 5, a preliminary concept design report was prepared by PMC and submitted to CMWSSB on 10 July 2020 for review and further discussions with the PIU team. Following the submission of the draft concept report, several meetings and discussions were held with PIU and a number of presentations were conducted by PMC to firm up the client's requirements and preferences in completion of Task 4. For ease of clarity and efficiency, the detailed scope of CP1 for the Chennai Perur desalination plant has been provided below.

This report provides the requirement for the fulfilment of the Concept Design Report.

1.2 Project Scope for Contract Package (CP1)

The major components within the Scope of Work for the CP1 components, i.e. 400 MLD Sea Water Reverse Osmosis (SWRO) Desalination Plant project of Perur, Chennai, are discussed below. The detailed components of the Contract Package (CP1) are summarised in Table 1.

Table 1: Project Scope of Work for CP1

S. No.	Component	Construction Items
CP1	Construction of the Perur DSP (400 MLD)	▪ Seawater intake facilities, including twin intake pipelines ▪ Pre-treatment facility ▪ Seawater desalination facility by Reverse Osmosis (RO) technology ▪ Post-treatment facility for remineralization and disinfection ▪ Product Water Tank (30 ML Capacity) and Potable water (9 ML Capacity) ▪ Plant effluent, including brine discharge pipeline ▪ Wastewater treatment facility ▪ Administration and all other buildings and structures for the seawater desalination plant.

1.2.1 Design Works for CP1 Components

The Consultant has carried out the Consulting Services through the following work items for CP1. The conceptual design for CP1 will include the following works:

a) Review of the technical information on the Project.
b) Implementation of the supplementary natural condition surveys will be provided as a part of the tender document.
c) Conceptual design of the Perur DSP includes brine diffusion analysis using the previously conducted ocean current survey data.
d) Preparation of conceptual design report includes descriptions of all the processes, general layout plan, water and material balance sheet, overall process flow diagram and instrumentation plan.
e) Preparation of technical specifications to be included in the bid documents.
f) Preparation of a high-level Capital and Operational cost analysis and comparison with the similar large plants capital cost.

1.3 Conceptual Design (CP1) Scope and Objectives

It should be noted that CP1 is to be delivered under a DBO scheme which has a substantial impact on the present design requirements and deliverables since one of the main targets of this document is to prepare primary technical data in term of performance and specifications of the plant to be inserted in the bid document (RFP package) as below, but not limited to the following:

- Site conditions
- Raw water quality
- Battery limits and interfaces
- Existing laws, standards, regulations in India that apply to such a desalination plant (including Permit list to be obtained by DB (Design & Build) and O&M companies)
- MFS (Minimum Functional Specifications), which includes expected performance of the Plant
- Technical risk allocation
- Tentative DB works duration (including Commissioning and Testing)
- Plant final testing protocol

Furthermore, the PMC team will include the following in the Concept Design report but will not be included in the bid document package:

- Engineering details describing the process and the main part of the plant (as a construction practical feasibility study), including the Mass Flow Diagram and the sizing of the main equipment; and
- Cost analysis for DB cost (CAPEX for Capital Expenditures) and operation cost (OPEX for Operation Expenditures).

It is understood that significant study works were already performed by DPR and JICA consultants. The PMC team has completed a critical examination of these works for the main components (hypothesis and outcomes).

All the above tasks will provide opportunities to enter in fruitful discussions with PIU of CMWSSB aiming at:

- Making sure the PMC team has correctly understood the expectations and preferences of CMWSSB regarding the performance and the asset design and build.
- Allowing PMC to inform CMWSSB about the latest innovations related to recent large desalination plants.

The details of the Functional diagram for Conceptual Design are shown in Figure 1.

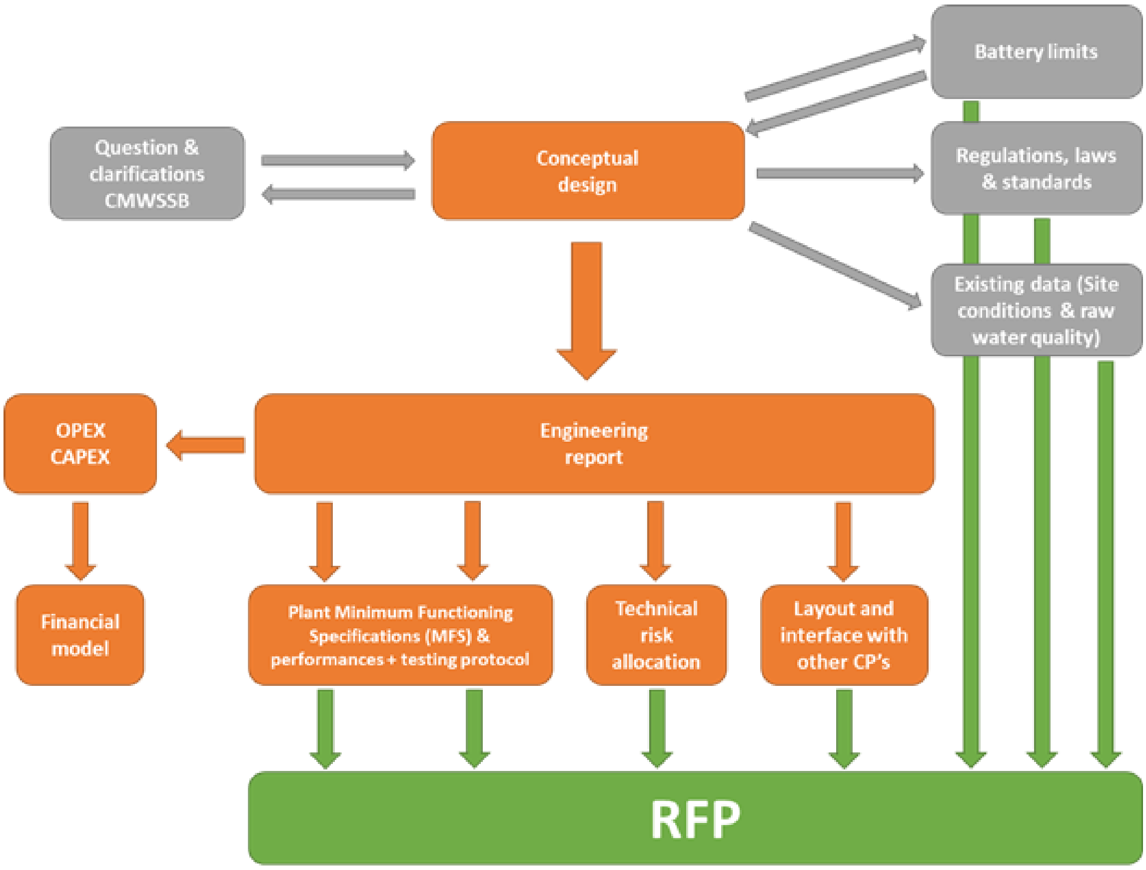


Figure 1: Functional Diagram for Conceptual Design

1.4 Structure of Concept Design Report (CP1)

The Concept Design Report for CP1 comprises of the following volumes:

- Volume – I : Report
- Volume – II : Annexures
- Volume – III : Environmental & Social Safeguard Report
- Volume – IV : Drawings

2 CONCEPT DESIGN REPORT INPUTS

The Concept report has been prepared by duly considering the available data and information collected from various sources, preliminary discussions with CMWSSB and the existing desalination plants visit. Based on the information/ data collation and analysis, the inferences are presented below.

The objective of this Report is below but not limited to the following:

- To present the inferences based on the available technical information/data
- Identification of further study and investigations requirements
- Evaluation and providing observations on the past study reports
- Provide recommendations on each of the process units from offshore seawater intake to product water tank.
- Provide a platform to discuss the design and recommendations and obtain early feedback from PIU to proceed further.

The draft concept design report covered only the major process issues, which required early feedback from the PIU team to make significant progress towards the completion of the final concept design report scheduled by the end of July 2020, depending on the post-COVID-19 lockdown situation. The final concept design report now includes all the plant features and process issues discussed during several meetings and discussions with PIU through the preparation of the bid documents of the 400 MLD SWRO desalination plant.

3 DATA COLLECTION AND REVIEW OF TECHNICAL INFORMATION

The PMC team has collected the various data/report/details/drawings as a part of the preparation of an interim report to facilitate the development of the Draft Conceptual Design Report for CP1 components and the related study of the work. The following key reference data information has been reviewed by the PMC team during project activities. It informs our view on the required approach and methodology and key Project risks, as defined in the Inception Report submitted to CMWSSB on 28.02.2020:

- Terms of Reference (TOR) of the Consultancy Services
- Preparatory Survey on Chennai Seawater Desalination Plant Project, Final Report (February 2017, JICA, Nippon Koei et al.)
- Technical Appraisal Report for 400 MLD SWRO Desalination Plant at Perur, East Coast Road, Chennai (JICA)
- Loan Agreement No. ID-P267, Loan Agreement for Project for Construction of Chennai Seawater Desalination Plant (I) between Japan International Cooperation Agency and The President of India (29 March 2018)
- Minutes of Discussions on Chennai Seawater Desalination Plant Project between Japanese International Cooperation Agency and Chennai Metropolitan Water Supply and Sewerage Board (19 January 2018) – complete with all attachments
- Volume 1 Detailed Project Report for Proposed 400 MLD Sea Water Reverse Osmosis Desalination Plant at Perur Along ECR, Chennai, Tamilnadu, India (AECOM)
- Sea Water Analysis Monthly Cumulative Reports for the Nemmeli DSP covering the period 1/01/2015 to 31/12/2017 (WABAG)
- Nemmeli Seawater analysis report, Based on a sample collected on May 31, 2019 (WABAG)
- A preliminary report on seawater quality received from CMWSSB-Desalination Wing 100 MLD Desalination Plant at Nemmeli (NIOT, August 2018)
- Physiochemical and the biological parameters of the seawater of the 100 MLD Desalination Plant – Nemmeli (NIOT, May 2019)
- CRZ Clearance for setting up of 400 MLD capacity desalination Plant at Perur, East Coast Road, Chennai, Tamil Nadu – reg. (Ministry of Environment, Forest and Climate Change, GOI, 25/10/2018)
- FMB Sketch for Perur Desalination Plant
- Sea Water and Product Water Analysis Cumulative Report for Minjur 100 MLD Existing DSP
- COD details of Minjur DSP (March 2019 to March 2020)
- Tidal Current Survey for Perur Desalination Plant (for 3 seasons)

In addition to client-supplied data, relevant Indian and international standards and practices have been referenced to guide the initial review of Project details and gain insight into the areas of the Project scope that warrant further investigation by the PMC team.

A comprehensive “first pass” list of information requirements was compiled and formally issued by the PMC to CMWSSB on 23 January 2020 to kick off the Consulting Services shortly after mobilisation and arrival of the International specialists on 20 January 2020. The following data and information collected from CMWSSB and the PMC gratefully acknowledge the assistance of the PIU in coordinating with departments to collect and furnish copies of this information listed below in Table 2.

Table 2: Details of Documents and Data Sources

Sl. No.	Components	Documents / Previous Study Reports / Data	Source	Status of Data Collection
1	NIOT Report	A Preliminary Report on Seawater Quality Collected from CMWSSB – Desalination Wing - 100 MLD Desalination Plant at Nemmeli (National Institute of Ocean Technology, August 2018)	CMWSSB	Completed
2	NIOT Report	Report on Physicochemical and the biological parameters of the seawater of the 100 MLD Desalination Plant - Nemmeli (National Institute of Ocean Technology, May 2019)	CMWSSB	Completed
3	AECOM DPR	Detailed Project Report for Proposed 400 MLD Sea Water Reverse Osmosis Desalination Plant at Perur along ECR, Chennai, Tamil Nadu (Prepared by M/s AECOM)	CMWSSB	Completed
a	Geotech Report	Geotechnical Investigation Report (Dept. of Soil Mechanics, Anna University, Chennai)	CMWSSB	Completed
b	IRS Report	Demarcation of High Tide Line, Low Tide Line, Preparation of Coastal Land Use Map for Proposed Desalination Plant in Nemmeli Village (Dept. of Institute of Remote Sensing, Anna University, Chennai)	CMWSSB	Completed
c	White Particle Report	Nemmeli Seawater analysis report Report based on a sample collected on May 31, 2019	CMWSSB	Completed
4a	JICA Drawings	Preparatory Survey for Chennai Desalination Plant Project - Draft Final Report Drawings (JICA & M/s Nippon Koei Co. Ltd. On Nov.2016)	CMWSSB	Completed
4b	JICA Report Appendices	Preparatory Survey for Chennai Desalination Plant Project - Draft Final Report Appendices (JICA & M/s Nippon Koei Co. Ltd. On Nov.2016)	CMWSSB	Completed
5	CRZ Letter	CRZ Clearance: Letter from Ministry of Environment & Forest and Climate F&CC, New Delhi (Oct'2018)	CMWSSB	Completed
6	Sea Water Quality Report	Sea Water Analysis Cumulative Report for Nemmeli 100 MLD Existing Desalination Plant for **January 2015 to December 2017**	CMWSSB	Completed
7	Sea Water Quality Report	Sea Water Analysis Cumulative Report for Nemmeli 100 MLD Existing Desalination Plant for January 2018 to December 2018	CMWSSB	Completed
8	FMB Sketch	FMB Sketch for Perur Desalination Plant	CMWSSB	Received
9	Sea Water & Clear Water Quality Report	Sea Water and Product Water Analysis Cumulative Report for Minjur 100 MLD Existing DSP	CMWSSB	Received

Sl. No.	Components	Documents / Previous Study Reports / Data	Source	Status of Data Collection
10	Sea Water Quality Analysis	COD details of Minjur DSP (March 2019 to March 2020)	CMWSSB	Received
11	AECOM	Tidal Current Survey for Perur Desalination Plant (for 3 seasons)	CMWSSB	Received
12		Noted operational issues of existing Nemmeli and Minjur plants	Site Visit	

A formal incoming document register was maintained by the PMC to monitor the status of information requests and ensure that outstanding information was actively managed.

As stated above, the present report has referred as much as possible to the Past DPR prepared by M/s AECOM and to the JICA Preparatory Survey in order not to duplicate existing studies. Existing studies and reports were studied and further carefully reviewed and evaluated to get all relevant information for the concept design report. Accordingly, the design and recommendations have been updated and modified.

PMC has reviewed the following design inputs to the project, including site condition, raw water quality issues, intake and waste discharge locations etc., with reference to the collected information and has given the recommendations.

- PMC team met with the Client several times for project-related discussion. Critical outcomes resulting from client meetings to date include:
- Prevailing water quality issues at the existing Nemmeli DSP, which have now persisted for more than 12 months, need further investigation to ascertain the potential impact on the preferred process train for pre-treatment.
- Lack of critical standby infrastructure at existing DSP sites results in plant shutdown during regular O&M activities, which needs further study to enhance the same.
- The Project technical requirements must deliver assets capable of maintaining a high level of availability to ensure a reliable climate-independent source of supply at nameplate capacity – other existing surface and groundwater sources are subject to significant variations in water availability due to drought conditions.
- Acceleration of the Project schedule is of key importance to the CMWSSB to help address the current water shortage experienced in Chennai.

Based on the review of reference information, observations made from site visits and early client meetings with the CMWSSB, the following initial observations apply to the formulation of the approach and methodology:

i. Raw water quality for Perur DSP (CP1) – the existing Nemmeli DSP has experienced ongoing adverse seawater quality issues since early 2019, which introduces additional considerations for pre-treatment process selection and warrants further investigation;

ii. Process arrangement for Perur DSP (CP1) – the opportunity exists to evaluate options for the process train arrangement for a baseload operation;

iii. Project specifications for Perur DSP (CP1) – the balance between performance-based requirements and minimum technical standards needs careful consideration in the development of the Specification for this CP1 package to ensure sustainable long-term (20 years) performance of the DSP asset;

iv. Availability of the land for construction of facilities – given the importance of the Project, any delay in acquiring the possession of the land would delay the completion of project components, thereby increasing the project cost and the gap in demand-supply.

v. Initiation of approvals from other government departments – project components require many approvals from the government agencies for construction activities such as permission from TNPCB (Tamil Nadu Pollution Control Board), NCSCM (National Centre for Sustainable Coastal Management), TNFD (Tamil Nadu Forest Department) etc. Therefore, it is better to communicate with the other government agencies regarding this upcoming project and required permission to execute works in the best interest of project progress.

The topographical surveys, bathymetry surveys, water sample analysis and other requisite investigation activities as noted in this report were carried out by the PMC, and the results are included in the report. The geotechnical investigations have not been done for CP1 as it has been already conducted during the DPR preparation. The Final Detailed Design for the DB works shall be done following the award of the contract.

The details of site information, seawater quality analysis and clear water quality analysis and its assessment are explained in Chapter 5 (Design Inputs).

4 PROFILE OF PERUR DESALINATION PLANT SITE FOR CP1

4.1 Site Conditions

4.1.1 Location

The proposed construction site for the Desalination plant is located at Perur village, about 40 km from the Chennai city centre. The total area of the plot is approximately 34 ha. It is situated along the coastal side of the East Coast Road (ECR). Its ground elevation is chart datum +3.0 to +7.5m. ECR is approximately CD + 11 AMSL.

There are two numbers of graveyards identified within the proposed site. The one on the southern side of the sea coast and another one on the northern side towards the East Coast Road. It is understood that the graveyards must be left undisturbed and shall be protected by a compound wall all across, and proper drainage shall be made draining towards the sea. Nevertheless, the unused area available at the proposed site is enough for the construction of the proposed plant in all respect.

The proposed land has been identified under survey number – 208/ 2B3 belonging to the M/s. Arulmigu Alavandar Nayakar Trust maintained by The Hindu Religious and Charitable Endowment Board (HR & CE) Department, Government of Tamil Nadu (GoTN). CMWSSB has procured the land on a long term lease basis.

The details of the local site conditions are given below in Table 3.

Table 3: Details of local site conditions for the proposed DSP site

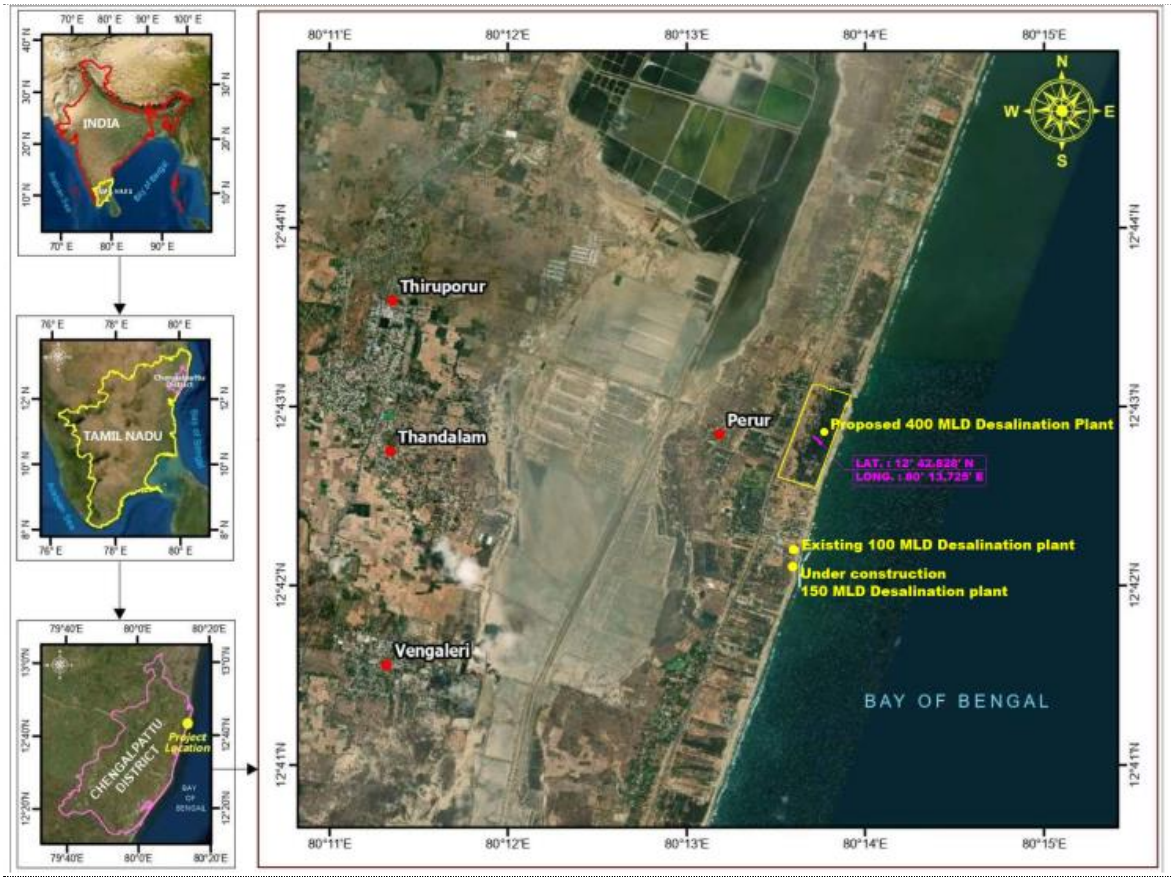
Particulars	Details
Site Location	District: Kancheepuram / Taluk: Thiruporur / Village: Perur
Site coordinates	12°42'44"N, 80°14'26"E
Nearest highway	State Highway SH 49, East Coast Road
Nearest railway station	Othivakkam railway station
Nearest Airport	Chennai Airport
Nearest town/ City	Chengalpattu, Pudupattinam, Tirukalukundram, Nandivaram-Guduvancheri
Archaeologically Important places	Mahabalipuram

The site condition assessment performed by DPR and JICA Study report does not deserve any comments. Few observations are made as below:

- It seems that only seaside options were contemplated when selecting land for Perur DSP. The plant elevation @ 6.5 m above Mean Sea Level (MSL) is a minimum elevation for such a large plant. In this case, as the plant site has already been selected, the site is required to be raised up to CD +6.5m to keep the proposed 400 MLD Perur desalination plant safe from high waves during stormy climate and Tsunami situation.

- The previous studies are lacking any investigation on the potential source of pollution to the sea. Pollution (river, sewage outlet, others) or marine activities (marine traffic, harbour) impacting raw water quality have been assessed in detail for the 10 km coast in southern and northern directions.

The location of Perur proposed 400 MLD Desalination Plant and Nemmeli existing 100 MLD and 150 MLD ongoing Desalination Plant is shown below figure:



During the site visit, we have seen the land earmarked for the 400 MLD Desalination plant, which includes land for the potable water storage reservoir and pumping station. The picture given below shows the proposed Perur site.

Figure 2: Photo of the Proposed Site for 400 MLD Perur DSP

The onshore investigations and surveys required access to the proposed Perur site (refer to Figure 3), which was restricted initially. This constraint was resolved (Enter upon permission) by the access permission granted through the CMWSSB.

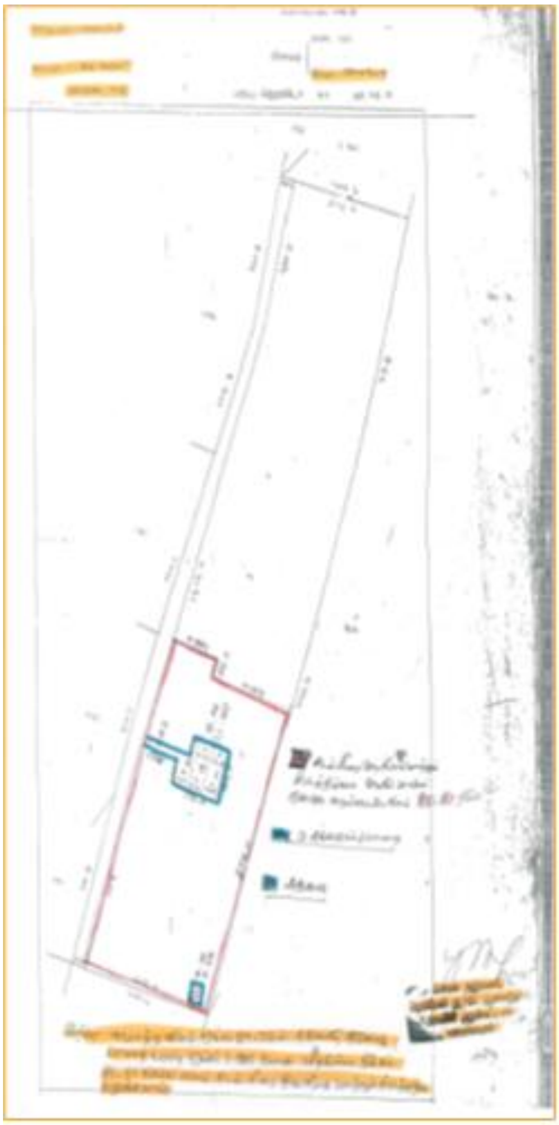


Figure 3: FMB Sketch of Proposed Location of Perur DSP

4.1.2 Topography

Based on the study report, the onshore topographic survey and offshore topographic survey were carried out on behalf of CMWSSB as part of DPR for 400 MLD, and the major findings are very interesting and furnished below:

4.1.2.1 Onshore topography:

The Existing Ground Level (EGL) at the test conditions varied from +2m Chart Datum (CD) to + 3 m CD, indicating the almost uniform site condition. The site is having a tree plantation of Casuarina. The site falls under Seismic Zone III as per BIS code IS:1893 (Part I).

The contour map and spot level of the proposed desalination plant site, including two burial ground locations, are shown in the following figure.

The topography of the proposed Perur DSP site is furnished in Figure 4.

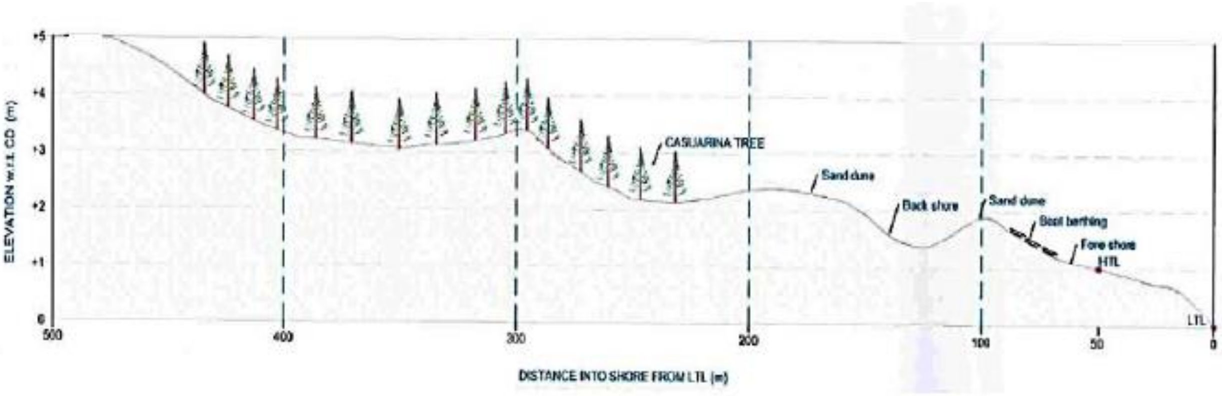


Figure 4: Typical Topography of Planned Perur DSP site

4.1.2.2 Offshore topography:

<u>DPR Study</u>

Based on the bathymetric survey conducted during DPR preparation, buried rocks have been found near the shore that is spread in different direction and depth. Figure 5 presents a seabed map indicating the location of buried rocks.

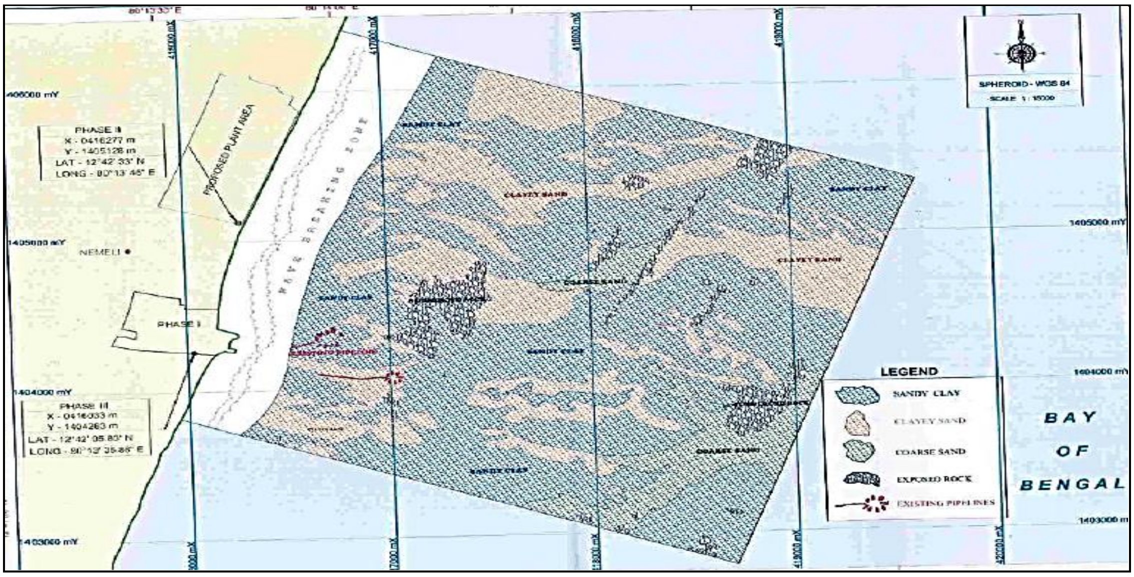


Figure 5: Seabed Map

The bathymetry survey shows that the depth contours are generally running parallel to the coast.

The slope of the seabed with respect to water depth is furnished in the below table:

Seawater depth	Slope
Shoreline till 7 m depth	1:70
7 to 15 m depth	1:250

The slope of the seabed with respect to the distance from the shore as obtained from the DPR is furnished below in Table 4.

Table 4: Variation of Sea depth with distance from Shore

Depth w.r.to CD (m)	Distance from Shore (m)
2	150
3	200
4	225
5	340
6	440
7	520
8	660
9	835
10	**1040**
11	1360
12	1890
13	2160
14	2480
15	2720
16	2950

Sedimentary layers of silty sand were identified between – 0.0 and -8.0 m below the seabed.

PMC Study

The bathymetric survey was also conducted by PMC in August 2020, which is discussed below. It provides the seabed information very close to the above study conducted during DPR formation.

The bathymetry survey covered an area of 1650 m distance along the coast and 2500 m distance from the coast. The survey transects were planned perpendicular to the coastline at 50 m spacing. In addition, the shore parallel tie-up lines were planned at 250 m spacing.

The bathymetry survey report is enclosed in **Annexure 1**.

The surveyed bathymetry lines are shown below in Figure 6.

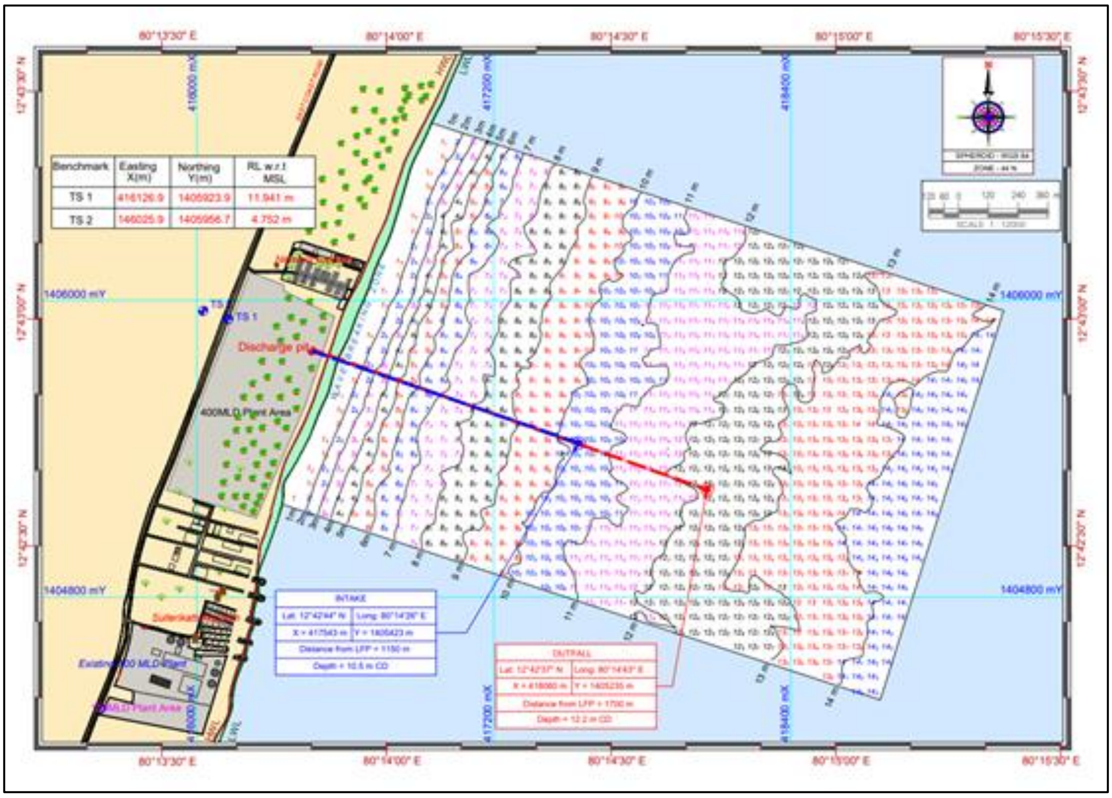


Figure 6: Depth of Seabed with distance from Coast

4.1.3 Climate

Chennai features a tropical wet and dry climate. Chennai lies on the thermal equator and is also coastal, which prevents extreme variation in seasonal temperature. For most of the year, the weather is hot and humid. Typical meteorological data for Perur DSP is furnished in the Table below. Cyclones are more common in the Bay of Bengal, and the proposed Perur site is expected to be affected by cyclones by approximately 3 times per year. The details of Typical Meteorological data for the Perur DSP site are furnished in Table 5.

Table 5: Typical Meteorological data for Perur DSP

Meteorological Parameters	Unit	Values
Mean Ambient temperature (min./ max.)	° C	24.5 / 33.5
Barometric pressure	K Pa	100.1/ 101.35
Relative humidity (min./ average/ max.)	%	57 / 70 / 83
Main wind direction		Southwesterly
Average Annual rainfall	**mm**	**1200**
Average rainfall during Northeast monsoon (June to September)	mm	440
Average rainfall during Southwest monsoon (October to December)	mm	760
Maximum rainfall within 24 hours	mm	346.6

Source: Indian Meteorological Department Chennai, Meenambakkam, 1981- 2010

4.1.4 Ocean Conditions

The oceanography of the region is influenced by 3 climatic conditions viz., southwest monsoon (June – September), northeast monsoon (Mid – October to Mid – March) and a fair-weather period (Mid -March to May). The coast is more influenced by the northeast monsoon than the other two seasons. Wave action is high during the northeast monsoon and cyclonic period. The coastal current within a 5 km radius distance is greatly influenced by winds and tides. The near shore remains more dynamic and turbulent due to the persistent action of seasonal wind, high waves and sea currents. The distribution of temperature and salinity indicates that the near shore water is well mixed without stratification. The influence of littoral drift is significant, and the annual net drift takes place in a northerly direction. The tide elevation at Perur with reference to Chart Datum (CD) is furnished in Table 6 below:

Table 6: Tidal Elevation at Perur

Tidal elevation	Chart Datum (CD) in m	RL (m)
Mean High water spring	1.15	RL 0.5
Mean High water neaps	0.84	RL 0.2
Mean Sea Level	**0.65**	**RL 0.0**
Mean low water neaps	0.43	RL -0.22
Mean low water spring	0.14	RL -0.51

Note: Onshore survey levels are recorded as m above sea level. Hence, the mean high water springs conversion of CD to MSL is 1.15 -0.65 m = RL 0.5m.

4.1.5 Geotechnical data

A comprehensive geotechnical survey has been carried out on behalf of CMWSSB during the year 2014. PMC has not conducted any geotechnical survey at the CP1 site. The subsoil is made up of three distinct layers, as indicated below:

- Greyish silty fine sand : From - 0.0 to – 10.0 m (SPT N value = 10 to 64)
- Brownish silty stiff clay : From - 10.0 to – 13.0 / - 15 m (SPT N value = 7 to 9)
- Soft Disintegrated Rock : From - 13.0 to -15 m to – 19 m (SPT N value ≥ 100)
- Hard granite rock : From -17m to -23 m

Note: SPT – Standard Penetration Test

The groundwater table readings were recorded between 28th October 2014 to 5th November 2014. The groundwater table was encountered within depths of 1.54 m to 1.72 m below the EGL. In general, the groundwater table was almost consistent with the ground surface undulations, which implies that the groundwater is not perched water.

5 REVIEW ASSESSMENT, GAP ANALYSIS AND DESIGN INPUTS

As previously stated, the present report will refer as much as possible to the previous DPR and the JICA Preparatory Survey Report in order not to duplicate existing studies. Existing studies and reports will be carefully reviewed and, if necessary, will be updated and modified. PMC team has reviewed the following design inputs to the project, including raw water quality issues, intake and waste discharge locations, etc., with reference to the studies of the above agencies and has given its recommendations.

5.1 Raw Water Assessment

As highlighted in both DPR and JICA reports, the raw water quality assessment is of paramount importance to determine the pre-treatment technologies for implementation and their sizing. A successful pre-treatment will provide trouble-free SWRO operations concerning the RO membrane system (subject to proper sizing of the membranes stage).

A close review of the available raw water data revealed that the set of historical data for various essential constituents of seawater over at least five years was not available to investigate and recommend the essential pre-treatment processes for producing safe feed water for the large RO system. Some of the important seawater constituents are total organic carbon (TOC), Colour, Barium (Ba), Strontium (Sr), Phosphate (PO_4), Fluoride (F) etc., which were required to be analysed.

PMC organised to carry out seawater analysis through different agencies. A report on the seawater analysis was already submitted to the CMWSSB in December 2020. The details of the quality of raw seawater are discussed below.

5.1.1 Requirements for a satisfactory raw water assessment

a) Raw water sampling was organised by PMC as close as possible of the intended location of the intake heads and at the usual intake head depth (2-3 m above the seabed). The DPR highlights quite different water analysis results between bottom and surface (bottom conditions being worse than surface's, which is unusual, but sampling protocol or methods of the statement were not available for review.).

b) Raw water sampling shall be organised all year long to capture maximum values and minimum values, which are the ones to be considered for the pre-treatment design. DPR and JICA report have based their design on average values, far from the extreme value (TSS @ 75 mg/l when values above 150mg/l are frequently met by plant operators during monsoon season); the minimum values may also be a design issue, for instance, TDS @ 25 g/l during monsoon season while @ 36 g/l is the yearly average.

c) Membrane fouling being the major issues in SWRO operations, raw water shall be assessed toward its fouling potential, mainly related to TOC (Total Organic Carbon) content. The reported TOC content up to 250 mg/L by Nemmeli desalination plant during 2019 till Feb'2020 is highly unrealistic, which brings seawater organic contents close to that of the domestic sewage. The realistic figure of TOC in seawater is critical for pre-treatment process design. TOC, whatever alive or dead, is food for bacteria that will develop at the surface of membranes, creating a biofilm. The DPR and JICA reports mainly determined their design with only focus on TSS reduction along the pre-treatment process but not with a TOC concern which is a major challenge. The extreme fouling issues met at Nemmeli before retrofitting and after even if less should have been alarming and clear red light for the new DSPs at the same site. The NIOT report addressed the TOC content aspect due to the white fibre issues. If this report brought some valuable qualitative information, the quantitative aspects are more questionable (as TSS content higher after disc filters than before; TSS content higher after UF than before). The PMC team has referred to the National Institute of Ocean Technology (NIOT) report prepared during August 2018 and May 2019.

d) PMC suggested for the analysis of raw seawater to be carried out from different laboratories and crosschecked the vital constituents, including TOC content. This is precisely what JICA did with the support of a Japanese laboratory and evidenced the issue of TDS measurements. The method of analysis shall be detailed for every analysis. For example, the high-temperature combustion method is the right approach for TOC analysis. Similarly, oven drying at 180°C then remaining salt weighting is the right method for TDS determination; deriving TDS from conductivity is acceptable for field measurement, not laboratory measurement. Furthermore, if analysis synthetic reports are appreciated, basic data from laboratories are requested to evaluate and control the accuracy of analysis (ionic electrical balance to be checked, for instance).

e) Boron is a very specific parameter to be followed. According to Boron regulation and Boron raw water contents, a RO second pass may be compulsory. This is not the case for the Perur DSP project, with Boron maximum content at 3.8 mg/l and Indian water standards @ less 1 mg/l. Single-pass plant at Minjur and Nemmeli are presently able to meet the Boron requirements. The membrane projection software confirms it. A similar approach shall be taken for 400 MLD DSP to maintain Boron level <1 mg/l in the product water.

Records of specific events as HABs (Harmful Algae Blooms or “red tides”) and jellyfish attack in Chennai and vicinity are also a must. Both Minjur (North of Chennai) and Nemmeli existing plant operators confirm the occurrence of jellyfish attacks. Regarding algae blooms, they have no specific records. However, such events were reported in the local press and research papers.

https://www.researchgate.net/publication/257632867_Algal_blooms_a_perspective_from_the_coasts_of_India

5.1.2 Raw Water Available data / Study and Analysis

5.1.2.1 Raw water assessment by DPR

The assessment period was quite short from Feb’2013 to Dec’2013 and did not cover a full year time. A few analyses were performed in July and August 2013. TSS content addressed on an extended period is not mentioned (only Turbidity); TOC content is not addressed at all. The design parameters are provided in Tables 7 & 8 (Tables 4 & 5 of the DPR report -page 54 and 55).

Table 7: Sea Water Quality - Design Parameters (DPR)

Criteria Description	Unit	Normal based on field measurement	Minimum	Maximum
Water Temperature				
surface	°C	28.4	26.0	30.0
bottom	°C	27.9*	25.0	32.0*
Turbidity	NTU	<10	10	125
Total Suspended Solids	mg/L	75	50	200
pH		8.2	7.7	8.5
Total Dissolved Solids	mg/L	35,200	32,000	38,000
Alkalinity (as mg $CaCO_3$/L)	mg $CaCO_3$/L	110	100	120

Note: * The design of the RO Plant will make provision for a rise in seawater temperature of 1°C resulting from the energy input at the pumps.

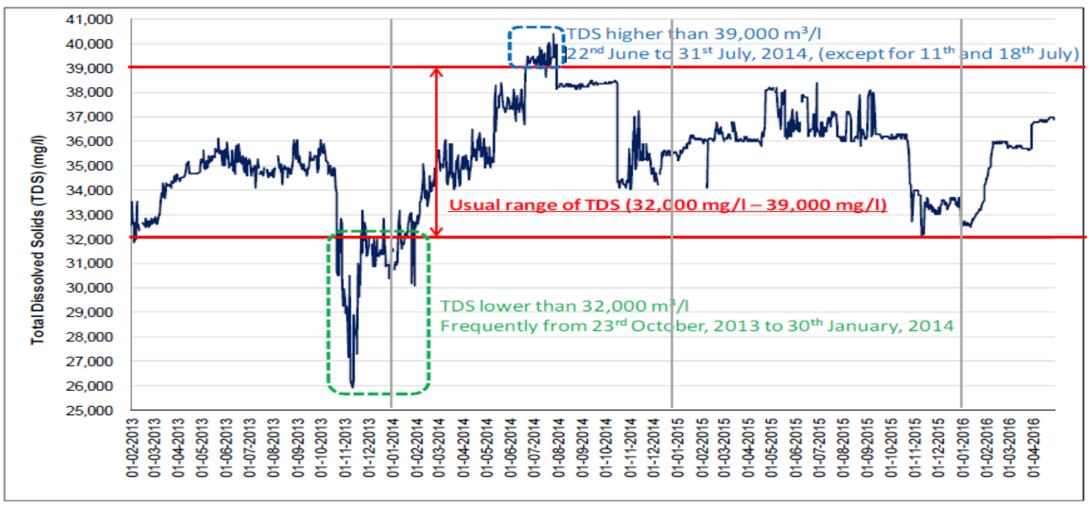
Table 8: Sea Water Quality - Design Criteria – Dissolved Solids (DPR Report)

Criteria Description	Unit	Normal Data- based on average field measurements
Temperature	°C	27.90
Total Dissolved Solids	mg/L	35,200
Bicarbonate (HCO_3)	mg/L	126.30
Magnesium as Mg	mg/L	1258
Calcium as Ca	mg/L	467
Chloride as Cl	mg/L	19,247
Potassium as K	mg/L	391
Sulphate as SO_4	mg/L	2,878
Reactive Silica as SiO_2	mg/L	1.38
Fluoride as F	mg/L	1.63
Barium as Ba	mg/L	0
Boron as B	mg/L	3.17
Sodium Na	mg/L	10,789
Nitrate NO_3	mg/L	4
Ammonium	mg/L	0.2

5.1.2.2 Raw water assessment by JICA report

Raw water quality was also assessed in the JICA report from Nemmeli operator records; it procures the following diagram for the Nemmeli plant.

- Review of TDS data covered from February 2013 till April 2016, which includes at least 3 monsoon seasons
- Recommended TDS envelop by JICA is limited to 32-39 g/l
- Data from November 2013 (and following December) are discarded from the TDS envelope since they related to an intensive exceptional cyclonic period.



Source: CMWSSB

Figure 7: TDS profile over a period of 3 years (JICA Report) in the Raw Seawater of Nemmeli DSP

These data display the range of TDS values met around the year; specific events shall be “erased” not to increase the design and operational range. The following table procured from the JICA report also displays the discrepancies in the result between two laboratories (Indian and Japanese):

- (2) is likely using the conversion from conductivity measurement
- (3) is likely using the Oven 180°C + weight method, which is the right method.
- (4) is likely to lead to an HP pump design being oversized.

Table 9: TDS values by various sources

Unit: mg/l

Source		TDS (Minimum)	TDS (Maximum)
1	Seawater quality survey result in the DPR	32,000	38,000
2	Seawater quality survey in the Study (1) (Data: Indian Laboratory)	40,048	41,489
3	Seawater quality test by Japanese laboratory (Data: Japanese Laboratory)	37,300	38,100
4	Design criteria for the Nemmeli DSP (Data: Bid documents, February 2009)	33,000	41,900
5	Operational record of the Nemmeli DSP (Data: January 2014–April 2016)	25,900	40,390

Source: JICA Study Team

Again, like in the DPR report, the JICA report focussed on RO design parameters as TDS, pH and water temperature, but not too much on pre-treatment parameters, as TSS, Turbidity and TOC.

It is also requested from CMWSSB to provide all third parties laboratory analysis for raw water (last 3 past years) that will be considered as a second source.

Fortunately, the existing desalination facility operators in Nemmeli and Minjur recorded numerous parameters daily. Discussion with Plant Manager confirmed that the methods of analysing, data inter-correlation and instrument calibration were in place. These data represent the main sourcing of raw water data for the Perur Project.

These daily operational data for Minjur and Nemmeli DSPs were reviewed, and a few non-consistent data (out of trend) were not considered: The maximum, minimum and mean values are presented below Table 10 & 11. Being close to the Nemmeli DS plant, the data from the Nemmeli plant is more significant for Perur DSP design.

Table 10: Available site data from Minjur DS plant

July 2016 – July 2019	Minimum Value	Mean Value	Maximum Value
pH	8.01	8.14	8.27
TDS, mg/L	20476	32034	35667
Turbidity, NTU	0.90	10.24	100.30
TSS, mg/L	2.90	20.76	207.30
Temperature, °C	25.50	28.46	30.80
Boron, mg/L	3.60	3.96	4.20

The above data from Minjur plant covers a 3-year period; as highlighted in the plant visit report, the range of TDS values are quite large, with minimum values around 20,500 mg/l in the rainy season. On the other side of the range, the highest TDS values are less than even 36,000 mg/l, which is the average TDS earmarked by PMC for the Perur plant.

The records are performed by different operations teams (Befesa plant laboratory) and allow some cross-checking with Nemmeli records.

The records from the Nemmeli plant cover data for a period of 5 years which is quite uncommon when designing a new plant. It should be noted that the maximum TDS values @ 39,500 mg/l are recorded on a short period between April and May 2018 over 5 years. Apart from this short period, all TDS records at 100 MLD Nemmeli plant **are below 38,500 mg/l** (plant laboratory operated by Wabag).

Table 11: Site data from Nemmeli DS plant

Jan 2015 – Jan 2020	Minimum Value	Mean Value	Maximum Value
pH	8.05	8.13	8.22
TDS, mg/L	29260	35942	39500
Turbidity, NTU	1.0	12	391
TSS, mg/L	10.0	47	1478
FRC, mg/L	0.2	0.5	0.8
Temperature, °C	26.0	28.3	30.8
Hardness, mg/L as $CaCO_3$	5730	7301	7650
Chloride, mg/L	15394	19883	22194
Alkalinity, mg/L as $CaCO_3$	86	118	129
Iron, mg/L	0.01	0.07	0.07
Boron, mg/L	3.2	3.53	3.68
Sulphate, mg/L	1860	589419	2600

5.1.2.3 Raw water assessment by PMC

PMC engaged the following two laboratories by the end of June 2020 to analyse the seawater at the proposed seawater intake location. The main purpose of the analysis was to verify the critical seawater parameters falling within the 5 years of historical data collected from the Nemmeli plant. The assessment was not to include any analysis results in the finalization of the seawater quality envelope for the pretreatment and RO system design.

a) IIT, Madras

b) M/s. Indomer Coastal Hydraulics Ltd., Chennai

M/s. Indomer Coastal Hydraulics (P) Ltd., Chennai, carried out the task of seawater sample collection at four selected locations – details of the sampling locations and the results of the raw water assessment are provided in the seawater analysis report submitted by PMC in December 2020. The seawater analysis for all the important parameters, including the TOC and DOC were carried out by the above two laboratories. All critical parameters of seawater such as temperature, TDS, Turbidity, TSS and alkalinity are found within the range of the values obtained during 5 years of data collected from the Nemmeli plant. However, there was variation in TOC/DOC analysed results among the laboratories mainly due to the difference in analysis techniques, and so it was decided to engage two more reputed laboratories for analysis of only TOC/ DOC in raw seawater. After a thorough search of suitable laboratories, we realised that very few laboratories in

India conduct TOC/DOC analysis using the recommended high-temperature combustion technique. An effort was made to send the seawater samples to a Singaporean or Australian laboratory for TOC/DOC analysis, but it did not materialise due to customs issues in India during the Covid-19 pandemic. After consistent efforts, PMC contacted one laboratory, Eurofins (Unwelt West GmBH (Wessling) in Bangalore, who agreed to conduct TOC/DOC analysis in Germany using the high-temperature combustion technique. Later, the samples were also tested by the National Environmental Engineering Research Institute (NEERI).

Finally, the TOC and DOC characterisation of seawater was carried out by at least 4 different laboratories, namely:

1) IIT, Madras
2) M/s. Indomer Coastal Hydraulis Ltd., Chennai
3) Eurofins (Unwelt West GmBH (Wessling), Germany
4) NEERI

The seawater analysis results submitted by the above four laboratories are presented in the table below.

Table 12: TOC/ DOC Results from Three Different Laboratories

S. No.	Parameters	Unit	Indomer Pvt. Ltd., Chennai	IIT Madras	Eurofins (Unwelt West GmBH, Germany	NEERI
1	Total Organic Carbon (TOC)	mg/l	4.4	33.6	2.0	4.3
2	Dissolved Organic Carbon (DOC)	mg/l	2.2	12.9	1.9	3.2

The results in the above table indicate that the TOC/DOC values are very close for Indomer, Eurofins and NEERI while the values from IIT Madras are quite high. It is to be noted that Indomer has used a non-conventional method for TOC/DOC determination while IIT Madras, NEERI and M/s Eurofins have used the high-temperature combustion method, which is the most appropriate and recommended method for the TOC/DOC analysis. However, the IIT results for TOC/DOC are too high to perceive as the correct value. Usually, the TOC value is found within 5 mg/l in the seawater. NIOT has also reported the TOC concentration in seawater within the range of 8 mg/l. The results of seawater sample analysis are furnished in **Annexure 2**.

Considering the above seawater analysis results, the parameters to be taken for RO system design are discussed below.

5.1.2.4 Parameters to be taken into consideration for Reverse Osmosis design:

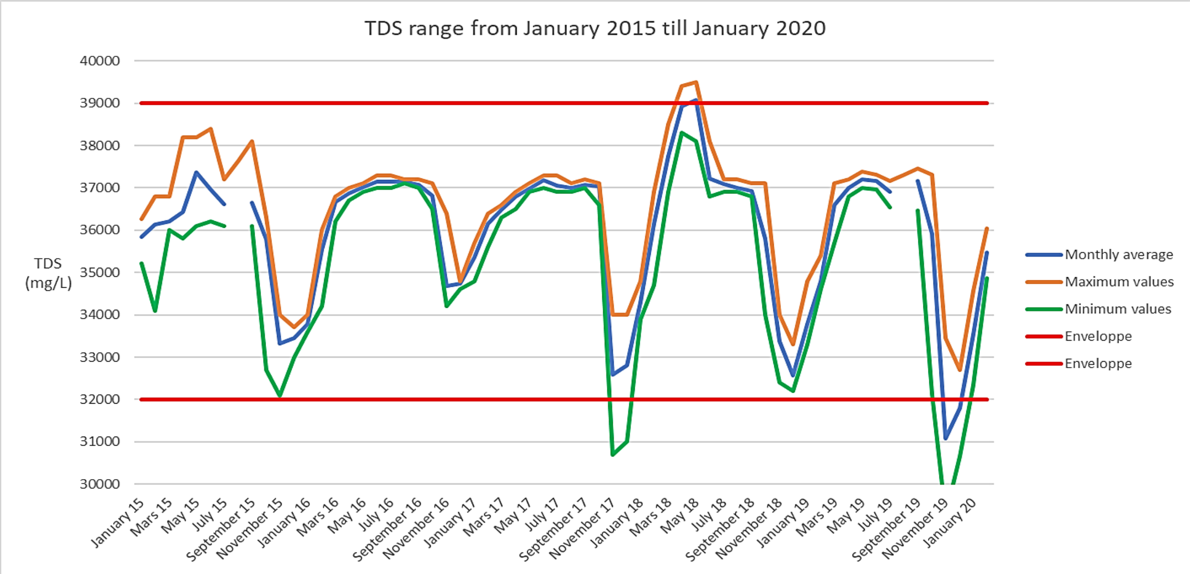
From the raw seawater quality at the Nemmeli plant that covers 5 years of data, it is possible to draw a profile for the main parameters. Such profiles allow a more accurate approach to design envelop. Also, it allows us to review correlations between parameters, for instance, conductivity, TDS and TSS or Turbidity, particularly during monsoon seasons.

If maximum and minimum parameter values are required for plant design, the average parameter values will feed the OPEX computation.

I. Total Dissolved Solids (TDS)

The variation of TDS over more than 5 years period is presented below in Figure 8.

Figure 8: TDS profile over a period of 5 years (Nemmeli Data)



The TDS range is quite extensive due to flesh water impact during the Monsoon period. The decrease of TDS in November is repetitive, and its intensity depends on the rainfalls. Except for two restricted periods in 2015 and 2018, repeatability of TDS values below 37,500 mg/l are observed during spring and summer before the rainy season.

Considering the above, the range of TDS adopted for the Perur RO design is 32000 mg/L to 39000 mg/L, which is quite reasonable. Higher than 39000 mg/L value may lead to the need for 2nd pass RO system for maintaining product water TDS limit of 500 mg/L, and in case of the use of the high-rejection membranes, this value will increase the operating range of the high-pressure pump resulting in an increase of the operating cost. The analysis done by PMC indicates the seawater TDS value within 37000 mg/l.

II. Temperature

The variation of temperature over more than 5 years period is presented below in Figure 9.

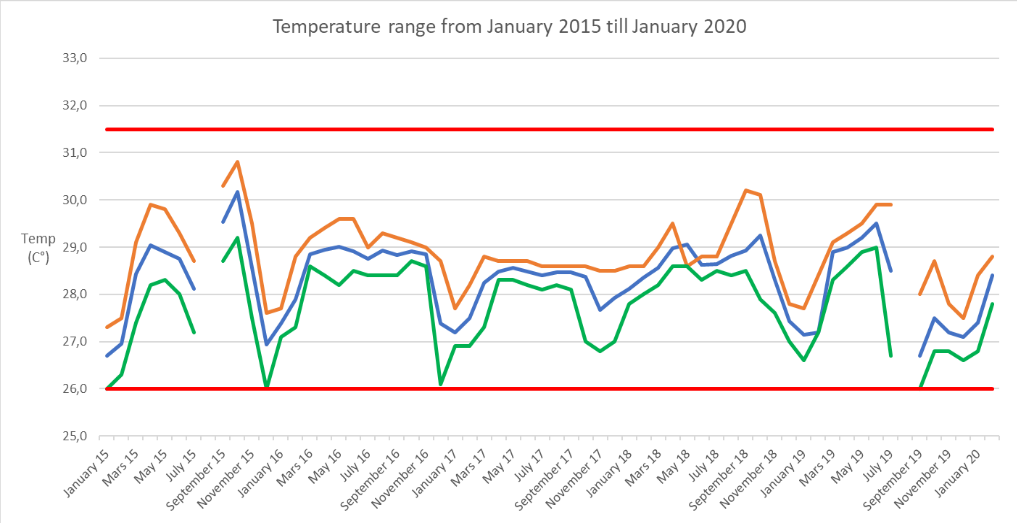


Figure 9: Temperature profile over a period of 5 years (Nemmeli Data)

Water temperature variation is also a parameter impacting membrane design. Temperature is presently monitored at the pumping station (sea bottom). Feedwater temperature for the membrane may be slightly higher in summer due to the warming in open-air pre-treatment, as recommended by the DPR report. This is why the maximum temperature kept for the design parameter envelope is one degree higher @ 31.5°C than the observed temperature over 5 years period. The temperature profile indicates that TDS follows the trend with the temperature. The PMC analysis results also show the seawater temperature within 26 to 28^{o}C.

5.1.2.5 Parameters to be taken into consideration for pre-treatment design:

Major parameters which are important in the selection and design of the pretreatment processes are total suspended solids (TSS), Turbidity and a total organic compound. The profiles of these parameters over 5 years at the Nemmeli plant are given below.

III. Total Suspended Solids (TSS)

The variation of TSS over more than 5 years period is presented below in Figure 10.

The profile of TSS shows a peak of TSS reached 1478 mg/l in December 2018. This abnormal value (for a day) can be considered as an outlier and discarded. The maximum value of TSS in seawater has been considered at 300 mg/L for the pre-treatment design purpose. The PMC analysis results indicate a very low TSS value within 11 to 14 mg/l.

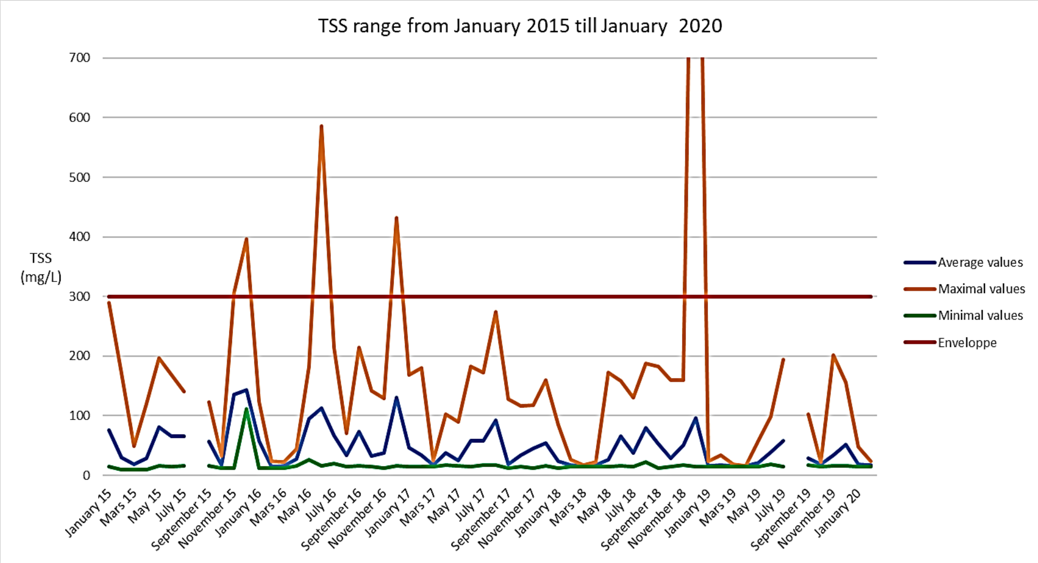


Figure 10: TSS profile over a period of 5 years (Nemmeli Data)

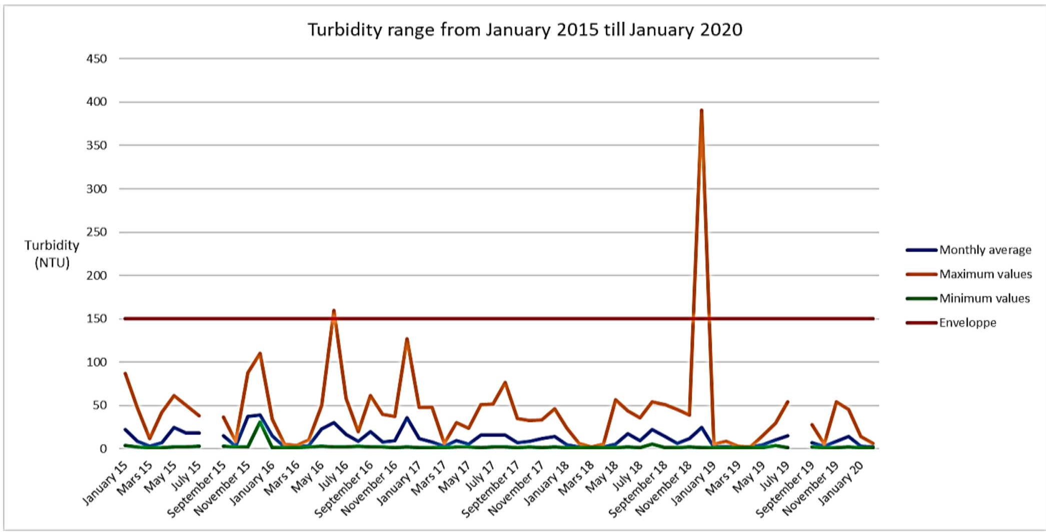


Figure 11: Turbidity profile over a period of 5 years (Nemmeli Data)

In Figure 11, turbidity displays a good correlation with TSS, evidencing a quite low colloid content. The maximum value of turbidity is 150 NTU. The PMC analysis of seawater shows the turbidity value within 8 NTU.

IV. Total Organic Carbon (TOC)

As evidenced during the Nemmeli site visit, TOC (total organic carbon) is an important parameter to monitor since it is responsible for biofouling on the membrane surface. It is also revealed during the Nemmeli plant visit that TOC fouls other equipment, too, such as disk filters, ERI etc. The set of values received from the Nemmeli DSP laboratory indicate exceptionally high TOC concentration in seawater, which is highly unbelievable. The TOC data profile in raw seawater and treated seawater (feed to RO) over a year from Feb 2019 to Feb 2020 as recorded by that Nemmeli plant is presented in Figure 12 below.

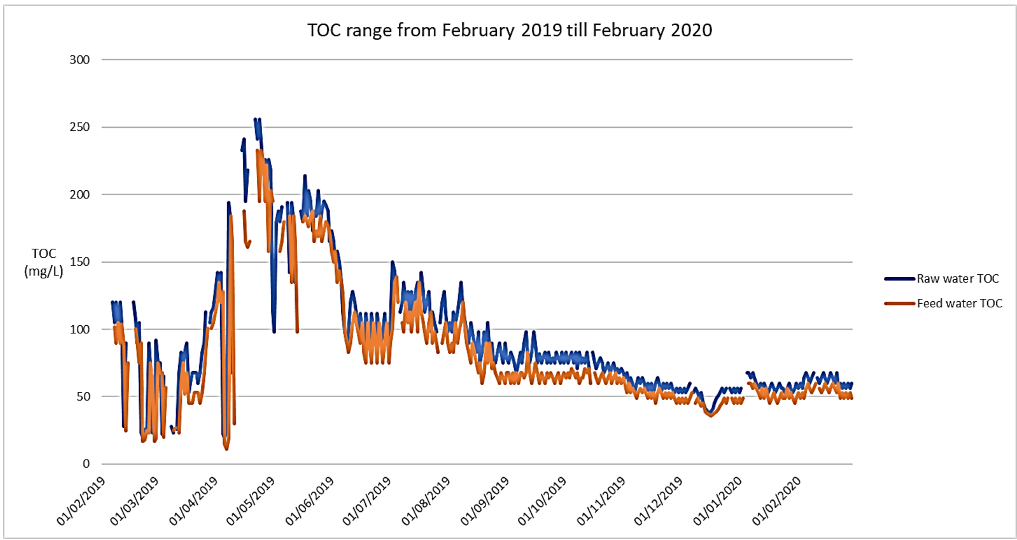


Figure 12: TOC profile over a period of 1 year (Nemmeli Data)

The range of TOC in seawater is ***very questionable*** and ought to be discarded until further laboratory for the following reasons:

- Range of values not consistent with seawater.

Feb'2019 to Feb'2020	Min.Value	Mean Value	Max.Value
Raw Water TOC (mg/l)	19.00	92.25	256.00
Feed Water TOC(mg/l)	11.00	80.20	233.00

The minimum value @ 19 mg/l provided by Nemmeli DSP Operators is already far beyond the usual data; the average values @ 92 mg/l would make quite impossible the membrane operations. No comment on the maximum value @ 256 mg/l, which is more in the domain of wastewater than seawater.

➔ **The Nemmeli Desalination Plant after retrofitting is delivering its full capacity, which indicates that TOC content is not high as indicated in the data.**

- **Method of analysis not defined (method, equipment, calibration)**
  - Observation of several constant ratios between COD daily values and TOC daily values is questionable since it may induce that one is derived from the other. The TOC is seen consistently 37.5% of the COD.

- **Lack of correlation with other parameters**
  - No clear correlation with TDS (low TDS meaning polluted surface water mixing), nor with TSS.
  - No correlation with Monsoon current going North to South from August to October and bringing pollution from Chennai to Nemmeli.
  - Limited correlation with TSS despite the difference between TOC raw water and TOC feed water (downstream UF) being small may induce TOC is mainly composed of DOC.

- **Risk of data corruption (or equipment failure)**
  - Limited variations during the last 6 months and repetition of a sequence of values.

If values higher than 20 mg/l were confirmed (**which is not expected**), consequences shall be significant for the project with the following mitigations measures:

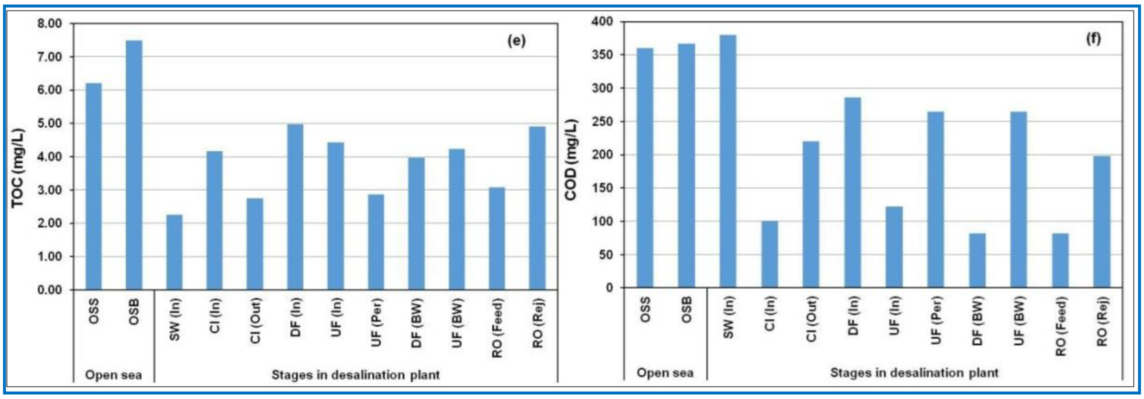
- Selection of a new site less exposed to Chennai wastewater pollution (municipal and/or industrial)
- Keep the same site, but this ultra-sophisticated pre-treatment being **first time in the world, plant piloting is compulsory.**
- Extend the intake (further from pollution source; deeper in sea where pollution in water is lighter).

All these mitigation measures will have a cost impact and a delayed impact on the Project.
This shall be first reminded that:

a. To avoid membrane biofouling, feed water TOC is recommended to be less than 2 mg/l (after pre-treatment).
b. In the extreme desalination process can cope up to 10-15 mg/l TOC in theory with 2 levels of MMF. For a better understating of TOC removal, lab/pilot test is essential.

The TOC value in seawater was expected within 5 mg/l, which has been confirmed by the reported TOC values by the National Institute of Ocean Technology (NIOT) and later by the seawater analysis carried out by PMC.

Figure 13: NIOT report on TOC at various stages of the Nemmeli plant



- TOC content of seawater is commonly between **3-5 mg/l** (site location being selected far from polluted areas to meet this target).
- Exceptional events like Algae bloom may raise these values to **20 mg/l**, but with a high level of TSS and chlorophyll A, which is not the case here.
- The NIOT report (Nemmeli Plant) highlighted rather high TOC values, but only in the range of **6-7 mg/l during white fibres events** (see below table extracted from NIOT report May 2019).
- The recent analysis by PMC indicates the seawater TOC values within 4 mg/l.

V. Silt Density Index (SDI)

The last parameter from the Nemmeli plant, which was reviewed, is the SDI of feed water. The variation of SDI over more than 3 years period is presented below in Figure 13.

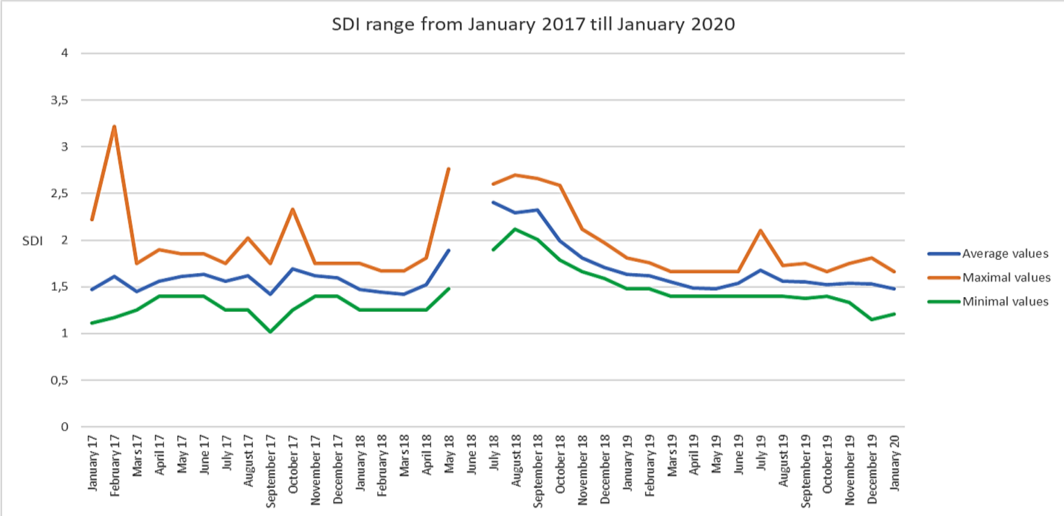


Figure 14: SDI profile over a period of 3 years (Nemmeli Data)

SDI (feed water) achieved by UF in Nemmeli is excellent, which demonstrated that SDI is not liable to capture the membrane issues. These excellent values confirm that most of the TOC is DOC (Dissolved Organic Carbon) lacking the colloid particles. The peak SDI in July 2018 does not correlate with other parameters and may be considered as a result of analysis or operating issues.

5.1.3 Design envelop for raw water

This concept is fully linked with the Risk Allocation Matrix, and 2 options shall be considered regarding the Raw Water risk.

- **Option 1:** CMWSSB keeps the raw water risk on its side and defines a design envelope. The design envelops for raw water is a range of parameters inside which the Contractor is not liable to pay the penalty if it does meet the quantity or quality requirements (basically 400 MLD and Indian Standards for drinkable Water). If only one parameter is outside the raw water design envelop, it waives any penalties or Liquidated Damage (LD) to the Contractor that may be liable. In such circumstances, when more than one raw water parameters are outside the design envelop, the Contractor shall employ reasonable endeavour to procure product water at the maximum reachable quantity without affecting the contractual quality. Therefore, such an envelop shall be "reasonable", meaning if too narrow (tight), the Contractor will be very often outside its contractual obligations; if too wide, the Contractor will have to design a plant costlier to meet requirements that may never happen. In some case, the Contractor may add some provision for LD's in its bid, increasing the tariff.
- **Option 2:** CMWSSB decides to keep the raw water risk to the Contractor, meaning the Contractor shall deliver the 400 MLD and product water quality, whatever is the quality of the raw water. In such a case, the Contractor may take several options, from very aggressive design to win the bid and accept to pay (or discuss later) liquidated damages (which means CMWSSB will not receive the expected amount of product water) or more conservative design leading to higher bid cost.

Unless otherwise stated and decided by CMWSSB, the PMC team considers Option 1 and will recommend an appropriate design envelop for raw water. This design envelop has not only contractual and economic impacts as stated above, but also technical impacts.

If the DPR report and JICA designs are based on average water quality, which is usual for Preparatory Survey, our final design must rely upon the reasonable extreme cases (minimum and maximum) to ensure that the plant will always be able to deliver the nominal capacity and quality with raw water inside the envelope. The proposed design envelope (design envelope is materialised by red lines in the above figures): based on the Nemmeli data over **5 years duration** is presented in Table 13 below.

Table 13: Raw seawater design parameters based on Nemmeli data

Jan'2015-Jan'2020	Minimum value	Mean value	Maximum value
SWRO parameter envelop			
TDS	32000	36000	39000
pH	8.00	8.13	8.20
Temperature	26.0	28.3	31.5
Boron	3.2	3.53	3.80
Pretreatment parameter envelope			
Turbidity	1.0	12	150
TSS	10	75	300
Total Organic Carbon (TOC)	3.0	5	8
Algae count (cells per ml)	100	500	30000
Jelly fish attacks	N.A	N.A	Yearly Occurrences

5.2 Treated Water Quality (Indian Standards)

The water quality requirements shall meet the following:

1. The Indian Standard Water Quality Standards as per IS:10500-2012 (provided in Appendix 1). Main parameters relevant to the requirements of the product water from the desalination process is furnished below:

➢	Turbidity (NTU)	< 1
➢	Chlorides (mg/l)	< 250
➢	TDS (mg/l)	< 450 at plant potable water tank exit
➢	Boron (mg/l)	< 1 mg/l
➢	pH	6.5<pH<8.5
➢	LSI	Slightly Positive
➢	Hardness	> 60 mg/l as $CaCO_3$ up maximum 200 mg/l

2. Regarding remineralisation, the PMC recommends a minimum value of 60 mg/l eq $CaCO_3$ of hardness which is already confirmed by CMWSSB.
3. In order to meet Indian standards at the customer tap, CMWSSB requires a safety margin of 50mg/L with product water TDS @ 450 mg/l on the exit of the plant.

5.3 Regulations, Laws and Permitting

The details of regulatory compliance requirements for the proposed Perur DSP project are furnished in Table 14.

Table 14: Regulations, Laws and Permitting

S. No.	Project Stage	Compliances/ Requirements	Remarks	Agency
1.	Project Development Stage	Environmental Clearance (EC) from State Environmental EIA Notification,2006- State level expert Appraisal Committee (SEAC) / State Level Environment Impact Assessment Authority (SEIAA)	Statutory	SEAC/ SEIAA (Not applicable)
2.	Project Development Stage	Coastal Regulation Zone (CRZ) Clearance	Statutory	SCZMA/ CRZ Clearance is already obtained
3.	Project Development Stage	Change of Land use		Concerned government authority
4.	Pre-Construction	NOC from Fire dept.		Fire Dept.
5.	Construction	Registration under The Contract Labour (Regulation & Abolition) Act, 1970 as Principal Employer	Statutory	State Labour Department
6.	Pre- Construction	Other Site/ Location Specific Clearances Required: - Forest Dept. Clearance	Statutory	Forest Department, GoTN/ Clearances from the authorities as per the Tamil Nadu Timber Transit Rules, 1968 and amendments
7.	Manufacture, Storage, and Import of Hazardous Chemical Rules, 1989	Storage of chlorine (threshold quantity greater than 10 tons but less than 25 tons) in WTPs will require clearance	Statutory	TNPCB/ Directorate of Industrial Health and Safety. As Chlorine cylinders are not proposed to be used for disinfection, these rules are not applicable
8	Pre-construction	Consent for the erection of offshore structure to be obtained	Statutory	Tamil Nadu Maritime Board. Intake and Outfall structure erection for DSP

- Forest Clearance for cutting trees at Perur to be obtained from Forest Department.
- Approval for the erection of offshore structure to be obtained from the Tamil Nadu maritime board.

5.3.1 Discharge Permit

The regulatory compliance requirements for the proposed DSP are identified for the proposed Perur project and are related to waste management and disposal and ambient noise pollution regulation and control is furnished in Table 15.

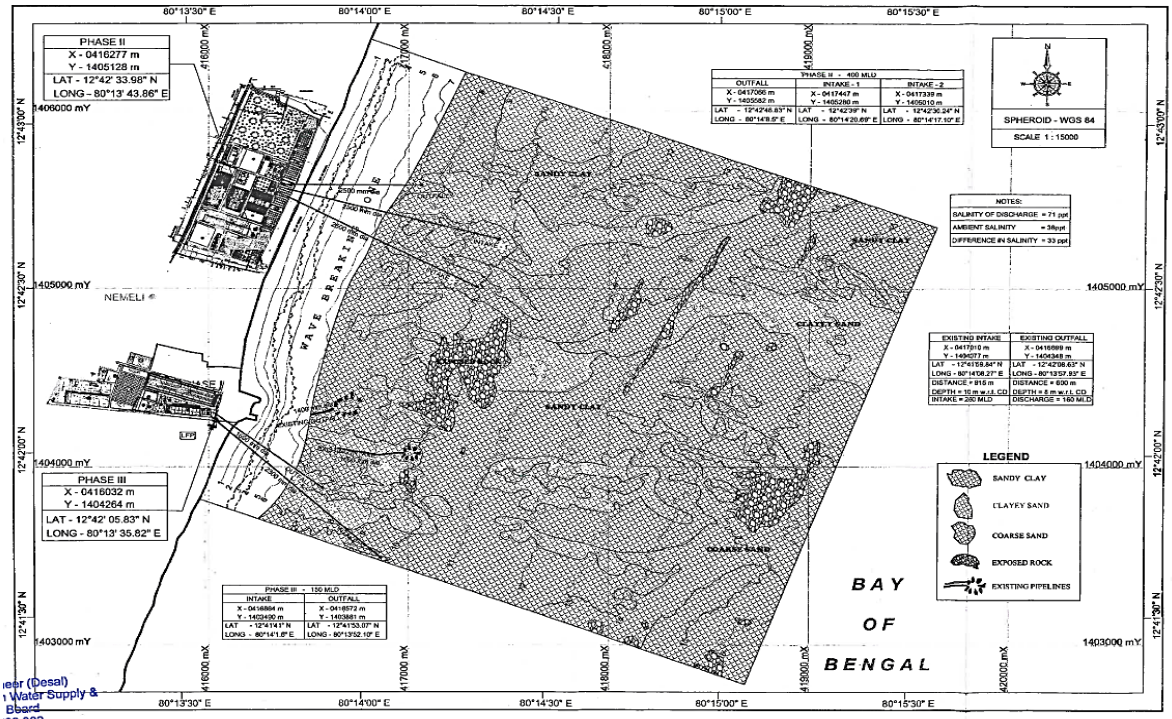
Table 15: Discharge Permit

1.	Pre-Construction/ Operational Phase	Consent to Operate from State Pollution Control Board under Water Act 1974 & Air Act 1981	Statutory	TNPCB
2.	Pre-Construction/ Operational phase	Authorization under MSW (M&H) Rules 2016 (State Pollution Control Board)	Statutory	TNPCB
3.	Pre-Construction/ Operation phase	Noise pollution (Regulation and Control) rules, 2000 and its amendments, 2010	Statutory	TNPCB

Based on discussion with CMWSSB officials, it is understood that the proposed desalination plant's land ownership transfer is in process. Upon receipt of the same consent to establish an application to TNPCB to be taken up by CMWSSB.

5.4 Brine dispersion study and intake location

The DPR report introduced intake pipes HDPE 2500 mm OD 6.4 bars nominal pressure. These 2 pipes were approximately 1 km long laid on 2 different profiles (40 and 34). Brine outfall pipe (same specification as intakes) was laid on a different profile with a length of 750 m. See below the implementation figure from the DPR report.



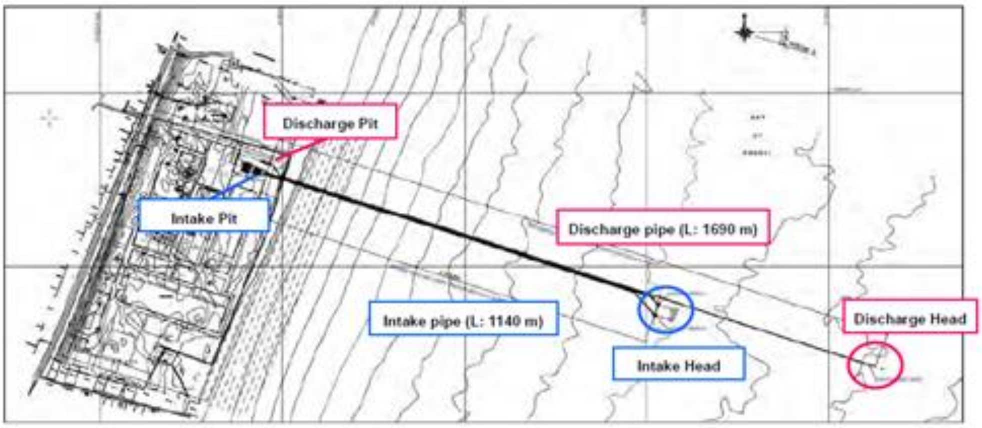
DETAILS OF INTAKES & OUTFALLS

No brine dispersion study was performed in DPR and JICA studies. PMC has conducted a brine dispersion study with the approval of CMWSSB. Main comments regarding this configuration are the following:

1. 3 different profiles (routes) for the 3 pipes are not of common usage in desalination practices since it implies a significant extra cost for the marine works. This is due to the additional dredging equipment required to complete works on time. As the DPR report highlights, the marine works window (waves < 0,5-1 m) is quite short during the year, with only one slot between February and April. To execute significantly, the amount of marine works is, therefore, a risk of delay for the whole project.
2. Even positioned in the north of the intake pipes (high current from south to north during August till October), there are still current in the opposite direction from November till March, bringing back the brine discharge toward the intake pipes. 250 m difference of length is likely to be very insufficient to avoid mixing (an increase of salinity at intake heads). The higher distance due to different routes can be taken into consideration only in the static model (no current), which can be hardly be considered in Chennai.
3. A minimum of 600m between brine outfall and intake usually applies for the extra-large plant to ensure an increase of TDS less than 1% at a 400 m radius around the brine diffusers (static model). Even with such margin, the brine dispersion model is always recommended for this size of plants, regarding the significant extra energy requirement (= significant increase of OPEX) in case of inappropriate design. Each 1 g/l of TDS increase incurs within 1.0-2.0 bar increase in osmotic pressure depending on temperature.

The JICA report proposes the 3 pipes (2 intakes + 1 discharge) in the same trench, which is consistent with desalination practices (see above cost and delay considerations) and implements a sound model of brine dispersion, taking into account not only Perur but also Nemmeli 100 MLD and Nemmeli expansion 150 MLD. For the expansion plant under construction, final intake and discharge shall be confirmed.

The final option proposed by JICA is a dual intake of 1140m length and a 1690 m discharge pipe, with the following implementation and dispersion plums (scenario no.3).



Source: JICA Study Team

Figure 15: General layout of Seawater Intake and Discharge heads (JICA proposal)

This pipe implementation is non-standard as per desalination practices, since intake pipes are always the longest, searching depth and calm conditions to improve water quality, since discharge pipe is searching shallow and rough conditions to achieve better mixing, and so is the shortest.

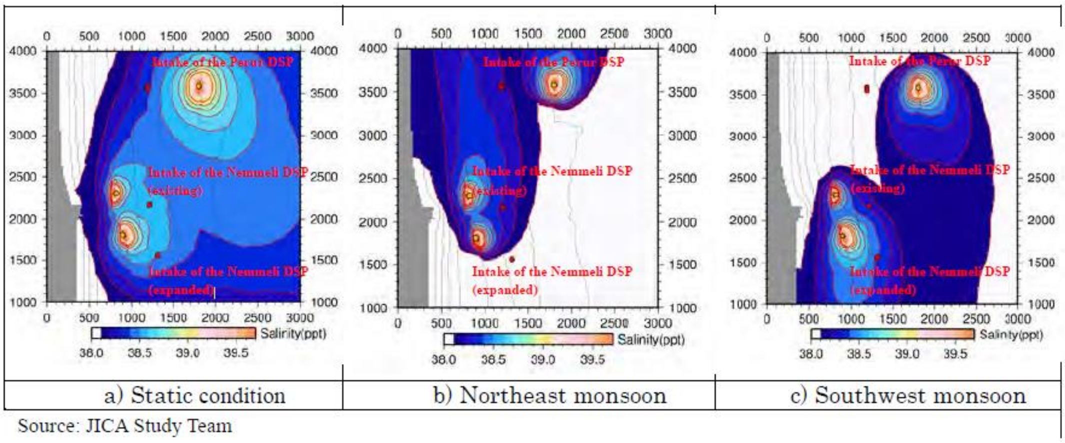


Figure 16: Dispersion simulation in 3rd Phase (JICA proposal)

In static conditions, according to JICA simulation, brine recirculation is observed, even quite low, and evidences that the “usual” 600m distance is not enough between intake heads and brine diffusers of Perur. In the Northern monsoon, some brine contamination is observed from Nemmeli plants. It should be noted that Nemmeli plants display significant recirculation between them.

Such option as proposed by DPR was presented in the JICA report (Figure 17) but not optimised;

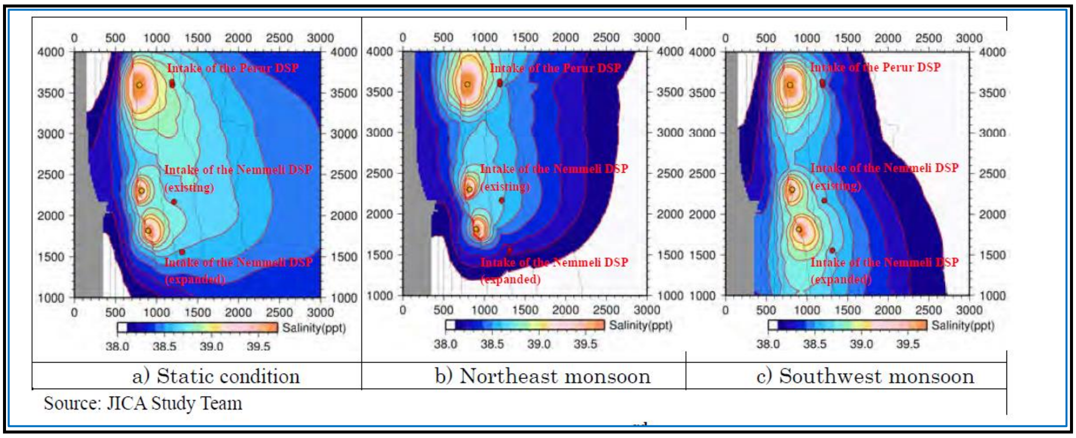
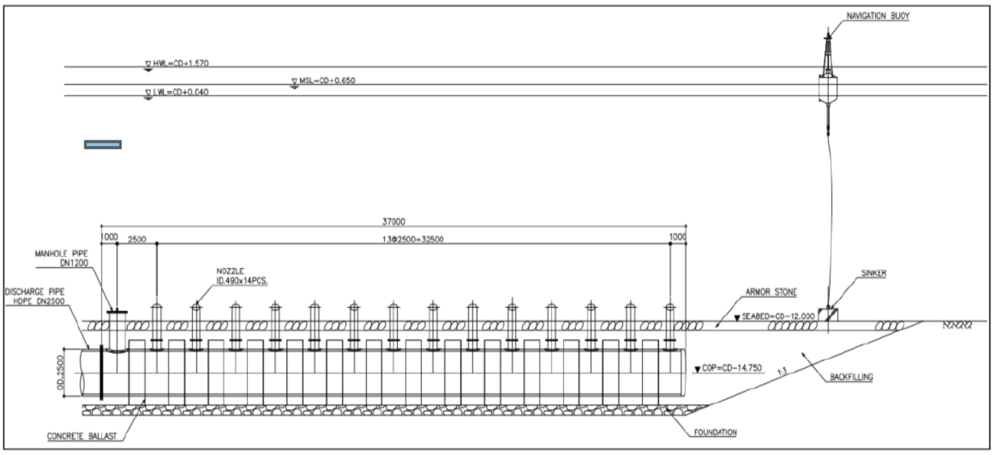


Figure 17: Dispersion simulation in 3rd Phase (DPR proposal)

Furthermore, the plum of Nemmeli plants during the Northern monsoon of phase 3 (Figure 17) is quite different from the one in Phase 3 (Figure 16): it should be quite similar since not yet impacted by Perur discharge.

1. Additional simulations for brine dispersion will help to fine-tune the diffuser location and arrangement.

   As described in the below sketch, 14 nozzles (diffusers) are installed within a 37m pipe length, with quite concentrated (2.5 m spacing). Various simulations with arrangement up to 40 diffusers spread on 195 m (5 m spacing) shall be performed.



Source: JICA Study Team

Figure 18: Design of Brine Discharge Head (JICA proposal)

PMC also conducted the brine dispersion study through an agency M/s Indomer. Three case studies were done as given below in Table 16. It was intended to evaluate and confirm the intake and brine discharge design locations proposed by M/s AECOM for DPR and JICA study team.

Table 16: Three (3) Case Studies Performed for Brine Dispersion Study by PMC

S. No.	Description	Outfall Head Offshore	Intake Head Offshore	Work Undertaken
Case 1	DPR design proposal	700 m	1200 m	Dec 2014
Case 2	JICA design proposal	1800 m	1200 m	Feb 2017
Case 3	Indomer's design proposal	850 m	1300 m	Nov 2020

The brine dispersion modelling study report is enclosed in **Annexure 3**. The effect of brine discharge and change in seawater TDS at the intake of 400 MLD plant for the design proposals of DPR, JICA and Indomer during all the three sea conditions is provided below in Table 17.

Table 17: TDS Increase at the Intake during Study conducted by PMC

Sea Conditions	Increase in TDS (mg/l) at Intake of 400 MLD Plant			Effect on Intakes of Two Nemmeli DSPs
	Case-1 DPR	Case-2 JICA	Case-3 Indomer	
Static Condition (Feb – May)	2000 mg/l	1200 mg/l	1500 mg/l	High effect
Northeast Monsoon (Oct – Jan)	000	000	000	No effect
Southwest Monsoon (Jun-Sept)	000	000	000	No effect

The details of the brine dispersion effect for the different positions of intake and outfall proposed by JICA and DPR are presented in the table above. After studying the above dispersion studies for the DPR and JICA proposed locations of intake heads and outfall diffusers, PMC recommends that the proposal given by JICA is more effective, which is expected to increase the brine dispersion and reduce the possibility of the brine mixing with the intake seawater.

5.5 Plant Main Specifications, Performances and Operating Philosophy

Before specifying the criteria for design, it is of the utmost importance to align our understanding of how the plant is expected to be operated according to CMWSSB. The PMC team understands so far:

5.5.1 Capacity

The Perur Plant Nominal Capacity is **400 MLD** (400 million litres per day).

5.5.2 Availability

The Perur DS plant is expected to work at full capacity every year; therefore, the highest Availability Factor is expected **at 97% or above**, which means:

- The amount of water to be delivered every year is expected at a minimum of:
  400000 x 365 = 146.000 Million m^3/year with plant availability of 97%. This means the plant has to operate at more than 400 MLD to compensate for the loss of production during plant non-availability.
- The aggregate stoppages of the Plant (preventive maintenance and forced outage) will amount: 365 x 0.03 = 11 days. The additional capacity of the plant per day must be about 11*400/354 = 12.43 MLD to compensate for the loss of production.

Although the tariff has not been discussed, a Take or Pay tariff is likely to be promoted.

5.5.3 Modularity (flexibility)

Consequently, the flexibility/modularity of the plant (Perur) is not a significant concern for CMWSSB. Aiming at reducing the capital expenditure (CAPEX) and operation expenditure (OPEX), pressure centres will be contemplated for RO systems:

- 6 operating units (66 MLD per HP pump) meaning 16.6% step of production),
- 8 operating units (50 MLD per HP pump), meaning 12.5% step of production
- And compare to the 16 operating trains (25 MLD per HP pump), meaning 6.25% step of production (as previously recommended by JICA and DPR).

The modularity of the other plant components will be adjusted to match the SWRO modularity. It is understood that a pressure centre with larger equipment provides lower modularity than a small train configuration. This could be mitigated at the level of Nemmeli (100+150 MLD), which will be mainly assumed by Nemmeli plants which offer low capacity train organisation; this is subject, of course, to amendments to the transmission system (by-pass between the 2 transmission lines).

5.5.4 Splitting the plant into 2 halves

As proposed by JICA, the capacity will be split into two process lines of 200 MLD each. It means that these 2 lines will be entirely independent of hydraulic, electric (energy) and process control perspectives. In case of failure on one line, the other line will not be affected and will keep producing its 200 MLD potable water. This configuration will serve up to 98% Availability Factor target. Depending on the layout feasibility, the two production streams may have the provision of hydraulically interconnected at the following points:

- Pumping station
- Filtered water tank
- Permeate water tank
- Product water tank

However, at present, due to keeping distinct two streams of 200 MLD plant, all tanks are kept separate in two streams except intake raw water pumping station and clear water pumping station (out of CP1 scope). The CP1 battery limit will be at a position on the combined pipeline coming out from the two product water tanks and feeding to the clear water tank. The pipelines from two product water tanks and the combined pipeline will be equipped with online quality measuring devices and the metering system (electromagnetic flowmeters inline) + full flow draining system and sampling system (online monitoring + local and one tap for laboratory sampling).

5.5.5 Asset life

The DPR report states Design Life options which are quite with the desalination standards:

• Civil works, buildings and buried pipelines:	50 years
• Concrete tanks, process chambers	50 years
• Heavy mechanical and electrical equipment	25 years
• Other mechanical and electrical equipment	15 years
• Automation and sensors equipment	15 years
• Metallic reservoir and tanks (not for seawater or brine)	25 years
• Polyethylene tank (or other chemical containers)	10 years
• Pressure vessels	30 years
• SWRO membranes	>5 years

DPR recommends 8-year life for SWRO membranes which is an aggressive option, particularly considering the fouling potential of raw water (i.e. frequent CIP requirement). Even if such an extended life might be reached, considering the product water quality, the Contractor-Operator will have to determine if such an option has an economic ground.

5.5.6 Perur Plant design philosophy

The Perur project is expected to be the spine of the water production for Chennai and will be operated at its maximal available capacity; therefore, it shall offer the lowest cost (CAPEX and OPEX combined) compared to the other desalination facilities.

Design at every stage shall optimize the Capex and Opex distribution by using "Net Present Value" computation and implementing the best practices of the desalination Industry. While aiming at reducing the Opex, a specific focus on energy consumption will be considered.

6 ENGINEERING REPORT (NEW PROPOSAL)

A number of treatment process alternatives are being used worldwide to meet the desired goals and objectives of finished water quality that is supplied to the consumers. The selection of a unit process or a combination thereof depends upon several factors such as raw seawater quality, availability of the site, site conditions, constructability and operability of the unit process, standards to be met, and finally, the associated cost. Of all these factors, the raw water quality and the ultimate finished water quality play an important role in deciding the overall unit process train.

As part of this report, various treatment alternatives, including the options proposed in DPR and JICA reports, were studied, and their pros and cons were evaluated. The evaluation is based on the total product water flow availability of 400 MLD and a number of criteria such as influent raw water quality and characteristics, finished water quality, suitability of a particular alternative for design and implementation in Chennai, operation and maintenance issues, availability of spares and finally cost of implementing such a unit operation/ processes.

The proposed process flow diagram is similar to that provided by the JICA report, and it is presented in Drawing no.7061563/PMC/400 MLD/CP1/P/PFD/001.

6.1 Pre-treatment Process Selection

The DPR and JICA report suggested implementing together with the 3 possible pre-treatments technologies (UF and pressure filters being alternatives to gravity filters). The reports did not explain too many comments about or the reasons for the process selection, nor the expectations of treatment results at each of the selected process unit.

If the raw water quality is supposed to stay stable during the coming 20 years, the addition of these 3 technologies (i.e. Lamella + DAF + DMF) together would have been questionable, and it would be an option to leave it open (2 or 3 technologies) at the RFP stage for the bidders to decide.

Even, if the 2-technology stages are working (sometimes with difficulties!) at Nemmeli and Minjur, the major Perur plant for Chennai working on baseload shall not take this risk, especially with the strong world trend of red tides upcoming and the recent white fibres issues. Therefore, the pre-treatment process will include the following, along with the standard screening equipment.

1. A **coagulation/flocculation system**. If the standard injection rate of ferric chloride is around 1 mg/L as Fe^{+3}, the dosing rate will be to increase during monsoon season up to 10 mg/L as Fe^{+3} to participate in better TSS reduction and also in TOC reduction.

2. A **Lamella Clarifier** in charge of decreasing approximately 50-80% of TSS (heavy particles) and approximately 30% TOC – jar/pilot tests are required to confirm this.

3. A **Dissolved Air Flotation (DAF)** in charge of decreasing approx. 20% of TSS (light particles) and approximately 20-30% TOC – jar/pilot tests are required to confirm this. The DAF will be operated mainly during the monsoon season and during algae blooms and if organic removal is required during the normal season.

4. **Gravity Dual Media filter (GDMF)** will fine-tune the process of removing the remaining parts of TSS and approximately 20-40% of the remaining TOC. The GDMF is reputed to be an efficient technology, and so it is usually preferred more than UF and pressure DMF if the availability of the plant footprint area is not an issue. In addition, deep media beds (1.0- 1.5 m/media thickness) will be implemented to enhance its efficiency.

The two active media to be presently considered are anthracite at the top, then silica sand; garnet between bed floor and silica sand is implemented for mechanical reasons, but not considered as an active media. With such pre-treatment, the PMC team is confident in achieving, even in rough raw water conditions with max TSS content, a level of feed water acceptable for the RO membrane:

- SDI: (SDI <2-3) and below membranes warranty supplier (80% time<4, 100% time <5).
- Feed water TOC content < 2 mg/l
- The bidder should be allowed to demonstrate any alternative pretreatement processes to meet the RO feed water quality proposed above.

Important notice: If the raw water TOC content in raw seawater goes higher than 8 mg/l, then significant change in the design must be considered:

1. Two stages of filtration, one roughing + one polishing, shall be considered for a total TOC removal up to 40% of the feed TOC content.
2. In such the above conditions, DAF implementation is questionable unless HAB events are considered as high probability repeatable situation (every year, medium intensity with middle size algae) and not a possible option for the future (every two or three years, low intensity). In this second scenario, Lamella settlers and the first stage of filtration (coarse) shall be able to handle the situation.

An option could also be to include the DAF option in the hydraulic process, but to construct the civil works and to install the electro-mechanical equipment only if further raw water quality deteriorates.

6.2 Flow rates (Mass Flow Diagram simplified)

The Mass Flow Diagram (MFD) helps at computing the amount of water strictly required by each stage of the plant. The main hypothesis is as follows:

1. **Service water** 0.5-1%
   - Flushing/cleaning the plant
   - Irrigation
   - Administrative building
   - Flushing the membranes (accounted at this level even though permeate is used)
   - Chemical building requirement (accounted at this level even though permeate is used)
   - Extra capacity when not used

2. **Reverse Osmosis** 42-46%
   - Recovery: the plant will be designed for a nominal recovery of 46%. In case significant fouling conditions are met, then as per DPR and JICA; the plant should be able to reduce its recovery down to 42%. In this last option, the requirement for raw water will be at its maximum (1040 MLD). PMC understands that reduction of recovery down to 42% as suggested by DPR and JICA is not techno-economically feasible. Such provision will be reviewed after the RO fouling assessment since its cost impact is more than significant.
   - Overflow at ERD inlet (to mitigate mixing according to ERD technology) <1%

3. **Pretreatment** 4-7%
   - Backwash/ media rinsing for gravity filters (3 to 5% as per water quality) 4%
   - Waste drain from DAF and Lamella settlers (drain, cleaning) 3%

The below Table 18 (recovery ratio @42%) computes the max raw water requirement for the Plant. It will be used to design the marine works (intake, pumping station) and the pre-treatment section. Similar table @ 46% (operating base case) will be computed, and the maximum pump efficiency shall be obtained for this recovery.

The necessary amount of raw water is slightly higher than in the DPR report (1052 MLD vs 1014 MLD).

The difference is coming from the hypothesis for gravity filter backwash and operations:

The DPR report requirement is only 1.4% for backwash, which can fit only very good raw water conditions but certainly not the monsoon period. Furthermore, it assesses another loss for filter maturation of 1%, which is also very short. Our design estimated a backwash requirement of within 3-5% of the raw water, related to the worse water quality during monsoon, and no additional maturation requirement as maturation is performed in close circuitry for large plants.

Table 18: Mass balance around plant at 42% RO recovery

Process Stage	m^3/day	Rate	Factor to Feed Flow
Intake Pumps	1,052,180		100.00%
Service Water	2,000		0.19%
Utility and Leakage		2,104	0.20%
Lamella + DAF waste		31,437	2.99%
GMF Backwash		30,706	2.92%
Pre-filtered water	988,145		93.91%
Feedwater RO+ERD	988,145		93.91%
Feed to RO	988,095		93.91%
HP pumps	415,000		39.44%
Recir. Pump	573,095		54.47%
Feed to ERD	573,145		54.47%
RO permeate	415,000		39.44%
RO Reject		573,145	54.47%
CIP & Flushing		2,000	0.19%
Total plant waste discharge		639,393	60.77%
Net Plant Product Water	413,000		
Overall Plant Recovery	39.2%		

A detailed mass balance sheet is attached in **Annexure 4.**

6.3 Marine Works

The major basic objective of the seawater intake system is to provide the following:

- Good seawater quality, i.e., Aid in the reduction of TSS and dissolved organic matter present in seawater
- No entrainment of materials
- Low environmental impact
- Lesser operation and maintenance
- Supply a sufficient amount of raw seawater reliably.

In the direct water intake system, the seawater is drawn directly from the shoreline or through long-distance pipelines from above the sea bed in the marine area. Direct water intake systems are more suitable for large capacity seawater, typically more than 40 MLD, and result in low energy consumption. The main advantage of direct water intake are as follows:

- The quality of feedwater is better and consistent, which results in a better quality output of the downstream pretreatment process.
- Floating matter does not enter into the seawater intake system since the entry of seawater is from the intake head slightly above the seabed.
- In the case of the Oil spill, a deep-sea intake system can avoid the inlet of spilled oil into the system for a reasonable period.

However, the temperature is cooler, which could result in relatively lesser treatment inefficiency in the SWRO system and higher construction cost due to the installation of offshore pipelines. Marine life will develop for sure in the large intake pipes; by marine life, it should be understood shells as barnacles and mussels, various algae and biofilms. If divers were appointed for a long time to clean the intakes, it should be noted the long duration of such manual or semi-mechanical works, plus the risks are taken by the divers to speed up such cleaning operations (several casualties per year).

Pigging operation to restore the hydraulic capacity of intakes is now a standard practice in the desalination industry to safely clean the intake pipes with better efficiency (a few days per year compared to a few weeks) that serves, of course, the Availability Factor.

Consequently, **pig suppliers shall be associated with marine works design** to ensure pigs will be able to enter the intake pipes at the pumping station (pig launching station) correctly, to work from the pumping station to the intake towers, to be ejected and recovered at/ beside the intake towers (within all debris). Most pigging companies are involved in oil industries; a few of them, as Pigtek (UK) developed a specific product for the desalination industry; more info is available on their website: https://www.pigtek.com/products/desalination-technology-and-sea-water-intake-pipe-pig/. Figure 19 provides a photo of the pig from Pigtek used in the desalination plant at Ashdod, Israel and at Baraka 4, Oman and Figure 20 gives the typical hydraulic curves before/ after pigging operation.

Figure 19: Pig from Pigtek Co. (2.1 m diameter)

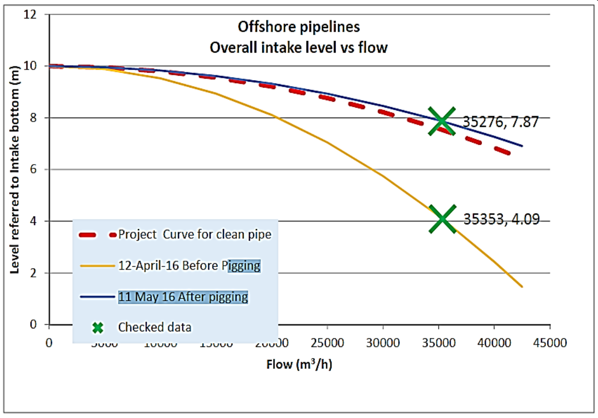
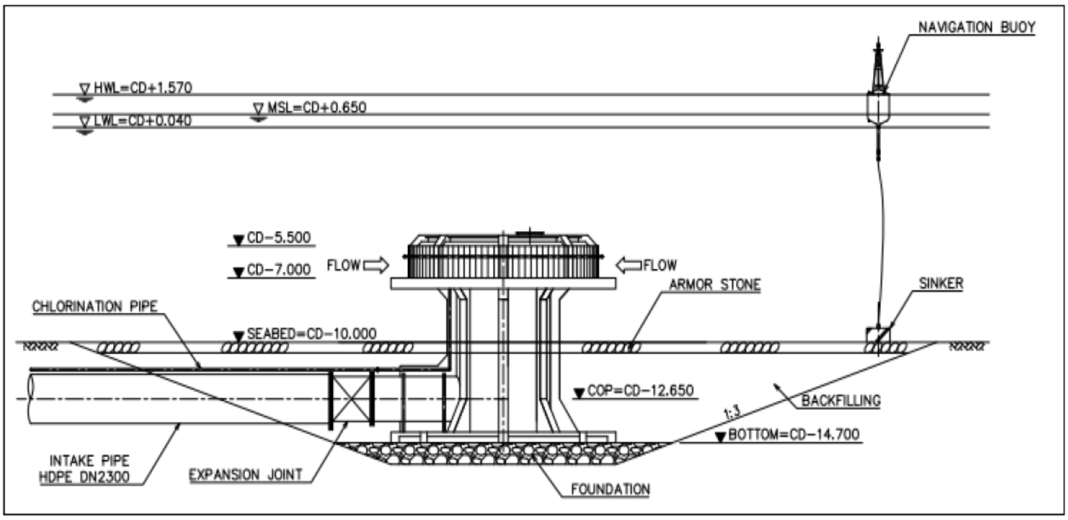


Figure 20: **Intake hydraulic curves before/after pigging operation**

6.3.1 Intake towers (2 units)

The design proposed by the JICA team is quite robust with the following specifications:

- Velocity cap type (horizontal velocity can be reduced below 0.10 m/s due to frequent jellyfish attacks)
- Screen bars spacing to be reduced from 30cm down 10 cm as per DPR recommendations
- Seawater flows inside the at 3 m above sea bed to avoid suspended sediments around seabed to be sucked
- Chlorination pipe (1 + SB) for shock chlorination
- Compressed air pipe (1 + SB) to clean the water inlets in case of jellyfish attacks (air curtain)



Source: JICA Study Team

Figure 21: Design of seawater intake head (JICA proposal)

NB: It should be noted that such design (very low horizontal inlet velocity) is implemented even in very shallow water as 3-4 m deep with **no risk of a vortex**. Adding an extra hydraulic load of 7 m makes it further remote to occur any vortex at the intake.

6.3.2 Intake pipes

DPR design includes 2 x DN 2500 mm HDPE pipes (ID 2230, SDR 21); the thickness of 135 mm, which is quite high and therefore the pipe will be very stiff; SDR 21 achieves a nominal pressure (PN) of 8 bars, which is quite an oversized pressure for an intake. The DPR is considering an assessment of maximum head loss from the sea tower to the pumping station.

It should be noted the following:

- DPR does not contemplate the worse scenario (maximum intake flow requirement);
- DPR does not make any provision for intake pipe incrustation or fouling.
- DPR adds 0.42 m to its result of 1.18 m (35%) as a safety margin

Final head loss computation in pumping station is therefore 1.6 m according to DPR

JICA study includes smaller pipes 2 x DN 2300mm HDPE pipes (ID 2100mm, SDR22) which are also PN 8 bars. Such diameter achieves a velocity of 1.74 m/s, which is quite high but still acceptable. However, no provision is made to compensate for incrustation and fouling of the pipe; such provision is achieved extra depth (hydraulic load) in the pumping station.

Our recommendation will match with DPR selection, in term of diameter, i.e. 2 x DN 2500 mm HDPE but with a smaller pressure rating @ 6 bars (SDR 26 with ID=2308mm); in the same range of diameter, the cost of the pipe is linear with the amount of raw material (HDPE powder), so decreasing the thickness of the pipeline will reach to a significant cost saving. The pipe thickness of 96 mm should be sufficient for a long life of the intake piping system.

Velocity will remain in an acceptable range of 1.20-1.80 m/s (1.46 m/s when clean, 1.74 m/s when clogged).

Table 19: Design of Intake Pipe

01. INTAKE PIPE	Unit	Value	Remarks
Number in operation	N	2	
Nominal flow per intake	m^3/h	21921	1052.2 MLD
Material	/	HDPE	
Length	m	1800	
Diameter (OD)	mm	2500	
Depth of intake tower head (3 m above the seabed)	m	10	
SDR Class	mm	26	
Diameter (ID)	mm	2308	
Velocity at Nominal Flow	m/s	1.46	**MFS< 1.6m/s**
Roughness coef K or C value		130	
Head loss at nominal flow (after pigging)	m	**1.13**	Using Hazen & William Eq.
Incrustation thickness	mm	100	
Reduced Diameter by Incrustation	mm	2108	
Velocity at a reduced diameter	m/s	1.74	
Roughness coef K or C value		85	
Head loss in incrusted pipe	m	**3.85**	
If intake capacity computed with a safety margin of	%	180%	**MFS**
Extended capacity	m^3/h	39457.5	
Diameter (ID)	mm	2308	
Velocity at extended capacity	m/s	2.62	
Roughness coef K & C value		135	
Headloss at extended capacity	m	**3.12**	

Such design will offer a safety margin of 80 % (extra amount of raw water available at the pumping station when intake is clean) and will ensure pigging operations only once a year (meaning in safe seawater conditions). The intake pipe design will be reviewed if CMWSSB wants to keep the expansion provision for the Perur desalination plant. The computation of overall head loss in the pumping station is performed below.

6.3.3 Pumping Station

The pumping station design, in particular its depth, is a critical point to ensure a proper amount of raw water to be available for the pre-treatment stage, therefore for the RO stage. Many projects are suffering from an insufficient or inaccurate design of the pumping stage in association with the intake piping.

Restoring initial planned design capacity (if the loss of capacity or poor availability factor is not accepted) is always very costly in terms of Capex and obliges the plant to shut down, which is sometimes hardly acceptable. Mitigations measures, consisting of treating the pre-treatment backwash waters or using the brine to backwash the pre-treatment, can be considered but have their limitations.

Despite a strong strategy in terms of controlling the biofouling and incrustation development by shock chlorination, clogging of the intake pipe is something that would happen sooner or later. Whatever the cleaning process, divers or pigging, some provision in intake + pumping station capacity design shall be taken to keep the heavy maintenance operation only every year (generally related to appropriate seawater conditions), this also serves, of course, the availability factor of the Plant.

None of the DPR or JICA reports has addressed the issue of intake clogging or its computations. DPR only approached a computation of head loss in "clean intake" conditions. Such computation is far from ensuring a long term period without cleaning the intake. The head loss in the intake pipe due to clogging is presented in Figure 22.

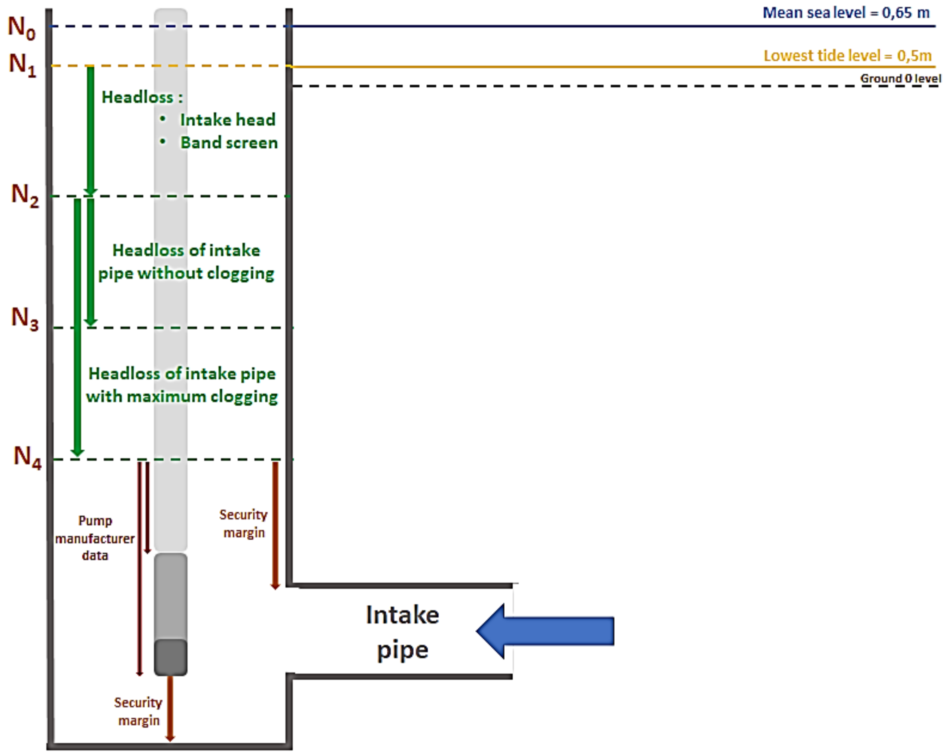


Figure 22: Presentation of head loss due to clogging of the intake pipeline

The above table procures the various levels N as described on the pumping station sketch above. The following hypothesis is taken:

- Head loss in intake head (tower): 20 cm as a usual average loss without a specific design (mainly depends on the spacing of bar screen)
- Travel bands (screen bands) shall be designed not to impact by more than 30 cm the water level in the pumping station at nominal capacity. Such value needs to be increased to 50 cm for extra capacity due to one travel band under maintenance
- Head loss in intake (after piping): linear head loss computation using Hazen & Williams equation formula with roughness coefficient C = 85; it is considered that pigging will never restore the full capacity of a new intake pipe with C= 130; the result is 1.13 m and lead to **level N3 = -1.68m**
- Head loss in the intake before pigging (meaningfully clogged): same formula as above with a diameter reduction of 20 cm (10 cm thickness for incrustation) and a roughness coef = 5 mm; **result 3.85 and leads to level N4= -4.40m**

- **The difference between these 2 levels (2.72 m) represents the provision between 2 cleaning operations.**
- **At full capacity plant operation, if the level in the pumping station reached N4, it means that intake cleaning operation should be considered soon.**
- **A successful cleaning operation should restore a water level at N3 in the pumping station (always at full capacity).**

The head loss at the lowest tide level and the nominal flow is presented below in Table 20.

Table 20: The Head loss at lowest tide level

02. INTAKE PUMPING STATION		Unit	Value	Remarks
Mean sea level		m	0.65	
Lowest tide level		m	0.5	
TOTAL N1		m	**0.15**	
Head loss at the intake head		m	0.2	
Head loss at screening bands (max when 1 under maint.)		m	0.5	
TOTAL N2		m	**-0.55**	
Head loss in intake (after pigging)		m	1.13	
TOTAL N3		m	**-1.68**	
Head loss with maximal clogging		m	3.85	
TOTAL N4		m	**-4.40**	
Minimal pump coverage		m	2	supplier data
Pump length		m	1.5	supplier data
Safety margin (sump)		m	1	
Pumping station depth		m	**-8.90**	
Intake pipe Crown at pumping station (pipe radius below N4)		m	**-5.65**	= N4 - OD/2
Sea Depth at intake tower		m	-11.00	
Intake pipe Crown at Intake tower (sea depth -1.5m)		m	**-12.5**	1.5 coverage
intake slope		m/km	**5**	
INTAKE PUMPS				
Number of pumps in operation		N	6	
Number in Stand by		N	2	
	In warehouse (one pump)	N	1	
Total		**N**	**9**	
Type				Wet well vertical turbine pumps
Design flow		m^3/h	**7307**	
Design discharge pressure		m	**17.4**	
VFD			**YES**	
Pump efficiency at the design point		%	87	
Motor efficiency at design load		%	97	
VFD efficiency		%	98	

The hydraulic diagram of the intake pipeline is presented below in Figure 23.

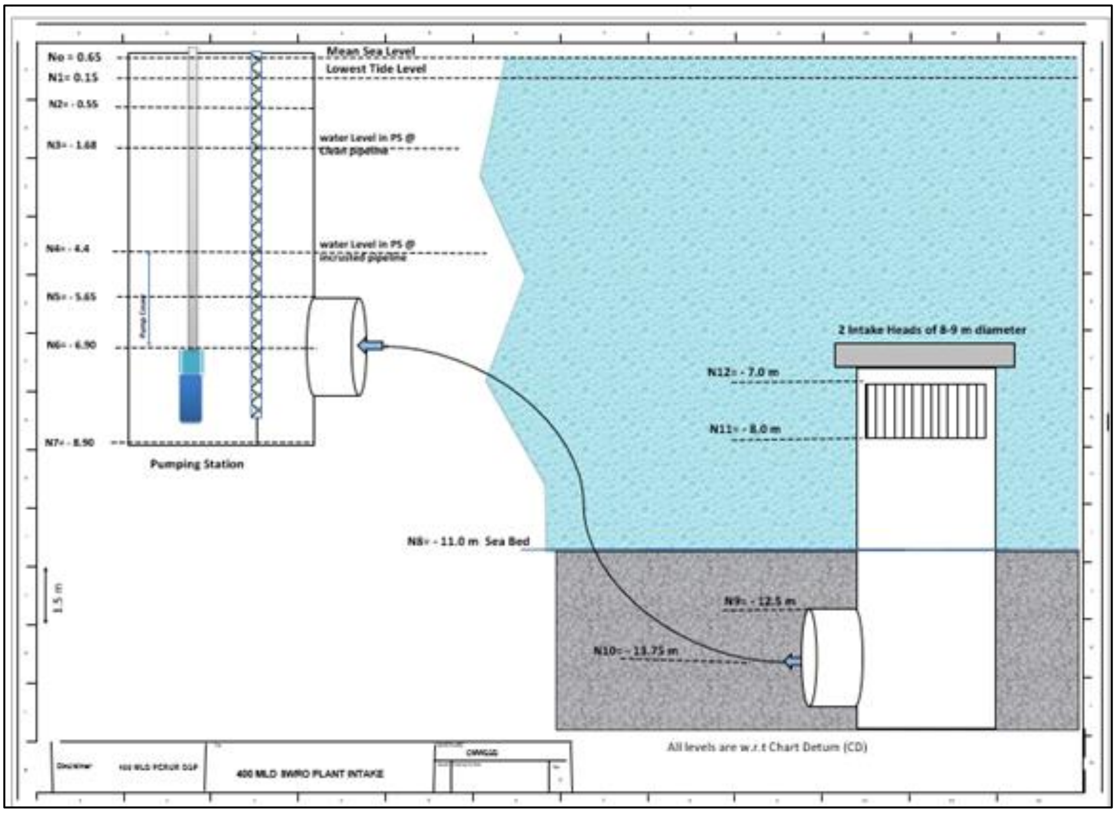


Figure 23: Presentation of Intake pipeline hydraulic positions

6.3.4 Intake pumps

The process specifications are furnished in the table above. The pump specifications will be detailed in the equipment list specifications. However,

- As part of the equipment in contact with seawater, all material shall display a PREN (Pitting Resistant Number) > 41. Such value will guaranty the expected design life.
- To ensure the lowest energy requirements, the following efficiencies are expected:

  - **Pump efficiency at design point > 86%**
  - **Motor efficiency at design working load > 96% (including VFD)**

6.3.5 Shock Chlorination

The shock chlorination is the only preventive way to control the fast installation and growing of shells (barnacles, mussels etc.), algae and marine life organisms in the intake (1st third length of the pipes). The best efficiency is met after 3 hours at an injection rate of up to 12 PPM minimum. The frequency is usually adjusted to once a week at the beginning of the operation period. It is later optimized in a global strategy of maintenance with pigging which is more corrective action.

Table 21: Process design for shock chlorination

03. SHOCK CHLORINATION		Unit	Value	REmarks
Processed flow (total 2 intakes)		m^3/h	43842	
Commercial reagent		/	NaOCl	
Concentration		%	10.3%	
Max dosage		g/m^3	15	
Mass flow (100% pure)		kg/h	657.6	
Density		1.18	1.18	
Volumetric flow		L/h	5410.8	
Frequency		h/week	3.5	to be adopted at an operation level
Dosing pump				
	Number in operation	1	1	
	Number in stand-by	1	1	
	Unit flow	8000	8000	
	Capacity safety margin	47.9%	49.8%	
Injection point				intake tower

A constant chlorine dose of up to 3 ppm in the intake well or intake pump discharge shall be provided to eliminate the growth of micro-organism/ algae in the pretreatment units over time. The dose rate shall be adjusted to get the minimum level of residual chlorine in the filtered water tank so that excessive use of sodium bisulphite can be avoided.

6.3.6 Band screens

The band screen is the first efficient pre-treatment stage after the intake tower bars; a screen mesh of 5 mm or lower is recommended to discard the largest sizes of TSS material. This has an impact on the intake pump selection and hydraulic efficiency. The process design of the band screen is given below in Table 22.

Table 22: Process design for moving band screen

04. BAND SCREENS	Unit	Values	Comments
Processed flow (total 2 intakes)	m^3/s	12.18	
Number in operation		3	All pumps designed at 33%
Number in standby		1	
Screen size (mesh)	mm	5	
unit flow	m3/s	4.06	
max headloss 3 units in operation	m	0.2	
max headloss 2 units in operation	m	0.5	
backwash pump per unit			
discharge flow	m3/h	20	
head	m	30	
band screen power requirement (all units)	kW	20	

All metallic equipment in contact with seawater shall display a PREN >40 (PREN standing for Pitting Resistance) Equivalent Number); other metallic components, non in contact with seawater but being exposed to the saline atmosphere, shall be in plain corrosion-resistant material (painted or galvanized soft steal not accepted).

6.4 Pretreatment

The pre-treatment processes aim at transforming the raw seawater into feedwater which will be able to allow optimised membrane operations. The target feed water is set as below in Table 23.

Table 23: RO Feed Water Design Parameters

Parameters	Concentration (mg/l) or level
Turbidity NTU)	0.1<Turbidity<0.5
Silt Density Index (SDI)	According to membrane supplier specs <3 (90% of the time) and <5 (all the times)
Total Organic Carbon (TOC) (mg/l)	<2
pH	6<pH<9
Oxidation-reduction Potential (mV)	<200
Chlorine residual (mg/l)	<0.02
Hydrocarbon contents (mg/l)	<0.04

6.4.1 Coagulation/Flocculation/pH adjustment

pH adjustment is performed by injection of sulphuric acid, usually at the pumping station. It occurs mainly in summer when the water temperature is higher; therefore, optimum flocculation pH is lower. The acid injection is always limited since by lowering the pH, it also reduces the membrane rejection (in addition to the higher temperature), and in an extreme case, it must be compensated by caustic soda injection before the membrane to restore proper rejection, particularly to meet the Boron rejection level.

The best option for coagulation is flash mixing. After injection, coagulant and polymer are mixed in small chambers (a few cubic meter) with impeller running at 40-100 RPM and contact time about 10-20 seconds. Another option is the static mixer, but specific care should apply to keep a velocity higher than 2 m/s in the device to procure enough differential pressure. Such velocity is sometimes difficult to maintain on the full modularity of the plant, especially if only one pipe is implemented between the pumping station and Lamella settlers. In our case, the plant is at 100% capacity most of the time, it should not be a problem.

The flocculation is an important part of the process since the larger flocs, the better decantation. Flocculation takes place in a larger chamber with slow impellers (3-6 RPM) and contacts time 12-20 min.

In the present specific case, a good coagulation/flocculation is also critical for satisfactory removal of TOC; in case of very high TOC content evidenced by the additional sampling campaign, the second stage of coagulation/flocculation may be considered before DAF.

Table 24: Process design for coagulation and flocculation

05. COAGULATION/FLOCULATION/ pH ADJUST	Unit	Value	Comments
Feed water			
Design flow rate	m^3/d	1054920	
Design flow rate	m^3/h	43955	
Turbidity	NTU	150	
TSS	mg/l	300	
Coagulation (flash mixing)			
Contact time	s	20	Design data
Contact time	h	0.006	

05. COAGULATION/FLOCULATION/ pH ADJUST	Unit	Value	Comments
Total volume of coagulation tanks	m3	244	
Nb of tank	m	4	as per modularity
Tank volume	m3	61	
Unit Energy requirement	kW/m³	0.7	
Total Energy requirement	kW	170.9	
Flocculation			
Contact time	min	15	Design data
Contact time	h	0.25	
Total volume of coagulation tanks	m3	10989	
Nb of tank	m	18	as per modularity
Tank volume	m3	610	
Unit energy requirement	kW/m3	0.01	
Total energy requirement	kW	109.9	
Ferric chloride injection			
Commercial reagent	/	$FeCl_3$	
Concentration	FeCL3	40%	
Max dosage	g/m3	**20**	
Mass flow	kg/h	2198	
density	kg/L	1.42	
Dosing pumps	n	5	
Volume flow	L/h	1547.7	
Number in operation	n	2	
Number in stand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	1000	
Capacity safety margin	%	29%	
Injection point			Flash mixers or static mixers
pH adjust			
Optimum flocculation pH highly dependent on water temperature			
Optimum floculation pH @ avg 28°C		**7.5**	Design Data (NV desalination Engineering p255)
(To be tested and confirmed by jar test)			
Commercial reagent		H_2SO_4	
Concentration	H2SO4	98%	density
Max dosage	g/m3	**20**	design data
Mass flow	kg/h	897	
Density	kg/L	1.83	
Dosing pumps	n	5	
Volume flow	L/h	490	
Number in operation	n	2	

05. COAGULATION/FLOCULATION/ pH ADJUST	Unit	Value	Comments
Number in stand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	300	
Capacity safety margin	%	22%	
Injection point			intake pumping station
Polymer			
Commercial reagent		Anionic Polymer	
Concentration		100%	
Max dosage	g/m^3	**1**	design data
Mass flow	kg/h	44	
density		1	
Solution Concentration		0.5%	
Dosing pumps	n	5	
Volume flow	L/h	8791	
Number in operation	n	2	
Number in stand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	6000	
Capacity safety margin	%	37%	
Injection point			Flash mixers or static mixers

6.4.2 Lamella Clarifier and Dissolved Air Flotation (DAF)

Lamella Clarifiers and DAF implemented on extra-large plants are delivered as prebuild modules fitting in predesigned concrete chambers. They are designed and optimized by suppliers and are the fruit of a long experience regarding the dispatch of the internal hydraulic flows. DPR report provided some detailed design of Lamella filters and DAF, but contractor can't erect such design without any experience, or if so with a significant loss of efficiency.

Key desalination players have their own patented models (Degremont's Densadeg/PulseAzur/Posseidon or Veolia's Actiflow/Speed flow).

The Perur DSP project will require equipment modules that have a minimum of 20 successful references implemented in larger desalination plants (beyond 100 MLD). However, all these modules have minimum standard and proven specifications described as below (which will be part of MFS):

6.4.2.1 Lamella Clarifier:

The Lamella settlers shall have an efficiency within 85-90% for the removal of TSS and turbidity. TOC removal is also expected up to 30% with proper coagulation and flocculation.

The main design specification is the Surface Loading Rate per module area which must be kept below 1.1 m/hr and preferably below 1.0 m/hr for an effective performance of the Lamella clarifier during the worst seawater condition.

(DPR is recommending a value of 1.3 m/hr, named "rise rate"). The below tentative design is mainly provided to compute the surface for the layout is furnished in Table 25.

Table 25: Process Design for Lamella Settler

06. LAMELLA SETTLERS	Unit	Value	Comments
Design flow rate	m^3/h	43955	
Max Turbidity	NTU	150	
Max TSS	mg/l	300	
TSS removal	%	90%	
TOC Removal	%	20-40%	
Lamella Settlers			
Surface loading rate per module area	$m^3/m^2.h$	**1**	Design Data
Number of settler tanks		36	
Number of Lamella modules per tank		**6**	
Total number of modules		216	
Width of Lamella modules	m	**1.24**	Supplier data
Length of Lamella modules	m	**8.67**	Supplier data
Depth of Lamella modules	m	**2.59**	Supplier data
Net surface area per Lamella module	m^2	**235**	Supplier data
Total surface area for Lamella modules	m^2	50760	
Settler tank surface area	m^2	64.5	
Total surface area for settler tank	m^2	2322	
Settler tank surface loading rate	$m3/m^2.h$	**18.9**	
Water depth	m	**5.5**	Supplier data

6.4.2.2 Dissolved Air Flotation (DAF):

DAF technology is very efficient, removing light particles (floating elements, algae cells, oil, grease, that cannot be trapped by sedimentation (Lamella filters).

Again, from a detailed design perspective, it will be quite challenging to compete with a proprietary design that cumulates years of experience. It shall be noted that initially, DAF technology applied to freshwater treatment and specifications for desalination are quite different due to:

- The size of particles in seawater is much smaller than in freshwater (40-80 µm versus a few µm - 20µm in particular in case of algae blooms). Consequently, the average bubble size will be selected @15 µm to be adjusted to particle size to be captured. Previous preliminary studies did not pick this vital point.
- Recycling rate, injection pressure and air saturation are higher in seawater than in freshwater application.
- Recommended recycling rate: 10-15% (DPR recommended only 8%)
- Recommended pressure: 6-9 bars (no recommendation by DPR)
- Surface loading rate: 20-30 $m^3/m^2/h$ (DPR recommended 15$m^3/m^2/m$ (called "SOR"), which is quite low (and footprint consuming), especially if DAF participates in pre-treatment as second players after Lamella filtration. Figure 26 provides the process design for the DAF system.

Table 26: Process design for DAF

07. DISSOLVED AIR FLOTATION		Unit	Value	Comments
Feedwater				
	Design flow rate	m^3/d	1033830	
	Design flow rate	m^3/h	43076	
	Max Turbidity	NTU	40	
	TSS	mg/l	60	
	Algal content	cell/ml	30000	
	TSS removal	%	80%	
	TOC Removal	%	20%	
Design chemical dosages				
	Ferric chloride	mg/l	5	
	Max Cationic polymer	mg/l	0.5	
Static mixer				
	Minimum speed	m/s	2	Design data
	Diameter static mixer)	m	2	
	No. of the static mixer		2	for two-stream of 200 MLD
	Other data as per supplier specification			
DAF tanks				
	Number in Standby		0	
	Surface loading rate with recycling	$m3/m^2.h$	25	MFS <25-30
	Recirculation rate	%	15%	
	Total surface flotation area	m^2	1723	
	Surface Flotation per tank	m^2	156	
	Number of the tank in operation		12	
	Surface contact zone area/tank	m^2	40	
	Total Surface contact zone area	m^2	482	
	Width	m	6	
	Depth	m	5	
	Length	m	30	
	Number of tanks		12	
	Total area		2160	
	hydraulic detention time	min	15.04	MFS >15
Circulation pumps				
	Number in operation	u	4	
	Number in standby	u	2	for two-stream of 200 MLD
	Discharge flow	m3/h	1615	
	Discharge pressure	m	85	MFS>80
	Pump efficiency at the design point	%	85%	
	Motor efficiency at design load	%	95%	
Air compressors				
	Number in operation		4	
	Number in standby	u	2	
	air loading	g air /m3	10	
	Capacity	kg air /h	431	
	Delivery pressure	bar	10	MFS>8
	Power	KW		
DAF saturator tanks				
	Number		4	
	Capacity per tank	m3/h		
	Net volume per tank	m3	16	
Air bubbles				
	Average size	µm	15	MFS: to fit targeted particle size

6.4.3 Dual Media Gravity Filters

Media filters can be designed for several targets in a desalination plant and at different stages of pre-treatment.

- From good to average raw water quality, they can be implemented upfront (Mediterranean Sea) with or without polishing stage;
- From average to rather bad raw water quality, they can be implemented after the sedimentation stage (Lamella settlers or DAF); and
- In extreme conditions (High TSS and TOC), 2 stages of media filter can be considered specially to cope with high TOC content (coarse and polishing stages).

Two types of Media filters

- **Gravity filters** which offer low filtration rate (surface loading rate), thick media layers (up to 3m total thickness) for a better removal of TSS. Gravity filters by their higher retention capacity can cope with moderate algae blooms (options 1, 2 and 3 (coarse) above).
- **Pressure filters**, which offers higher filtration rate, have also a lower filtration capacity due to the reduced media thickness (1-1.2 m); they can also be met in all options above (polishing stage in option 3). Pressure filters has smaller footprint area and can be consideration, if there is space issue particularly due

Removal of TOC content:

Gravity filters, especially “deep bed” (meaning thick media layer beyond 2 m), will capture micro-organisms able to consume part of the TOC content. This biological activity will increase with the following:

- Depth of media
- Decreased Surface Loading Rate (slower filtration rate)
- Temperature
- Length of the cycle between 2 backwash sequences

For the Perur DSP, about the raw water envelop “deep bed” dual media gravity filters are selected with the below specifications given in Figure-27. This selection is subject to the TOC content, evidenced by the proposed raw seawater analysis campaign, which is on average below 6 mg/l. It is expected that the average TOC in seawater is below 5 mg/l most of the time all over the year.

A filtrated water tank will be part of this filtration stage to procure the necessary backwash amount of water. Two options could be considered:

- Inline tank with 2 compartments (first one backwash overflowing to the second compartment to ensure bask wash reserve is always full). In this condition, maturation flow is in a short circuitry for each filter or pumped back to filtration inlet.
- Side process fed tank with maturation flow (+ some filtrated flow if necessary).

As the pre-treatment purpose is to remove all contaminants before the membrane stage, it should not generate additional pollutants. Therefore, all pre-treatment facilities shall be covered by building and operating in the dark and not in the sunlight, which encourages algae growth.

Table 27: Process design for Granular Media Filtration

08. GRANULAR MEDIA FILTRATION		Unit	Value	Comments
Feedwater				
	Design flow rate	m³/d	1,023,550	
	Design flow rate	m³/h	42,648	
	Turbidity	NTU	30	
	Operation cycle	h/BW Cycle	36	MFS>24h in worse conditions
	TSS removal	%	100%	
	TOC Removal	%	30%	
	Surface loading rate	m³/m²/h	**7.4**	MFS< 8
	Type		DM gravity	
	Total filtration area	m²	5763	
	N filters in operation		80	40 for two streams of 200 MLD each
	Unit surface	m²	72	Max =>40 to 100 (Gravity) 15 to 40 (Pressure)
	Unit flow	m³/h	533	
	N-1 filters in operation		78	1 in each stream of 200 MLD
	Total filtration surface	m²	5619	
	Surface loading rate N-1	m³/m²/h	7.6	
	N-2 filters in operation - one in maintenance, one in the backwash		76.0	
	Total filtration surface	m2	5,475.1	
	Surface loading rate N-1	m³/m²/h	7.8	
Media description				
1	Top layer		Anthracite	
	Depth	m	1.2	
	Effective size	mm	0.8	
	Uniformity coefficient		1.4	MFS
	Bulk density	ton/m³	0.85	specific gravity =1.5 ton/m3
2	Bottom layer		Silica Sand	
	Depth	m	1.5	MFS>1.5
	Effective size	mm	0.6	ratio
	Uniformity coefficient		1.4	MFS
	Bulk density	ton/m³	1.8	specific gravity =2.6 ton/m3
3	Floor layer		Garnet	
	Depth	m	0.2	
	Effective size	mm	0.5	
	Uniformity coefficient		1.4	
	Bulk density	ton/m³	3.5	
Steps of backwash				
1	Air + water			
	Airflow rate	m³/h/m²	50	MFS≥50
	Airflow per Filter	m³/h	3,602	
	Water flow rate	m³/h/m²	10	higher than filtration velocity
	Water flow per Filter	m³/h	720	
2	Water only	m³/h/m²	36	MSF>30 (<50 no loss of media)
	Water flow rate	m3/h	2,593	
3	Filter maturation	m3/h/m²	8.5	higher than filtration velocity
	Water flow rate	m3/h	612	
Filter backwash pumps				
	Type		Mono-stage	horizontal
	Total - Step-1	N	6	
	In operation (step 1)	N	4	2 in each stream of 200 MLD
	Discharge flow	m³/h	720	

08. GRANULAR MEDIA FILTRATION		Unit	Value	Comments
	Discharge pressure	m	8	
	Pump efficiency at the design point		85%	
	Motor efficiency at design load		95%	
	VFD efficiency		100%	100% if No VFD
	Total - Step-2	N	6	
	In operation (step 2)	N	4	2 in each stream of 200 MLD
	Discharge flow	m³/h	2,593	
	Discharge pressure	m	20	
	VFD efficiency		100%	
Air suppressor				
	Type		Rotary screw drive and air cooling	
	Total	N	6	
	In operation	N	4	
	Stand-by	N	2	
	Air Flow	Nm³/h	3,602	
	Discharge pressure	m	6	
	Power at design load	KW	120	To be confirmed
Backwash tank				
	% of daily backwash requirement	%	50%	
	Tank capacity	m³	20,098	
	Per half-plant	m³	10,049	

6.4.4 Cartridge Filters

Although Cartridge Filters (CF) are considered as the last component of the pre-treatment, they are not expected to modify the quality of the water feeding the membrane system. Their implementation is mainly to offer a last mechanical barrier to protect membranes against damaging elements as sand from sand filters or any other failure of pre-treatment equipment. Cartridge Filter mesh size was initially 5µm, nowadays are an available product with 20 µm mesh, offering less head loss, but it is preferable to stick to 5µm initial products that provide better protection to membranes. Furthermore, the colour of CF after replacement and the operational duration of CF set between 2 replacements is providing a lot of information regarding the "health" of pre-treatment. CF design specifications are provided in below Table 28:

Table 28: Process design for Cartridge Filers

09. CARTRIDGE FILTERS	Unit	Value	Remarks
Material		Polypropylene	
Filtration size	µm	5	
Cartridge length	cm	102	40 inches
Total flow	m³/h	40,196	
Cartridge requirement		7,768	
Unit flow	m³/h	5.3	
CF cartridge vessel			
Material		GRP	
CF vessel content	unit	250	
nb of vessel required		31.1	
nb of vessel installed		37	20% margin vs supplier max capacity
Nb of cartridges installed		9,250	
Head loss when new	m	2	
Head loss when clogged	m	7	
The extra cartridge in Warehouse	50%	4,625	

6.5 Reverse Osmosis

6.5.1 New flow rates

Due to the water quality fouling expectations, marine works and pre-treatment are sized to operate the RO system with a conservative recovery of 42%.

That being said, 46% recovery is still assumed to be acceptable for the Perur project, and RO equipment will be optimized (energy) to work at such recovery.

The following flow rate presented in Table-29 is therefore computed for a 46% recovery ratio. The overall plant recovery (product water flow/intake water flow) is equal to 43%. The detailed mass balance is available in **Annexure 4**. The overall plant recovery (product water flow/intake water flow) is up to 43%.

Table 29: Mass Balance for operation at 46% RO recovery

Process Stage	Process water	Wastewater	Rate wrt Feed
Intake Pumps	960,705		100.00%
Service Water	2,000		0.21%
Utility and Leakage		1,921	0.20%
Lamella + DAF waste		28,711	2.99%
GMF Backwash		28,043	2.92%
Pre-filtered water	902,224		93.91%
Feedwater RO+ERD	902,224		93.91%
Feed to RO	902,174		93.91%
HP pumps	415,000		43.20%
Recir. Pump	487,174		50.71%
Feed to ERD	487,224		50.72%
RO permeate	415,000		43.20%
RO Reject		487,224	50.72%
CIP & Flushing		2,000	0.21%
Total plant waste discharge		547,590	57.00%
Net Plant Product Water	413,142		
Overall Plant Recovery	43.0%		

6.5.2 Membrane selection

The Perur Project is based on a single RO pass with a Boron requirement for product water >1 mg/l. Two technical options are available and shall be economically compared:

- High boron rejection or high rejection membranes shall be able to meet the boron target with no chemical injection (pH reduction) or a minimum injection in summer. These membranes exist within most of the reputed manufacturers as:

Manufacturers	Model	Boron Rejection
Nitto (Hydranautics)	SWC4max	95%
DOW (Filmtec)	SW30 – XHR-	93%
Toray	TM820K	96%

- Low energy membranes were more recently developed membranes, aiming at reducing energy consumption. Operated in similar conditions as the high rejection membranes, pressure requirement may be reduced by 3-4 bars. Unfortunately, the counterpart is a lower Boron rejection and a requirement of increasing the pH with a significant amount of Sodium Hydroxide.

These membranes will be competitive only if the over-cost chemicals do not fully compensate for the energy saving. Manufacturers and models are the following:

Manufacturers	Model	Boron rejection
Nitto (Hydranautics)	SWC5max or SWC6maw	91%
DOW (Filmtec)	SW30 – ULE	89%
Toray	TM820L	92%

Some hybrid configurations (such as 4 high rejection membranes + 4 low energy membranes) were also adopted on several extra-large plants (Ashdod). Projections have been run to present the cost comparison.

6.5.3 Projections

The raw water parameters are detailed below. The values in bold are the minimum and maximum envelope for the important parameters. To reach extreme TDS values, only chloride and sodium values are adjusted. The ion projection is given below in Table 30. The projections have been prepared with the seawater TDS equal to 39000 mg/l, which is considered the maximum TDS value expected for the Perur desalination plant. In the case of the seawater TDS reaching more than 39000 mg/l up to 41000, the production will be maintained with the required product water quality by reducing recovery down to 44% and adjusting pH in RO feed.   The details are given below.

Table 30: Seawater ionic projection for RO feed

Cations	Unit	Value
Ca	mg/l	480
Mg	mg/l	1,350
Na	mg/l	12,101
K	mg/l	409
Ba	mg/l	0.45
Sr	mg/l	0.1
NH4	mg/l	0.2
Fe	mg/l	0.1
HCO_3	mg/l	99
Cl	mg/l	21,516
SO4	mg/l	2,972
NO3	mg/l	4
F	mg/l	1.63
Br	mg/l	67
B(Boron)	mg/l	3.8
SiO2	mg/l	1.4
PO4	mg/l	0.1
CO3	mg/l	4.021
CO2	mg/l	0.753
TDS	mg/l	39,009
Temperature- min	°C	26
Temperature- avg	°C	28.3
Temperature- max	°C	31.5
TDS - min	mg/l	32000
TDS - avg	mg/l	35942
TDS - max	mg/l	39000

For all the below projections, Hydranautics (Nitto group) software “IMSDesign” is used in version 1.222.81, and therefore membranes of the same manufacturer are simulated. This software, according to Hydranautics, procures about a 10-15% safety margin to cope with potential manufacturing discrepancies. Therefore, no additional safety margin needs to be considered.

Hypothesis set with the software:

- 8 membranes per pressure vessel
- The permeate back pressure is kept at 1.5 bar (15m) to allow water to reach the limestone beds.
- 7% pressure increase per year
- 10% salt passage increase per
- ERD selection is a “pressure exchanger.”
- ERD leaking 1%
- ERD mixing 4% (max)
- ERD differential pressure 0.8 bar
- Due to fouling conditions, membrane average flux is kept below 13.5 LMH
- The maximum average life of operating membranes is kept @ 3.5 years (consistent with 6 year life expectancy for each membrane)

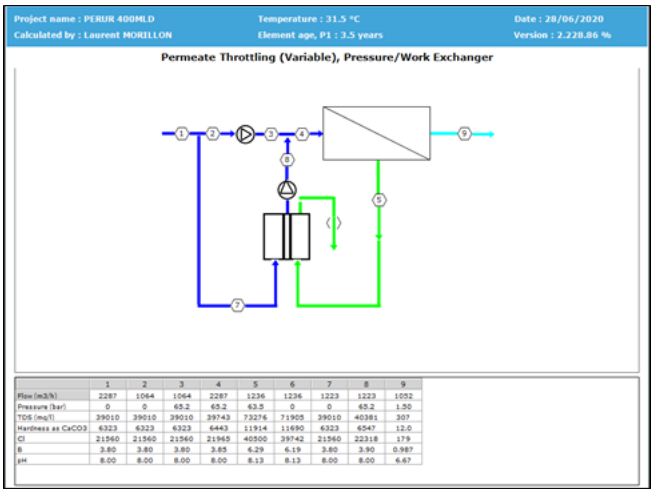
To ensure remineralisation while keeping **TDS below 450 mg/l,** permeate water TDS shall be kept below 300-350 mg/l (oldest membranes).

The pre-treatment process, including chemicals injection will modify the pH of feed water compared to raw water. At this stage of design, it will be considered that the initial pH will be restored for the feed water.

To select the best membranes or combination of membranes, Boron rejection in worse conditions (high Boron, low pH, high temperature, max average membrane life) has been first reviewed:

6.5.3.1 SWC4max projection (all high rejection membrane):

Boron, TDS, Chloride are meeting the requirements. TDS is in the limit to keep within 450 mg/L after remineralization.

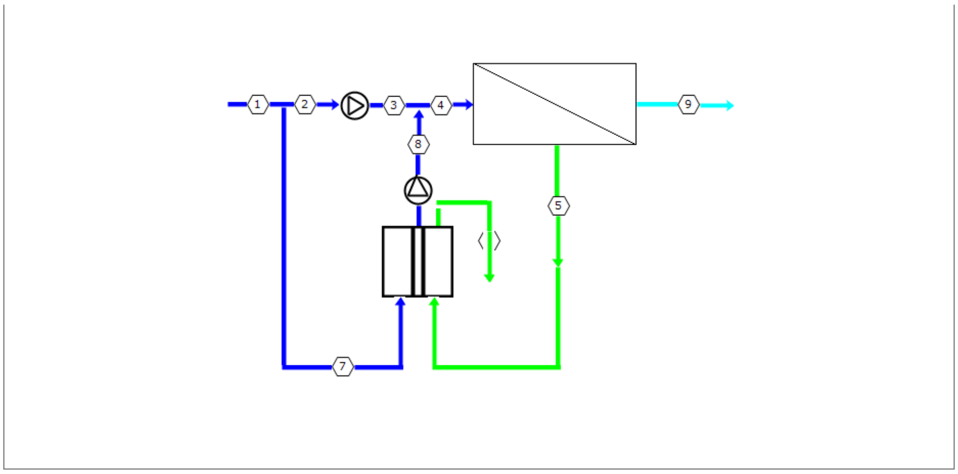


	1	2	3	4	5	6	7	8	9
Flow (m3/h)	2287	1064	1064	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	65.2	65.2	63.5	0	0	65.2	1.50
TDS (mg/l)	39010	39010	39010	39743	73276	71905	39010	40381	307
Hardness as CaCO3	6323	6323	6323	6443	11914	11690	6323	6547	12.0
Cl	21560	21560	21560	21965	40500	39742	21560	22318	179
B	3.80	3.80	3.80	3.85	6.29	6.19	3.80	3.90	0.987
pH	8.00	8.00	8.00	8.00	8.13	8.13	8.00	8.00	6.67

6.5.3.2 SWC5max projection (all low rejection membrane):

Project name : PERUR 400MLD	Temperature : 31.5 °C	Date : 28/06/2020
Calculated by : Laurent MORILLON	Element age, P1 : 3.5 years	Version : 2.228.86 %

Permeate Throttling (Variable), Pressure/Work Exchanger



	1	2	3	4	5	6	7	8	9
Flow (m3/h)	2287	1064	1064	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	61.3	61.3	59.6	0	0	61.3	1.50
TDS (mg/l)	39010	39010	39010	39741	73172	71805	39010	40377	435
Hardness as CaCO3	6323	6323	6323	6443	11911	11687	6323	6547	17.0
Cl	21560	21560	21560	21964	40439	39684	21560	22315	253
B	3.80	3.80	3.80	3.84	5.76	5.68	3.80	3.88	1.59
pH	8.00	8.00	8.00	8.00	8.12	8.12	8.00	8.00	6.82

Boron level is 1.59, which is not acceptable, and chloride is at the very limit. TDS is not sufficiently reduced to keep it within 450 mg/L after remineralization. The RO feed pH can be adjusted to bring down the Boron concentration in RO permeate. However, as both TDS and Boron concentrations are high in RO permeate, there is no benefit in adjusting the pH of RO feed, bringing the Boron level down while the TDS will remain high in RO permeate. So, it is clear that the use of a full low rejection membrane, i.e. SWC5max is not suitable for meeting the product water quality.

6.5.3.3 Hybrid configuration projections

Projections with hybrid RO membrane configuration at 46% recovery have been done to check the suitability of its use for economical operating cost. Three hybrid configurations have been tried as given below.

1) 6 high rejection + 2 low rejection membranes
2) 3 high rejection + 5 low rejection membranes
3) 2 high rejection + 6 low rejection membranes

Due to the excessive increase in capital cost of the plant due to consideration of lowering the plant recovery, PMC is proposing to bring down the recovery down to 44% only during the worst raw seawater condition. Two more RO projections (given below) are made to check the performance of the most economical configuration (i.e. 2 high rejection + 6 low rejection membranes) during low RO recoveries 45% and 44%.

4) 3 high rejection + 5 low rejection membranes @ 45% recovery
5) 3 high rejection + 5 low rejection membranes @ 44% recovery

The below Table 31 provides the details of the projections done for the above cases. The information illustrated in the table provides the following information.

- The provision of maintaining Boron level below 1.0 mg/l in RO permeate is not an issue as the required value can be achieved any time with pH adjustment by addition of 2-7 mg/l of caustic soda in the RO feed water.
- Main limiting condition for the use of a low rejection membrane (low energy) is the max limit of product water TDS at 450 mg/l. The configuration with all low rejection membrane is not able to maintain the required TDS concentration (<450 mg/l) in RO product.
- High rejection membrane is suitable to produce product water with TDS below 450 mg/l all the time without a need for the feed pH adjustment. However, it will incur a high operating cost.
- For average feed water quality (TDS = 35942 mg/l), the product water TDS can be maintained within 450 mg/l with all 3-membrane configuration given above.
- Hybrid membrane configuration with 2 high rejection and 6 low rejection membranes is not suitable to produce product water TDS below 450 mg/l with maximum feed water quality having TDS at 39000mg/l.
- Hybrid membrane configuration with 3 high rejection and 5 low rejection membranes provides RO product water TDS < 500 mg/l all the time and with average feed water quality < 450 mg/l. The operating cost saving for the use of this hybrid configuration compared to all high rejection membrane configuration is up to USD 1 million per year that is about INR 63 lakh per month.
- Operation of RO system at the low recovery of 44% is suitable to produce product water TDS < 500 mg/l for max feed quality - TDS 39000 mg/l. This option of operation can save about USD 1.8 million per annum (i.e. INR 1.1 Cr per month) in RO operation cost. However, there will be an additional cost for the increased flow of raw feed seawater.

Table 31: Projections for different RO membrane configurations

Chemical (NaOH) cost per kg ₹ 45

105 mg/L is the expected TDS addition by remineralization INR/USD = ₹ 76

Arrangement	Condition	TDS (ppm)	Temp, °C	Avg age	Permeate Boron (ppm)	Soda dosing (ppm)	Permeate TDS (ppm)	TDS product	Test @ Hardness 80	Pressure, Bar	HP Energy Cost/year (MUSD)	Chemicals Cost/year (MUSD)	Total Cost/year (MUSD)	Saving/year (MUSD)
								Hardness -	105					
Run with RO recovery @ 46%														
8HR	Max	39000	31.5	3.5	0.99	0	306	411	OK <500					
	Avg	35942	28.3	3.5	0.75	0	245	350	< 450	60.9	30.94	0	30.9	1.0
6 HR + 2 LE	Max	39000	31.5	3.5	0.95	4.5	337	442	OK <500					
	Avg	35942	28.3	3.5	0.87	0	270	375	< 450	59.7	30.33	0.0	30.3	0.4
3 HR + 5 LE	Max	39000	31.5	3.5	0.98	7.7	385	490	OK < 500					
	Avg	35942	28.3	3.5	0.96	2	308	413	< 450	58.1	29.51	0.38	29.89	**Base**
2 HR + 6 LE	Max	39000	31.5	3.5	0.98	8.9	400	505	> 500					
	Avg	35942	28.3	3.5	0.96	2.9	321	426	< 450	57.6	29.26	0.55	29.81	-0.1
Run with RO recovery @ 45%														
3 HR + 5 LE	Max	39000	31.5	3.5	0.97	8.9	380	485	OK < 500					
	Avg	35942	28.3	3.5	0.98	1.2	299	404	< 450	56.8	28.85	0.23	29.08	-0.4
Run with RO recovery @ 44%														
3 HR + 5 LE	Max	39000	31.5	3.5	0.96	7.7	374	479	OK <500					
	Avg	35942	28.3	3.5	0.99	1.2	303	408	< 450	57.4	29.16	0.23	29.39	-0.7

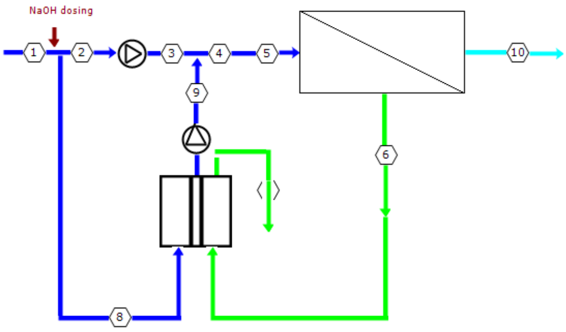
Due to the above saving in operating cost, PMC recommends the 3 HR + 5 LR membrane configuration for the RO system. DPR and JICA have recommended only high rejection (HR) membranes for the RO system. The RO projections for this membrane arrangement (3 HR + 5 LR) with max feed seawater quality (TDS 39000 mg/l, temperature 31.5 °C and Boron 3.8 mg/l) are presented below.

3 high rejection + 5 low rejection membranes @ 46% recovery – max seawater quality

Project name : PERUR 400MLD | Temperature : 31.5 °C | Date : 28/06/2020

Calculated by : Laurent MORILLON | Element age, P1 : 3.5 years | Version : 2.228.86 %

Permeate Throttling (Variable), Hybrid, Pressure/Work Exchanger



	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2287	1064	1064	2287	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	62.6	62.6	62.6	60.8	0	0	62.6	1.50
TDS (mg/l)	39010	39012	39012	39744	39744	73197	71830	39012	40380	386
Hardness as CaCO3	6323	6323	6323	6443	6443	11912	11689	6323	6547	15.1
Cl	21560	21560	21560	21964	21964	40462	39706	21560	22316	225
B	3.80	3.80	3.80	3.85	3.85	6.30	6.20	3.80	3.90	0.977
pH	8.00	8.40	8.40	8.40	8.40	8.44	8.44	8.40	8.40	7.16

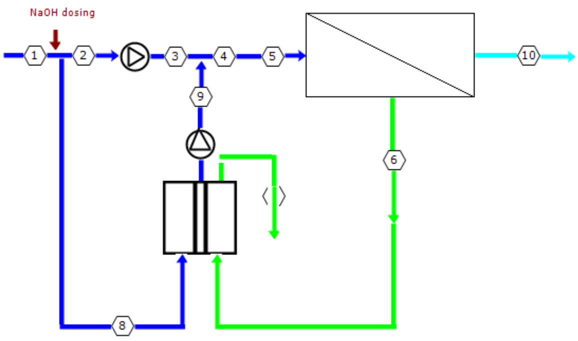
3 high rejection + 5 low rejection membranes @ 45% recovery – max seawater quality

Flow Diagram

Project name : PERUR 400MLD | Temperature : 31.5 °C | Date : 28/06/2020

Calculated by : Laurent MORILLON | Element age, P1 : 3.5 years | Version : 2.228.86 %

Permeate Throttling (Variable), Hybrid, Pressure/Work Exchanger

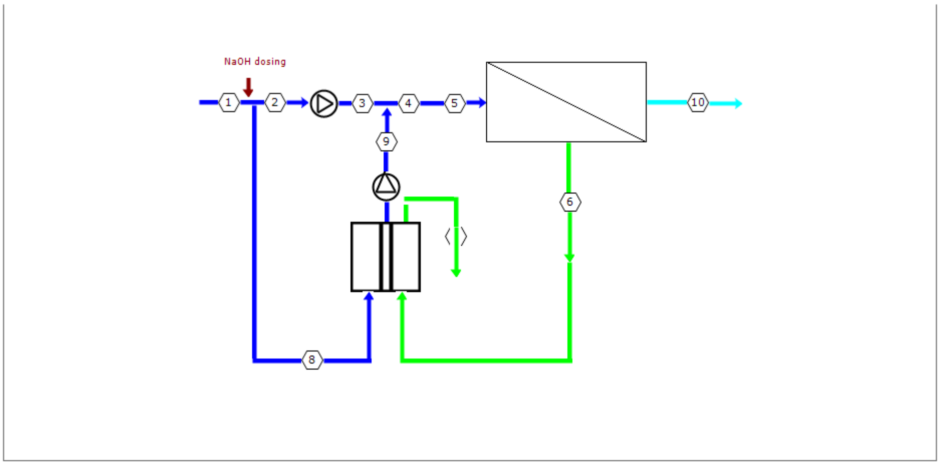


	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2338	1064	1064	2338	2338	1286	1286	1273	1273	1052
Pressure (bar)	0	0	61.8	61.8	61.8	60.0	0	0	61.8	1.50
TDS (mg/l)	39010	39012	39012	39728	39728	71864	70550	39012	40327	380
Hardness as CaCO3	6323	6323	6323	6440	6440	11694	11479	6323	6538	14.8
Cl	21560	21560	21560	21956	21956	39725	38999	21560	22287	221
B	3.80	3.80	3.80	3.85	3.85	6.21	6.11	3.80	3.90	0.969
pH	8.00	8.40	8.40	8.40	8.40	8.43	8.43	8.40	8.40	7.16

3 high rejection + 5 low rejection membranes @ 44% recovery – max seawater quality

Project name : PERUR 400MLD | Temperature : 31.5 °C | Date : 28/06/2020
Calculated by : Laurent MORILLON | Element age, P1 : 3.5 years | Version : 2.228.86 %

Permeate Throttling (Variable), Hybrid, Pressure/Work Exchanger



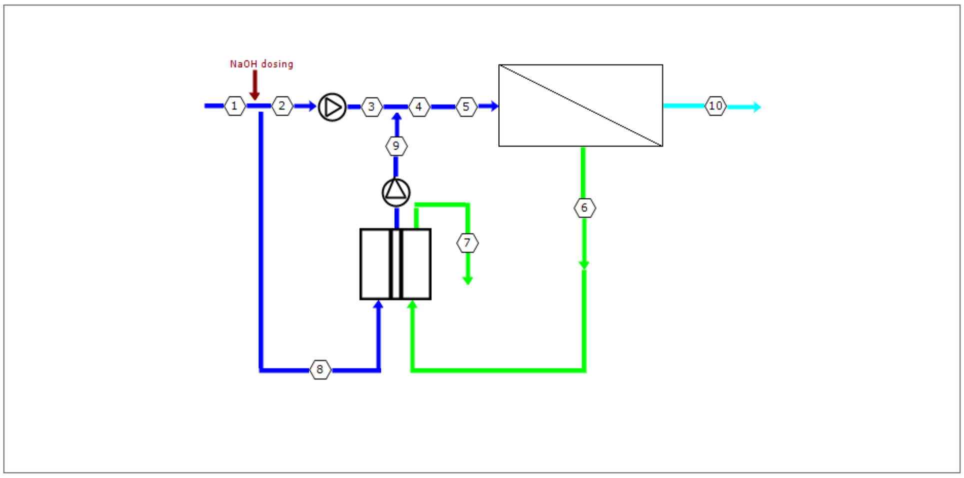
	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2391	1065	1065	2391	2391	1340	1340	1326	1326	1052
Pressure (bar)	0	0	61.0	61.0	61.0	59.1	0	0	61.0	1.50
TDS (mg/l)	39010	39012	39012	39712	39712	70542	69280	39012	40274	374
Hardness as CaCO3	6323	6323	6323	6438	6438	11477	11271	6323	6529	14.6
Cl	21560	21560	21560	21947	21947	38994	38297	21560	22257	218
B	3.80	3.80	3.80	3.85	3.85	6.12	6.03	3.80	3.89	0.962
pH	8.00	8.40	8.40	8.40	8.40	8.42	8.42	8.40	8.40	7.15

3 high rejection + 5 low rejection membranes @ 46% recovery – max seawater flow & quality

Flow Diagram

Project name : PERUR 400MLD | Temperature : 31.5 °C | Date : 16/02/2021
Calculated by : Dr. Ghulam Mustafa | Element age, P1 : 3.5 years | Version : 2.228.86 %

Permeate Throttling (Variable), Hybrid, Pressure/Work Exchanger



	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2349	1093	1093	2349	2349	1269	1269	1257	1257	1081
Pressure (bar)	0	0	62.9	62.9	62.9	61.1	0	0	62.9	1.50
TDS (mg/l)	39000	39002	39002	39733	39733	73192	71825	39002	40369	375
Hardness as CaCO3	6323	6323	6323	6443	6443	11913	11689	6323	6547	14.6
Cl	21557	21557	21557	21961	21961	40462	39706	21557	22313	219
B	3.80	3.80	3.80	3.85	3.85	6.23	6.13	3.80	3.90	1.05
pH	8.00	8.30	8.30	8.30	8.30	8.36	8.36	8.30	8.30	7.05

The above projection is based on the maximum production during operation to compensate for the loss of production during 3% unavailability of the plant. Minimum guaranteed availability of the plant is 97%. The details of the RO projections are given in **Annexure 5**.

6.5.3.4 Test of Hybrid configuration for TDS 41000 mg/l

There is a concern for the increase of seawater TDS up to 41000 mg/l. To check the suitability of the selected RO membrane arrangement (3HR + 5 LR) in this condition of elevated seawater TDS, RO projections were also run for the following cases.

i. Seawater TDS 41000 mg/l, temperature 31.5 °C, 46% recovery
ii. Seawater TDS 41000 mg/l, temperature 31.5 °C, 44% recovery

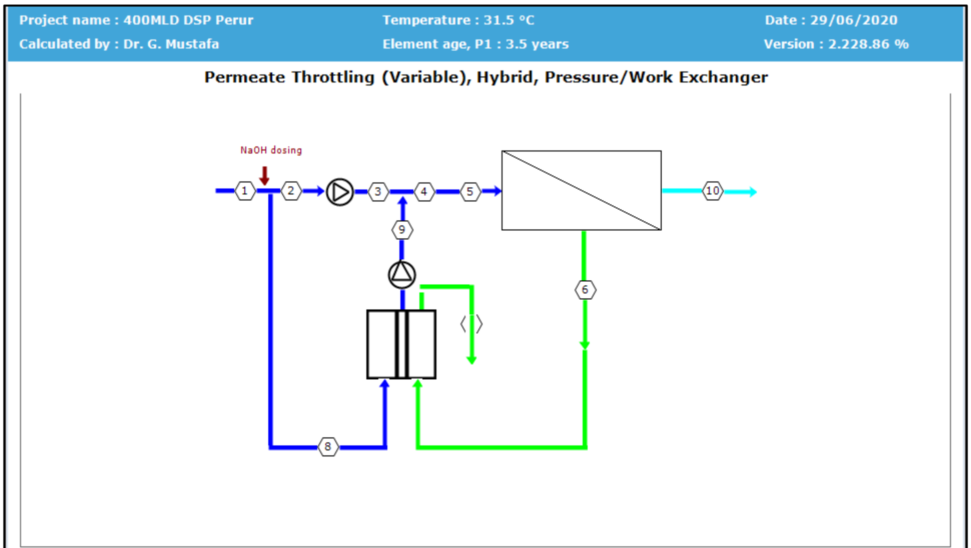
The projection results are presented below in Table 32.

Table 32: Projections for 3HR + 5LR membrane configurations with feed TDS 41000 mg/l

Arrangement	Condition	TDS (ppm)	Temp, °C	avg age	Permeate Boron (ppm)	Soda dosing (ppm)	Permeate TDS (ppm)	TDS product
Recovery 46%								
3 HR + 6LE	High Max	41000	31.5	3.5	0.96	7.7	410	509
Recovery 44%								
3 HR + 6LE	High Max	41000	31.5	3.5	0.95	7.7	397	496

The above results indicate that even in the case of very high TDS up to 41000 mg/l, the 3HR + 5LR membrane configuration is suitable to maintain the product TDS around 500 mg/l when operated at the reduced recovery of 44%. It is to be noted that this estimate is based on hardness = 80 mg/l as $CaCO_3$. The product water TDS can also be maintained within 500 mg/l by reducing hardness by 10 mg/l. There is a maximum hardness limit of 200 mg/l as $CaCO_3$ in drinking water but no minimum threshold of hardness as per CPHEEO drinking water guidelines. The short RO projection for operation under these conditions of high TDS is presented below. The detailed RO projections have been provided in **Annexure 5.**

3 high rejection + 5 low rejection membranes @ 46% recovery – TDS of 41000 mg/l

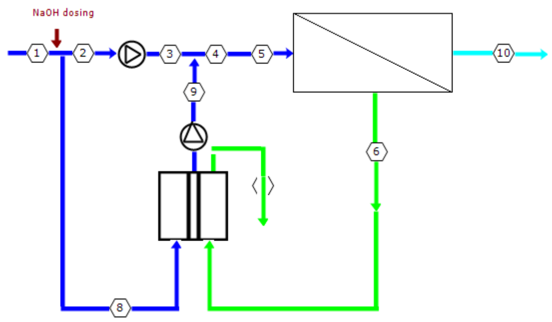


	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2287	1064	1064	2287	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	66.3	66.3	66.3	64.5	0	0	66.3	1.50
TDS (mg/l)	40997	41000	41000	42177	42177	77679	75479	41000	43200	410
Hardness as CaCO3	6733	6733	6733	6928	6928	12808	12443	6733	7097	16.3
Cl	22755	22755	22755	23409	23409	43119	41898	22755	23977	240
B	3.80	3.80	3.80	3.88	3.88	6.37	6.21	3.80	3.95	0.959
pH	8.00	8.40	8.40	8.40	8.40	8.46	8.46	8.40	8.40	7.17

3 high rejection + 5 low rejection membranes @ 44% recovery – TDS -41000 mg/l

Project name : 400MLD DSP Perur	Temperature : 31.5 °C	Date : 29/06/2020
Calculated by : Dr. G. Mustafa	Element age, P1 : 3.5 years	Version : 2.228.86 %

Permeate Throttling (Variable), Hybrid, Pressure/Work Exchanger



	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2391	1064	1064	2391	2391	1340	1340	1326	1326	1052
Pressure (bar)	0	0	64.5	64.5	64.5	62.7	0	0	64.5	1.50
TDS (mg/l)	40997	41000	41000	42126	42126	74828	72798	41000	43029	397
Hardness as CaCO3	6733	6733	6733	6919	6919	12334	11998	6733	7069	15.7
Cl	22755	22755	22755	23380	23380	41536	40410	22755	23882	232
B	3.80	3.80	3.80	3.88	3.88	6.18	6.04	3.80	3.94	0.944
pH	8.00	8.40	8.40	8.40	8.40	8.44	8.44	8.40	8.40	7.15

6.5.3.5 Projection performed in DPR:

In DPR, RO projections have been performed with SW30-XHR membranes (high rejection model of Filmtec (DOW))

Projections are run with maximum TDS @ 38020 mg/l, maximum Boron @ 3.43 mg/l; most of the projections were also run at pH@8.2.

In such a condition as above, permeate Boron and TDS thresholds are easily achieved with a high rejection membrane from any supplier. However, the maximum RO feed pressure value being @ 61.5 bars with our selected configuration compared to 63.91 bars with Case 3-DPR, which will result in a saving of operating cost by about 1 million USD per annum.

6.5.3.6 Summary of Hybrid Membrane Configuration

RO projection was conducted at average feed water condition (TDS- 35942 mg/l) to check the product water quality over 5 years of operation using a hybrid membrane. The condition of the test was as follows:

- Test at the average seawater temperature, i.e. 28.3 °C and at the subsequent 1 °C increase in temperature up to 31.3°C.
- The RO seawater feed pH is maintained at 8.4 to bring the boron concentration below 1 mg/l in RO permeate.
- The permeate hardness from 11 to 16 mg/l as CaCO3 has been taken into account in maintaining the product seawater hardness within 80 mg/l as CaCO3.
- The projection is run at 46% recovery.
- Table 33 below presents the summarised details of the parameters and permeate water quality. Apart from TDS and feed pressure, the table includes the concentrations of Ca, Mg, Cl and Boron.

Table 33: RO Projections for 3HR + 5LR membrane configurations with average feed quality

Feed Temperature (°C)	Membrane age (years)	Permeate recovery (%)	Feed pH	Feed Pressure (bar)	Permeate Flow (m^3/h)	Permeate TDS	Product TDS	Hardness in RO permeate	Remineralization ppm addition	Ca	Mg	Cl	Boron	System Sp. energy (kwh/m^3)
28.3	1	46	8.4	56.3	1052	254.7	354.1	11.0	99.4	0.81	2.18	147.96	0.69	1.97
28.3	2	46	8.4	57	1052	276.1	374.2	11.9	98.1	0.88	2.36	160.38	0.75	1.99
28.3	3	46	8.4	57.9	1052	299.1	395.7	12.9	96.6	0.95	2.56	173.72	0.81	2.03
28.3	4	46	8.4	58.5	1052	318.4	413.8	13.7	95.4	1.01	2.72	184.94	0.86	2.05
28.3	5	46	8.4	59.4	1052	339.3	433.4	14.6	94.1	1.08	2.90	197.08	0.91	2.08
29.3	1	46	8.4	56.2	1052	265.5	364.2	11.4	98.7	0.84	2.27	154.22	0.72	1.97
29.3	2	46	8.4	56.9	1052	287.8	385.2	12.4	97.4	0.91	2.46	167.15	0.78	1.99
29.3	3	46	8.4	57.5	1052	309.8	405.8	13.3	96.0	0.98	2.65	179.97	0.83	2.01
29.3	4	46	8.4	58.3	1052	331.7	426.3	14.3	94.6	1.05	2.83	192.70	0.89	2.04
29.3	5	46	8.4	59.2	1052	353.5	446.8	15.2	93.3	1.12	3.02	205.31	0.95	2.07
30.3	1	46	8.4	56.2	1052	276.7	374.7	11.9	98.0	0.88	2.36	160.70	0.75	1.96
30.3	2	46	8.4	56.8	1052	299.8	396.4	12.9	96.6	0.95	2.56	174.17	0.81	1.99
30.3	3	46	8.4	57.4	1052	322.8	418.0	13.9	95.2	1.02	2.76	187.49	0.87	2.01
30.3	4	46	8.4	58.2	1052	345.6	439.3	15.0	93.7	1.10	2.97	201.19	0.94	2.04
30.3	5	46	8.4	59	1052	368.2	460.6	15.9	92.4	1.17	3.15	213.86	0.98	2.06
31.3	1	46	8.4	56.1	1052	288.2	385.5	12.4	97.3	0.91	2.46	167.42	0.77	1.96
31.3	2	46	8.4	56.7	1052	312.3	408.1	13.5	95.8	0.99	2.67	181.43	0.84	1.98
31.3	3	46	8.4	57.3	1052	336.2	430.5	14.5	94.3	1.07	2.87	195.29	0.90	2
31.3	4	46	8.4	58.3	1052	362	454.7	15.6	92.7	1.15	3.09	210.29	0.97	2.04
31.3	5	46	8.4	58.8	1052	383.4	474.8	16.5	91.4	1.22	3.28	222.69	0.99	2.06

The trend of TDS and Boron over 5 operating years at different temperatures from average to the maximum is given below in Figure 24 and Figure 25.

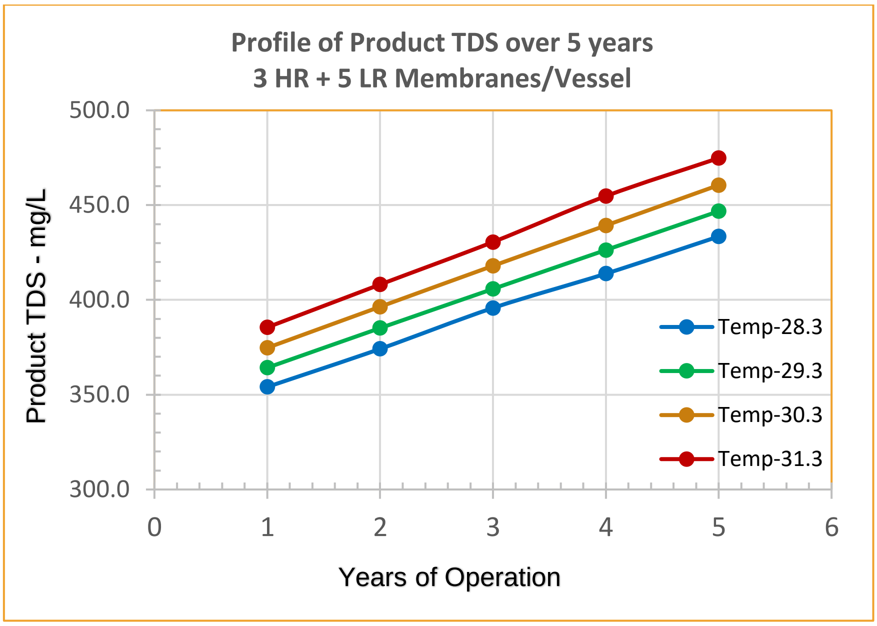


Figure 24: Trend of product TDS at various temperature and average feed seawater quality

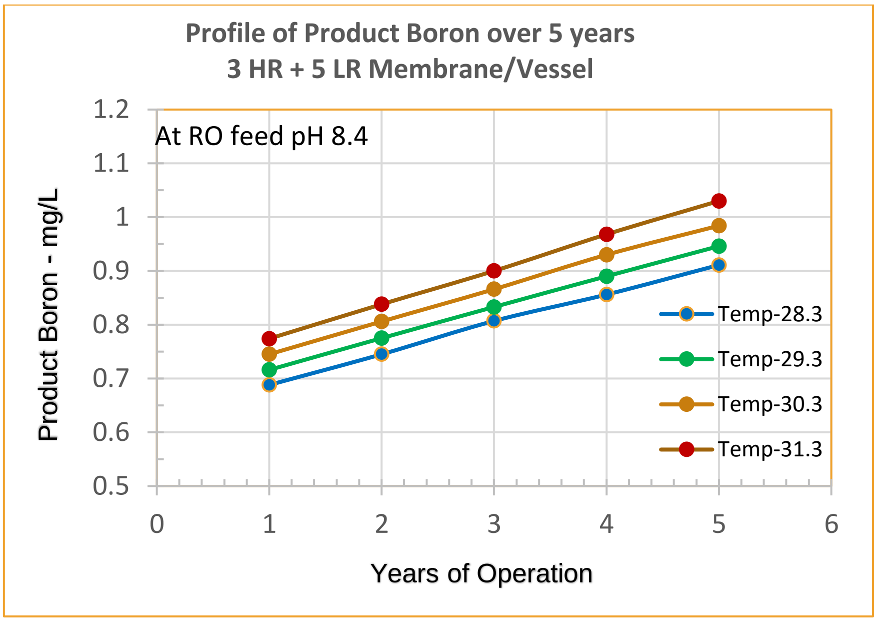


Figure 25: Trend of product Boron at various temperature and average feed seawater

The above trends presented in Table 33 and in Figures 24 & 25 indicate that the arrangement of 3 high rejection and 5 low rejection membrane per vessel can maintain the product water quality over the period of 5 years in terms of TDS, Boron and chloride concentration and that the specific energy consumption for RO system is around 2 kWh/m3. This increase in TDS is based on a very conservatively high (10%) increase in TDS of membrane per year. Boron level can be maintained within 1 mg/l as needed by adjusting feed pH.

6.5.4 SWRO configuration

DPR and JICA report have recommended train configuration (16 trains), and so far, the above membrane projections were performed according to this scheme. Train configuration commonly offers a plant availability of 94-95%. With one stand-by train, also recommended by DPR and JICA, availability can reach 96-97%. As the 400 MLD plant will be split into 2 half plants, the one-half plant will be provided with 9 trains (8 trains in operation and 1 train standby) while another with 8 trains – all operating. Another option is to provide 1 standby train per half plant.

The train configuration is presented in Figure 26 below.

6.5.4.1 Conventional "train" configuration

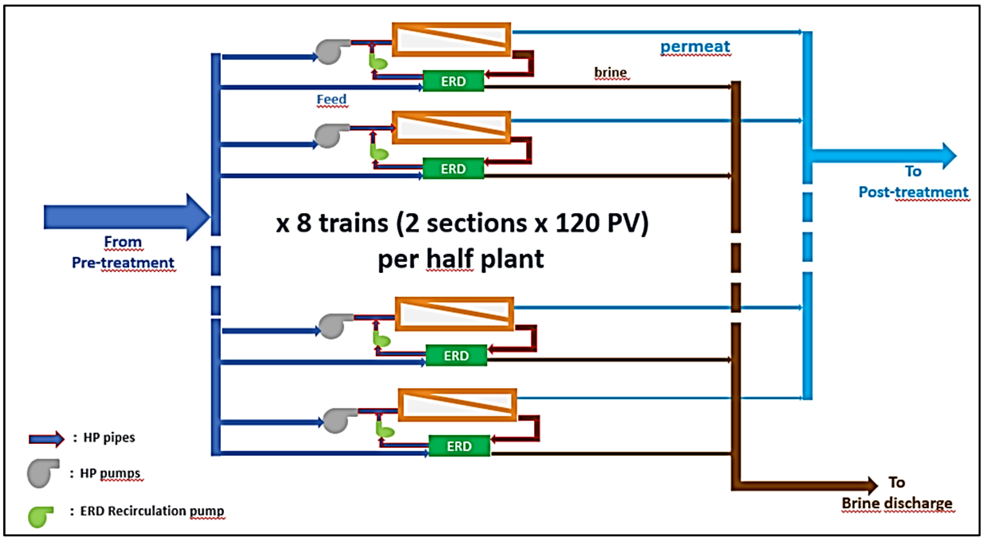


Figure 26: Train configuration option for the Perur Project (one-half plant)

6.5.4.2 An alternate configuration for the Perur DSP 3-Center design (for baseload operation)

Nowadays, a lot of existing plant is designed to supplement existing sources. Therefore, those plants do not need to get the flexibility to follow the diurnal and monthly water demand and are operated at constant production capacity. The main target of these plants is to achieve an optimum (lowest) tariff with the highest availability factor.

An answer to the previous paradigm is the 3-Center design configuration allowing them to get a high availability factor (>97%) with acceptable flexibility. With this configuration, the RO skids, the High-Pressure Pumps (HPP) and the Energy Recovery Devices (ERD) are no longer organized in individual RO trains but associated in "center" as presented in Figure 27.

- **Pressure Center**: all operating HP pumps (and HP Booster pumps not draft on the blow scheme) + one online standby pump together. In case of failure or preventive maintenance within the HP or HP booster pumps, the standby equipment can take over an operating pump, and the **CAPACITY IS MAINTAINED.**

- **Membrane Center**: all pressure vessels organised in section (with isolation valves) together. The size of the membrane section is limited for CIP and flushing operation efficiency (about 120-150 PV). All sections are operated at the same flux and recovery. In case of a leak or preventive maintenance (CIP, membranes replacement), the section is isolated, and its flow balanced to the other sections. Flux is slightly increased (9%), which shall be taken into consideration at the design stage. **CAPACITY IS MAINTAINED.**

- **ERD (+ recirculation pumps) Center:** all ERD and recirculation pumps are operating in parallel with available online standby. In case of failure or preventive maintenance within the ERD or a recirculation pump, the standby equipment can take over, and the **CAPACITY IS MAINTAINED.**

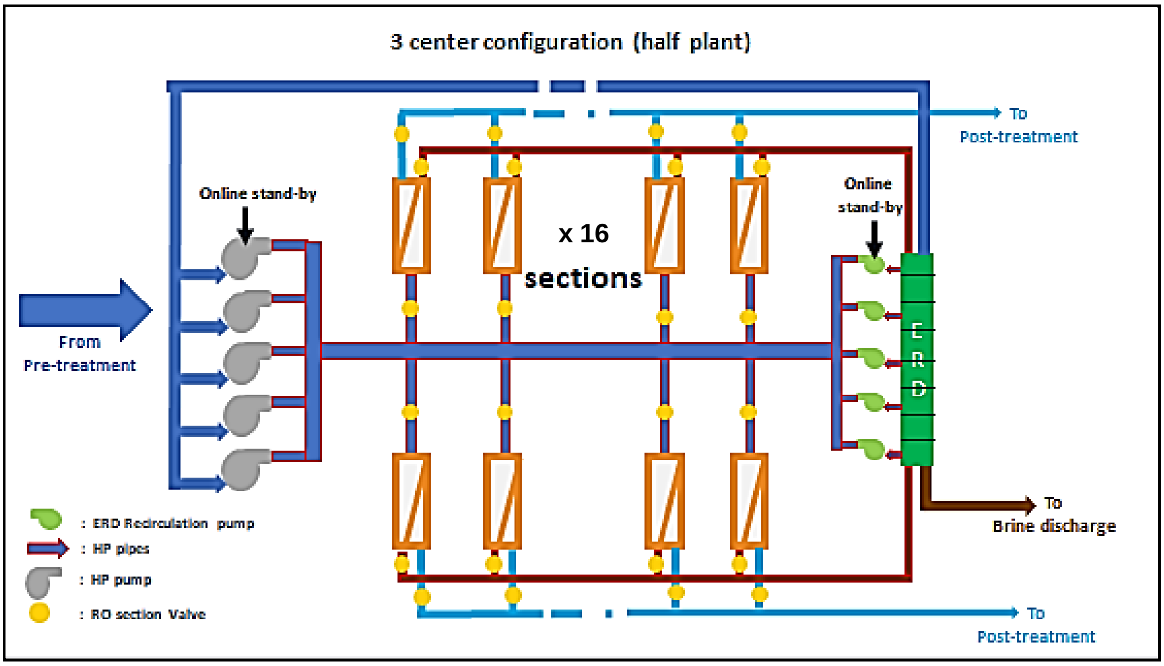


Figure 27: 3-Centre Train configuration option for the Perur Project (one-half plant)

Because of this specific design, pumping equipment is significantly larger than in a train configuration (ratio 3 or 4 in the case of Perur), which means:

- A significant energy saving in overall pumping equipment achieved by implementing a small number of large-capacity pumps (HPP, HP, ERDP: efficiency from 80%-85% up to 88%-90%).
- Less equipment for same capacity: **Capex saving**
  Most of the desalination plants installed in Israel (one of the top Desalination country) had implemented the 3-center design with great success and efficiency. Experience is now 15 years with Ashkelon (2005).

All these plants are still very competitive, as demonstrated in the Table-34 below, issued by the Israeli Water Authority.

Table 34: Cost of water in plants with 3-Centre Design

SWRO Prices

	Ashkelon 2005	Palmahim 2007	Hadera 2009	Sorek 2013	Ashdod 2013
Mm³/Year AFY (x 10³)	120 97	45 36	127 103	150 122	100 81
Water Price US$/m³ US$/Kgal	0.81 3.07	0.88 3.32	0.73 2.78	0.54 2.04	0.65 2.46

6.5.4.3 Conventional train design vs. 3-Center design (Comparison)

The comparison of conventional design with the 3-centre design concerning Capex, energy, availability and flexibility of capacity augmentation is presented in Table 35 below.

Table 35: Comparison of Conventional design with 3-Centre design

Sl. No.	Item	Conventional Design	3-Centre Design
1	Capital cost		At least 10-15% less capital cost – saving in the order of USD 8 Million
2	Energy Cost		-2% to -3% (up to USD 0.5 -1.0 Million saving per year)
3	Availability	> 95%; 97% achievable with one standby train	>97% (standby online)
4	Flexibility in capacity increase	7% with 16 lines	12.5% to 17%

For baseload operation, the 3-Center design offers many advantages. Even if the addition of a spare train (conventional design) reduces the availability gap between the 2 designs, it should be noticed that the price to pay for it will increase the Capex gap.

If the 3-Center design operates at constant flux, the flexibility will be lower than with a conventional design. But it should be noted that most of the 3-Center design plants operate at variable flux, around their maximum capacity (higher output delivery in summer).

Based on quotations received from a supplier, precise cost computation has been done to assess the saving related to the Perur DSP. (see later in this section)

6.5.4.4 Pressure Center design – An alternative design to 3-center design:

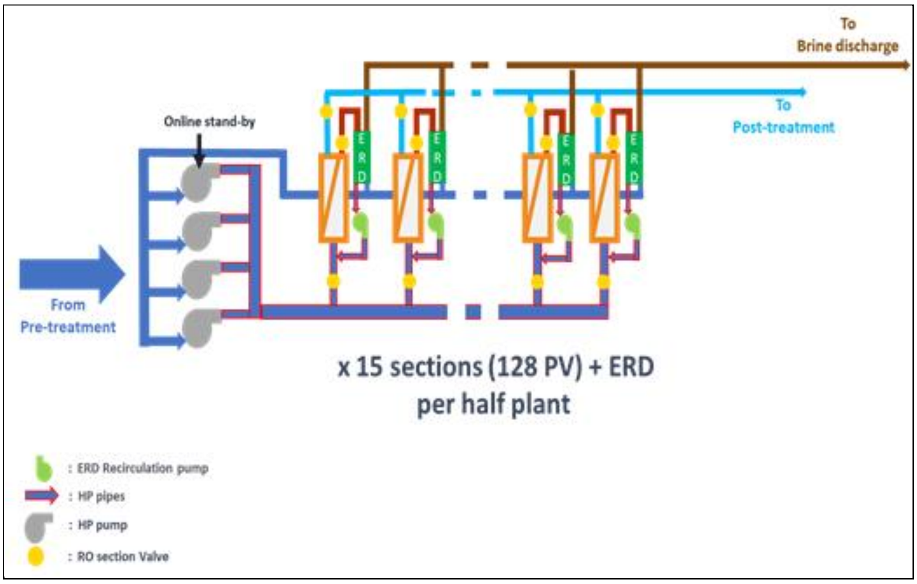


Figure 28: Pressure Centre Train configuration (one-half plant)

This design is also implemented within the large plants (Ashdod 380 MLD). The above sketch displays such a design for the Perur project. Without offering all the advantages of the 3-center design, in particular its highest availability, the main advantages of a pressure design are:

- Large pumping equipment providing energy efficiency (similar to 3- center design)
- Cost-effective (similar to 3-center design)

6.5.4.5 CAPEX and Energy comparisons (using Supplier's pump offer)

Pump offers were received from supplier Flowserve for 16 train configuration, 8 and 6 HP operating pumps for 3 center design and pressure center configurations (same pumping equipment). Capex is assessed not only for the basic capacity but also for the stand by capacity (achieving the same availability).

In parallel, quotations were also received for Energy Recovery Device suppliers (ERI and Calder (Flowserve group)); There is a large CAPEX advantage of the Dweer equipment (Calder) on the ERI equipment (5.5 MUSD vs 8.16 MUSD).

A first quick comparison will be performed between 6 and 8 operating HP pumps (center configuration), then the best option will be kept and compared for the 3 different configurations (16 train, 3 center design and pressure center design)

Table 36: Capex for 8 pumps–3 Centre design for RO system

8 Trains - 3 Centre Design								
Pump service	Pump model	Unit	Flow (m3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
Booster feed HP	400-DS-553	8	2125	35	84.0%	90000	0.72	6.12
HPP	10x22A DVSH	8	2125	526	88.1%	500000	4.00	34.00
Booster feed ERD	400-DS-55	8	2474	25	83.1%	90000	0.72	6.12
ERD recirculation	18HHPX22A	8	2495	35	88.0%	167000	1.34	11.36
						Total pump	**6.78**	**57.60**
ERD	D-1550	56	356		19936	81200	4.55	38.65
						Total ERD	**4.55**	**38.65**
Membranes		30720				320	9.83	83.56
Pressure Vessels		3840				1500	5.76	48.96
						Total RO	**15.59**	**132.52**
Civil works (including RO building)		8				700000	5.60	47.60
RO trains support frame		32				200000	6.40	54.40
RO piping		8				500000	4.00	34.00
RO instrumentation and control		8				150000	1.20	10.20
						Total Misc.	**17.20**	**146.20**
						Grand Total	**44.11**	**374.97**

Table 37: Capex for 6 pumps–3 Centre design for RO system

6 Trains - 3 Centre Design								
Pump service	Pump model	Unit	Flow (m3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
Booster feed HP	400-DS-553	6	2834	48	84.5%	178000	1.07	9.08
HPP	10x22A DVSH	6	2834	513	89.2%	518000	3.11	26.42
Booster feed ERD	400-DS-55	6	3298	25	85.5%	115000	0.69	5.87
ERD recirculation	18HHPX22A	6	3326	35	89.0%	170000	1.02	8.67
						Total pump	**5.89**	**50.03**
ERD	D-1550	60	333			81200	4.87	41.41
						Total ERD	**4.87**	**41.41**
Membranes		30720				320	9.83	83.56
Pressure Vessels		3840	3840			1500	5.76	48.96
					Total RO	**15.59**	**132.52**	**132.52**
Civil works (including RO building)		6	6			900000	5.40	45.90
RO trains support frame		30	30			200000	6.00	51.00
RO piping		6				600000	3.60	30.60
RO instrumentation and control		6	6			180000	1.08	9.18
						Total Misc.	**16.08**	**136.68**
						Grand Total	**42.43**	**360.64**

From a CAPEX perspective, compared to 8 operating pumps, 6 operating HP pumps offers a saving of about INR 14.5 crores. The energy cost calculations for the two type (6 & 8 pump) of 3 centre design are carried out and presented below.

Table 38: Energy Cost for Operating of 8 pumps in 3 Centre design of RO system

8 Train				
Motor efficiency(%)	VFD efficiency(%)	kWh/day	kWh/year	Cr INR/year
96.5%	100.0%	48005	17521891	13.1
96.5%	98.0%	701913	256198145	192.1
96.5%	100.0%	40353	14728956	11
96.5%	97.0%	55466	20244986	15.2
Total		**845737**	**308693978**	**231.5**

Table 39: Energy Cost for Operating of 6 pumps in 3 Centre design of RO system

6 Train				
Motor efficiency(%)	VFD efficiency(%)	kWh/day	kWh/year	Cr INR/year
96.5%	100.0%	65461.5	23893453.4	17.9
96.5%	98.0%	676282.2	246843008.4	185.1
96.5%	100.0%	39212.7	14312618.5	10.7
96.5%	97.0%	53182.9	19411773.5	14.6
Total		**834139**	**304460854**	**228.3**

From an Energy perspective, compared to 8 operating pumps, 6 operating HP pumps in 3 center design offers a saving of INR 3.2 Cr per year, meaning INR 63.5 Crores in 20 years.

Therefore, 6 operating HP pumps offering both CAPEX and OPEX advantages is the selection of PMC for comparison of three RO skid configuration, i.e. Train configuration, 3-Centre configuration and Pressure Centre configuration below.

6.5.4.6 CAPEX comparisons - train configuration, 3 center design and pressure center design (with 6 pumps)

The comparison is performed about:

- the main process equipment to deliver the nominal capacity
- The additional standby process equipment to achieve the best availability of the system configuration
- Civil works (pump basement, RO building)

No manpower consideration about design, erection, commissioning, testing is included.

No electrical equipment is considered in the following comparison. However, it remains obvious that reducing the number of equipment while keeping the same implemented power will provide savings.

Energy cost estimated at 7.5 INR/kWh based on Nemmeli desalination plant expenses.

Dweer equipment (Calder) has been used for the below comparison due to the pump supplier's selection owing to its significant Capex advantage.

For the 16-train configuration, 2 stand train are considered (1 SB per half-plant) to achieve a plant availability of 98% or higher; special care shall be implemented to periodically flush the SB trains to avoid the development of corrosion of super duplex HP equipment. MIC (microbiological induced corrosion) may be very aggressive in stagnant water due to the lack of oxygen, especially with water temperature above 26°C, as monitored for the Perur plant.

Table 40: Capex for 16+2 (SB) Train Design

16 Trains Conventional Design								
Pump service	**Pump model**	**Unit**	**Flow (m3/h)**	**Head (m)**	**Efficiency (%)**	**Unit price (Euros)**	**Total price (MEuros)**	**CR INR**
Booster feed HP	3K10x8-16HRV	16	1063	30	81.6%	49500	0.79	6.73
HPP	8x15DMX-3	16	1063	531	87.9%	290000	4.64	39.44
Booster feed ERD	ME 300-400	16	1237	25	84.3%	66000	1.06	8.98
ERD recirculation	12HHPX15A	16	1247	35	87.9%	69000	1.10	9.38
						Total pump	**7.59**	**64.53**
ERD	D-1550	64	312			81200	5.20	44.17
						Total ERD	**5.20**	**44.17**
Membranes	30720					320	9.83	83.56
Pressure Vessels		3840				1500	5.76	48.96
						Total RO	**15.59**	**132.52**
Civil works (including RO building)		16				350000	5.60	47.60
RO trains support frame		32				200000	6.40	54.40
RO piping		16				400000	6.40	54.40
RO instrumentation and control		16				100000	1.60	13.60
					Total Misc. RO		**20.00**	**170.00**

16 Trains Conventional Design								
Pump service	Pump model	Unit	Flow (m3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
						TOTAL	48.38	411.22
Standby for 16 Train Configuration								
Booster feed HP	3K10x8-16HRV	2	1 063	30	81.6%	49500	0.10	0.84
HPP	8x15DMX-3	2	1 063	531	87.9%	290000	0.58	4.93
Booster feed ERD	ME 300-400	2	1 237	25	84.3%	66000	0.13	1.12
ERD recirculation	12HHPX15A	2	1 247	35	87.9%	69000	0.14	1.17
						Total pump	0.95	8.07
ERD	D-1550	8				81200	0.65	5.52
						Total ERD	0.65	5.52
Membranes		3840				320	1.23	10.44
Pressure Vessels		480				1500	0.72	6.12
						Total RO	1.95	16.56
Civil works (including RO building)		2	2			350000	0.70	5.95
RO trains support frame		4	4			200000	0.80	6.80
RO piping		2				400000	0.80	6.80
RO instrumentation and control		2	2			100000	0.20	1.70
						Total Misc. RO	2.50	21.25
						TOTAL SB	6.05	51.40
						GRAND TOTAL	54.43	462.63

For the 3 center design (6 operating pump) configuration, 2 standby sets of pumps are considered (1 SB set per half-plant) to achieve a plant availability of 98% or higher; this configuration associated with Dweers offers an internal standby capacity of 2 Dweer units per half-plant, therefore does not require any additional Dweers SB units (unit flow from 333 up 356 m³/h); additional membranes and pressure vessel are installed (see standby section) to allow stoppage of one membrane section per half-plant for maintenance without impairing the nominal capacity of each half-plant (nominal flux is therefore reduced to 13,0 lmh, and N-1 flux is equal to 13,9 lmh, which is kept reasonable). Such configuration allows quiet routine maintenance all over the year for the membranes (CIP, replacement), implementing a risk of corrosion due to stagnant water (as frequently met with idle SB trains).

Table 41: Capex for 6-pumps – 3 Centre Design with Standby

6-pump – 3 Centre Design								
Pump service	Pump model	Unit	Flow (m3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
Booster feed HP	400-DS-704	6	2834	48	84.5%	178000	1.07	9.08
HPP	14x22C DVSH	6	2834	513	89.2%	518000	3.11	26.42
Booster feed ERD	400-DS-603	6	3298	25	85.5%	115000	0.69	5.87
ERD recirculation	18HHPX22A	6	3226	35	89.0%	170000	1.02	8.67
						Total pump	5.89	50.03
ERD	D-1550	60	333			81200	4.87	41.41
						Total ERD	4.87	41.41
Membranes		30720				320	9.83	83.56
Pressure Vessels		3840				1500	5.76	48.96
						Total RO	15.59	132.52
Civil works (including RO building)		6				900000	5.40	45.90
RO trains support frame		30				200000	6.00	51.00
RO piping		6				600000	3.60	30.60
RO instrumentation and control		6				180000	1.08	9.18
						Total Misc. RO	16.08	136.68

6-pump – 3 Centre Design								
Pump service	Pump model	Unit	Flow (m3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
							42.43	360.64
Standby for 6 Pump 3-Centre Configuration								
Booster feed HP	400-DS-704	2	2834	48	84.5%	178000	0.36	3.03
HPP	14x22C DVSH	2	2834	513	89.2%	518000	1.04	8.81
Booster feed ERD	400-DS-603	2	3298	25	85.5%	115000	0.23	1.96
ERD recirculation	18HHPX22A	2	3226	35	89.0%	170000	0.34	2.89
						Total pump	**1.96**	**16.68**
ERD	D-1550	0	312			81200	0	0
						Total ERD	**0**	**0**
Membranes		960				320	0.31	2.61
Pressure Vessels		120				1500	1500	0.18
						Total RO	**0.49**	**4.14**
Civil works (including RO building)		0.5				900000	0.45	3.83
RO trains support frame		0.5				200000	0.10	0.85
RO piping		0.5				600000	0.30	2.55
RO instrumentation and control		0.5				180000	0.09	0.77
					Total Misc. RO		**0.94**	**7.99**
							3.39	**28.81**
					GRAND TOTAL		**45.82**	**389.45**

For the pressure center design (6 operating pump) configuration, 2 standby sets of pumps are considered (1 SB set per half-plant) at Booster Feed HP pump, HP pump, Booster Feed ERD pump level; at ERD recirculation level, it not possible to install on-line standby, thus 2 spare units are kept in the warehouse. This configuration does not allow or hardly keeping the full capacity of the half-plant while maintaining the RO skids (CIP or membranes replacement). This configuration associated with EDR does not offer any internal stand by capacity per operating HP pump (less than one). Therefore 1 standby EDR equipment per operating HP pump is added (6 in total). It means that if 2 units related to the same HP pump simultaneously fail, the HP pump must stop. For a 3-center design HP pump to stop, 3 EDR units need to simultaneously fail on a single half-plant. For the above 3 reasons (ERD recirculation pump SB, no membrane SB, Dweer units SB less efficient), the availability is with this configuration is lower than with the 3-center configuration.

Table 42: Capex for 6-pump – Pressure Centre Design with Standby

6-pump – Pressure Centre Design								
Pump service	Pump model	Unit	Flow (m^3/h)	Head (m)	Efficiency (%)	Unit price (Euros)	Total price (MEuros)	CR INR
Booster feed HP	400-DS-704	6	2834	48	84.5%	178000	1.07	9.08
HPP	14x22C DVSH	6	2834	513	89.2%	518000	3.11	26.42
Booster feed ERD	400-DS-603	6	3298	25	85.5%	115000	0.69	5.87
ERD recirculation	18HHPX22A	6	3226	35	89.0%	170000	1.02	8.67
						Total pump	**5.89**	**50.03**
ERD	D-1550	60	333			81200	4.87	41.41
						Total ERD	**4.87**	**41.41**
Membranes		30720				320	9.83	83.56
Pressure Vessels		3840				1500	5.76	48.96
						Total RO	**15.59**	**132.52**
Civil works (including RO building)		6				900000	5.40	45.90
RO trains support frame		30				200000	6.00	51.00
RO piping		6				600000	3.60	30.60
RO instrumentation and control		6				180000	1.08	9.18

6-pump – Pressure Centre Design								
Pump service	**Pump model**	**Unit**	**Flow (m^3/h)**	**Head (m)**	**Efficiency (%)**	**Unit price (Euros)**	**Total price (MEuros)**	**CR INR**
					Total Misc. RO		**16.08**	**136.68**
							42.43	**360.64**
Standby for 6 Pump Pressure-Centre Configuration (in Warehouse)								
Booster feed HP	400-DS-704	2	2834	48	84.5%	178000	0.36	3.03
HPP	14x22C DVSH	2	2834	513	89.2%	518000	1.04	8.81
Booster feed ERD	400-DS-603	2	3298	25	85.5%	115000	0.23	1.96
ERD recirculation	18HHPX22A	2	3226	35	89.0%	170000	0.34	2.89
						Total pump	**1.96**	**16.68**
ERD	D-1550	6	312			81200	0.49	4.14
						Total ERD	**0.49**	**4.14**
Membranes		1536				320	0.49	4.18
Pressure Vessels		192				1500	0.29	2.45
						Total RO	**0.78**	**6.63**
Civil works (including RO building)		0.5				900000	0.45	3.83
RO trains support frame		0.5				200000	0.10	0.85
RO piping		0.5				600000	0.30	2.55
RO instrumentation and control		0.5				180000	0.09	0.77
					Total Misc. RO		**0.94**	**7.99**
							4.17	**35.43**
					GRAND TOTAL		**46.60**	**396.08**

6.5.4.7 Discussion and Recommendation

The summary of the capital and energy costs for conventional, 3-centre and pressure centre design are presented in Table-43 below.

Table 43: Comparison of CAPEX and Energy

SUMMARY Cost in Cr INR (MUSD)				
Configuration	**CAPEX (400 MLD)**	**CAPEX Standby**	**TOTAL CAPEX**	**Energy (Year)**
16 trains	411.22	51.40	462.63	232.2
	(54.11)	(6.76)	(60.87)	(30.55)
3 Center 6 pump	360.64	28.81	389.45	228.3
	(47.45)	(3.79)	(51.24)	(30.05)
Pressure Center 6 pump	360.64	35.43	396.08	228.30
	(47.45)	(4.66)	(52.12)	(30.05)

Table 44: All criteria comparison table

S. No.	Item	Conventional Design	3-Centre Design	Pressure Center
1	Capex	as reference	Saving of INR 73 Crores, i.e. USD 9.6 Million (not including saving on electrical/ automation equipment)	Similar to 3 center design
2	Efficiency (Energy)	as reference	Saving of INR 3.4 Crores, i.e. USD 0.45 Million.	Similar to 3 center design
3	Availability	>95%	>98% with extra membranes	>97%
		>97% achievable with standby train	(all standby online)	(standby in the warehouse)

4	Modularity	7% with 16 trains	12.5% to 17% (3 or 4 lines per half-plant)	12.5% to 17% (3 or 4 lines per half-plant)

The capital and operating cost of conventional Train configuration is always higher than the 3 centre/ pressure centre design. The capital cost of train configuration is about INR 60-70 crores higher while operating cost is about INR 3.85 crores/ year higher than that of 3 centre/ pressure design.

3 Center design is obviously the configuration that offers the lowest CAPEX, the lowest energy requirement and the highest plant reliability and availability.

IDE technologies have patented the 3 Center design in early 2000, and as per the recent information, this patent is no longer applicable. Legal, due diligence is necessary to get the precise situation of this patent. However, the PMC team will not take the responsibility to recommend a technology that may drastically reduce/cancel the competition among bidders. If the IDE part of the bidders, it may be allowed to present such configuration in an alternative offer but not in the main offer.

The Pressure center configuration requires slightly higher CAPEX and offers the same energy requirement compared to the 3 Center design configuration (same process equipment) with marginally lower availability. Compared to conventional train configuration, it offers a significant advantage in terms of Capex and Energy requirements; **therefore, it is the PMC recommendation**. However, it will be bidders’ choice to select the RO system configuration offering the overall low CAPEX and OPEX system.

6.5.5 SWRO Equipment specifications

The SWRO equipment specifications are given below.

Table 45: Booster Feed HP Pumps Design for Pressure Center Configuration (6 Pumps)

10. BOOSTER FEED HP PUMPS		Unit	Values	Comments
Number				
	Total	N	8	
	In operation	N	6	
	In online stand by	N	2	
	In warehouse	N		
Type		/	Mono-stage horizontal	
Material			Super duplex PREN>41	
Normal Design flow @ 46% recovery		m3/h	2836	
Flow rate during compensation mode and 42% recovery		m3/h	3191	
Discharge pressure		m	48	depend on HP NPSHr
VFD			NO	
Pump efficiency at the design point		%	84.5	
Motor efficiency at design load		%	96.8	
VFD efficiency		100% if No VFD	100.0	

NB the discharge pressure of the Booster Feed HP Pump (BFHPP) will be between 3.5 and 5 bars and will be selected to achieve the best hydraulic efficiency of the couple BFHPP + HP pump from the supplier proposals.

This double component (BFHPP + HPP) is responsible for a significant portion of the energy consumed at the plant. Its selection is of key importance to achieve the lowest specific energy consumption of the plant.

Table 46: HP Pumps Design for Pressure Center Configuration (6 Pumps)

11. HP PUMPS		Unit	Values	Comments
Number				
	Total	N	8	
	In operation	N	6	
	In stand by	N	2	
	In warehouse	N		
Type		/	horizontal split	
Material			Super duplex PREN>41	
Normal Design flow @ 46% recovery		m3/h	2811	
Flow rate during compensation mode and 42% recovery		m3/h	3191	
Discharge pressure – average seawater		m	570	Normal condition
VFD			YES	
Pump efficiency at the design point		%	89.2	
Motor efficiency at design load		%	96.8	
VFD efficiency		100% if No VFD	98.0	

Due to the very low TDS met during the monsoon season, the difference between maximum & minimum operating pressures (61.5 bars – 49.2 bars) is 12.3 bars which are quite significant and thus does not allow the BFHPP to be driven by a VFD (unless it delivers a large part of the feed pressure). Therefore, the HP pumps will be driven by variable speed drive (VFD), which is a costlier option since the HP pump motor will be fed in medium voltage.

The booster feed ERD pumps provide pre-treated water to the Energy Recovery Device (ERD). The feed pressure must be as low as possible while complying with the ERD design guidelines.

Table 47: Booster Feed ERD Pumps Design for Pressure Center Configuration (6 Pumps)

12. BOOSTER FEED ERD PUMPS		Unit	Value	Remarks
Number				
	Total	N	8	
	In operation	N	6	
	In stand by	N	2	
	In warehouse	N		
Type		/	Mono-stage horizontal	
Material			Super duplex PREN>41	
Normal Design flow		m^3/h	3263	
Flow rate during compensation mode (permeate 415 MLD)		m^3/h	3671	
Discharge pressure		m	25	
VFD			NO	
Pump efficiency at the design point			85.5	
Motor efficiency at design load			96.8	
VFD efficiency		100% if No VFD	100.0	

The ERD recirculation booster pumps compensate for the head losses among the ERD loop composed of membrane pressure vessels, ERD, brine HP pipes. They are driven by VFD to adjust the RO recovery.

Table 48: ERD Recirculation Booster Pumps Design for Pressure Center Configuration (6 Pumps)

13. ERD RECIRCULATION BOOSTER PUMPS		Unit	Value	Remarks
ERD RECIRCULATION PUMPS				
Number				
	Total	N	8	
	In operation	N	6	
	Online stand by	N	0	
	In warehouse	N	2	
Normal Design flow		m^3/h	3263	
Flow rate during compensation mode (permeate 415 MLD)		m^3/h	3671	
Differential pressure		m	26	
Inlet max pressure		bars	65	
VFD			YES	
Pump efficiency at the design point		%	89.0	
Motor efficiency at design load		%	96.8	
VFD efficiency		%	97.0	

Membrane selection was previously discussed; the following table presents the membrane array organisation. A total of 5120 membranes installed in 640 PV are fed from the same HP pump. As it is not possible to perform efficient flushing and chemical cleaning in more than 100-140 PV in a single operation, the 640 PV will be divided into 5 sections of 128 PV. Such an array, of course, does not affect the overall membrane flux of the plant, which is kept @ 13.4 LMH. The flux during the loss of flow compensation mode will be up to 13.8 LMH.

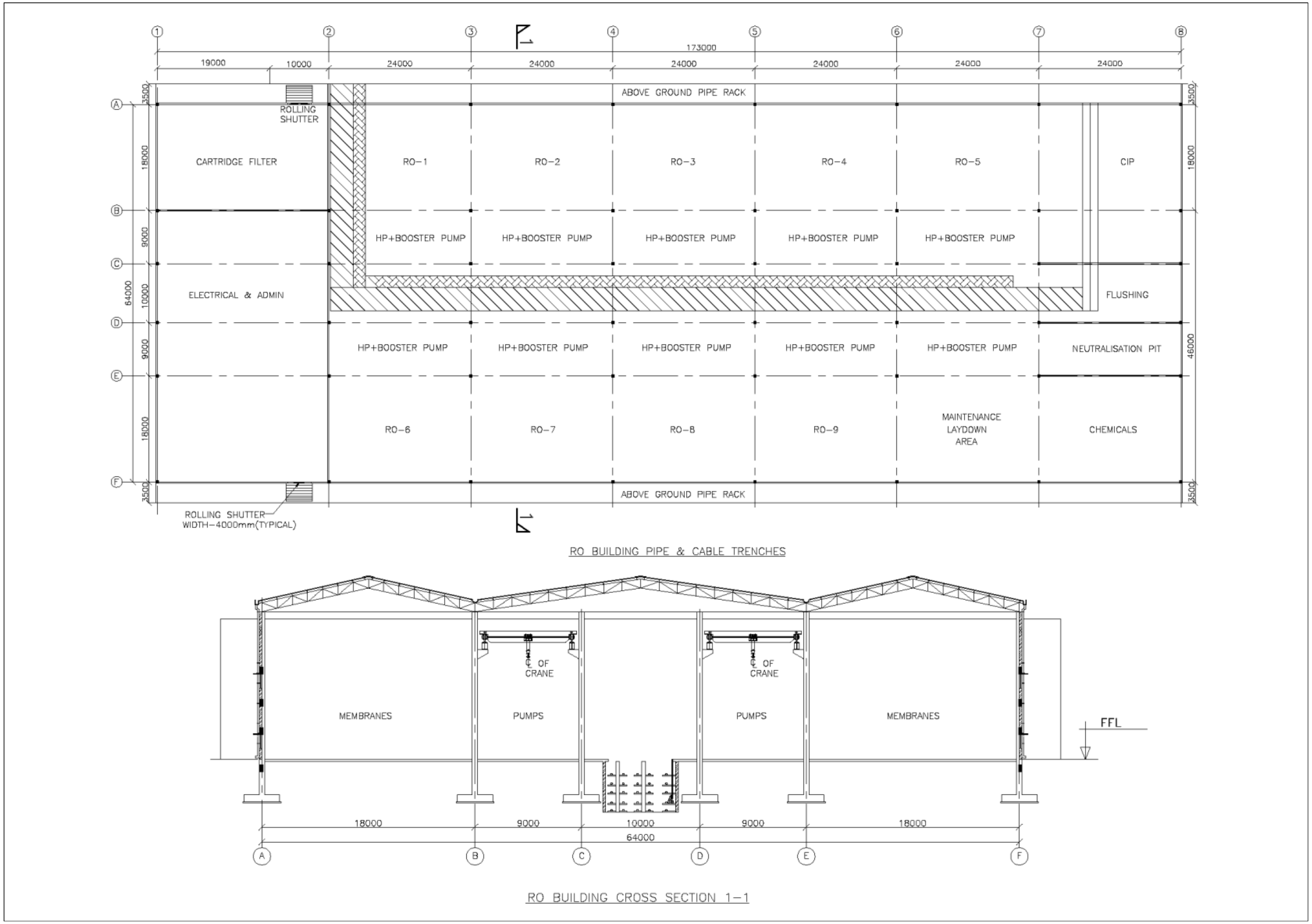
A total number of 1536 of membranes and 192 of PV (5% of the total capacity of the plant) will be required from the contractor and kept in the warehouse in case a reduction of flux is necessary to reduce fouling. All pipe headers for each section will be provided with an additional pressure vessel with an available connection to reduce permeate flux.

Table 49: Osmonic System for Pressure Center Configuration (6 Pumps)

14. OSMOSIS SYSTEM		Unit	Value	
Number of operating HP pumps		N	6	
Standby train		N		
Train specifications				
	Permeate	m3/h	2806	
	Recovery rate	%	46%	
	Concentrate	m3/h	3288	
	Feed	m3/h	6099	
Design criteria				
	TDS (average for design)	mg/l	**39000**	
	Temperature (average for design)	°C	**31.5**	
	pH	pH unit	**8.2**	

14. OSMOSIS SYSTEM		Unit	Value	
Membranes				
	Type		Spiral wound	
	Material		Composite Polyamide	
	Projections performed with			
	High Rejection model (Hydranautics)		SWC4MAX	
	Low energy model (Hydranautics)		SWC5MAX	
	Hybrid configuration (design)		3x SWC4MAX + 5 SWC5MAX	
	Performance at Start up for TDS	mg/l	210	
	Performance always for Boron	mg/l	<1	
	Dimensions	inch	8" x 40"	
	Active area	ft²	440	
	Max Pressure	psi	1200	82,7 bars
	Maximum Average flux	l/h/m²	**<13.5 LMH**	MFS
	Number of membranes per pressure vessels	N	**8**	
	Number of membranes per train	N	**5120**	
	Operating flux	l/h/m²	**13.4**	
	Number of membranes for the plant		**30720**	
	Extra membranes in the warehouse (5%)	%	1536	MFS
Pressure vessels				
	Type	/	Side port	
	Material		FRP	
	Number of the membrane by PV	N	8	
	Pressure rating min	psi	1200	
	Number of pressure vessels per train	N	640	
	Number of the train in pressure centre design	N	6	
	Number of section (100-140 PV) /train	N	5	
	Number of PV per section	N	128	
	Number of pressure vessels for the plant	N	3840	
	Extra PV in the warehouse	%	5%	MFS
	Extra PV in the warehouse		192	MFS

The General Arrangement Drawing for RO Building (typical) is shown in the following figure.



The Energy recovery device, as part of the SWRO equipment, is discussed in the next paragraph.

6.5.6 Energy Recovery Device (ERD)

6.5.6.1 Review and description

The ERDs are used to recover energy (pressure) from the brine flow. It is mainly thanks to the ERD that membrane desalination took over thermal desalination in the last 15 years (most thermal plants arriving at the end of their operating/contractual life are now replaced by membrane technology plants)

Only Isobaric ERD is considered for Perur DSP (other kinetic ERD as Pelton wheel or turbocharger cannot offer energy efficiency beyond 80%, while isobaric systems are reaching 95-97 %);

Isobaric device (also called pressure exchangers) working principles are as follows:

The exchange of pressure occurs in a chamber according to a 2-stroke process:

- First stroke:
  LP pre-treated seawater enters the chamber and expels LP Brine present from the chamber.

- Second stroke:
  HP brine enters the chamber and expelling the pre-treated seawater from the chamber while transferring its pressure (HP pre-treated seawater).

To keep a continuous flow to the four streams (LP seawater, LP brine, HP brine and HP pre-treated seawater) 2 chambers are always associated and work in an antiphase (one chamber in stroke one, while the other is in stroke two).

The two most popular isobaric ERD for XXL plants are present:

- ERI Model PQ300 (capacity 68 m^3/h) (2 x 2 chambers per element)
- Dweers Model Isobaric D-1550 (capacity 350 m^3/h) (2 chambers called “pressure vessels”)

Both of them offer the highest flow capacity of their make.

It should be noted that each EPC company has its preferences; Suez, Veolia had successfully implementing Dweers for XXL plants, although this technology is more complex (major failures in Dweer implementation were met out of these 2 companies). Other companies, US, Spanish or Asian, are more likely to implement ERI technology, although it is slightly less energy efficient.

As CMWSSB has already experienced ERI technology, only a description of Dweer technology is provided below (Figure 29).

A Dweer is composed of the following:

- 2 pressure vessels initially manufactured in super-duplex; for corrosion and cost reasons, super-duplex was gradually replaced by FRP (like membrane pressure vessels). A piston is running up and down each pressure vessel, not to avoid a mixture of the two flows but to inform the link valve about the flow frontier and reverse the operating stroke.
- The link valve allows the HP brine to be circulated from one vessel to the other and the LP brine to be alternatively expelled from the pressure vessels. Initially, the link valve was hydraulically operated, but now on is electrically controlled to ensure smoother operation.
- 1 set of 2 non-return valves per vessel (feed water side); the side one allows LP feed water to enter the pressure vessel; inline one enables the HP to feed water to be expelled from the pressure vessel.

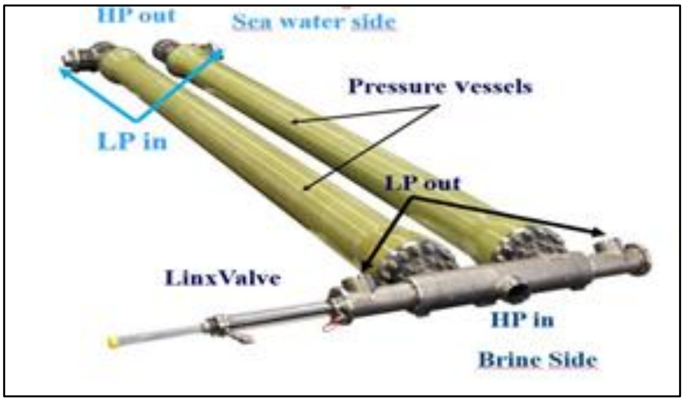


Figure 29: Typical design of Dweer ERD

- Specifications of isobaric devices (ERI and Dweer)

In a perfect world, a brine flow would be able to transfer its full pressure to the same flow of pre-treated seawater, with 100% efficiency and no losses.

In the real world, isobaric systems are suffering at a different level from the following “defaults” (Figure 30):

1. **Mixing** occurs during the contact between HP brine and LP pre-treated and the contact LP pre-treated seawater and the LP brine.
2. **Leaking** flow from HP brine to LP brine (call lubrication in ERI documentation)
3. **Overfeeding** the chamber with LP pressure pre-treated may reduce a little bit the mixing while consuming extra pre-treated seawater.
4. **Head losses** occur at HP side
5. **Head losses** occur at the LP side
6. Backpressure is requested to empty LP brine from the PV.

These “defaults” are illustrated in the below sketch for a Dweer system (ERI suffering from the same “defaults).

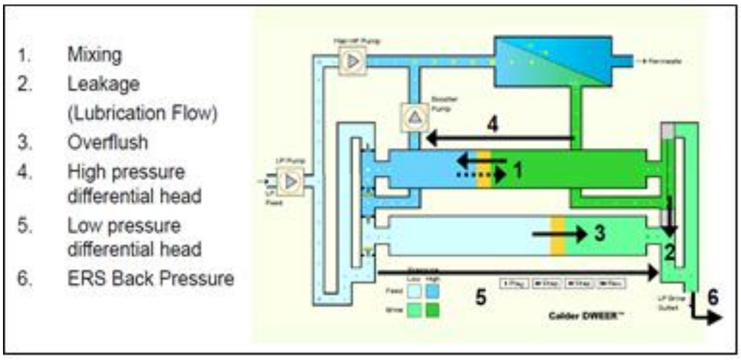


Figure 30: Illustration of defaults at isobaric devices

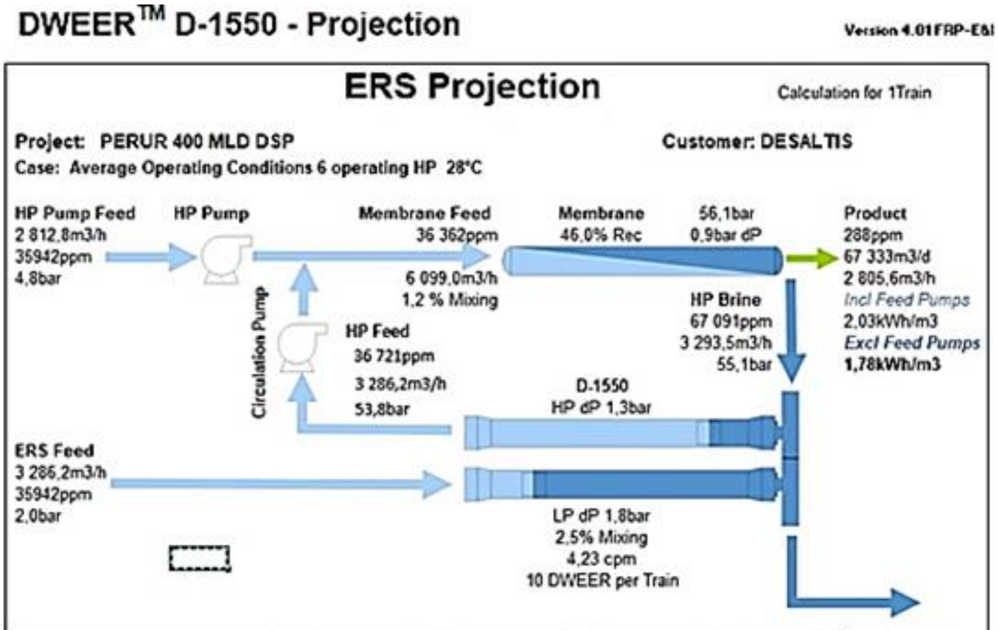
6.5.6.2 Projections

These 2 ERD have technical pros and cons that will be discussed in this section. A full comparison (CAPEX & OPEX) is therefore necessary, based on the following implementation data (see below table).

Table 50: Energy Recovery Device for Pressure Center Configuration (6 Pumps)

15. ENERGY RECOVERY DEVICE (ERD)	Unit	Values	Comments
ERD system			
Number			
Total Array	N	6	
In operation	N	6	
In stand by	N	6	
IF ERI Selected			
Element number per array		50	
Type		PX-Q300	
Material	Super duplex PREN>41; ceramic		
Design flow per array	m3/h	**3 293**	
Design brine pressure	bars	54.3	
PX-Q300 unitary flow	m3/h	65.9	
PX-Q300 unitary flow (N-1)	m3/h	67.2	
PX-Q300 Maximum flow	m3/h	68	
Safety Margin (N-1)	%	1%	
Total Number of units in operation	N	**300**	
Salinity increase at membranes	%	2.40%	
Volumetric mixing	%	4,6 %	MFD
Leakage (% of brine flow)	%	0.90%	
IF DWEERS Selected			
Element number per array		10	
Type		D-1550	
Material	Super duplex PREN>41; FRP		
Design flow per array	m3/h	**3293**	
Max flow per array	m3/h	3360	
Design brine pressure	bars	54.3	
Dweers unitary flow	m3/h	299.4	
Dweers unitary flow (N-1)	m3/h	329.3	
Dweers Maximum flow	m3/h	350	
Safety Margin (N-1)	%	6%	
Total Number of units in operation	N	60	
Salinity increase at membranes	%	1.20%	
Volumetric mixing	%	2.50%	MFD
Leakage (% of brine flow)	%	0.20%	

Projection for Dweers (10 units per operating HP pumps)



Pump	HP pump	HP Pump Feed	ERS Feed	Circulation pump
No. of pumps	6	6	6	6
Flow per pump	2 812,8m3/h	2 812,8m3/h	3 286,2m3/h	3 286,2m3/h
Total flow	16 876,9m3/h	16 876,9m3/h	19 717,3m3/h	19 717,3m3/h
dP	51,4bar	4,8bar	2,0bar	2,3bar
Pump efficiency	89,2 %eff	84,5% eff	85,5% eff	89,0% eff
Motor efficiency	96,8 %eff	96,8% eff	96,8% eff	96,8% eff
VFD efficiency	98,0 %eff	No VFD	No VFD	97,0% eff
Shaft power per pump	4 502kW shaft	444kW shaft	214kW shaft	236kW shaft
Electrical power per pump	4 746kW elect.	459kW elect.	221kW elect.	251kW elect.
Total electrical power	28 477kW elect.	2 751kW elect.	1 324kW elect.	1 507kW elect.

Figure 31: DWEER isobaric devices projection

Projection for ERI (50 units per operating HP pumps)

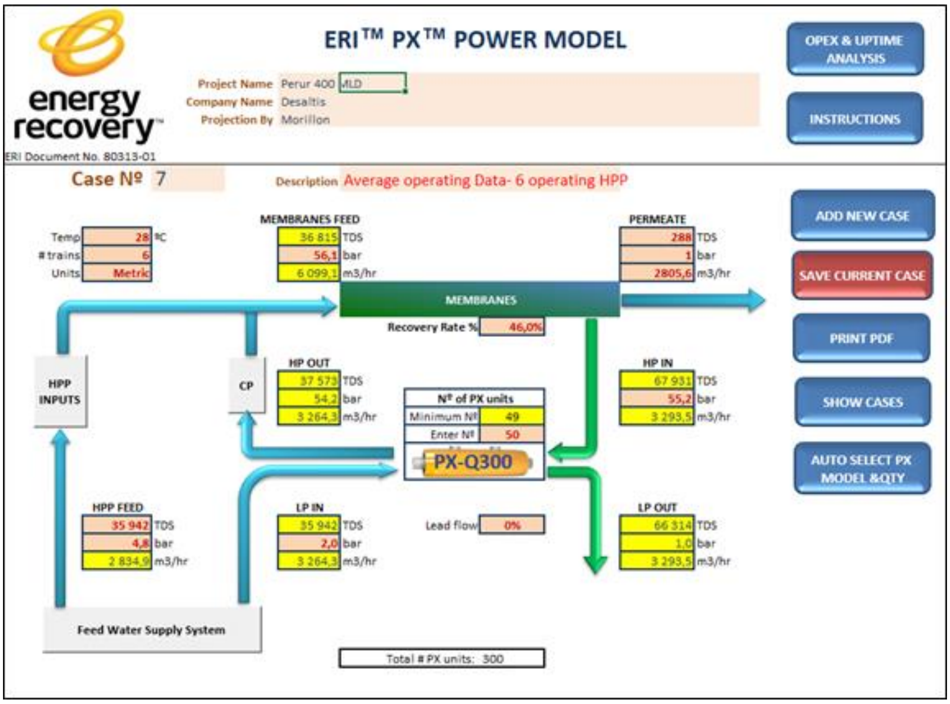


Figure 32: ERI Isobaric Devices Projection

Both suppliers are providing software to compare their own equipment to their competitors'; if both software is allowing energy comparison, only ERI software addresses other comparison aspects like availability, spare parts; it is therefore selected for presentation. In the below tables, "other isobaric" refers to Dweer.

NB: It is not possible to change the currency, which is "USD" per default; amounts, however, are entered in EUROS and shall be read as euros.

- **Energy comparison**

April 2020 energy bills from the Nemmeli desalination plant evidence a present energy cost of 7.26 INR, including the fixed charges (total bill divided by energy consumption), i.e. 0.096 USD per kWh. Despite Perur higher plant availability and output that may offer a slightly lower energy cost with the same tariff, the energy cost computation for the Nemmeli desalination plant is kept.

PX OPEX & UPTIME ANALYSIS

Project Name	Perur 400 MLD	
Company Name	Desaltis	
Projection By	Morillon	
Case Nº	7	

ERI Document No. 80313-01

ENERGY OPERATING COST	ERI	Other isobaric	
High Pressure Differential Pressure HP DP	1,0	1,2	bar
Low Pressure Differential Pressure LP DP	1,0	1,7	bar
Lubrication Flow	0,9%	0,00%	
Volumetric mixing	5,1%	2,50%	
Minimum LP inlet pressure	1,8	2,0	bar
Salinity Increase at membranes	2,4%	1,2%	
Membranes Feedwater TDS	36 815	36 363	ppm
Required Feed Membranes pressure	56,1	55,5	bar
Efficiency	95,8%	94,93%	
Hydraulic Control & PLC Unit Power	NONE	251,7	kW
Feedwater Pumps Power	4079,6	4079,6	kW
Circulation Pumps Power	1306,3	1037,7	kW
High Pressure Pumps Power	29564,4	28897,9	kW
Specific Energy consumption RO Section Only *	2,08	2,04	kWh/m3
Electricity cost	$0,09		USD/KWh
Interest rate	6%		
Project Life	20		years
Plant working days per year	355,875		days/year
Total Plant Capacity	404 006		m3/day
COST OF ENERGY	**27 462 943**	**26 925 950**	**USD/ Year**

* Includes Feedwater Supply Pump Energy consumption

Figure 33: Energy Operating Cost Comparison of ERI with Other System

Advantage is Dweer that can save USD 0.54M per year at full output.

Availability comparison

UPTIME ANALYSIS	ERI	Other isobaric	
Overall Water Price	1,00		USD/m3
Overall Plant Specific Energy Consumption	3,2		kWh/m3
Energy Cost to produce water	$0,29		USD/m3
Water Margin	$0,71		USD/m3
Daily Cost of Downtime	$285 067		USD/day
Preventive maintenance days	0	0,0	Days/year
DOWNTIME COST DUE TO PREVENTIVE MAINTENANCE	$0,00	$0	USD/YEAR
Average ERD Availability *	99,80%	99,00%	%
Corrective maintenance days	0,71175	3,56	Days/year
DOWNTIME COST DUE TO CORRECTIVE MAINTENANCE	202 896	$1 014 482	USD/YEAR
TOTAL DOWNTIME OPERATING COST	**$202 896**	**$1 014 482**	**USD/year**

* ERI PX Pressure Exchanger Device Availability based on real operating data among several plants

Figure 34: Availability and Downtime Cost Comparison of ERI with Other System

If no standby units are considered, the advantage is clearly to the ERI that does not need any maintenance (just water cleaning in case of heavy fouling); at the opposite, Dweer preventive and curative maintenance significantly impairs the overall availability of the plant (in the above table, it is considered that preventive maintenance is performed during the yearly stoppage of the plant). Therefore, Dweers should always be implemented with enough standby units to mitigate this lower internal availability.

It will be worthwhile to note that Plant Availability is very important in this case. ERI boosts up to a 99.7% availability factor that has been proved in the field over many years, with the number of Px units operating at all the major Desalination Plants worldwide. The reason being most of the projects awarded worldwide with Permeate production of 50 MLD and higher, under all kinds of Project structures, namely, BOO, EPC, EPC+O&M, etc., have gone with ERI. The latest Reference List is given below.

Capex and spare parts

SPARE PARTS COST			
	ERI	Other isobaric	
Yearly spare parts cost as Percentage of CAPEX	1,0%	3,0%	%
Estimated CAPEX	$10 400 000	$5 300 000	USD
SPARE PARTS COST *	$104 000	$159 000	USD/Year
* No ceramic cartridges needed to be replaced over a 25 year life period, PX unit spare parts estimation for corrective unplanned maintenance only			

Figure 35: Capex and Spare Parts Cost Comparison of ERI with Other System

Even with 6 Dweer standby units (one unit per train), the Capex advantage is widely for the Dweer technology, 50% less expensive.

Regarding spare parts, the advantage should be clear for the ERI since no spare part is necessary as preventive maintenance. However, as there is no way to fix a damaged ERI unit but a replacement, it is safe to provide the replacement of a few units per year (1% is equivalent to 3 units).

Noise

ERI equipment was reputed to be very noisy in the past (over 90 dB(A) for the PX-220 model). PX-Q300 brought significant progress from this perspective since its noise level is now limited to 85 dB(A). As a comparison, Dweer equipment reaches 81 dB(A), and the HP pump is also in the range of 80 dB(A). Whatever the equipment, ear protection is mandatory for any stay in the RO building.

Credentials

Following several implementation failures by careless EPC companies and general risk aversion from Lenders, Dweer technology was not very successful in the past 3 years, especially for the extra-large plant, which is the main market for Dweers (see below 2 references in 2018-19).

REFERENCE LIST

FLOWSERVE
Calder™ Energy Recovery Devices

DWEER
Energy Recovery Device

DOC.
REV.

PAGE 1 OF 1

Project / Location	Operation Date	Plant Capacity (m3/d)	Total No. of SWRO Trains	Train Capacity (m3/d)	Total Number of DWEER Units
Ashkelon, Israel	2007	330'000	Center Design 4 Racks	82'500	80
Aguilas, Spain	2010	180'000	12	15'000	36
Sydney, Australia	2010	250'000	12+1	21'000	65
Sorek +Extension, Israel	2013	560'000	Centre Design 22 Racks	25'500	88
Tuas 2	2013	350'000	16+1	22'000	68
Az Zour, Kuwait	2014	136'000	10	13'600	30
Larnaca, Cyprus	2015	65'000	2	32'500	12
Barka 4, Oman	2018	280'000	12	23'520	60
Minera Escondida+Expansion, Chile	2019	287'000	12	24'120	36

Above are a DWEER Reference liste, with high Plant Capacity or significant Train Capacity size.

On the opposite, ERI was more successful (see below list of awarded projects till 2017).

More recently, the last mega projects over 450 MLD awarded in the Gulf in 2019:

- Rabigh 3 and Shuqaiq 3 (Saudi Arabia)
- Taweelah and Um al Quawain (UAE)

were all equipped with ERI PX-Q300.

CUSTOMER REFERENCE LIST

MPD — Worldwide

01.01.2020 — All products

energy recovery

YEAR	COUNTRY	CUSTOMER	CAPACITY (M3/DAY)	PROJECT NAME	PRODUCT
2019	Egypt	TAM ENVIRONMENTAL SERVICES	80.000	Ain Sokhna SWRO	PX-Q300
2019	Saudi Arabia	ACCIONA AGUA S.A.	202.500	Shuqaiq 3 SWRO	PX-Q300
2019	China	QINGDAO FTZ GEM-IN INTERNATIONAL	33.340	Shandong Lubei	PX-Q300
2019	Chile	IDE PROJECTS LTD	102.300	Quebrada Blanca SWRO	PX-Q300
2019	Bahrain	SIDEM	120.000	AL Dur SWRO	PX-Q300
2019	Oman	Acciona	80.000	Sharqiyah IWP	PX-Q300
2019	Saudi Arabia	RAWAFID	238.000	Satellite Project	PX-Q300
2019	Tunisia	Abengoa	50.000	Sousse	PX-Q300
2019	Saudi Arabia	Metito (Overseas) Limited	153.840	DUBA SWRO	PX-Q300
2019	Singapore	IDE TECHNOLOGIES LTD.	136.000	Jurong Island	PX-Q300
2019	Saudi Arabia	Acciona Agua	235.020	South Dhahran	PX-Q300
2019	Oman	UTE Abeima Fisia Salalah	110.000	Salalah OPWP	PX-Q300
2019	Chile	TEDAGUA	87.000	Spence SWRO	PX-Q300
2019	China	QINGDAO FTZ GEM-IN INTERNATIONAL	17.642	Zhejiang Longsheng	PX-Q300
2019	United Arab Emirates	Acciona - Besix JV	210.816	Jebel Ali Power & Desalination complex	PX-Q300
2018	China	QINGDAO FTZ GEM-IN INTERNATIONAL	25.000	Hebei Fengyue SWRO	PX-Q300
2018	United Arab Emirates	TEDAGUA	121.968	Ras Al Khaimah IWP	PX-Q300
2018	Saudi Arabia	Metito (overseas limited) United Kingdom	32.000	KAEC King Abdulla Economic City	PX-Q300
2018	Egypt	TAM ENVIRONMENTAL SERVICES	105.000	Ain Sokhna SWRO	PX-Q300
2018	Saudi Arabia	UTE Abeima Fisia Shuaibah	278.000	Shoaibah III exp II	PX-Q300
2018	Singapore	KEPPEL SEGHERS ENG. SINGAPORE PTE	160.000	Marina East Desalination Plant	PX-Q300
2018	Egypt	METITO WATER TREATMENT SAE	75.000	East Port Saeid SWRO	PX-Q300
2018	Saudi Arabia	DOOSAN HEAVY INDUSTRIES & CONST.	400.000	Shoaiba 4	PX-Q300
2018	Egypt	TAM ENVIRONMENTAL SERVICES	105.000	Ain Sokhna SWRO	PX-Q300
2017	Egypt	METITO WATER TREATMENT SAE	150.000	El Galala SWRO	PX-Q300
2017	India	BGR ENERGY SYSTEMS LIMITED	34.200	Sri Damodaran TPS Ash Handling Water	PX-Q300
2017	Spain	CADAGUA S.A.	72.000	Valdelentisco Retrofit	PX-Q300
2017	Egypt	AQUALIA INFRAESTRUCTURAS. S.A.	150.000	El Alamein SWRO	PX-Q300
2017	Saudi Arabia	VA Tech Wabag Pune	82.250	JAZAN Economic city ARAMCO	PX-Q300
2017	Oman	Suez	250.000	SOHAR	PX-Q300
2017	China	HANGZHOU WATER TREATMENT TECHNOLOGY	88.200	Zhejiang Longsheng	PX-Q300
2017	Kuwait	DOOSAN HEAVY INDUSTRIES & CONST.	284.736	Doha SWRO Stage I Desalination Project	PX-Q300

Discussion and recommendation

The Dweer offers an advantage in term of CAPEX with a cost of roughly half the ERI's; Dweer is also slightly more efficient in term of energy. However, the Dweer equipment is more fragile and requires significant preventive and sometimes curative maintenance (it means a dedicated team at the maintenance level whose cost is counterbalancing the energy advantage). Dweer installation is critical and shall be left only to top desalination companies. To mitigate the lack of availability, significant standby equipment needs to be installed, which is possible due to the CAPEX advantage.

The operation is very much trouble-free with ERI and a bit troublesome with DWEER. Due to the perennial problems faced with DWEER, several users have been forced to retrofit the device for economic reasons. DEWA is also planning for Retrofitting ERD at one of their plants as they are finding the existing DWEER Energy Recovery System (ERS) is unreliable for the purpose. They are changing ERD with a reliable PX-Q300 ERS manufactured by Energy Recovery Inc. from the USA". The number of standby equipment depends on the SWRO configuration:

- For train organisation: 16+2 standby (one per HP pump)
- For pressure center design: 6 standbys (one per HP pump)
- For 3- center design: no standby (internal standby capacity)

As previously mentioned, EPC companies commonly favour one type of equipment they feel comfortable implementing. However, due to the above considerations, ERI is very likely to be selected by contractors on train configuration and not in 3-center configuration. At the same time, Dweer may be met on 3-Center configuration due to economic reasons and not on train configuration. But as usual, there are exceptions, like Barka 4 in Oman, where Suez implemented Dweers. However, the recent visit to the plant indicates that the Dweer ERD is posing huge maintenance issues to Suez.

For the pressure center, which is our recommendation for Perur DSP, both types of equipment can fulfil the purpose. However, as there is a strong requirement for the highest plant availability in Perur, the **PMC team recommends the implementation of ERI equipment.**

As a reminder, DPR did not mention specific recommendations between both suppliers. JICA technical review recommended isobaric system piston-type, without mentioning Dweer, which is the only robust supplier with these specifications.

6.6 Post-treatment

6.6.1 Remineralisation

The objective of remineralisation is to achieve sufficient Hardness and Alkalinity in the product water while maintaining acceptable turbidity according to the Indian standard, IS 10500 (2012), which shall be <1 NTU. Water Hardness is not only a housewife washing concern or pipe scale issue. Hardness is mainly added for health and medical reason. Without hardness, the digestive system will be strongly damaged within in a few weeks/months by permeate water (osmosis at cell level). Furthermore, calcium (and potassium) is required for heart regulation.

The level of water required hardness depends on the amount of calcium available in the food (milky product mainly); if the diet in India is deficient in Calcium, you have to compensate and add more in water and the other way round. Commonly, desalination projects dose hardness (as $CaCO_3$) between 50 and 100 mg/l. Until further notice, the PMC team proposes a dosing rate of @ 80 mg/l, which is an average value. The minimum level of hardness in the permeate being 11 mg/l, the selected equipment is required to dose a minimum of 69 mg/l of hardness.

For this last significant stage of the process, our recommendation is the implementation of an Upflow Limestone Bed with Continuous Feeding Remineralization. With such a design, the bed thickness always remains the same. To reduce the size of the limestone building, only a portion of the main flow is treated (45-55%) in the limestone filter, and the remaining flow bypasses the filter. Both the streams are mixed outside the limestone building. Consequently, the stream passing through the filter must receive the amount of hardness necessary for the full flow before mixing again with the bypassed flow. The bypass is commonly operated through a controlled valve to allow flow and dosing rates optimization during the first months of operation.

Limestone building quick description:

- The permeate treated water enters via the lower part of a contactor tank, and it is distributed through an underdrain system.
- Then the water flows upwards from the lower part and through the crushed calcite bed as it moves upwards, its chemical composition changes. The CO_2 dissolved in the incoming water reacts with the Calcite forming soluble calcium bicarbonates. That increases pH and water hardness until reaching a chemical equilibrium.

- The limestone filters have an in-built reserve silo in their upper part. A series of small feeding funnels are placed at the bottom of the silo. The funnels guide the calcite from the silo to the surface of the bed located underwater. In this way, the calcite feeds the bed by gravity, replenishing it continuously as it becomes dissolved. As a result, dosing occurs very gradually, approximately one granule of calcite per funnel per minute, under normal operating conditions. The in-built silo of the tanks allows operating autonomously for several weeks. Consequently, dosing occurs very gradually and without creating turbulence. The system feeds itself automatically depending on the natural demand of the water.
- A backwash system is installed, which is composed of air and water circulation. A backwash cycle is started when turbidity at the outlet of the filter touches the maximum tolerance limit (>0.5 NTU). With high purity calcite, backwash cycles occur only a few times per year per cell.

A diagram from supplier Drintec is provided in the Figure-33 for better understanding:

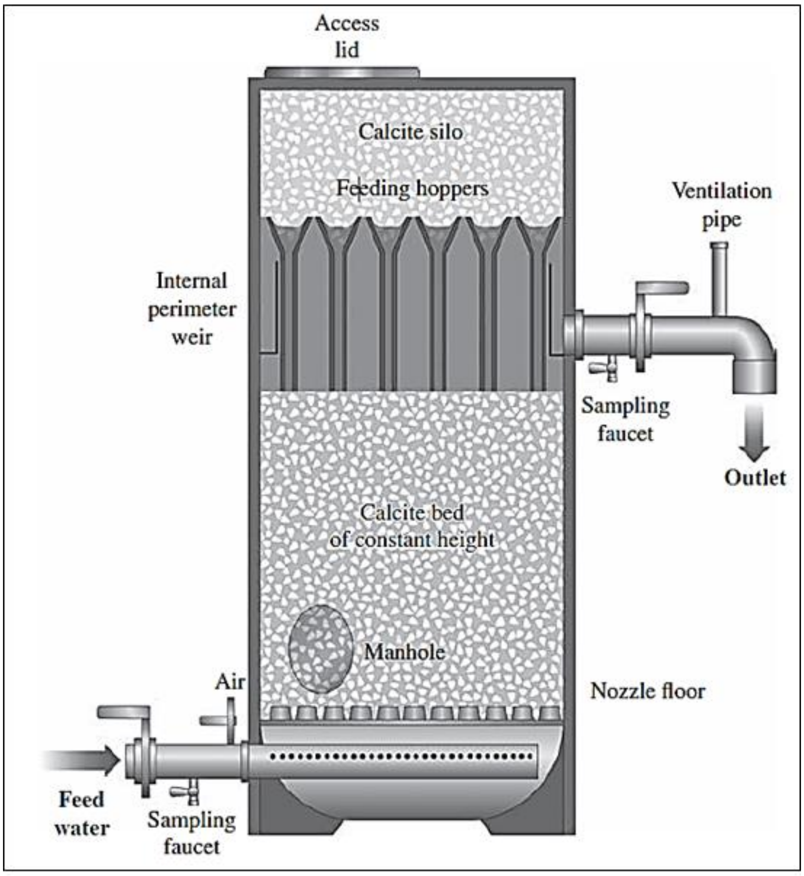


Figure 36: Cross-section of Drintec Calcite Contactor Cell

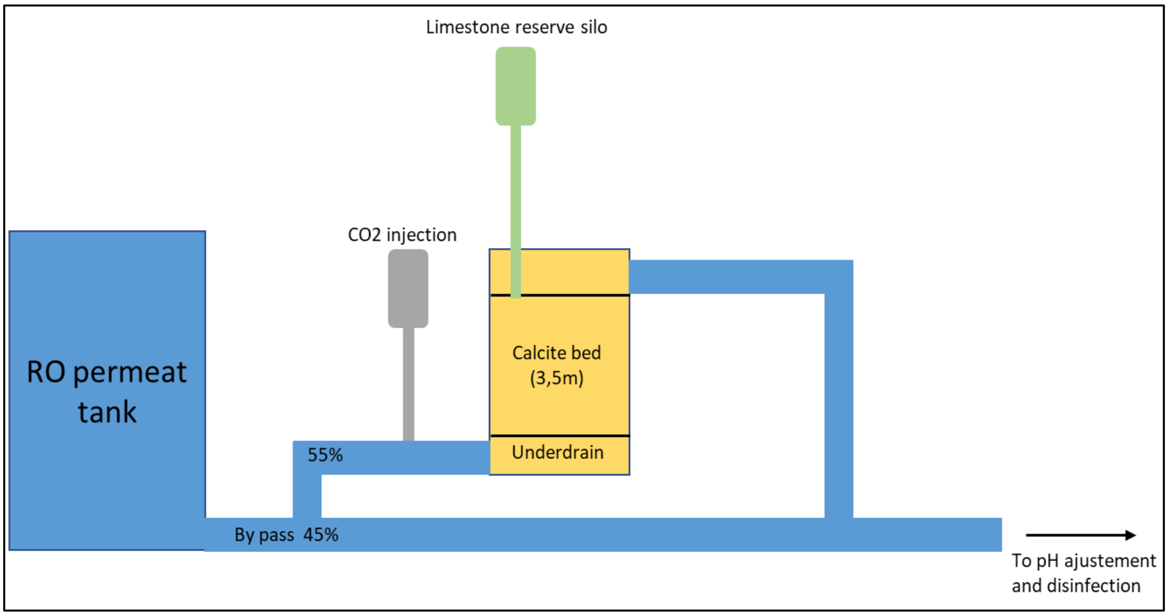


Figure 37: Illustration of Limestone Filter Process

The amount of dissolved Calcite depends on the height of the limestone beds, pH of treated water (low pH brought by CO2), and contact time. The relationship between the quantity of CO2 present in the water and the hardness/alkalinity achieved from the calcite beds is obtained from the following reaction:

$$CaCO_3 + CO_2 \Leftrightarrow Ca^{2+} + 2HCO3^-$$

Strict stoichiometry of the reaction is hardly achievable, and CO2 is overdosed.

Acceptable surface loading rates for limestone beds are from 10 up to 20 m/h; it is presently kept in its lowest range at 10 m/h to ensure final turbidity less than 0.5 NTU in standard conditions.

The design calculations are provided below in Table 51.

Table 51: Post Treatment - Remineralisation

16. POST TREATMENT: REMINERALISATION	Unit	Value	Comments
Design flow rate	m^3/d	404000	
Max Turbidity (product water)	NTU	<0.5	
Targeted hardness (product water)	$ppmCaCO_3$	>80	MFS
Limestone Filter			
Limestone Filter bypass	%	52%	Design data
Treated water flow rate (48%)	m^3/h	8300	
Limestone bed thickness	m	3.5	Design data
Limestone bed Module length	m	7.5	Design data
Limestone bed Module width	m	4.0	Design data
Net surface area per module	m^2	30	
Targeted Module surface loading rate	$m^3/m^2.h$	10	
Total number of modules (all plant)	No.	28	
Total number of modules (half-plant)	No.	14	
Module surface loading rate (actual)	$m^3/m^2.h$	9.9	MFS <10 (for turbidity purpose)
Module surface loading rate N-1	$m^3/m^2.h$	10.6	MFS <11 (for turbidity purpose)
Media contact time	min	24.3	MSF ≥20 min

16. POST TREATMENT: REMINERALISATION	Unit	Value	Comments
CO_2 excess addition	%	15%	Excess CO_2 - Not Stoichiometric
Total hardness in water after remineralization	mg/l CaCO3	60	
Calcium Hardness addition in the product water	mg/l CaCO3	49	
Limestone purity	%	99%	
Calcite daily consumption	T/day	20.5	
Automatic loading storage capacity	Tonnes	620	MSF : 30 days
TDS impact (at Max TDS membrane projection)			
Average hardness in RO permeate	mg/l $CaCO_3$	11	
Calcium Hardness addition in the product water	mg/l $CaCO_3$	49	
CO_2 addition in the product water	mg/l	10.3	
Air blowers (full plant)			
Operating unit	U	1	
Stand by unit	U	1	
Discharge flow	m3/h	1500	
Discharge Head		5	Headloss in filter : 1 m/ m media filter + 1 m
Operating time	h/year	42	max 6 times per year (15 min)
Average power rating	kW	29	
Backwash pumps (full plant)			
Operating unit	U	1	Double requirement for two streams
Stand by unit	U	1	
Discharge flow	m3/h	1500	
Discharge Head		20	Headloss in filter: 0.8 m/m media filter + losses in pipe
operating time	h/year	84	max 6 times per year (30 min)
Average power rating	kW	117	

6.6.2 Disinfection

Chlorine, in the form of sodium hypochlorite (NaOCl) is selected as a disinfection chemical for biological growth control for its remanence property. Desalination water product does not require a high level of disinfection chemical dosing, and most of the injected chlorine will remain as free active chlorine. However, to ensure protection during transportation in the product distribution line, a dosing of 1 mg/l is recommended.

The point of application will be in the pipeline at the outlet of the limestone beds. Common contact time for disinfection with NaOCl being 30 min, full disinfection will be performed in the product water tanks (2-hour contact time).

It should be noted that the NaOCl concentration in commercial solution decreases very quickly with time when stored at high temperature (over 30°C), which is the case in Chennai. Therefore, the storage will be limited to 10 days.

The design of the disinfection equipment is given in Table 52.

Table 52: Design Calculation for Disinfection

17. POST CHLORINATION	Units	Values	Comments
Processed flow	m^3/h	16833	
Commercial reagent	/	NaOCl	
Concentration	%l Cl_2	10.5%	
Max dosage	g/m^3	1	0.5>product water>1
Mass flow (100%)	kg/h	168.3	
Volumetric flow as product	L/h	1358.6	
Density		1.18	
Dosing pump			
Number in operation	n	2	
Number in stand-by	n	2	
Unit flow	L/h	679	
Unit flow provided	L/h	1000	
Capacity safety margin	%	32%	
Injection point			limestone bed outlet
Storage			
total storage for post treatment	m^3	326	for 10 days consumption

6.6.3 LSI adjustment

Dosing CO2 in limestone building will decrease the pH and make the water aggressive to concrete (internal pipe coating). Water aggressiveness will be mitigated by Sodium Hydroxide dosing (pH increase); the final optimal pH is obtained when the Langelier Saturation Index (LSI) is slightly positive (saturation of calcium carbonates). For this purpose, sodium hydroxide storage and dosing system are proposed as follows.

The point of application will be in the pipelines before the product tank to ensure sufficient contact time.

Table 53: Design Calculation for LSI Adjustment

18. LSI ADJUSTMENT	Units	Values	Comments
Flow	m^3/h	16833	
Reagent	/	NaOH	
Concentration	active product	48%	
Max dosing rate	mg/l	5	
Mass flow (100%)	kg/h	84.2	
density		1.4	
Dosing pumps	n		
Volume flow as product	L/h	125.2	
Number in operation	n	2	
Number in stand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	100	
Capacity safety margin	%	37%	
Injection point			limestone bed outlet
Storage			
total storage for post treatment	m^3	90	for 30 days consumption

6.7 Process reservoirs and storage

6.7.1 Filtrated water tanks and Gravity filter backwash tanks

There will be one tank for each production line (interconnection). The capacity of each will be designed for 30 minutes of filtered water flow, i.e. 10000 m^3 each. To ensure gravity filter backwash water is always available, the tank design will offer a two-compartment design. The first compartment will serve the backwash requirement and provide a capacity of 2,000 m^3 (backwash requirement for at least 3 filters). In case of emergency, this first compartment will have a provision to be fed from the outlet of DAF. The first compartment will feed the second compartment by overflow. The ERD and HP booster pumps will be connected at the outlet of this second compartment that will offer a capacity of 8,000 m^3 (at least 25 min residence time). As the main process flow reservoir, these two compartment tanks will be constructed in concrete.

6.7.2 1st Pass Permeate tank

There will be one tank per production line (no interconnection). To ensure membrane flushing water is always available, the tank design will offer a large capacity of 5000 m3 allowing more than two skid CIP, two skid flushing and one backwashing of the limestone filter. This tank will serve membrane flushing pumps and a service network providing water to limestone bed backwash, chemical building and RO building (flushing all the seawater pumps at the stoppage, rinsing leaks to avoid corrosion). As a side process flow reservoir, this tank will be constructed from bold metallic plates.

6.7.3 Product water tank

There will be two tanks for the two production lines (last interconnection). To allow cleaning operation, the tank will offer two-compartment in a parallel design. The tanks will provide a capacity of 15,000 m3 each (about 2-hour product water production). Therefore 30 min contact time for sodium hypochlorite dosing will safely be achieved. The tank will serve the main outlet pipe till the metering system (battery limit with CP2), potable service water for the potable plant requirement (administrative building, toilets, safety showers) and a fire system (pumps, diesel pump, network). As the main process flow reservoir, these two compartment tanks will be constructed in concrete below ground. The demineralised water from the limestone filter will gravitate to the potable water tank.

JICA study recommended a metallic reservoir (4 units x 9000 m^3), but the PMC team recommends providing a concrete tank. The overall size of the product water tank has been reduced by 6 ML and added in the Clear Water Reservoir (CWR), which has increased its capacity from 3 ML to 9 ML.

6.8 Wastewater Treatment Plant and Sludge treatment

During coagulation, flocculation, and clarification, solids settle to the bottom of clarifiers in the form of sludge which is usually disposed of to the sea or further dewatered, and dry solid is transferred for landfilling. Coagulation is the addition of the chemical agent(s) to the raw feed water, which allows the particulates to agglomerate and settle. Ferric Chloride is conventional coagulant aids that produce insoluble $Fe(OH)_3$ in water which adsorb the suspended particles. An electrolytic polymer is added, which helps in the agglomeration of small finely separated particles into larger particles that become heavier than water and get settled. The underflow sludge is removed from the clarifier basin on either a continuous or batch basis. The volume of coagulation sludge generated depends on the plant feed seawater flow, the amount of coagulant, and the amount of suspended solids in the water. The characteristics of coagulation sludge vary depending on initial water quality and the amount and type of coagulant used (in this case, higher iron concentration in the sludge due to iron-based coagulant). Coagulation sludge predominately contains the coagulant metal hydroxides along with source water organic matters, suspended solids, microorganisms, radionuclides, and other organic and inorganic constituents.

The pretreatment process for 400 MLD Perur Desalination Plant includes Lamella Clarifier (LC) and Dissolved Air Flotation (DAF) followed by Gravity Dual Media Filter (GDMF). Most of the solids in raw seawater will be eliminated in the Lamella filter, and some lighter particles will be removed in DAF. The concentration of suspended solids in the seawater to GDMF will be less than 5 mg/L, which will be removed in filter beds. The filtered water out of GDMF will be of quality with turbidity less than 0.5 NTU all the time. The sludge generation in LC, DAF and GDMF at a high feed flow rate (42% recovery) are given below.

		Lamella	DAF	DMGF	Total
Sludge Flow	**MLD**	**21**	**10**	**40**	**71**
Dry Solids (Ton /day)	**Peak**	**276**	**51**	**5**	**332**
	Normal	**70**	**17**	**2**	**89**

The generation of sludge streams from LC, DAF and DMGF will be about 21, 10 and 40 MLD. The primary solid loads are in the Lamella clarifier and DAF waste streams which are in the ratio of 4:1. The solid load from the DMGF waste stream will be within 2 tons/day, which is very low compared to LC and DAF. The concentration of solids in the backwash waste from GDMF will usually be within 200 mg/L which is not sludge, and so a large sedimentation tank will be required to settle its suspended solids. The treatment of GDMF wastewater is not economical and conducive, particularly for the limited space available at the site. Therefore, only LC and DAF sludge have been considered for treatment. The selected sludge treatment units are sludge balance tank (SBT), thickener and belt filter press (BFP). All the sludge will be collected in the sludge balance tank and mixed for a homogeneous sludge solution. From SBT, the sludge will be pumped to the thickener, where it will be thickened up to 5% solid consistency. The thickened sludge will be transferred to the sludge holding tank under gravity which will then be pumped to BFP units for dewatering. Polymer will be used before thickener and BFP to promote solid separation.

The design of the sludge treatment system with unit sizing is given below in Table 54.

Table 54: Design Calculation for Wastewater Treatment

S. No.	Item	Unit	Design Description
1	**Sludge Balance Tank**	1	31m dia. x 3.5m SWD – RCC tank
	Submersible Mixers in SBT	3	10kW mixers - submersible
	Static Mixer in the pipeline after polymer dose	1	600 NB mild steel pipe with epoxy coating
	Sludge Transfer Pump	2 (1W+1S)	1500 m³/hr – submersible non-clog type
2	**Thickener**	2	2 x 35m dia x 4m SWD - RCC with sludge scraping mechanism
3	**Sludge Holding Tank**	1	28m L x 14.0 m W x 3.0m SWD - RCC
	Agitators in sludge holding tank	2	Vertical top-mounted suspended type – 7.5kW motor rating
4	**Belt Filter Press**	18 (15W+3S)	Dry case consistency - 25%
	Filter Press Feed Pumps	18 (15W+3S)	27 m³/hr - Progressive cavity pumps
	Belt Filter Press Washing Pumps	4 (3W+1S)	30 m³/hr – thickener supernatant water
	Belt Press Building (2 storied)	50m x 20 m	BFP on the first floor
5	**Polymer Dosing System for Thickener**	Non- Food Grade	For both thickener and dewatering system
	Dosing Pumps for Thickener	2 (1W+1S)	0-15 m³/hr –Diaphragm metering pumps
	Dosing Pumps for Dewatering	18 (15W+3S)	0-1.5 m³/hr –Diaphragm metering pumps
	Polymer Dosing Tank	2 (2W+2S)	6.5x 6.5m x 4m SWD -
	Agitators in Polymer Dosing tank	4	Vertical top-mounted suspended type – 5kW motor rating

The Sludge Treatment Flow Diagram is presented below in Figure 35.

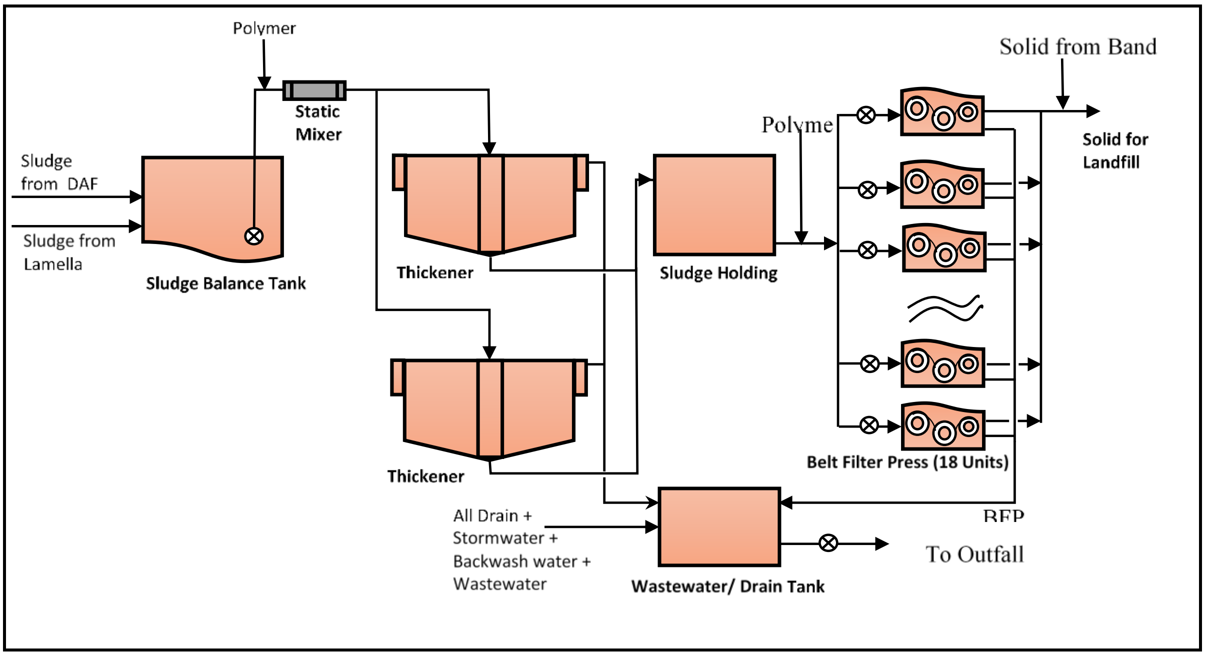


Figure 38: Sludge Treatment Flow Diagram

The detailed design of the Sludge Treatment System is presented in **Annexure 6**.

6.9 Process Flow Diagram

The process flow diagram taking into consideration of the two distinct streams of 200 MLD each has been provided in Drawing no.7061563/PMC/400 MLD/CP1/P/PFD/001.

6.10 Plant Layout

6.10.1 Total area to install the plant

The tentative footprint area required for processes and buildings and installation of the yard piping is given below. The area estimated by JICA is very close to the recommended area by PMC, and it is presented in Table 55 below.

Table 55: Foot Print Area of Facilities at Perur DSP

Sl.No.	Process/ facility	JICA Estimated size (m)	unit	PMC Estimated size (m)	unit	Key Function
Main	Intake pit	30 x 70	1	30 x 70	1	Receiving seawater and pumping to Lamella filter
	Coagulation + Flocculation		2	100 x 20	2	Coagulation of SS
	Lamella Filter	100 x 60	2	150 x 27	2	Removal of suspended solid with inclined plate
	DAF	130x40	2	70 x 50	2	Removal of suspended solid by up flow stream
	DMF	200 x 30	2	130 x 60	2	Removal of suspended solid by dual media filter
	Filtrate tank	25 x 100	1	50 x 50	2	Storage of pre-treated sea water
	RO building	260 x 40	2	250 x 40		Cartridge filter. HP pump. RO block and ERD etc.
	Permeate tank			25 m dia.	1	For permeate CIP & Flushing
	Post treatment	80 x 100	2	50 x 30	2	Mainly preparation of limestone
	Potable water tank	60 x 40	1	50 x 70	2	Underground tank for disinfectant and pumping
	Product water tank	30 m dia (9000 m^3)	4	50 x 50 x 6 m	2	Storage tank for product water
	Transmission pump room	20x40	1	-	-	Transmission of product water to Chennai
	Brine discharge	30x30	1	25 m dia.	1	Wastewater discharged to sea
Auxiliary	Power receiving	80 x 80	1	80 x 80	1	Power receiving, substation
	Chemical Building - Pre-treatment	30x60	1	30x60	2	Chemicals arrangement for pre-treatment
	Chemical Bldg - RO	20 x 90	1	20 x 90	2	Chemical Arrangement for RO Building
	Waste treatment	40 x 80	1	120 x 60	1	Especially for sludge treatment
	Workshop	50 x 40	1	50 x 40	1	Workshop for the site
	Warehouse	80x40	1	80x40	1	Warehouse for plant operation
	Administration building	60x40	1	60x40	1	Administration office + Laboratory
	Firefighting	20x40	1	20x40	1	Fire Fighting Unit
	Gate house	20x20	1	20x20	1	Gate keeper
	Parking	50x40	1	50x40	1	Car parking space

6.10.2 Tentative plant layout

In a DBO project, the Contractor has the responsibility to optimise the layout in term of cost (length of pipes, electric cables). There are 2 ways to organize the layout of the extra-large plant.

First option is to build process stages in parallel (RO streams in the same building, for instance), which save footprint and ease production lines interconnections and is, therefore, the most cost-effective. This is the most common option in DBO/BOO when operation and construction are under the same contractor scope.

The second option is to physically isolate the plant into two separate streams and to implement them according to a symmetry axis; such design is not particularly cost-effective but implemented usually in an extra-large plant to allow proper contractual operation of the first half-plant when the second half-plant is still in the construction phase. Such a case was met, for instance, in Ashkelon, when the second half operation started more than one year after the first one.

The layout recommended by PMC is as per the second option, which includes the construction of two process streams given below in Figure 36. As discussed in Section 5.5.4, the two production streams may hydraulically be interconnected at the pumping station, filtered water tanks, permeate water tanks and product water tanks. This concept is not reflected in the present layout diagram. The diagram represents a very preliminary layout that is under review by PIU. It will be worked out again after getting feedback from PIU and further discussion with them.

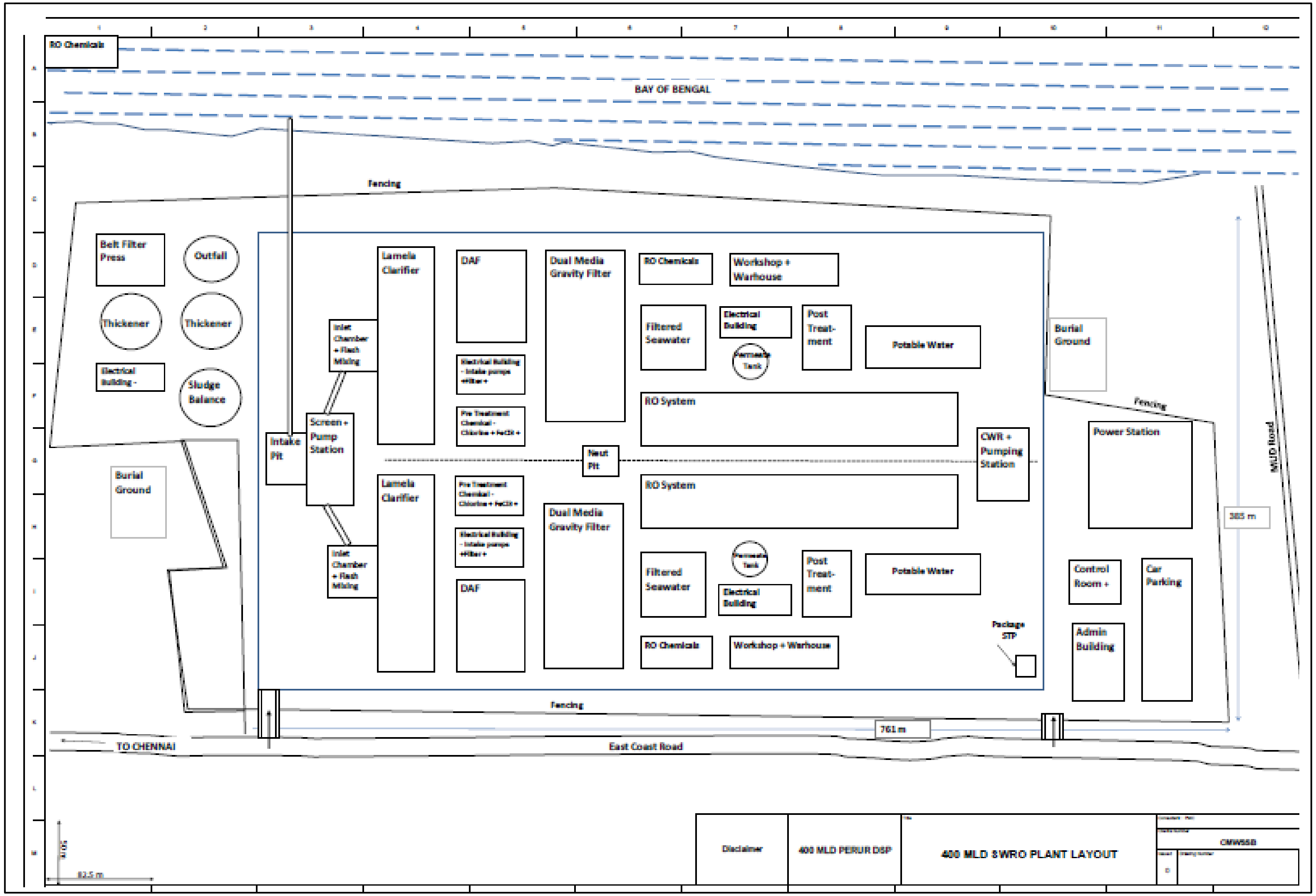


Figure 39: Tentative Plant Layout of Perur DSP

The proposed layout of the 400 MLD Desalination Plant at Perur is furnished below:

The summary of major proposed components including a number of unit and Material of Construction is furnished below Table.

Sl. No.	Component Name	No. of Unit	Material of Construction (MOC)
01	Intake Pumping Station	1	RCC Epoxy
02	Lamella Settlers	36	RCC Epoxy
03	Dissolved Air Flotation (DAF)	12	RCC Epoxy
04	Gravity Dual Media Filter (GDMF)	80	RCC Epoxy
05	RO Feed Tank	2	RCC Epoxy
06	RO Building	2	PEB Shed
07	Limestone Filter	28	RCC Epoxy
08	RO Permeate Tank	2	Metallic Tank/ RCC Epoxy
09	CO_2 Storage Area	2	-
10	Product Water Tanks (7.5 ML Each)	4	Metallic Tank/ RCC Epoxy
11	Clear Water Reservoir (9 ML)	1	RCC Epoxy
12	Sludge Balancing Tank	1	RCC Epoxy
13	Thickened Sludge Thickeners	2	RCC Epoxy
14	Sludge Holding Tank	1	RCC Epoxy
15	Belt Filter Press Building	1	RCC
16	Outfall Tank	1	RCC Epoxy
17	Chemical Building for RO	2	RCC with Chemical Resistant Lining
18	Chemical Building for Pre-Treatment	2	RCC With Chemical Resistant Lining
19	Power Receiving Station/Control Building	1	RCC
20	Electrical Building for Intake Pump Station & Pre-Treatment	2	RCC
21	Electrical Building for RO Building	2	RCC
22	Warehouse	1	PEB SHED
23	Workshop	1	PEB SHED
24	Package STP	1	-
25	Fire Fighting Station	1	RCC
26	Administration Building (Officer's Room/ Conference/ Canteen) (G+2 Floors)	1	RCC
27	Administration Building (Laboratory cum Meeting/ Training Room) (G+1 Floor)	1	RCC
27.a	Parking Area	1	PEB SHED
28	Security Room	1	RCC
29	Additional Security Room	1	RCC
29a	Lay Down Area	1	-
31	Lay Down Area	1	-
32	Landscape & Park Area	1	-
33	Watch Towers	2	-

7 BATTERY LIMITS AND CP1 INTERFACES (to be supplied by PMC)

7.1 Battery limits

Table 56: Battery limits and CP1 interface

Sl. No.	The function of the terminal point	Description of the terminal point and relevant requirements
1.	Seawater intake and outfall locations in sea	Seawater intake at 1150m from seashore and outfall at 750m from seashore.*
2.	Product supply to Clear Water Reservoir (CWR) interface with package CP2	CWR exit pipeline up to 5 m with the flanged end.
3.	Electrical supply to Project – interface with package CP5	Supply of 230kV line to the substation building.
	Any Others	

- JICA and PMC have recommended for brine discharge at further inside into the sea at about 1800m from the seashore.
- The contractor will be advised to conduct the Brine Diffusion Analysis to find out the effect of brine discharge on the intake seawater quality, particularly in terms of total dissolved solids. The contractor will be responsible for designing the SWRO system considering any increase in intake seawater salinity due to brine discharge out of three DSPs in the vicinity.

8 ELECTRICAL WORKS

CMWSSB requested Tamil Nadu Electricity Board (TNEB) to provide reliable power supply for the 400 MLD Perur DSP and 150 MLD upcoming Seawater Desalination Plant at Nemmeli. In response to the request, the TNEB proposed a power transmission plan, where two transmission lines would provide power to a new 230/110 kV S/S to be constructed for the Nemmeli and Perur DSPs.

It is intended that TNEB would carry out the construction of the two transmission lines of 230 kV and allied works. As per TNEB guidelines, the power supply shall be given at the Power Receiving Facility/Terminal Points of Perur DSP. The 230kV power supply shall be stepped down to 110kV and 110kV shall be further stepped down to 11kV through the Auto Power Transformers as per TNEB latest Codes, Standards and Regulations.

The reliability of the existing power supply was ascertained based on the power supply to the existing Nemmeli DSP which is 98.7%. This was attained based on the number of hours of power failure over a period of one year at existing 100 MLD Nemmeli DSP. However, currently existing 100 MLD Nemmeli DSP relies on the non-dedicated lines, while for the proposed 400 MLD Desal Plant, TNEB is intended to provide a dedicated power supply from Ottiambakkam, 440/230 kV S/S and Omega 230 kV S/S. Moreover, the new grid to Perur DSP is considered as more reliable than existing current grid because, the new grid is of 230kV compared to the 110 kV existing system. Therefore, the reliability may be more than 99%. The power demand for the 400 MLD Perur DSP is approximately 90 MVA, while 33 MVA is for the 150 MLD DSP. TNEB has agreed to supply 150 MVA from the TNEB grid for both the desalination plants. This section of the report shall deal with the electrical power system requirement for the 400 MLD Desal Plant at Perur.

The electrical substation of the CP1 400MLD Sea Water Reverse Osmosis Desalination Plant covers a major part of the electrical power system requirements. Due to the high salinity and close proximity of the plant to the sea, a Gas Insulated Switchgear (GIS) Substation has been envisaged for the project to prevent corrosion of the major electrical equipment. To meet the power demand load of the 400 MLD Perur Sea Water Reverse Osmosis (SWRO) Desalination Plant (approximately 90 MVA), the Gas Insulated Substation shall be fed with a 230kV Power Supply as per Tamil Nadu Electricity Board (TNEB) latest Codes, Standards and Regulations.

A Power Receiving Facility / Terminal Point as part of CP1 Contract Package has been considered for this project to receive the TNEB 230kV Overhead Transmission Line, including its Optical Ground Wire (OPGW). The 230kV Overhead Transmission Line shall be terminated to the 230kV composite outdoor termination unit and outdoor type lightning arrester by the Overhead Line Contractor under CP5 Contract Package while the Optical Ground Wire (OPGW) provided under CP5 Contract Package shall be terminated to the terminal joint boxes by the Substation Contractor under CP1 Contract Package.

Bonding of the incoming OPGW to the station earthing screen, supply of earthing conductor and connection of the air terminal earth electrodes into the substation earth grid shall be carried out by the Substation Contractor under CP1 Contract Package.

The connection between OPGW joint boxes at 230 kV GIS Substation Receiving Gantry Area and Control Room building via underground optical fiber cables shall be carried out by the Substation Contractor under CP1 Contract Package, which shall include supply and installation of fiber optic cable of a size similar to OPGW.

The voice communication, tele-protection signalling and main distribution frame (MDF) for optical fiber cable shall be supplied and installed by the Substation Contractor under the CP1 Contract Package. Necessary equipment for incorporating the 230kV and 110kV GIS Automation System into the SCADA system shall also be supplied and installed under the CP1 Contract Package.

Supply of Mandatory Spares at the plant along with Maintenance Tools and Test Equipment of Power Transformers, Earthing Transformers, Distribution Transformers, GIS Switchgears, Control Equipment, Protection Relays, Meters, Vacuum Circuit Breakers, Isolators, Battery Chargers, UPS, Switchgears, LV Switchgears, Motor Control Centers etc. shall be provided.

8.1 General

This section shall cover the electrical works of the 400 MLD Perur Seawater Reverse Osmosis Desalination Plant under CP1 Contract Package, which consists of the following facilities:

i. Power Receiving Facility/Terminal Points
ii. 230/110/11kV Gas Insulated Switchgear Substation
iii. Sea Water Intake Facility
iv. Chemical Dosing System
v. Pre-Treatment System Facility
vi. Reverse Osmosis Plant
vii. Post Treatment System Facility
viii. Water Storage and Transfer Facility
ix. Seawater Outfall Facility
x. Administration Building
XI. Electrical Rooms

8.2 Design Philosophy

The electrical works for the above facilities shall be designed in accordance with the criteria presented in this section. The electrical concept design report covers all the basic guidelines to be followed for all the electrical works in this contract. However, it is not intended to cover all aspects of the system design, but It shall indicate the basic requirements only. The following factors were kept in mind while designing the electrical system for this project:

i. Safety of life and property;
ii. Reliability of power supply to the extent possible;
iii. Automatic protection of all electrical equipment through selective protection system;
iv. Simplicity of operation;
v. Ease of operation and maintenance;
vi. Flexibility of system;
vii. Initial Cost; and
viii. Power Factor Improvement & Harmonic Filter

Besides the Tamil Nadu Electricity Board (TNEB) requirement, improving the power factor has added advantages that it reduces the overall demand on to the Incoming Supply Authority, thereby adding to the overall economy. Thus, for power factor improvement, suitable sized capacitor panels in the Bank formation shall be provided. The capacitor bank shall be connected to the Main 11kV Switchgear Bus and 415V Low Voltage Switchgear Bus and will be located along with the 11kV Switchgear and 415V Low Voltage Switchgear Panels. An automatic power factor correction relay of reputed make shall be provided to improve the system's power factor and switch on the capacitor depending on the system requirement. The power factor shall be maintained at around 0.95. Necessary online detuned harmonics filters shall also be provided in the capacitor banks.

8.3 Scope of Work

The scope of work on this section shall include Design, Supply, Delivery, Installation, Testing and Commissioning, Operation and Maintenance of all electrical equipment for the 400 MLD Sea Water Reverse Osmosis Desalination Plant, which include but not necessarily limited to the following schedule of requirements:

1. Power Receiving Facility or Terminal Points of Incoming TNEB 230kV Overhead Line Circuit Connections and Optical Ground-Wire (OPGW) with Composite Outdoor Termination Unit, Outdoor Type Surge Arrester with counter, Steel Structures, and Claustra Block Wall Fencing with a stainless steel door, Lightning Protection and Earthing System.

2. 230kV Gas Insulated Switchgear Double Bus Indoor Type 4000A, 50Hz, 3Ph, 50kA/3sec. as per Key Single Line Diagram (Drawing No. 7061563/PMC400MLD/CP1/SLD/001).

3. 230kV Cu/XLPE/AWA/HDPE Cables.

4. 230kV Cable Sealing Ends, Cable Plug-in, Composite Outdoor Cable Termination Unit and Accessories, and Earth Link Boxes.

5. 110kV Gas Insulated Switchgear Double Bus Bar Indoor Type 3150A, 50Hz, 3 Ph, 40kA/3sec. as per Key Single Line Diagram (Drawing No. 7061563/PMC400MLD /CP1/SLD /001).

6. 110kV Cu/XLPE/AWA/HDPE Cables.

7. 33kV and 11kV Cu/XLPE Cables and Cable Termination Accessories.

8. 110kV Cable Sealing Ends, Cable Plug-in, Cable Termination Accessories, and Earth Link Boxes.

9. 2 Nos. 230/110/33kV 150MVA ONAN/ONAF Auto Power Transformers with Vector Group YNa0d1 and 2 Nos. 315kVA 33/0.415kV Earthing Transformers.

10. 4 Nos. 110/11/11kV 50MVA ONAN/ONAF Auto Power Transformers with Vector Group YNd5 and 4 Nos. 315kVA 11/0.415kV Earthing Transformers.

11. Metering, Control and Protection.

12. Substation Automation System (IEC-61850)

13. Digital Fault & Disturbance Recorder (DFDR)

14. Fiber Optic Multiplexer Equipment for Communication and Protection

15. SCADA system for Telecontrol and Telemetering
16. 110V DC & 48V DC and LVAC System
17. Standby Diesel Generator Set
18. Uninterruptible Power Supply (UPS) System
19. Subgrade Earthing System, Potential Gradient Earthing System, Above Ground Earthing System, Electronic Earthing System and Equipment Earthing System
20. Lightning Protection System
21. 33kV Outdoor Type Vacuum Circuit Breakers (for Earthing Transformers)
22. 33kV Outdoor Type Isolators (for Earthing Transformers)
23. 11kV Outdoor Type Vacuum Circuit Breakers (for Earthing Transformer)
24. 11kV Outdoor Type Isolators (for Earthing Transformer)
25. 33kV Neutral Earthing Resistors
26. 11kV Neutral Earthing Resistors
27. 4000A, 3Ph, 3W, 50Hz, 50kA/3secs. 11kV Switchgears
28. 1250A, 3Ph, 3W, 50Hz, 40kA/3secs. 11kV Switchgears
29. 11/0.433kV Distribution Transformers
30. 11/0.69kV Converter Transformer
31. 11kV Capacitor Banks
32. 11 kV Motors
33. 415V Capacitor Banks
34. 415V Low Voltage Switchgears
35. 415V Low Voltage Busducts
36. 415V Motor Control Centers
37. 690V Variable Frequency Drives / 11kV Soft Starters / 11kV Primary Resistance Starters / 11kV Variable Frequency Drives
38. 415 V Direct Online Starters / Wye Delta Starters / Variable Frequency Drives
39. 415 / 240 V AC Distribution Boards
40. 110V DC Distribution Boards / 48V DC Distribution Boards and Batteries

41. Lighting and Small Power System
42. Central Battery System
43. Street Lighting System
44. Area Lighting System
45. Tel/LAN System
46. Low Voltage Power & Control Cables
47. FM200 System
48. Auto Power Transformer Nitrogen Injection Fire Protection (NIFPS) System and Transformer Fast Depressurization System
49. De Luge Water Spray System
50. Supply of Mandatory Spares, Maintenance Tools and Test Equipment for the above Electrical, Telecommunication/LAN, SCADA and Mechanical equipment.
51. Third-party inspection for the Factory Acceptance Test (FAT) of the major electrical equipment specified below and the contract price shall be deemed to include all these costs.
52. Foreign and Local Training for Employer's Engineers.
53. Site Acceptance Test (SAT) by the Manufacturer's Testing and Commissioning Engineer to be witnessed by the Employer's Engineer.
54. Submission of Start-up and Energization procedures prior to Commissioning.
55. Commissioning.

8.4 Design Criteria

8.4.1 Extra High Voltage System (EHV)

Rated Voltage	230 kV nominal
Highest System Voltage	245kV
Phases	3
Rated Frequency	50 Hz
Rated Short Duration Power Frequency Withstand Voltage (1Min.)	460kV
Rated Lightning Impulse Withstand Voltage (1.2/50 µs)	1050kV
Rated Normal Current Bus Bar	4,000 A
Rated Normal Current Feeder	4,000 A
Rated Short Circuit Breaking Current (<3 cycles)	50 kA

8.4.2 High Voltage System (HV)

Rated Voltage	110 kV nominal
Highest System Voltage	145kV
Phases	3
Rated Frequency	50 Hz
Rated Short Duration Power Frequency Withstand Voltage (1 Min.)	275kV
Rated Lightning Impulse Withstand Voltage (1.2/50 µs)	650kV
Rated Normal Current Bus Bar	3,150 A
Rated Normal Current Feeder	3,150 A
Rated Short Circuit Breaking Current (<3 cycles)	40 kA

8.4.3 Medium Voltage System (MV)

Rated Voltage	11 kV nominal
Highest System Voltage	17.5 kV
Phases	3
Rated Frequency	50 Hz
Rated Short Circuit Breaking Current	50 kA
Rated Short Time Withstand Current	50 kA /3 sec.
Rated Short Circuit Making Current	125 kA
Rated Peak Withstand Current	125 kA
Rated Normal Current	4000 A

8.4.4 Low Voltage System (LV)

Phase to Phase Voltage	415 V
Phase to Neutral Voltage	240 V
Frequency	50 Hz
Connection	3 Phase 4 Wire
Off Load Transformer Secondary Voltage	433 V
System Earthing	TNS (Neutral Solidly Earthed)
Rated Normal Current	1250A / 4000A
415 V maximum fault level	50kA / 3sec.

8.4.5 Control Voltage for 230/110kv Gas Insulated Switchgears

Voltage : 110 V DC

8.4.6 Control Voltage for Scada and Telecommunication Equipment

Voltage : 48 V DC

8.4.7 Space Heater Power Supply

Voltage : 240 V AC (UPS Power)
Phases : 1
Frequency : 50 Hz

8.4.8 Instrumentation Power Supply

Voltage : 240 V AC (UPS Power)
Phases : 1
Frequency : 50 Hz

8.4.9 PLC Input / Output Circuits

Supply Voltage : 24V DC

8.4.10 Climatic Condition

All the plant and equipment supplied under this work shall be entirely suitable for the climatic conditions mentioned below, and that will prevail over any data in the specification.

The project area and vicinity are close to the sea and are in a humid and tropical climate. The ambient shade temperature variation is between 4˚C and 45˚C with periods of high humidity. The project area is designated a zone of moderate intensity for earthquakes. The seismic factor is 0.05 g to 0. 1 g.

Maximum ambient shade temperature	45˚C
Minimum ambient shade temperature	4˚C
Maximum daily average temperature	35˚C
Maximum annual average temperature	25˚C
Maximum wind velocity	160 Km/h
Minimum wind velocity for line rating purposes	3.2Km/h (110/230kV)
Solar radiation	100mW/sq.cm
Rainfall	2.5 m/annum
Relative humidity, maximum	95%
Relative humidity, average	80%
Altitude	less than 10 m
Atmospheric Pollution	light
Salinity Level	High
Soil type	Sandy / Alluvial
Soil temperature (at 1.1m)	30˚C
Soil thermal resistivity	1.5˚C m/W
Isokeraunic Level (Thunderstorm days/year)	80

All outdoor equipment shall be corrosion proof and be fitted with a sunshade cover to provide effective protection against the sun and rain.

8.4.11 230 kV & 110 kV Gas Insulated Switchgear

The switchgear and its accessories shall be designed, manufactured, and tested according to the latest IEC Standards and other publications quoted in these concept design reports. General design, material and manufacturing techniques used shall generally conform to IEC.

Switchgear and substation equipment shall be suitable for continuous operation on a 3-phase, 50 Hz system of 230kV & 110kV nominal voltages as per Key Single Line Diagram, Technical Requirements and under the specified climatic conditions. The 230 kV &110 kV system shall be effectively earthed.

The switchgear shall be of the SF6 gas-insulated metal-enclosed type capable of continuous operation under the climatic conditions existing at the Site. Double busbar switchgear shall be provided. Busbar selector isolators specified in the Schedules are required to facilitate the changeover of individual circuits from one busbar to the other with the circuit on load and a bus coupler closed. Test report on the capability of on load bus transfer shall be submitted for the Engineer’s approval.

The design of the switchgear shall be such as to enable extensions to be added at either end with the minimum of disturbance to the installed equipment and with one busbar in service. A suitable arrangement shall be provided with the switchgear for the HV test of future extension part to keep the outage of the existing switchgear to a minimum.

The design shall include all facilities necessary to enable the performance of the specified site checks and tests during pre-commissioning and commissioning tests and after any repair and maintenance.

Key Single Line Diagram and Technical User Guide manuals for the 230kV & 110kV GIS Switchgears, 230kV/110kV/33kV/11kV Cu/XLPE Cables, Surge Arresters, Composite Outdoor Terminal, Auto Power Transformers, Earthing Transformers, 33kV & 11kV Vacuum Circuit Breakers and Isolators, 11kV Main Switchgear, Instrument Transformers, Meters, and Protection Relays shall be submitted to the Engineer for approval.

8.4.12 Power Transformers

The transformers shall be of the auto power transformer type with automatic voltage control, oil-immersed, suitable for outdoor installation and shall comply with IEC 60076, Parts 1 to 8 & 10 inclusive. Transformers supplied against each item shall be designed to operate in parallel satisfactory, one with the other, when operating on the same tap position. Transformers shall be designed with particular attention to the suppression of harmonic voltages, especially the third, fifth and seventh harmonics, and minimize the detrimental effects resulting there from.

Automatic Control shall be suitable for the control of transformers in parallel. In addition to the methods of control, the following methods shall also be provided:

1.) Automatic Independent - It shall be possible to select automatic independent control for each transformer irrespective of the method of control selected for any other of the associated transformers.

2.) Automatic parallel - It shall be possible to select any transformer for a master or follower control.

3.) It must not be possible to operate any tap changer by supervisory, remote or local electrical hand control while the equipment is switched for automatic operation.

Auto Power Transformers are to be provided with Cable Termination Modules (instead of porcelain insulators), which act as a link between the Power Transformer and the High voltage cables complying with IEC 62271-209.

The cable termination module shall have the inspection hole with connecting flange for the high voltage cable testing set. During high voltage cable testing, the primary conductor between the cable sealing end and the switchgear can be removed.

Neutral for the power transformer shall be terminated to the Earth through the porcelain bushing.

8.4.13 Earthing Transformers

Earthing transformers shall comply with IEC 60076-6 and shall be of the oil-immersed ONAN type suitable for outdoor installation. They have a main interconnected star winding brought out via oil/air terminal bushings, which will be directly connected to the lower voltage terminals of the associated system transformer. The neutral point of the interconnected star winding shall be brought out of the tank through a bushing insulator. This point may be isolated or connected to earth directly or through resistance in order to provide an earthing point for the neutral of the system.

The earthing transformers shall have a secondary winding to supply the substation auxiliary load. The voltage ratio shall be 33/0.433kV and 11/0.433kV. The star-connected secondary windings shall be arranged to give a three-phase, four-wire supply with the star point solidly earthed. The secondary winding shall have a continuous rating as stated in the Schedule of Requirements and shall conform to IEC 60076.

8.4.14 Protection, Control and Metering

The types of protection relays to be designed and supplied in this project shall be as per the Key Single Line Diagram Drawing and shall comprise equipment from the reputable manufacturer. The protection shall be sufficiently sensitive to cater for the minimum fault level condition. The protection shall also be suitable for a system fault level equal to the switchgear rating specified in this specification. All instrument transformer design shall be based on these fault levels. All relays shall operate correctly within system frequency limits of 47Hz to 51Hz.

Relays shall conform to IEC 61850 standards, be of approved types complying with IEC 60255 or BS 142 and 5992, parts 1, 2 and 3 as appropriate, fully tropicalized, and shall have approved characteristics. Relays designed identical to relays with a minimum of five years proven field experience will only be accepted. The supplied record of proposed relays shall be furnished for the last five years. The Employer will reject any design he considers unsatisfactory or having insufficient field experience. All the Protective relays shall be numerical type. Numerical relays shall be configured in such a way that at least two (2) nos relays shall be provided for each feeder.

Load Flow Analysis, Short Circuit Calculation and Final Relay Settings from upstream to downstream shall be calculated using ETAP Software/Cyme Software/SKM Software.

8.4.15 Substation Automation System (SAS)

Substation Automation System (SAS) shall comprise full station and bay protection as well as control, monitoring and communication functions and provides all functions required for the safe and reliable operation based on IEC 61850 standards supplied in cubicles. It shall enable local station control via PC by means of a human-machine interface (HMI) and control software package and perform the necessary system control and data acquisition functions. It shall include a communication gateway to NLDC, inter-bay-bus, intelligent electronic devices (IED) for bay control and protection. The contractor shall design the Substation Automation System general system architecture drawing as part of their scope of work.

The communication gateway shall secure control from and information flow to remote network control centers. The inter-bay bus shall provide independent station-to-bay and bay-to-bay data exchange. The bay level intelligent electronic devices (IED) for protection and control shall be directly connected to the instrument transformer and trip/close coils in the switchgear without any interposing equipment and perform control, protection, and monitoring functions subject to a detailed proposal approved by the Engineer.

8.4.16 Digital Fault and Disturbance Recorder [DFDR]

For standardization of operation performance, facilities and spare requirements, the Digital Fault and Disturbance Recorder [DFDR] to be supplied under this project shall be from reputed manufacturers.

The DFDR shall have the following features:

The equipment shall be an independent, stand-alone system to monitor analogs and digital signals from all 230kV and 110kV feeders, including transformer and bus-coupler bays that require to be monitored.

The manufacturer shall prove the system reliability of good site performances by providing substantial evidence of the systems already installed and commissioned for at least a duration of 5 years, accompanied by the customer recommendations and type test reports from internationally acclaimed laboratories.

The DFDR system shall be modular in design for easy expansion, upgrade and easy maintenance. The acquisition system or its storage unit shall not be based on a PC platform. The system shall be equipped to monitor, detect and record simultaneously Fast transient faults (short term) and Slow phenomena disturbances (Long term) like power swing, frequency variation, voltage drop, etc., covering all the required feeders.

All input signals shall be able to scan and record simultaneously at least 2 or 3 user-programmable sampling rates from 500Hz to 6kHz for Fast (Short terms) transient monitoring and from 1Hz to 500Hz for Slow phenomena (Long terms) monitoring in order to detect and record Fast (short terms) and Slow phenomena (Long terms) events.

At least 25 Sec of memory for transient fault data recording (at 6 kHz – sampling rate) and over 1000 Sec for Slow (at 30 Hz) phenomena recording shall be provided in addition to the auto maintained inbuilt Hard Disk unit, which shall be installed for data storage. The inbuilt Hard Disk Unit shall be managed and operated by the identical industrially proven operating system of the DFDR.

8.4.17 Fibre Optic Multiplexer Equipment for Communication And Protection

This describes the communication requirements for the transport of voice, data and protection signals, including Engineering, configuration, testing, installation and commissioning. For standardization of operation performance, facilities, and spare requirements, the Fiber Optic Multiplexer Equipment for Communication and Protection to be supplied under this project shall comprise equipment that can totally be integrated into the existing Telecommunication system TNEB Network including the Telecommunication Network Management System. All materials and equipment offered shall be brand new, from the manufacturer's normal and standard construction, designed and manufactured according to the latest technological methods.

8.4.18 230kV Outdoor Surge Arresters

Surge arresters with counter shall be of the type employing non-linear metal oxide resistors without spark gaps. The Contractor shall demonstrate by calculations that the surge arresters will adequately protect the switchgear arrangement proposed.

Operating Duty and Performance

The arresters shall give consistent protection to their associated equipment against over voltages produced by lightning, switching, station internal or external faults, and other system disturbances. The arresters shall be rated and tested such that they are able to discharge a specified maximum energy due to the application of temporary voltages of form and magnitude which can occur in service as determined by insulation coordination studies, without coming into the temperature region where thermal runaway could result upon subsequent application of maximum transient and steady-state voltage conditions.

Particular attention shall be given to the high discharge currents which some of the arresters may experience in service due to the requirements to discharge the energy of the shunt capacitors and reactive compensating equipment or in other circumstances. The design of the arresters shall take into account and shall maximize the degree of current sharing between complete arresters. Similarly, the design shall also take into account and shall maximize the degree of current sharing between parallel columns of the same arrester. The reference current of the arresters shall be high enough to eliminate the influence of grading and stray capacitance on the measured reference voltage. The arresters shall be fully stable thermally under site conditions and shall take care of the effect of direct solar radiation.

8.4.19 33 kV & 11kV Outdoor Type Off-Load Isolator

All control devices shall be suitable for operation on 110 V DC supplies from Substation. Operating mechanism shall be fully tropicalized and housed in corrosion-proof housing. Complete supporting steel structure. All supporting steel structure shall be hot-dipped galvanized with three coats of powder epoxy after completion of fabrication. Isolating devices shall be in accordance with IEC-62271-102. They shall be complete with supporting steelwork and installed to the maintenance of any section of the sub-station plant when the remainder is alive and shall be so located that the minimum safety clearances are always maintained. The air gap between terminals of the same pole with the isolator open shall be of a length to withstand a minimum impulse voltage wave of 115 Percent of the specified impulse insulation rating to earth. Isolating switches shall be designed for life operation, and isolators shall be hands operated. Where used for feeders, they shall be capable of switching transformer-magnetizing currents. Main contacts shall be of the high-pressure line type, and acing contacts provided shall be to the Engineer’s approval.

8.4.20 Instrument Transformers

Conventional inductive voltage and current transformers according to IEC 61869- 1/61869-2/61869-3 shall be used and shall be acceptable. Current & Voltage Sensors are not acceptable. Terminal and polarity marks shall be indelibly marked on each Potential Transformer (PT) and Circuit Transformer (CT) on the associated terminals, and these marks shall be in accordance with relevant standards. Secondary terminals of each potential and current transformer shall be brought out in a weather-proof terminal box. The facility shall be provided for shorting and Grounding the CT secondary at the terminal box. The star point, whenever required, shall be formed at the terminal box only. Each PT and CT shall be provided with a rating plate showing the particulars required by the relevant standard.

8.4.21 GIS Surge Arresters

The surge arresters shall fully comply with IEC-60099-4. Gap-less ZnO arrestors shall be provided before the termination to the transformer. Surge arrestor shall be of the hermetically sealed, Gapless Metal Oxide, suitable for use with gas-insulated switchgear. They shall have adequate thermal discharge capacity for severe switching surges, long-duration surges and multiple shocks. Normally isolable surge arrestors on the Bus Bar shall be used. This will facilitate quick isolation and coupling whenever bus bars are required to be exposed to high voltage test. Self-contained discharge counter shall be provided for each single pole unit. A leakage current detector as an integral part of the discharge counter shall be supplied. A counter along with a detector shall be so arranged that it will be possible to read the leakage current values from the outside cubicle. The value of leakage current beyond which the operation is abnormal shall be clearly marked in red colour on the detector.

8.4.22 33 KV / 11 KV Outdoor Type Vacuum Circuit Breaker

This shall be capable of the interrupting duties produced by the switching of transformer magnetizing current and the switching of line charging current. Test certificate demonstrating this ability of the circuit breakers shall be submitted with the offer.

Circuit Breaker closing mechanism shall be 230 Volt AC motor wound spring-operated type such that the closing speed is independent of the operator.

- Shall be two tripping coils and one closing coil.
- Hand closing and tripping shall be done through manual levers.
- Trip free mechanism, i.e., tripping, is independent.
- Local “Close” and “Trip” controller.
- Operation Counter.
- Supporting Steel Structure.
- Bushing Insulator as Specified in IEC-60137.

Corrosion Proof sheet steel control kiosk, with a hinged door on three sides and necessary multi-core cable glands. Controls from this position will normally is used under maintenance and emergency conditions only. AC 230V lighting system inside the door of the control kiosk shall be provided.

8.4.23 Termination Point Conductor and Jumpers

Termination point conductors and jumpers shall be of continuous length between supports. Conductors to be used shall be stressed not more than 33% of their breaking strength. Overhead line conductors carried by the Substation Gantry structures shall be erected with such a tension that when the conductors are subject to a transverse wind pressure of 640 pascal’s on the whole projected area, the factor of safety is not less than 2 (Two).

When dissimilar metals are in contact, approved means shall be provided to prevent electrochemical action and corrosion.

8.4.24 Electrical Hardware for 230kV Overhead Line Termination Point

230kV Overhead Line (OHL) connection to composite type outdoor termination unit and Surge Arrester in the 230kV OHL Gantry Area shall be of ACSR and shall be in accordance with BS 215, 159 and 2898 in respect of current rating and material analysis. All connectors shall be of compression type and made of Aluminum alloy suitable for the conductor. The current carrying capacity of all connectors & clamps shall not be less than that of the equivalent length of the respective conductor. Load support clamps shall be complete with stainless steel 304 bolts, nuts, lock washers etc. and of the appropriate size.

8.4.25 Electrical Equipment Enclosures

Equipment enclosures for electrical equipment shall comply with IEC 60079, IEC 60529 and IEC 60947-1 as applicable. Equipment enclosures for use in hazardous areas other than explosive gas atmosphere shall comply with National and Local Regulations relating to this application.

Unless otherwise specified, minimum equipment enclosure classifications for non-rotating electrical equipment shall be as follows:

Indoors only in totally enclosed rooms with provision for limiting ingress of dust	IP31
Indoors except as noted otherwise	IP54
Outdoors and indoors in areas subject to water spray or heavy condensation	IP55W

The enclosure classification of main and auxiliary cable boxes with the cable(s) terminated shall not be less than that of the associated equipment, subject to a minimum classification of IP55.

8.4.26 Medium Voltage Switchgears

The works shall include installation of the appropriate concrete pad/foundation and other mounting accessories. The switchgear and its components shall be designed, manufactured, and type-tested according to the latest applicable standards of IEC, NEMA, and IEEE. MV switchgears shall be free-standing, indoor type, designed for operation on a 11 kV, 3-Phase, 3-wire and 50 hertz system.

The switchgear assembly shall consist of individual vertical sections housing various combinations of vacuum circuit breaker/or fusible load interrupter, switches and other auxiliaries, bolted to form a rigid metal-clad, dead front switchgear assembly. Metal side sheets shall provide grounded barriers between adjacent structures, and solid removable metal barriers shall isolate the major primary sections of each circuit.

The stationary primary contacts for the circuit breaker shall be silver-plated and recessed within insulating tubes. A steel shutter shall automatically cover the stationary primary disconnecting contacts when the breaker is disconnected or out of the cell. Rails shall be provided to allow withdrawal of each 11 kV circuit breaker for inspection and maintenance without the use of a separate lifting device. Each vertical section containing a switch shall have a single, full- length flanged front door and equipped with two rotary latch type handles that can be padlocked. Provision shall be made for operating the switch and storing the removable handle without opening the full-length door. The medium voltage switchgear shall be an integrated assembly of the withdrawable type vacuum circuit breaker coordinated electrically and mechanically for high voltage circuit protection.

8.4.27 11KV Capacitor Bank

11kV capacitors shall comply with IEC 70/BS 1650 and shall be suitable in all respects for installation outdoor housed in metal-clad cubicles and for operation in the specified site conditions on the Medium Voltage system. The capacitor shall be capable of the following permissible overloads as a minimum:

Current / Voltage

- Output 1.3 times rated current continuously
- 1.1 times rated voltage of 11kV continuously
- 1.3 times rated output continuously

The capacitor container shall be of stainless steel welded construction. Alternative price shall be quoted with mild steel container which shall be protected with the following treatment:

- short blast
- Zinc spray
- primary coat
- undercoat
- finishing coat

Bushings shall be of porcelain to withstand an impulse voltage of 75kV and shall have a minimum creepage of 275mm. The capacitor shall include in-built discharge resistors inside the container permanently connected across the terminals to discharge the capacitor to 50 Volts in less than 5 minutes. Lifting and fixing brackets shall be provided on low sides of the capacitor container.

8.4.28 Low Voltage Switchgears

Main switchboards and MCB sub-distribution boards for substation and building supplies will be constructed to IEC 439, (BS EN 60439) in accordance with the following:

The classification of the main switchboards shall be:

i. The external design of switchboards shall be of the multi-tier, multi- cubicle type.
ii. Installation shall be indoors.
iii. Switchboards shall be free standing and fixed to the floor.
iv. Enclosure degree of protection shall be not less than IP42.
v. Switchboards shall be of metal clad construction.
vi. All instrumentation and metering shall be fixed to a hinged lockable compartment.

Switchboards and all associated equipment shall be suitable for use on a 415 / 240 Volt, three phase, four wires, and 50 Hz system having the neutral solidly earthed.

Each circuit shall be clearly labelled to show the destination of the associated cable and the “ON” and “OFF” positions of the switches.

Distribution boards for exterior use shall be galvanized, weatherproof and to category IP55 degree of protection.

The equipment shall be of the single busbar type with circuit equipment housed in separate compartments.

Where two or more incoming circuit breakers are provided at substations, these shall be mechanically and electrically interlocked to prevent more than one circuit closing at the same time.

The enclosures of all switchboards shall be dustproof and vermin proof. Access doors shall be mounted using concealed hinges. All removable covers shall be fitted with captive screws. Anti-condensation heaters with control switches shall be provided on switchboards. They shall be suitable for a tropical climate.

Incoming supplies to all switchboards shall be protected at the point of supply. All switchboards shall be suitably rated for a prospective short-circuit breaking capacity of 44 kA/3sec. at 415V

Busbars shall be capable of carrying the full rated current continuously without exceeding the maximum temperature specified in IEC 60439 under site ambient conditions.

8.4.29 Low Voltage Capacitor Banks

Capacitors shall be properly selected to attain 98% power factor. Group of motors fed in motor control center shall be provided with capacitor bank with automatic switching of the controller for power factor correction with the following specifications:

Standard	:	IEC 831 or Approved Equal
Type	:	Dry type Design
Frequency	:	50Hz
Degree of protection	:	IP42
Execution	:	Indoor
Discharge Resistor	:	Permanently connected built-in discharge resistors are sized to ensure safe discharge of the capacitor to less than 50V in 1 min. after switch off.
Losses	:	0.5 W/kVAR
Max. ambient temperature	:	+50 deg. C
Min. ambient temperature	:	-25 deg. C

Network studies should be carried out to ensure the correct rating of capacitors and their operation without causing a resonance.

8.4.30 Motor Control Center (MCC)

The work covered by this report includes the design and manufacture of motor control center (MCC) equipment completely assembled. The manufacturer shall also provide technical assistance during the installation and placement in service of the equipment. All equipment shall be designed, built, rated, tested and shall perform in accordance with the latest editions of the applicable standard.

Service conditions

The MCC and all components therein, shall function in a satisfactory manner within the rated capacity under the service conditions specified regardless of whether or not all necessary specific performances are set forth in this Specification or in the applicable standards.

Design Construction Details

General

The MCC within this Specification shall be compartmentalized and shall comply with IEC 439 Form 4 Type 7, and be rated to the levels specified in the Equipment Specification for operation on a 415 Volt 3 phase 4 wire 50 Hz supply.

The MCC shall be constructed with suitably folded and stiffened corners and edges with an integral supporting structure and shall be manufactured as per section in Low Voltage Switchgears. The MCC shall be free standing, front connected and front wired. The front of the MCC shall have doors supported with chrome-plated pintle hinges. The door shall not extend more than 450 mm perpendicular to the MCC face. The door locking shall be designed to prevent opening when subjected to forces caused by an internal fault. Master locking system on all doors. All openings shall be fitted with a suitable non-distorting compressible seal, which shall engage onto the MCC panel's stiffened return surround on one side and the door's rear face within the stiffened return on the other side. Each section of the MCC shall be supported on the identical 75 mm RHS hot-dip galvanized plinth, fully braced and welded, turned outwards.

Gland plates shall be fitted to the top and the bottom of the MCC, and at the incoming supply cable entry, this gland plate shall be 3.5 mm Aluminium, and all other gland plates shall be made out of the MCC construction material. All gland plates shall be gasketed and bolted. A minimum of 150 mm clear space shall be available above and below the gland plate for access to the glands. Air duct shall be provided for every VFD / Soft Starters compartment to eliminate hot air circulation inside MCC. Wiring diagram pockets shall be provided. Provision for 25% spare for future expansion shall be provided.

8.4.31 Variable Frequency Drive (VFD)

The Frequency drives shall be Voltage Source Inverter Pulse Width Modulated (VSIPWM) with GTO/IGBT/IGCT/SGCT/DTC technologies or later version precise speed and torque control of standard squirrel cage motors with optimum efficiency. All frequency drives shall be suitable for data connectivity with PLC /SCADA system and shall have a suitable communication port and protocol. The drives must be easily programmable. The drives shall be provided with surge protection, programmable lockable code. The Frequency drive shall have the following characteristics:

- Accurate open-loop torque control
- Torque step rise time typically less than 5 ms
- Speed control inaccuracy typically 0.1% to 0.5% of nominal speed
- 150% overload capacity for 60 second

Total Harmonic Distortion shall comply with the provisions of IEEE 519. Necessary metering, self-diagnostic arrangement (including display and alarm facilities) shall be provided for local/ remote monitoring.

It shall be possible to manually start the motor locally from the local push button station, starter panel, or Auto mode through PLC.

8.4.32 Soft Starters for MV and LV Motors

Constructional and Performance Features

Motor soft starters shall be switched reactance type or flux compensated type or electronic type. Soft starter panel shall be indoor, metal clad with separate metal-enclosed compartments for:

a) control, metering and current transformers for differential protection if specified
b) shorting (bypass) arrangement
c) bus bars
d) power cable terminations
e) pushbuttons with indicating lamps.

Soft starter shall achieve soft starting by torque control for gradual acceleration of the drive, thus preventing jerks and extending the life of the equipment. Starting current shall be limited to 2.5 to 3 times the rated current of the motor. The soft starter manufacturer shall coordinate with the motor manufacturer for this purpose. Separate removable gland plates shall be provided for power and control cables. Each cubicle shall be fitted with a label in the front and rear of the cubicle, indicating the panel designation, rating and duty. Each relay, instrument, switch, fuse and other devices shall be provided with separate labels. Necessary wiring diagram shall be provided considering starting interlock, trip circuit, starting and running mode signal. It shall be possible to manually start the motor locally from the local push button station, starter panel or in Auto mode through PLC.

8.4.33 Distribution Boards

Distribution Boards for use as service disconnecting means shall be circuit breaker equipped. Design shall be such that any individual breaker can be removed without disturbing adjacent units or without loosening or removing supplemental insulation supplied as a means of obtaining clearances as required. Where "space only" is indicated, provisions shall be included to allow future installations of breaker sized as indicated. All panelboard locks included in the project shall be keyed alike.

Directories shall be typed to indicate load served by each circuit and mounted in a holder behind the transparent protective covering. The enclosure shall be constructed as per the section on Low Voltage switchgears. The door seal shall be of high quality, and a pressured catch handle shall be employed. Exterior cables (power source cables as well as feeding cables) shall be directly connected to the MCCB or isolator. Adequate space for exterior wiring shall be provided.

A permanent connection diagram identifying the feeders shall be provided in a holder fitted with a transparent cover inside the door on completion of construction. Provision for 25% spare for future expansion shall be provided. Busbars shall be of tinned, hard-drawn, high conductivity copper. They shall be insulated throughout their lengths by means of phase colour sleeving. The busbar assemblies and joints shall be in accordance with the manufacturer's/supplier's recommendations.

8.4.34 Electric Motors

Motors shall comply with the requirements of IEC 60034 and IEC 60072 as amended and supplemented by this specification.

Type and Rating

Except where specified otherwise or economically justified, all AC motors shall be of the constant speed, cage induction type with windings adequately braced for direct-on-line starting at the rated voltage. They shall be suitable for control by either circuit breaker or fused contactor. Motors shall be continuously rated, Duty Type S1. Three-phase AC motors shall be rated for the voltages specified in the Specification and Single Line Diagrams. The minimum rated output of HV motors shall comply with IEC 34-1. The maximum rated output of LV motors shall not exceed 150 kW, except where the Engineer approves it.

Induction Motors Starting Method shall be either of the following types:

i.	Less than 10 kW	:	415V Direct On-Line (DOL)
ii.	10 to 100 kW	:	415V Star-Delta / Variable Frequency Drive
iii.	101 Kw to 999 Kw	:	690V Inverter / Soft Starter / VFD
iv.	More than 1000 kW	:	11kV Primary Resistance Starter / Soft Starter / VFD

Air duct shall be provided for every VFD / Soft Starter/ Primary Resistance Starter compartments to eliminate hot air circulation inside the MCC.

Total Harmonic Distortion (THD) in the plant shall be limited to a maximum of 5% for 415V system and a maximum of 4% for 11kV system by installing suitable harmonic filters or reactors.

8.4.35 Push Buttons and Separately Mounted Local Pushbutton Stations

Pushbuttons, which may be of the illuminated or non-illuminated type, shall be shrouded or well recessed in their housings in such a way as to minimize the risk of inadvertent operation. In instances where "enable" pushbuttons are required, they shall be electrically interlocked with the normal control such that deliberate operation of the "enable" push-button is required before the normal control can take place. The colour of pushbuttons shall be as follows:

i. When mounted on pushbutton stations adjacent to the running plant, the stop button shall be coloured red and the start button coloured green.
ii. When mounted on the front of the contactor panel, the stop button shall be coloured red and the start button coloured green.
iii. When mounted on panels or desks with adjacent indication lights, both buttons shall be coloured black.

Loose pushbutton stations, unless supplied as weatherproof free-standing enclosures, shall be of the metal-clad weatherproof type suitable for wall or bracket mounting with a minimum enclosure classification of IP55. All outdoor mounted pushbutton stations shall incorporate a protective cover or guard (i.e., toughened glass door) to prevent inadvertent operation.

Control stations shall be clearly labelled, showing the duty or drive to which, they are applicable. Location of ammeters shall be agreed with the Engineer. Pushbuttons used on covered desks, panels etc., may be of necessity require to be of special types (e.g. miniature, illuminated). The specifications and requirements for these special pushbuttons shall be agreed with the Engineer.

Isolator and Emergency Stop Push Button shall be provided in addition to the local push button station adjacent to all motors and machinery with exposed moving parts, couplings etc., to prevent any danger or harm to the operator. These shall also be provided on main and local control panels. The emergency pushbutton shall have a large "mushroom" head, be coloured red and incorporate a protective cover or guard to avoid accidental operation. These buttons shall automatically lock in the depressed position, requiring twist or key resetting. Contacts shall be provided to cause tripping of the associated circuit, prevent the restart of the circuit and bring up an alarm in the Central Control Room. Stop pushbuttons mounted local to motors shall trip the associated circuit breaker or contactor regardless of the control position selected. The contacts of all pushbuttons shall be shrouded to minimize the ingress of dust and accidental contact and shall be amply rated for voltage and current for the circuits in which they are used.

8.4.36 Earthing and Bonding

This section covers the complete Subgrade Earthing System, Potential Gradient Earthing System, and Above Ground Earthing System for the CP1 230/110/11kV Substation and the whole CP1 Seawater Reverse Osmosis Plant Buildings and facilities. The maximum permissible earthing system resistance of 1 ohm shall be designed for the Subgrade Earthing System to be able to:

a) stabilize the circuit potentials with respect to ground and limit the overall potential rise,
b) to protect life and property from overvoltage,
c) to provide low impedance path to fault currents,
d) to ensure prompt and consistent operation of protective devices during ground faults and
e) to keep the maximum voltage gradient along the surface inside and around the substation within safe limits during a ground fault.

The main earthing conductors for connection to all electrical equipment, cables, motors, panels, etc., shall be provided for connection to the main earthing system. All non-current carrying metal parts of electrical equipment shall be bonded to an earth terminal or terminals mounted on the equipment and readily accessible.

All electronic equipment which is vulnerable to possible conductive interference, or if the equipment generates electrical noise, which could interfere with other plant or equipment, a separate earthing may be supplied and the actual means of interconnecting with the station earth system shall be agreed with the Engineer.

8.4.37 Lightning Protection System

The entire lightning protection system shall be designed and installed in accordance with the following codes and standards:

i. National Fire Protection Assoc. (NFPA) Document # 780
ii. Underwriters' Laboratories, Inc. (UL) Standard # 96A
iii. Lightning Protection Institute (LPI) Standard # 175

The shop drawing shall show the extent of the system layout designed for the structure along with details of the products to be used in the installation. Equipment shall be the manufacturer's latest approved design of construction to suit the application where it is to be used in accordance with accepted industry standards and with NFPA, LPI, and UL requirements. Strike termination devices shall be provided to place the entire structure under a zone of protection as defined by the Standards. Air terminals shall project a minimum of 10 inches above protected areas or objects. Air terminals shall be located within 2 feet of exposed corners and roof edges. Ground terminations suitable for the soil conditions shall be provided for each downlead conductor. A separate earth pit with ground electrode shall be provided for each of the downlead conductor and should be a minimum 7m away from the plant subgrade earthing system conductors and electrodes.

8.4.38 Conduits and Accessories

Conduit installations shall comply with IEC standards 60364, 60621 and 60981. Installations shall also be compliant with local regulations, unless otherwise approved by the Engineer.

All conduit and conduit fittings shall comply with IEC 60423. Unless otherwise approved, all conduit and conduit fittings shall be thread able steel conduit with minimum enclosure classification IP55, heavy mechanical protection and high resistance to corrosion inside and outside. No conduit smaller than 20mm diameter shall be used.

8.4.39 Cable Support system

Cable ladder racking, trays and ducting shall have a minimum of 20 percent spare capacity at the end of the contract. All fixings to concrete or masonry shall be of the expansion type set in holes. Explosive powder-charged fixings shall not be used.

Fixings to structural steelwork shall be by clamping, not welding or drilling, except with the specific prior approval of the Engineer. Cable support systems shall be installed in accordance with the manufacturer recommendations to give a maximum between support deflections of 10 mm when carrying the final number of cables to be installed.

All steel supports, frames, hangers and the like shall be electroplated and in most-areas hot dip galvanized with three coats of powder epoxy. All exposed threads on support systems, conduit and other places where the galvanizing finish has been removed shall be painted with galvanized paint and three coats of powder epoxy. Sprays cans types of paint shall not be used. All lengths of the cable support system shall be bonded to earth.

8.4.40 Cables and Wire

EHV / MV / LV Cables shall comply with the following International Standards, including those referred to therein.

IEC 60183, 60227, 60502, 60885 and IS 7098, 5831, 8130, 1554, 10810.

Control cables shall be 2C, 3C, 4C, 7C, 12C and 19C type. Minimum size of conductor for control cables shall be 1.5 sq.mm Copper. All power cables shall be sized based on continuous current capacity, maximum permissible voltage drop of 3% and rated short circuit current withstand. In addition, de-rating factors for variation in ground/air temperature, grouping of cables, depth of laying, number of racks, etc., shall be considered for cable sizing. All EHV, MV and LV cables shall be subject to routine tests in accordance with the relevant IEC and Indian Standard Specifications.

Test certificates shall be provided against each drum and/or cable length. The tests carried out on every cable length and / or drum at manufacturer's premises shall include the following tests as applicable, but not limited to:

i. high voltage DC insulation pressure test, between cores, each core to earth, metallic sheath or armour as applicable;
ii. insulation resistance test;
iii. core continuity and identification;
iv. conductor resistance test;
v. Elongation test;
vi. Smoke density test;
vii. HCl gas generation test; and
viii. Anti-rodent test (Presence of lead)

All power cables shall be sized for continuous current carrying capacity at the ambient temperature of 50deg.C. The design current of any circuit shall exceed the full load current of the supplied device by at least 25%. Power cables shall be sized to limit the maximum voltage drop to no more than 3 %. Under motor starting conditions, the corresponding voltage drop shall not affect the operation of the motor controls or the ability of the motor to start and run effectively and, in any event, shall not exceed 10%. While sizing cables for the remote operation of shunt trip coils shall be used and it will take due account of the voltage drop caused by the momentary current surge taken at the instant of energisation.

Cable Colours

All cable cores shall be colour coded throughout their length and shall be so connected between switchboard, distribution board, plant and accessories, that the correct sequence or phase colours are preserved throughout the system. The colour coding should be as follows:

3 Phase+ N	-	red, yellow, blue & black
Single Phase	-	red & black, yellow & black, Blue & black
Earth Wire	-	yellow/green
Control	-	blue (DC) Red (AC)

Cable Conductors

Copper conductors shall be used throughout. Cores of cross-sectional area greater than 1.5 mm^2 shall be stranded. Lighting final distribution circuits shall be of a minimum cross-section of 2.5 mm^2. Small power and control cables shall be of a minimum cross-section of 4 mm^2. Internal wiring of control panels shall be of a minimum cross-section of 1 mm^2 flexible and stranded. Instrumentation and control cabling shall be of a minimum cross-section 1 mm^2. EHV/ MV and LV cables shall be sized as a minimum for a fault clearance time of 0.5 seconds for the incoming feeders and 0.16 seconds for switchboard feeders controlled by circuit breaker.

8.4.41 Cable Installation

Underground Cable Duct with Concrete Encasement

Underground duct lines shall be designed with concrete encasement. The concrete encasement shall be rectangular in cross section and shall provide at least 75 mm concrete cover for ducts. Conduits shall be separated at least 50 mm apart. The kind of conduits used in anyone-duct bank shall not be mixed. The top of the concrete envelope shall not be less than 460 mm below grade except those under roads and pavement, which shall be not less than 610 mm.

Duct lines shall have a continuous slope towards hand holes with a pitch of 75 mm in 30 meters. Except at conduit risers, changes in direction of runs exceeding a total of 10 degrees, either vertical or horizontal, shall be accomplished by long sweep bends having a minimum radius of curvature of 7.62 meters. Sweep bends may be made up of one or more curved or straight sections or combinations thereof. Manufactured bends shall have the following minimum radii corresponding to the given conduit diameters, as shown in Table below.

Minimum Radius Requirements

Conduit Diameter	Minimum Bending Radius
< 75 mm	457 mm
≥ 75 mm	914 mm

Conduits shall be terminated in end-bells where duct lines enter hand holes or cable trenches. Separators shall be of pre-cast concrete, high impact polystyrene, steel or any combination thereof.

Cables Installed in Conduit

Conduits shall be galvanised heavy gauge solid drawn or welded screwed steel type/ PVC type and be in accordance with IS 9537 Part 2 or BS 4568. Accessories shall either be malleable cast iron screwed type or pressed steel and galvanised.

A space factor of 40% shall not be exceeded, but in any-case conduit of less than 25 mm diameter shall not be permitted. The tubing shall be perfectly smooth inside and out and free from flaws and imperfections of any kind. Both ends of every length of tubing shall be properly reamed with all sharp edges removed before erection.

Where a number of conduits converge, malleable cast iron or heavy gauge sheet steel adaptable boxes shall be employed in order to avoid crossings. Conduits shall be connected by means of male brass bushes and couplings.

Cable Installed in Flexible Conduit

Flexible conduit shall be of the waterproof galvanised type or PVC wire-wound type with cadmium plated mild steel couplings. Lengths of flexible conduits shall be sufficient to permit withdrawal, adjustment or movement of the equipment to which it is attached and shall have a minimum length of 300 mm. Flexible conduit shall not be used as a means of providing earth continuity. A single earth conductor of adequate size shall be installed external to the conduit complete with earth terminations.

Cables Installed on Cable Tray

Cable tray shall be of perforated sheet steel with formed flanges and of minimum thickness not less than 1 mm for trays up to 100 mm width, not less than 1.25 mm for trays from 100 mm to 150 mm width and not less than 1.5 mm for trays from 150 mm to 300 mm width and not less than 2 mm for trays from 300 mm to 600 mm width.

Cable Ladders and Perforated Cable Trays, its supports, and accessories for outdoor installation shall be of hot dipped galvanized with three coats of powder epoxy coating in order to have resistance to corrosion. Cable tray for use in areas where chlorine gas and other corrosive chemicals that may be present shall be constructed from rigid non-metallic PVC with UV Resistant. Cable tray supports shall be of a compatible finish (hot dipped galvanized with three coats of powder epoxy coating) with the associated cable tray.

8.4.42 Fireproof Sealing (FPS) System

Fireproof sealing system shall be provided and shall consist of firestops / fire-seals for sealing of cable/ cable tray and conduit/ pipe penetrations, both horizontal and vertical, through brick or RCC walls/floors, to prevent the spread of fire from one area to Other areas by fire-resistant barriers. The FPS system shall also include all the necessary accessories and equipment required for supporting, holding in position, fixing, and installing the fire stop. The FPS system shall comply in all respects with the requirements of the codes and standards mentioned herein IEC-331 and IEC-332.

Fire Stop / Seal

The FPS system adopted for cables or cable trays penetrating through walls and floor openings, or cables passing through embedded conduits/pipes / pipe-sleeves, constitutes a `fire stop/seal', which is meant to prevent the spreading of fire between areas separated by fire-resistant barriers.

Performance Requirements

The material, design and construction of the fire stops shall be such as to provide a fire rating of 120 minutes for a fire on any side and meet all requirements listed in this specification and the relevant codes and standards. The materials used in the fire stops shall be non-hygroscopic, compatible with the type of cables. The fire stops shall be suitable for retrofitting of cables through the penetration seal without disturbing the sealing of the cables already existing.

8.4.43 Nitrogen Gas Injection Fire Protection System and Transformer Fast Depressurization System

Design, Supply, Delivery, Test and Commission the Nitrogen Gas Injection Fire Protection System and Transformer Fast Depressurization System for the protection of the Auto Power Transformers at the 230/110/11kV GIS Substation as per NFPA 850 2020 edition recommendation. The system shall be linked with the Main Fire Alarm System of the CP1 Plant.

NFPA 850 Recommendation for Transformer Fast Depressurization System:

The Fast Depressurization System shall comply with the description for all Power Plants and Substations of the National Fire Protection Association, NFPA 850 Recommendation, 2020 edition, which defines the following criteria as detailed below:

i. "a passive mechanical system", without the use of sensors, detectors, actuators, or switches sending electrical signals to activate a Depressurization Section.
ii. "fast depressurization", with no obstructions to a direct depressurization flow such as pistons, butterfly valves or other internal parts.
iii. "triggered by the transient pressure peak generated by the short circuit" that propagates at a speed of approximately 4,000 feet per second (ft/s), or 1,200 m/s.
iv. "activates within milliseconds before static pressure increases" which means that the Depressurization Sections should be correctly sized to avoid the static pressure to increase as soon as opened.

8.4.44 Deluge Water Spray System

Design, Supply, Install, Test and Commission a complete Deluge Water Spray Fire Protection System or Medium Velocity Water Spray System Operated by Deluge Valve as per NFPA 15 on the Power Transformers at the GIS Substation Power Transformer Bays. The system shall be linked with the Main Fire Alarm System of the CP1 Plant. Medium Velocity Water Spray System (MVWSS) operated by Automatic Deluge Valve shall be designed to protect the Power Transformers at the 230/110 kV GIS Substation from any external fire. Water spray nozzles shall be provided to protect the surface area of the Power Transformers from fire and provides cooling and prevents structural destruction in the event of a fire. The deluge valve actuation shall be controlled by Hydraulic, Electric Relay command and Manual release mode.

Sprinklers with Quartzoid bulb (Temperature rating 68°C) shall be provided around the areas to be protected for deluge valve actuation in hydraulic release mode. In electric release mode, manual command using solenoid ON I OFF switch from remotely located control panel (PXI console) operates the integral solenoid valve which actuates the Deluge valve. In relay command-based mode, the command output signal from the flame detectors (UV/IR2) located in the Transformer Bay are to be interfaced with the solenoid valve for automatic actuation of deluge valve in the event of flame detection. In manual release mode, local needle valve which is the integrated part of deluge valve assembly actuates the operation of deluge valve.

8.4.45 FM200 System

The design, equipment, installation, testing and maintenance of the Clean Agent Suppression System shall be in accordance with the applicable requirements set forth in the latest edition of the following codes and standards.

A. NFPA 2001 - Clean Agent Fire Extinguishing Systems.
B. NFPA 70 - National Electric Code.
C. NFPA 72 – National Fire Alarm and Signaling Code.
D. FM - Factory Mutual Approval Guide.
E. UL - Fire Protection Equipment Directory.
F. NEMA - Enclosures for Industrial Controls and Systems.
H. All Requirements of Authority Having Jurisdiction (AHJ)

The Suppression System installation shall be made in accordance with the drawings, specifications and applicable standards. The work listed below shall be designed and submitted to the Engineer for approval.

a) System control panel and accessories.
b) Interlock wiring and conduit for the shutdown of HVAC, dampers and/or electric power supplies, relays or shunt trip breakers.
c) Connection to local/remote fire alarm systems or listed central alarm station(s).

8.4.46 Batteries, Chargers and DC Distribution Switchgear

The following clauses describe the General Technical Requirements for Batteries, Chargers and DC distribution switchgear for use in GIS Substation, Electrical Rooms for 110V DC power for switchgear operations, protection, control, alarms, indications and 48V DC power for Telecommunication and SCADA System.

Design Requirements

Batteries shall be located in separate mechanically ventilated rooms, which shall be provided with facilities for quick drenching of the eyes and body like sinks, eyewash fountain and water supplies within seven meters of battery handling areas. Storage facilities will be provided for electrolyte, distilled water and maintenance equipment. The voltage measured at the main distribution switchgear shall not vary by more than plus 10 percent or minus 20 percent of the nominal voltage under all charging conditions when operating in accordance with the requirements of this Section.

8.4.47 Central Battery System

The emergency lighting system & all its components shall be designed and installed to meet the Local authority requirements & the respective EN 50172 and the system designed in compliance with EN50171, EN50272-2, EN50172, and EN1838 standards applicable to this project. Central Battery System shall be connected to an emergency power supply connected to a standby generator set. Emergency lighting shall fulfil the following functions:

i. Illuminate the escape routes
ii. Indicate the escape route direction clearly
iii. Provide the Exit signs on all the Exits
iv. Permit operations concerned with safety measures & to shut down the hazardous process

Each emergency supply panel shall be used for supply automatic testing and monitoring of up to 32 Escape route, EXIT and safety luminaires on each circuit. Panel Shall automatically update new lights after new lamps are installed. The panel shall have the following electrical characteristics:

Input Voltage	:	415V AC 3 Ph (Emergency Power Supply)
Output mains	:	220-240 V AC
Output Emergency	:	216 V DC
Emergency Duration	:	Three (3) hours

The number of emergency lighting system panels shall be appropriately decided for maximum reliability to ensure continued emergency supply, and failure of one panel shall not result in total emergency lighting supply failure for the entire building. The system supplier shall be an authorized distributor of the equipment, maintaining a local staff of factory-trained personnel for Engineering assistance, installation and maintenance of such equipment in compliance with the above-mentioned EN standards' requirements.

8.4.48 Lighting and Small Power

This section includes the interior and exterior lighting and small power systems.

Whenever practicable, fixtures shall be sourced as per the approved list of manufacturers. All lamps, fittings, plugs, sockets and general accessories of the same size and types shall be similar and interchangeable throughout the installation.

The lighting and small power equipment and installation shall comply with other sections of this Specification as appropriate.

All civil works associated with this section of the works shall be deemed to be included as part of the works in this section. No additional payments will be made for such requirements.

The requirements of this section of the works are subject to the Main Conditions and Specifications laid down in the electrical requirements.

LIGHTING REQUIREMENTS

The lighting installations shall be designed to give the standard service illuminations and shall incorporate emergency lighting where indicated. Control Rooms, Relay Rooms, Telecommunications Equipment rooms, offices, conference rooms, and stores shall have the service illumination measured at 850mm above finished floor level. All other areas shall have the service illumination measured at floor level. The installations shall also meet the limiting glare index requirements as set out in the specified codes of practice. This section of work gives proposals for the types of lighting fittings to be used in the area, type of control to be employed, number of socket outlets and the types of mounting expected to be suitable for the respective areas. Where discharge and fluorescent light sources are to be used in areas containing rotating or reciprocating machinery, the fittings shall be allocated between the 3 phase and neutral in such a manner as to avoid stroboscopic effects. When 3 phase lighting installations are to be used, contactor switching controlled by pushbuttons located in the area to be illuminated is preferred.

SCHEDULE OF LIGHTING REQUIREMENTS

Location	Service Glare Illuminance (Lux)	Index
Control Relay Room	500	25
Behind panels	150	-
Offices , Conference Rooms	500	20
Battery Room	300	-
Kitchen/Canteen	400	20

Toilet	100	-
Corridors, Stairs	150	-
GIS Substation Flood lighting	30	-
230/110kV GIS Room	400	20
11kV Switchgear Room	400	20
Low Voltage Switchgear Room	400	20
Transformer Compounds	150	-
Roadway Lighting	30	-
Perimeter Wall Security	20	-
Control Building Exterior	30	-
Electrical Rooms	400	20
Plant Facilities	300	-
Workshop	400	-

8.4.49 Air Conditioning and Ventilation

This section of the works covers the design, supply, delivery, installation, commissioning and setting to work of the heating and ventilating systems for the 230/110kV GIS Substation Building and CP1 facilities. All heating and ventilating systems shall be fully automatic in operation and shall be capable of maintaining internal conditions within the bands of temperature and humidity specified hereafter. the substations are normally manned, and allowance shall be made for at least four persons on-site in the design.

Basis for Design

External Design Conditions

The external conditions for the calculation of duties for the mechanical services shall be with mean monthly, maximum and minimum values as below:

Maximum ambient shade temperature		45 deg C
Minimum ambient shade temperature		4 deg C
Maximum daily average temperature		35 deg. C
Maximum annual temperature		25 deg. C
Relative humidity	- maximum	100%
	- minimum	80%
Solar radiation		100mW/sq.m

All plant and equipment installed externally, or which can be affected by external condition shall be capable of withstanding without damage or deterioration the effects of solar radiation, rain, wind, dust, sandstorms or other weather phenomena prevalent in the area, which particular building is located.

Internal Design Conditions

Air conditioning systems shall be capable of maintaining internal conditions in all air-conditioned areas within the following bands or if necessary, for the satisfactory operation of the equipment housed, more stringent requirements:

For substations	22+4^{o}C DB
	40 to 70% R.H.

The following air change rates/hour shall be provided in mechanically ventilated area:

Switch gear Rooms	10
Battery Rooms	10
Toilets	12 (Extract only)
Cable basement	6
Other general areas	4

All air conditioning and ventilating systems shall be designed for continuous operation. Plant shall be arranged to facilitate maintenance and future replacement of equipment.

The Contractor shall calculate heat gains and losses under the specified conditions for each part of each building, taking into account solar radiation, thermal transmittance through roofs, walls, floors and windows, fresh air requirements, heat emission from installed e1ectrical equipment and lighting, personnel, infiltration and any other sources. The Contractor shall be responsible for determining the heat transfer coefficients for all materials used in building construction. In the event of any change in materials. design or method of building construction, the Contractor shall at all times be responsible for rechecking the design of all systems to ensure that they are capable of meeting the specified design requirements.

8.4.50 Telephone / LAN System

This section covers the Design, Supply, Delivery, Test and Commission a complete TEL/LAN System as per ANSI/TIA/EIA 568-B in 230/110/11kV Gas Insulated Substation, CP1 Facilities and Administration Building. Complete conduit /duct bank system shall be provided throughout the GIS buildings, Administration Building and CP1 Plant facilities to enable the telephone / LAN cables to be run to the proposed extension points. This includes telephone wiring to operators' desks, office in the GIS Control Building and Administration Building.

8.4.51 CCTV System

At least 12 (twelve) IP based CCTV Camera with complete necessary hardware and software for video recording, monitoring and storage, switch etc., shall be supplied, installed and commissioned inside and outside of 230/110/11kV GIS building for security purpose. The suitable location of the camera shall be finalized during execution. Data connection for individual camera shall be through a well-protected fiber optic cable.

8.4.52 Building and Civil Engineering Works

This Section shall cover the design of all Civil Engineering, building works and services for new 230/110/11kV indoor GIS substation at CP1. The design must cover all requirements and any other items not specifically mentioned but which are necessary for the satisfactory design, construction, operation and maintenance of all equipment to the satisfaction of the Employer. No additional costs will be considered for any items which have been overlooked but which are essential for the proper completion of the project in every respect. The design work shall include but not be limited to:

i. Site survey and subsoil investigation.
ii. Site preparation, cutting or filling up to the level specified in civil requirements and leveling.
iii. Roadways, car ports, paths and surfacing.
iv. Foundations for all equipment to be installed in power receiving facility gantry area, control building, indoor switchgear and any other building required for the project.
v. 230/110KV GIS Rooms, Transformer Bays, 11kV Switchgear Room, Control Room, Battery Room, Fire Pump Room, Cable Basements, Cable Trenches, Toilet, etc. (complete building consisting of concrete piles, foundations, structural reinforced concrete frames, brick walls, concrete roof and floor slabs).
vi. Motorized roller shutter door for GIS entrance.
vii. Floor finishing: screed for cable basement and GIS room, Nitocote epoxy resin coating in battery room, raised floor for control room and homogeneous tile for other floors.
viii. Cable trenches, cable tunnels, cable ducts and pipe ducts.
ix. Water supply and plumbing installations
x. Surface water and foul drainage.
xi. Guard house
xii. Security fence (claustra block wall with stainless steel gate).
xiii. Air conditioning and ventilation.
xiv. Electric Overhead Travelling Crane for the 230kV and 110kV GIS Rooms
xv. Lighting, small power, external floodlighting, emergency lighting and fire protection.

8.4.53 STANDBY DIESEL GENERATOR SET

Contractor shall design, supply, deliver, test and commission the frame sizes, KVA ratings, and sizes of fuel tanks of the Diesel Engine Generator Sets in order to supply all the Critical Loads (i.e.: UPS System, 110V DC Battery Charger, 48V DC Battery Charger, Central Battery System, Fire Pump Control Panel, Fire Pump, Jockey Pump, Deluge Water Spray System, Smoke Extract Fans, Battery Room Ventilation Fans, Potable Water Pumps, etc. on the following CP1 Facilities:

i. 230/110/11kV GIS Substation / Control Room
ii. Administration Building
iii. Sea Water Intake Building
iv. Pre-Treatment Building
v. RO Building 1
vi. RO Building 2

vii. Post Treatment Building

viii. Water Storage Building

The Diesel Generator set shall be locally supported and shall preferably be as per IEC, British Standards and NEMA Standards. The generator supplier shall have the capability to conduct on-site load bank tests. Generator set frame sizes and ratings shall not be less than that of the available electrical critical loads of the CP1 plant facilities. These ratings as a minimum should be acceptable for site conditions of altitude up to 305 M (1000 FT) and temperatures up to 50° C (122° F).

8.4.54 UPS System and its Batteries

This section covers the Design, Supply, Delivery, Test and Commission a fully functional Dual Redundant UPS System for the following CP1 facilities critical loads (i.e., space heater power supply, instrumentation power supply, fire alarm panel, FM200 panel, Deluge Water Spray System panel, Nitrogen Gas Injection Fire Protection panel, Fire Command Center Control Panel, PLC power supply and telecommunication/LAN system power supply):

- 230/110/11kV GIS Substation / Control Room
- Administration Building
- Sea Water Intake Building
- Pre-Treatment Building
- RO Building 1
- RO Building 2
- Post Treatment Building
- Water Storage Building

ELECTRICAL SYSTEM DETAILS

Design Temp. – 50 deg. C.

Power Supply Input for UPS: 3 Phases – 415V AC, +/- 10%, 1 Phase – 240VAC, +/- 10%, 50Hz+/- 3% (Emergency Power Supply connected to a Standby Diesel Generator Set).

DESCRIPTION & SYSTEM OPERATION

The UPS shall consist of a Dual Redundant System to continue to support the critical load should one or more UPS modules fail which consist of Rectifier / Charger, Battery, Inverter, Static Transfer Switch, Maintenance Bypass Switch, Synchronizing Equipment, Protective Device and other Accessories.

The UPS shall provide continuous electric power within specified tolerance, without interruption, to the critical loads.

Normal power supply of 415V, 50 Hz TP, shall be supplied to UPS System.

The solid-state rectifier / charger shall convert incoming AC power to DC power. The rectifier / charger output shall be fed to solid-state inverter. The inverter shall convert the DC power into AC power, which shall supply the load. Upon failure of AC power, input power for inverter shall automatically be supplied from the battery with no interruption / disturbance in inverter output in excess of limits specified herein (in these specifications). At the same time, UPS shall energize an alarm circuit.

The duration for which Battery shall supply A/C power to critical loads shall be minimum 15 minutes.

When A/C power is restored, the input power for the inverter and for recharging the battery shall automatically be supplied from rectifier / charger output without interruption/ disturbance in inverter output in excess of limits specified herein (in these specifications).

The solid-state circuitry used for both Rectifier & Inverter shall be IGBT technology.

8.4.55 LOAD REQUIREMENT

EQUIPMENT LIST FOR 400 MLD PERUR DESALINATION PLANT								
					Number			
Sl. No.	Description	Capacity (Need)	Unit	Input (kW)	Duty	Stand by	Total	Service Power (kW)
I	**SEA WATER INTAKE STRUCTURE**	1,080	MLD					
	Intake Terminal							
1	Trash Rack	1,080	MLD	1.5	4		4	6.00
2	Trash Rack Garbage Machine			1.5	4		4	6.00
3	Travelling Band Screen	1,080	MLD	5.5	4		4	22.00
4	Screen Back Wash Pump			15	1	1	2	15.00
5	Intake Pump	1,080	MLD	1000	4	2	6	4,000.00
6	Shock Dosing Pump (NaClO)	3.80	m3/d	3.7	2	1	3	7.40
II	**CHEMICAL DOSING SYSTEM**	1,077	MLD					
	Dosing Tank H2SO4							
1	Dosing Pump (H2S04)	20,905	L/d	0.4	4	4	8	1.60
	Dosing Tank NaOH							
2	Dosing Pump (NaOH)	7,582	L/d	0.4	4	4	8	1.60
	Dosing Tank $FeCl_3$							
3	Dosing Pump ($FeCl_3$ for Lamella)	47,072	L/d	0.4	24	12	36	9.60
4	Dosing Pump ($FeCl_3$ for DAF)	18,820	L/d	0.4	32	16	48	12.80
5	Dosing System (Polymer for Lamella)	269,250	L/d	11	24	12	36	264.00

EQUIPMENT LIST FOR 400 MLD PERUR DESALINATION PLANT								
					Number			
Sl. No.	Description	Capacity (Need)	Unit	Input (kW)	Duty	Stand by	Total	Service Power (kW)
6	Dosing System (Polymer for DAF)	161,550	L/d	7.5	32	16	48	240.00
	Dosing Tank SBS							
7	Dosing Tank Mixer (SBS)	150		15	8		8	120.00
8	Dosing Pump (SBS)	60.30	L/d	0.4	16	9	25	6.40
	Dosing Tank Antiscalant							
9	Dosing Tank Mixer (Anti Scalant)	150		5.5	2		2	11.00
10	Dosing Pump (Anti Scalant)	3	L/d	0.4	16	9	25	6.40
	Dosing Tank NaClO							
11	Dosing Pump (NaClO)	44.60	m³/d	0.4	4	2	6	1.60
III	**PRETREAMENT SYSTEM**	1,077	MLD					
	Coagulation Tank							
1	Flash Mixer (Coagulation Tank) / Rapid Mixer	1,500		37	4		4	148.00
	Flocculator							
2	Stage 1 Mixer	100		2.2	48		48	105.60
3	Stage 2 Mixer	50		3.7	48		48	177.60
	Lamella Clarifier (Gravity Settler)							
4	Sludge Scraper for Lamellar Filter			3.7	24		24	88.80
5	Sludge Mixer			5.5	4		4	22.00
	Dissolved Air Flotation (DAF) System							
6	Flash Mixer for DAF	36.74	m2	37	8		8	296.00
	Flocculator for DAF							
7	Stage 1 Mixer	70		11	64		64	704.00
8	Stage 2 Mixer	50		15	64		64	960.00

EQUIPMENT LIST FOR 400 MLD PERUR DESALINATION PLANT								
					Number			
Sl. No.	Description	Capacity (Need)	Unit	Input (kW)	Duty	Stand by	Total	Service Power (kW)
	Dissolved Air Flotation (DAF)							
9	DAF Recirculation Pump	127	MLD	22	32	32	64	704.00
10	Air Compressor	7	l/min	22	4	2	6	88.00
11	Sludge Scraper for DAF			11	32		32	352.00
	Dual Media Gravity Filters / Backwash Tank							
12	Backwash Pump	6,000	m3/hr	190	1	1	2	190.00
13	Air Scouring Blower	9,280	Nm3/hr	280	2	2	4	560.00
	Wastewater Tank							
14	Waste Disposal Pump	5,600	m3/hr	200	2	2	4	400.00
IV	**Reverse Osmosis Plant**	1,077	MLD					
	Filtered Seawater Storage Tank							
15	RO Filtered Water Pump	400	MLD	620	16	1	17	9,920.00
16	ERD Filtered Water Pump	470	MLD	230	16	1	17	3,680.00
17	ERD Recycle Booster Pump	470	MLD	230	16	1	17	3,680.00
18	RO High Pressure Pump	400	MLD	2150	16	1	17	34,400.00
	Sea Water Reverse Osmosis (SWRO)							
19	Crane	15	Ton	7.5	2		2	15.00
20	RO CIP Pump	1,250	m3/hr	260	5	1	6	1,300.00
	Flushing Tank							
21	Flushing Pump	1,063	m3/hr	120	2	2	4	240.00
	Chemical Cleaning Tank							
22	Chemical Cleaning Tank Mixer	60	m3	15	2		2	30.00
23	Chemical Cleaning Pump	1,800	m3/hr	290	1	1	2	290.00
24	Plant Air Compressor	330	Nm3/hr	180	3	1	4	540.00

EQUIPMENT LIST FOR 400 MLD PERUR DESALINATION PLANT								
					Number			
Sl. No.	Description	Capacity (Need)	Unit	Input (kW)	Duty	Stand by	Total	Service Power (kW)
	Air Tank							
25	Air Prefilter Dryer Filter	330	Nm^3/hr	3.7	3	1	4	11.10
	Cooling Water Tank							
26	Cooling Water Pump	200	m^3/hr	37	2	1	3	74.00
27	Cooling Tower	1	MMCl/h	5.5	2	1	3	11.00
28	Pressurized Service Water System			30	12	6	18	360.00
29	Permeate Water Pump	25,008	m^3/day	100	16	1	17	1,600.00
V	**Post Treatment**	1,077	MLD					
	Limestone Filter							
30	Limestone Filter Feed Pump	120,000	m3/day	60	8	2	10	480.00
	Degassing Tower							
31	Degassing Air Blower	4,188	m3/hr	5.5	2	2	4	11.00
32	Air Scouring Blower	911	m3/hr	22	4	2	6	88.00
33	Limestone Unloading System	150	m3/hr	15	1		1	15.00
34	Limestone Recharging System	135	m3/hr	45	2		2	90.00
	Backwash Waste Tank							
35	Waste Disposal Pump	190	m3/hr	15	1	1	2	15.00
	Process Water							
36	Process Water Pump	50	m3/hr	11	1	1	2	11.00
	Carbon Dioxide Plant							
37	Carbon Dioxide Plant	18,000	kg/day	30	2		2	60.00
	Chlorine Plant							
38	Chlorine Crane			75	4		4	300.00
39	Chlorine Evaporator			22	7		7	154.00
	Carbon Dioxide Absorber							

EQUIPMENT LIST FOR 400 MLD PERUR DESALINATION PLANT								
					Number			
Sl. No.	Description	Capacity (Need)	Unit	Input (kW)	Duty	Stand by	Total	Service Power (kW)
40	Recarbonation Tower Feed Pump	2,100	m3/hr	160	6	2	8	960.00
VI	**Water Storage and Transfer**	1,077	MLD					
	Potable Water Tank							
41	Potable Water Delivery Pump	400	MLD	1200	4	2	6	4,800.00
42	Crane	10	Ton	5.5	2		2	11.00
	Dosing Tank NaClO							
43	Dosing Pump (NaClO)	5	m3/d	0.4	8	2	10	3.20
VII	**Sea Water Outfall**	1,077	MLD					
	Cathodic Protection							
44	Cathodic Protection			5.5	1		1	5.50
VIII	**Facility Power**	1,077	MLD					
45	Facility Lighting and Small Power			700	1		1	700.00
46	Street Lighting, Other Item			500	1		1	500.00
47	Fire Pump							122.00
					Total Loads in KW		KW	74,004.20
					Total Loads in KVA		KVA	87,063.76
IX	**Margin**	1,077	MLD					
47	Margin				1.20% Margin		KW	88,805.04
					1.20% Margin		KVA	104,476.52

9 INSTRUMENTATION AND CONTROL WORKS

9.1 Design Consideration

The entire desalination plant will be designed for automatic operation to minimize the requirement for manual intervention. Flow rates of main streams, seawater to the pre-treatment section, RO trains' feedwater, permeate product water, and so on shall be controlled as per the flow rates and shall be continuously monitored by the flow meters.

The plant's information and operation control system proposed shall be based on the network control system. The Distributed Control System (DCS) shall be configured in redundant control mode deployed and distributed in plant's field areas by process locations. The DCS shall function independently and autonomously, such that failure of any one element will not affect the operations of the other elements in the entire system. As a result, the system provides maximum availability and reliability for the operation.
The Proposed DCS system at Desalination Plant with the following features:

- Automation, Monitoring, Process Control, Management & Engineering or machine interface
- Reliable User Guidance
- Redundancy at all levels Station level, Controller, Power Supplies, & Communication
- Modern Object-Oriented Software Structure
- Fieldbus Communication
- Integrated diagnosis & documentation system
- State of Art Communication
- Historical data archiving and retrieval

The DCS will have the following sub-systems/functions.

- Measurement system
- Control system including closed-loop controls, interlock, protection and sequential control system
- Data bus system for control and communication with the process
- Shall be self-diagnostic both module level and channel level diagnostic
- Man-Machine interfacing system
- Smart Instrumentation with Fieldbus Interface
- Historical data & retrieval facility
- Process optimization system
- Computerized Maintenance Management System (CMMS)
- Alarm Rationalization management system & Sequence of event recording
- Interfacing with other control systems and equipment
- External network interfaces shall be through the industrial firewall.
- Dynamic mimic display, alarm monitoring, report trending, logs calculation and printing outs logs, reports and trends.
- All Peripheral hardware failures are hardwired & system status changes through the soft link as per OEM standard for Alarm logging in DCS.
- GPS Clock synchronizing with Control System, External Systems and external package PLC's.

9.2 Redundancy Levels of DCS system:

a. Station Level: All station level equipment will be considered to be redundant

b. Controller Level: Redundant Controllers will be considered as a minimum for all DCS controllers.

c. Communication Level: The communication redundancy for DCS shall be envisaged as follows,

    i. Controller to IO Modules -Redundant (communication protocol shall be considered as per OEM standard)

    ii. Controller to Operator/Engineering Stations - Redundant

    iii. DCS to third party control system - Redundant

    iv. Time Synchronization with GPS Master clock – Redundant at all interface level

d. Power Supply Level: The Redundancy shall be applicable on Power Supplies all DCS Controllers and Remote IO's (RIO) Bulk power supply shall be considered in the redundant scheme at all locations.

9.3 Central Control Room (CCR) System

The Central control room of the Desalination plant shall be facilitated with below,

i. Operator Work Stations (OWS's):

The Operator Workstations shall be interfaced with DCS controllers using Redundant Data Bus, and the same will be proposed in the Central Control Room of the Desalination plant.

ii. Historical Storage and Retrieval system (HSR) or Historian:

The Redundant Historical Storage stations shall be proposed for long term storage and retrieval facility.

iii. Control Servers:

The control servers will be considered in a redundant configuration, the control servers acts as the interface between the Plant process communication network and the station communication network. All process data acquisition and control happens through this control.

iv. Engineering Station & Laptop:

The Engineering station and Laptop shall be considered in Central Control Room for configuration of the DCS Logic & Graphics without affecting Real-time Process monitoring & control.

v. CMMS and Fieldbus Management:

A computerized Maintenance Management System (CMMS) will enable centralized, the CMMS will create automated maintenance management, all workorders for maintenance. The CMMS database will hold all maintenance data related to the past work order and create current work orders.

The Fieldbus Management system shall be considered for centralized configuration, maintenance, diagnostic and record-keeping of electronic smart transmitter data. A dedicated standalone PC-based HMS system shall be supplied at the Desalination plant's central control rooms.

vi. Printers :

The Printers shall be proposed in Central Control Room for Printing of Reports, Trends, etc. Those are to be interfaced with Hot Redundant LAN so that operators can take prints from multiple stations as and when required with the credentials of the Administrator.

vii. Large Video Screen:

Large Video Screens shall be proposed inside the Central Control Room for operator monitoring of entire plant screen systems.

9.4 Condition Monitoring Systems (CMS):

i. All critical pumps shall be envisaged in the CMS, the criticality of the pumps shall be based on

- The impact of the failure of a pump and auxiliaries will cause no reduction in the plant's output.
- The failure of the pump doesn't affect more than one process area.
- Size of the pump

ii. Vibration Monitoring System (VMS)

The Vibration monitoring system shall have condition monitoring of bearings of all HT motor drives in the desalination plant. The Vibration Sensors shall be provided for measurement in both X (Horizontal) and Y (Vertical) axis in 90 to each other for each bearing for DE and NDE.

iii. Temperature Monitoring System

The RTD sensors shall be supplied by the respective Motor & Pump manufacturer for HT Drives (wherever applicable), and sensor output is integrated to Temperature Scanner for interfacing with the DCS controller.

9.5 DCS One Line Diagram

An overall tentative DCS one-line diagram is illustrated in below Figure: 40.

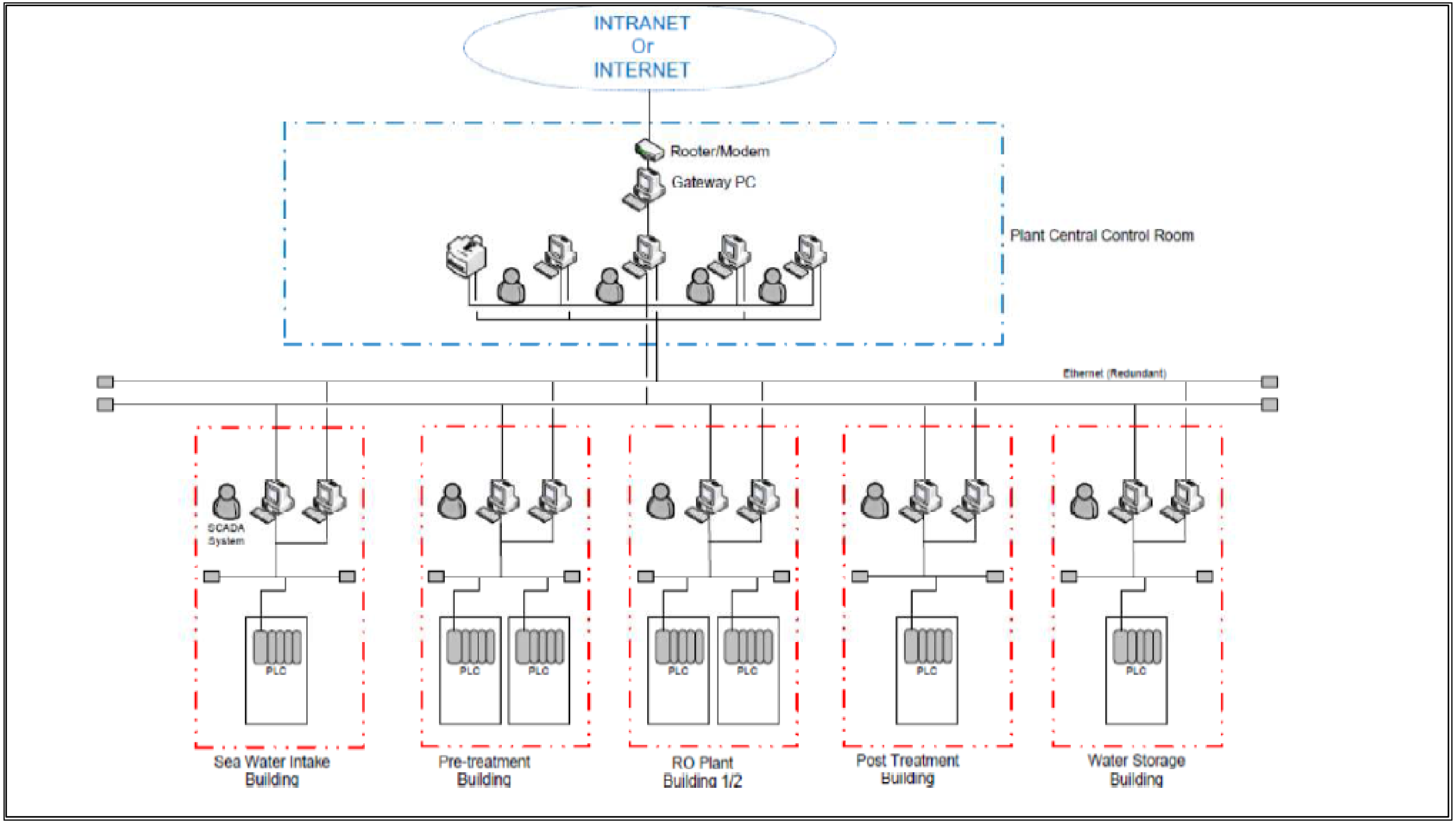
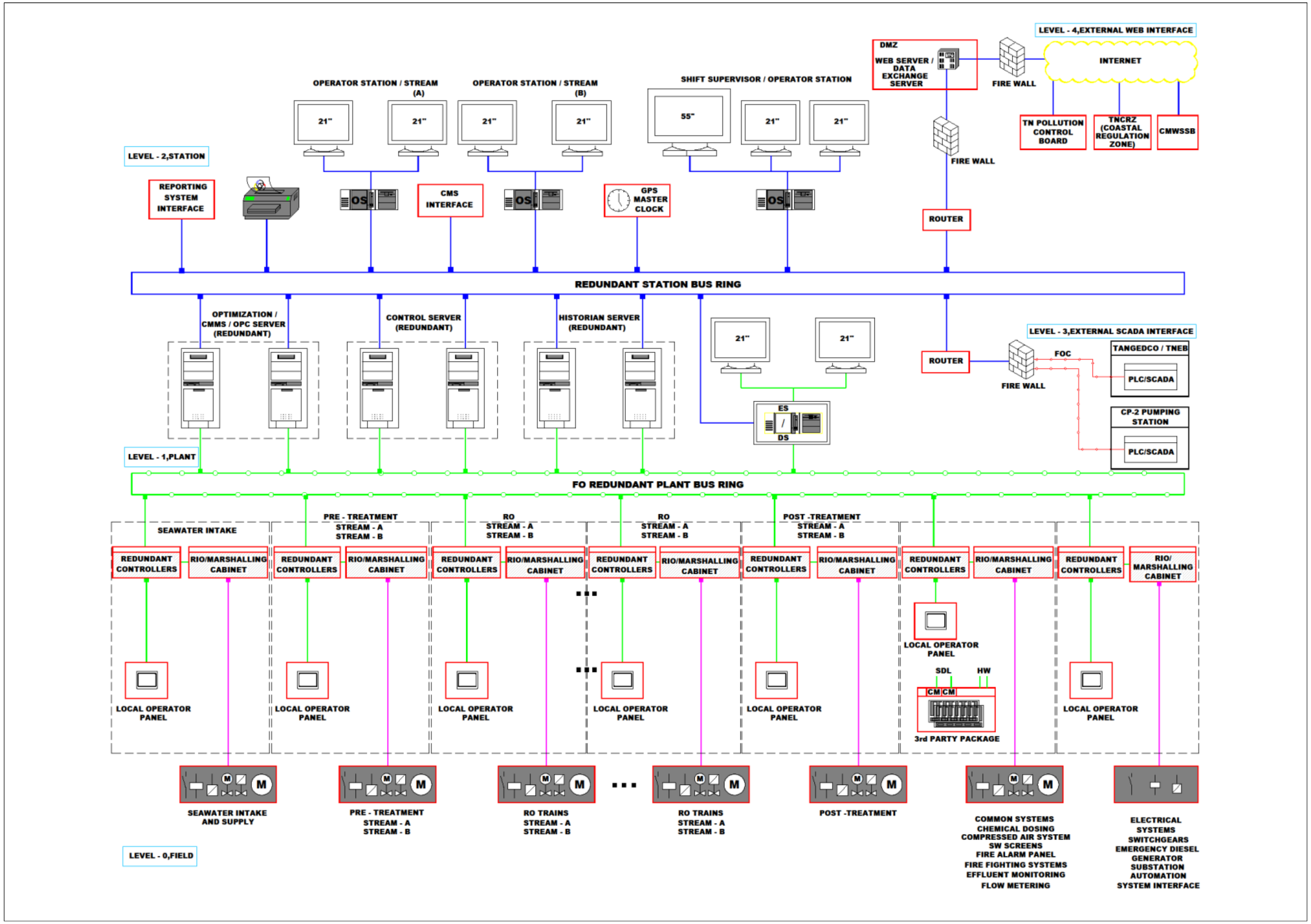


Figure 40: DCS One Line Diagram

The Tentative DCS Architecture and Interfaces for 400 MLD Perur DSP is furnished below:



LEGEND:

1.AMR - AUTOMATIC METER READING SYSTEM	5.ES - ENGINEERING STATION	10.TNCRZ - TAMIL NADU COASTAL REGULATION ZONE
2.CMMS - COMPUTERIZED MAINTENNACE MANAGEMENT SYSTEM	6.GPS - GLOBAL POSITIONING SYSTEM 7.HW - HARDWIRED	11.TANGEDCO- TAMIL NADU GENERATION AND DISTRIBUTIO
3.DMZ - DEMILITARIZED ZONE	8.OS - OPERATOR STATION	12.TNEB - TAMIL NADU ELECTRICITY BOARD
4.DS - DIAGNOSTIC STATION	9.SDL - SERIAL DATA LINK	13.FOC - FIBRE OPTICAL CABLE

9.6 Cyber Security

Cyber Security specifications will be considered and shall specify the requirements to implement a secured system.

9.7 Instrumentation

Instrumentation shall be considered for continuous operation at the maximum output and part loads and shall be designed to permit unconstrained operation over the full range of ambient conditions and under the anticipated transient operation conditions and climatic conditions peculiar to the Site and environmental pollution restrictions. Instrumentation shall be designed such that the impact of a failure of any single piece of instrument and auxiliaries will cause no reduction in the plant's production.

9.8 Instrumentation Plan

The following table presents the list of major online sensors for each process units of the Proposed Perur 400 MLD DSP.

Sl. No.	Location	Instrumentation Plan
1.	Seawater pumping station	i. Travelling band screens - Ultrasonic differential level Sensors ii. Intake forebay – Total Hydrocarbon, Turbidity, Oil, Conductivity, Temperature, pH and Residual Chlorine Analysers. –

Sl. No.	Location	Instrumentation Plan
		iii. Pumps station: Level, Pressure, Protection/ Condition Monitoring
2.	Chemical building - Pre-treatment	i. The dosing tanks shall be provided with an Online Non-Contact Radar Type level sensor, and the dosing pumps shall be provided with an Electromagnetic flowmeter at dosing pump discharge headers for the following chemicals - NaOCl (Chlorination), Sulphuric acid, Ferric Chloride, Polyelectrolyte etc.
3.	Pre-treatment – Dissolved air floatation	i. Dissolved Air Floatation Common effluent outlet - Turbidity meter and other specific quality analyser to ensure the pretreatment efficiency. ii. Electromagnetic meter on the sludge discharge line.
4.	Pre-treatment – Gravity dual media filtration	i. Differential Pressure sensors at each Gravity dual media filtration unit, Ultrasonic level sensors at each filter. ii. Backwash pump discharge header- Electromagnetic meter iii. Pumps: Pressure, Protection/ Condition Monitoring
5.	Pre-treatment – RO feed/ Backwash tank	i. Ultrasonic level sensors
6.	RO Feed Water	i. Chlorine, pH, conductivity, temperature, SDI and Boron Analyser before cartridge filter ii. Feed Water Pumping – Pressure, flow, Protection and Condition Monitoring
7.	Chemical building for Seawater Reverse Osmosis (SWRO)	i. The dosing tanks shall be provided with an Online Non-Contact Radar Type level sensor, and the dosing pumps shall be provided with Electromagnetic flowmeters at pump discharge headers for the following chemicals - Sodium hydroxide, Antiscalant and Sodium meta-bi-sulphite, Biocide (as needed)
8.	RO building	i. RO feed pump discharge header – Online Pressure sensor ii. Micron Cartridge filter – Differential Pressure sensor iii. SWRO High-pressure pump suction – Electromagnetic flow meter, Online

Sl. No.	Location	Instrumentation Plan
		Pressure sensor iv. SWRO High-pressure pump discharge – Online pressure sensor v. ERD booster pump discharge – Online Pressure sensor vi. CIP dosing tanks- Online non-contact radar type level sensor vii. CIP dosing pumps discharge header – pH, Online Pressure sensor viii. RO flushing pump discharge header – Online Pressure sensor, Electromagnetic flowmeter ix. RO permeate line outlet – pH, Conductivity, Electromagnetic flowmeter x. Pumps: Pressure, Protection/ Condition Monitoring
9.	RO permeate tank	i. Ultrasonic level sensor
10.	SWRO Reject discharge line	i. Electromagnetic flowmeter, Online Pressure sensor, Temperature, pH, Turbidity, Conductivity, Residual Chlorine
11.	Post-treatment area	i. Lime filter inlet/outlet – pH, Electromagnetic flowmeter and Turbidity ii. Lime filter backwash – Electromagnetic flowmeter, residual chlorine iii. Lime filter Backwash air blower- Online Pressure sensor iv. Lime Silo level v. All required sensors and flow meters for CO_2. vi. The dosing tanks will be provided with an Online Non-Contact Radar Type level sensor, and the dosing pumps will be provided Electromagnetic flowmeter at pump discharge headers for the following chemicals – Sodium hydroxide and Sodium hypochlorite
12.	Product water storage tank	i. Ultrasonic level sensor in the tank ii. Float type level sensor in the tank iii. Product water storage tank outlet line –

Sl. No.	Location	Instrumentation Plan
		Electromagnetic flow meter, Conductivity, pH, Turbidity, Residual chlorine, Temperature.
13.	Autosamplers	i. Seawater intake area ii. Lamella/DAF effluent and sludge line iii. Gravity dual media filter outlet iv. Remineralised water lines v. Product water lines to CWR vi. Seawater/ Brine outfall discharge area
14.	Package sewage treatment Plant	i. Inlet Electromagnetic flowmeter and treated water flowmeter and all other process sensors
15.	Wastewater treatment units	i. Lamella clarifier sludge discharge common line – Electromagnetic meter ii. DAF sludge discharge common line – Electromagnetic meter iii. Sludge balance tank and Thickeners - Ultrasonic level sensor iv. Sludge holding tank -Ultrasonic level sensor v. Sludge transfer pumps discharge header to thickener- Electromagnetic flowmeter, Online Pressure sensor vi. The dosing tanks will be provided with an Online Ultrasonic level sensor, and the dosing pumps will be provided Electromagnetic flowmeter at pump discharge headers for the Polyelectrolyte dosing in Thickener inlet and Belt filter press inlet vii. All pumps pump discharge line – Electromagnetic flowmeter, Online Pressure sensor viii. Neutralisation pit – Electromagnetic

Sl. No.	Location	Instrumentation Plan
		flowmeter, Online Pressure sensor. ix. Outfall tank -Ultrasonic level sensor

9.9 Integrated Security System

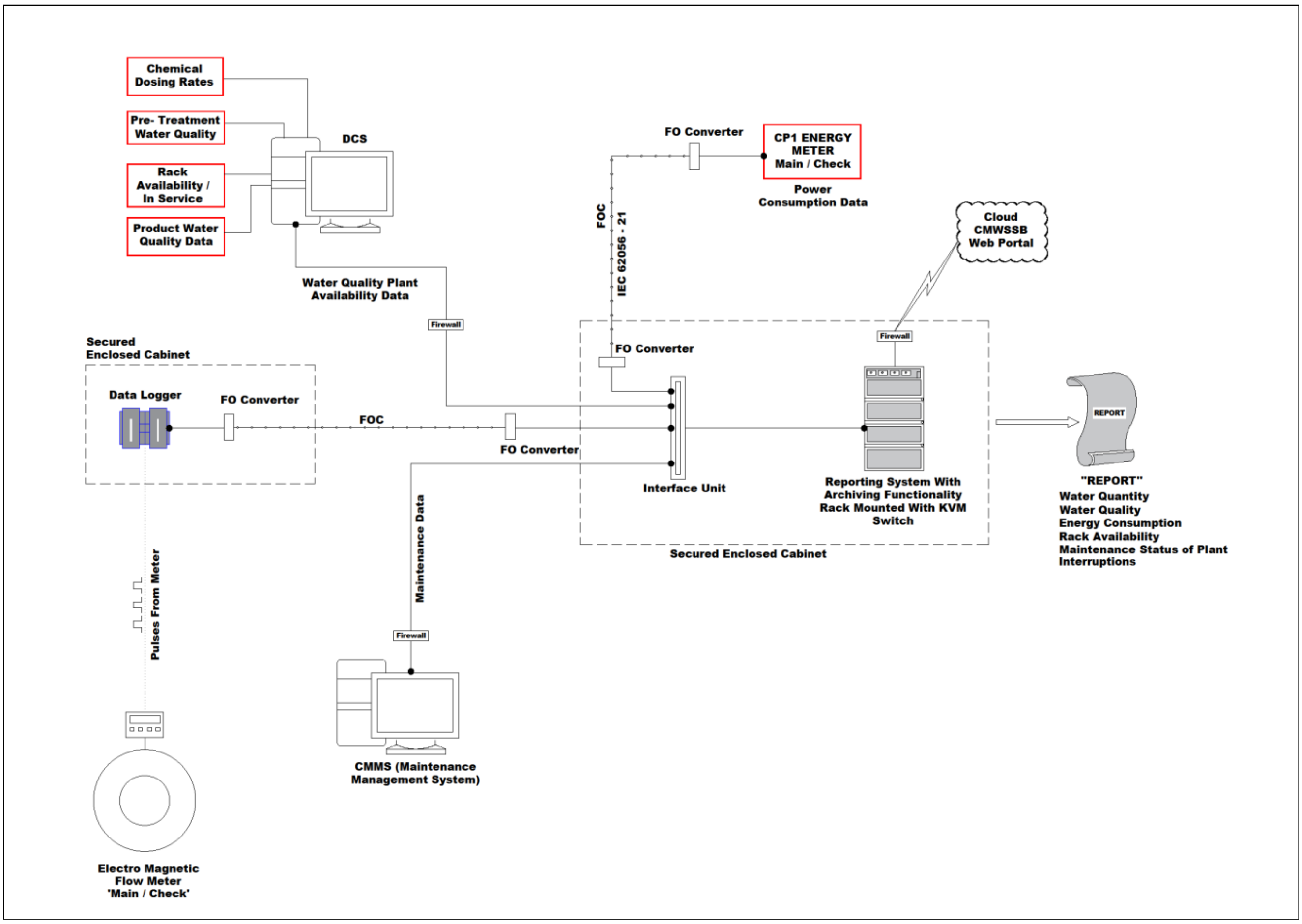
The Integrated Security System (ISS) shall be considered and will comprise the following discrete systems:

- CCTV Surveillance System
- Access Control System
- Identity Management system
- Central Security Control
- Public Addressing System
- Communication System

The above systems are required to safeguard the assets by various collusion threats from insider or outsider and improve overall security and surveillance.

9.10 Reporting System Architecture

The Tentative Reporting System Architecture is furnished in the following figure.


Chemical Dosing Rates
Pre- Treatment Water Quality
Rack Availability / In Service
Product Water Quality Data
DCS
FO Converter
CP1 ENERGY METER Main / Check
Power Consumption Data
Cloud CMWSSB Web Portal
FOC
IEC 62056 - 21
Water Quality Plant Availability Data
Firewall
Secured Enclosed Cabinet
Data Logger
FO Converter
FOC
FO Converter
FO Converter
Firewall
REPORT
Interface Unit
Reporting System With Archiving Functionality Rack Mounted With KVM Switch
"REPORT"
Water Quantity
Water Quality
Energy Consumption
Rack Availability
Maintenance Status of Plant
Interruptions
Secured Enclosed Cabinet
Maintenance Data
Pulses From Meter
Firewall
CMMS (Maintenance Management System)
Electro Magnetic Flow Meter 'Main / Check'

10 CAPITAL AND OPERATING COSTS

Project capital, operation and maintenance (O&M), and overall water production costs depend on a number of factors, most of which are site-specific to the desalination project location, size, and technical and socio-economic circumstances. In general, there are two types of factors that strongly influence desalination project costs: (1) factors controlled by the decisions of the facility owner; and (2) subjective factors beyond the control of the facility owner, including those which result from regulatory requirements.

10.1 Country risks

The country risks include:

- The economic risk reflects the stability of the economy and of the currency which will be used to pay the contractor (despite eventual financial tools to mitigate the main impacts)
- The political risk reflects the stability of the central governmental institutions
- The business risk reflects all aspects that prevent a project from smooth and clean development.
- The legal risk addresses the stability and completeness of law + specific provisions applying to international projects; the legal risk assessment will review all past and current law cases for similar projects.
- The financial risk (that could also be classified as Project risk in case of foreign financing) reflects the solidity of the financing entity.

10.2 Project risks

The projects risks include:

- Difficulty in the adoption of outfall location recommended by PMC & JICA. There is the risk of increasing intake salinity with the intake and outfall locations proposed by DPR.
- Abrupt change in seawater quality with an increase in TSS and/or TOC.
- No confirmation of funding allocation for O&M contract before the release of RfP.
- Expected project delay during site land filling up to CD +6.5m.
- Complexity in contract award resulting project delay.
- The risk allocation between the Employer and the Contractor.
- The technical risk addresses mainly the complexity of the plant itself compared to other projects, which may result in not achieving the technical performances of the plant. For the Perur project, the main items to be considered are:
  - High level of TOC (to be confirmed)
  - High level of TSS (3 pre-treatment stages)
  - Wide range of TDS (32000 mg/l up 38500 mg/l (revised 39000 mg/l)
- The market situation leading to high competition (few projects at the same time, low project and country risks) or low competition (many projects at the same time, a large project and country risks).

10.3 Capital Cost Evaluation

Project capital costs can be divided into two broad categories: (1) construction costs (also referred to as "direct capital costs) and (2) other project-related capital costs (engineering, development, financing, and contingencies), which are also known as "indirect capital costs.

The construction portion of the capital costs varies with the size and complexity of the individual projects and typically ranges between 50% and 85% of the total capital costs. The indirect (non-construction) portion of the capital cost is usually within 15%–50% of these costs.

For evaluation of the capital cost for 400 MLD Perur DSP, the following method has been used, which rely on the analysis of EPC costs worldwide. Most of the desalination projects (number and size) being in Near and the Middle East, the averaged EPC costs are more reflecting these region conditions. From overall comparisons between conditions in India and those in the Middle East, the EPC cost in India is assessed to be 15 to 25% less expensive than in the Middle East. This is mainly due to the local supply of building material, mechanical/electrical equipment, labour and transportation. **Therefore, a coefficient of up to 0.25 will apply at the end of the following methods to adjust for region conditions.**

10.3.1 Presentation and Methodology

At the Concept Design stage, after the Engineering Report has confirmed the main options for processes, it becomes critical importance to establish the financing level required for the CP1 package of the project. To assess the EPC cost of the plant, the estimates given by Voutchkov have been used, and then it is verified by the cost of the recent project awarded worldwide.

(i) Using the tables and graphs developed by Nikolay Voutchkov in its book: “Desalination Project Cost Estimating and Management” edition 2019;

- Mr Voutchkov has over 25 years of experience in the field of desalination and water reuse and currently works as an independent technical advisor to public utilities implementing large desalination projects in Australia, the USA, and the Middle East; and to private companies and investors involved in the development of advanced membrane technologies. He has extensive expertise with all project delivery phases: from conceptual scoping, pilot testing and feasibility analysis; to front-end and detailed project design, permitting; contractor procurement; project construction and operations oversight/asset management. For over 11 years before establishing his project advisory firm, Mr Voutchkov was a Chief Technology Officer and Corporate Technical Director for Poseidon Resources, a private company involved in the development of large seawater desalination projects in the USA.
- Mr Voutchkov has published over 30 technical articles and co-authored 10 books on membrane water treatment and desalination, including technology and design guidelines for the American Water Works Association and the Australian Water Association. In recognition of his outstanding efforts in the field of seawater desalination, Mr Voutchkov has received a number of prestigious awards from the International Desalination Association, the International Water Association, and the American Academy of Environmental Engineers. Mr Voutchkov is the author of more than ten books about desalination. *(Source: https://idadesal.org/profile/nikolay-voutchkov-pe-bcee/).*

Mr Voutchkov has produced cost estimating graphs. The graphs are based on exposure to the most significant SWRO projects all over the world. His book - 2019 revision provided up-to-date information until 2018 projects.

The cost evaluation is performed stage by stage, from marine works to post-treatment.

(ii) Review of selected recently awarded projects of similar size; detailed analysis of main differences with Perur DSP and adjustment of unit capacity cost (USD/m^3/d).

As a synthesis, this method will be compared and discussed to assess the most accurate range of EPC cost for the Perur DSP.

10.3.2 Project Cost Estimate using N. Voutchkov's graphs

- A recovery rate of 42% will be taken to compute the CAPEX as it takes into consideration the oversizing of marine works and pretreatment. However, PMC recommends a recovery reduction down to 44% only, which will save a significant amount of money.
- The graphs provided in the book cover plant up to 200 MLD, which obliged to some extrapolations, but this is not too much of an issue since the PERUR DSP will be erected with a 2 half concept (2 mostly separate plants of 200 MLD; the cost of the 200 MLD Plant will be not just doubled to achieve the 400 MDL plant, but some discount rate will apply on the specific items of half-plant to ensure a more accurate final result (for instance: marine work equipment mobilisation or pipe transportation for marine works). The details of the graphs have been presented in **Annexure 7.**
- The calculation of the project cost estimate has been presented in Table 57 below.

The flow rates have been taken from the mass balance flow rate presented in **Annexure 4**.

Table 57: Capital cost for 400 MLD Perur Desalination Plant

Items	Capacity, MLD	Cost for Half Plant[1]	Co-eff. for full plant	Cost for Full Plant	Cost per m³ product,	Cost for full plant (400 MLD)	% cost	Cost Reduction due to the following factors		
		(KUSD/ 200 MLD)	(400 MLD)	(KUSD/ 400 MLD)	(USD/m³)	(INR Cr)		Common Mobilization	Common Procurement	Common Trench
	a	b	c = 1+(1-h)* (1-i)	d = b*c*j	e =d/400	f = d/10000 *74	g	h	i	j
Open offshore intake (1800m)	526	63250	1.63	82478.0	206.2	610.3	20.3%	30%	10%	20%
Wet well pump station	526	4451	1.81	6444.7	16.1	47.7	1.6%	10%	10%	20%
Band intake screen	526	5260	1.90	8994.6	22.5	66.6	2.2%	10%		10%
Lamella filters	526	10115	1.81	13914.7	34.8	103.0	3.4%	10%	10%	24%
DAF	526	14162	1.81	19480.6	48.7	144.2	4.8%	10%	10%	24%
GMF	526	29335	1.81	40352.7	100.9	298.6	9.9%	10%	10%	24%
Cartridge Filters	480	4940	1.81	8941.4	22.4	66.2	2.2%	10%	10%	0%
RO System	494	68000	1.81	123080.0	307.7	910.8	30.3%	10%	10%	0%
Limestone beds + CO_2	207	5175	1.81	7493.4	18.7	55.5	1.8%	10%	10%	20%
Disinfection (sodium hypochlorite)	207	776	1.81	1124.0	2.8	8.3	0.3%	10%	10%	20%
Full 400 MLD plant outfall (800 m)	207	93600	0.63	47174.4	117.9	349.1	9.6%	30%	10%	20%
Chemical System Building	400	4000	1.81	5502.4	13.8	40.7	1.4%	10%	10%	24%
Product water + wastewater + Outfall Tank with pumping	400	11500	1.81	15819.4	39.5	117.1	3.9%	10%	10%	24%
Administrative, control room and other infrastructure including site development	400	6000	1.81	8253.6	20.6	126.1	4.0%	10%	10%	24%
Wastewater treatment system	31	8084	1	8084.0	20.2	59.8	2.0%			
Startup, commissioning and acceptance test	400	5800	1	5800.0	14.5	42.9	1.4%			
Substations and Cables	400			2701.0	6.8	20.0	0.7%			
Total Cost	**400**			**405639**	**1014.1**	**3077**	100.0%			

1. The EPC cost estimate is taken from Voutchkov's graphs provided in Annexure – 7
2. Plant Outfall pipeline length - 1800 m

The capital cost provided above is based on the increased size of the intake and pretreatment systems to entertain the flow rate up to 1052 MLD to RO system @ 42% recovery in case of worst seawater quality and increased fouling tendency of the membrane.

This provision gives an overall construction cost of about **405.6 Million USD** for the 400 MLD plant, which is **about 1014 USD/m³** (INR 75043/m³) at an INR/USD conversion rate of INR 74/USD after taking consideration of cost reduction due to several factors including the local supply.

An explanation for the computation of cost reduction coefficients to derive 200 MLD Cost to 400 MLD Cost is given below.

- Open offshore intake coefficient: 1.47
    - -30% for no extra mobilisation
    - -10% for saving on procurement for the second intake pipe

  - 1 + (1 x (1-0.3)x(1-0.1)
  - 1 + (1 x 0.7 x 0.9) = 1.63

- As the above costing is based on works implementation in Europe, there will be considerable cost reduction due to local suppliers in India of the civil materials, mechanical equipment and labours. To incorporate this, a cost reduction factor for local supply has been introduced, and the above construction cost of USD1014/m³ is after the introduction of this local supply factor. Without local supply or any other reduction factors, the overall construction cost will be about **USD 475 Million** for the 400 MLD desalination plant, which is **about USD 1189/m³** (INR 87957/m³) at an INR/USD conversion rate of 74.
- The value of the local supply factor will vary for different units/system based on the portion of the civil, mechanical and E&I work involvement. In the case of Lamella clarifier/DAF/DMF, the civil, mechanical and E&I/other works are 50%, 30% and 20%, respectively, of the total costs. The per cent cost reduction for these items has been adopted as 30%, 20% and 15%, respectively.

  For example, the total reduction in the cost of the Lamella clarifier will be

  0.5*0.3+0.3*0.2+0.2*0.15 = 24%

  Similarly, the cost reduction due to local supply for other units/system has been calculated.

This method, computing the cost of each unit/system according to its flowrate, allows comparing the impact of oversizing of the marine works and the pre-treatment (RO recovery @ 42%). The same computation is also performed with the operating recovery of 46% at a reduced flow rate of 961 MLD.

Taking 46% recovery into consideration, the cost of the intake system and the pre-treatment system will be reduced accordingly, and the revised CAPEX will be USD 391.8 Million for the 400 MLD desalination plant, which is about USD 979.5/m³ (INR 72481/m³) at INR/USD conversion rate of 74.

The CAPEX difference for oversized marine works and pre-treatment for 42% RO recovery against 46% is equal to USD (405.6 – 391.8) = USD 13.8 Million (equivalent to about INR 102 Crores). Moreover, there will be an additional cost of bigger size pumps to handle the high flow rate to the RO membrane. In case the intake system is not complex with the length of the pipeline within 1000m, the cost will further be reduced to USD 945/m³ of product water.

As evidenced above, there is a significant increase in cost due to the provision of lower recovery (42%) in the design. It is essential to review the significance of the recovery drop from 46% to 42% as adopted in the DPR and JICA report. Taking into consideration of the increased cost, PMC recommends allowing a decrease in recovery by only 2%, i.e. from 46% to 44%, which should be sufficient to cope with any issue with the raw water quality and the RO system. This will limit the construction cost due to recovery drop to at least half.

Table 58: Capital cost with different process options

Process Option Description	Total Project Cost for 400 MLD Plant	Project Cost per unit product water
Plant cost (42% recovery) without consideration of local supply	INR 3518 Cr (USD 475.5 Million)	INR 87957 / m3 (USD 1189 / m3)
Plant cost (42% recovery) with consideration of local supply	INR 3077 Cr (USD 405.6 Million)	INR 75043 / m3 (USD 1014.1 / m3)
Plant cost (46% recovery) with consideration of local supply	INR 2899 Cr (USD 391.8 Million)	INR 72481 / m3 (USD 979.5 / m3)
Plant cost (44% recovery) with consideration of local supply	INR 2950 Cr (USD 399 Million)	INR 73762 / m3 (USD 997 / m3

10.3.3 Review of recently selected projects

This review will compare several large plant EPC costs, recently build, awarded or under construction. Due to the limited information available, the complexity of these projects can't be assessed and compared to PERUR DSP. However, the cost of the project and MUSD/m^3 product can be compared for a few large desalination plants completed or under construction.

The projects are selected according to their size (250 MLD or above) and the date of the award not more than 3 years to keep similar market conditions. The details of the projects are given below in Table-59.

Table 59: Capital cost for recent Desalination Plants elsewhere

Sl. No.	Project	Country	Contractor	Contracted in	Plant Capacity	Construction Cost	Cost/ m^3 product	
				(Year)	**(MLD)**	**(M USD)**	**USD**	**INR**
1	Jubail 3a	Saudi Arabia	ACWA Power	2020	600	675	1125	83250
2	Yanbu 4	KSA	Engie	2020	450	550	1222	90444
3	Soreq	Israel	IDE	Jun'20	620	600	968	71613
4	Umm al Quawain	UAE	ACWA Power	2019	682	800	1173	89150
5	Taweela	Saudi Arabia	Abengoa	Oct'19	909	870	957	70825
6	Shugaig 3	Saudi Arabia	Acciona	May'19	450	600	1333	98667
7	Rabigh 3 IWP	Saudi Arabia	ACWA Power	2018	600	700	1167	88667
8	Barka 4	Oman	Suez	2016	281	279	993	84360
	Average				**574**	**634**	**1105**	**83977**

The cost of the product water per m3 for Jubail 3A, Yanbu 4, Rabigh 3, Shugaig 3 and Umm al Quawain is above USD 1100, and for Sureq, Taweela and Barka, it is less around USD 1000. **Average of the Construction cost for the first 8 plants is 634 MUSD for an average of 574 MLD water production, and the product water cost per m3 is USD 1105/m^3.** Taking into consideration of a cost reduction of 15% due to local supply, the average construction cost goes to 539 MUSD for a 574 MLD plant with a unit cost up to USD 939/m^3.

The sourcing of recent EPC costs is difficult since such information may impact further competition, and internet available info may also be questionable.

Technical comparisons

1. All the above projects only include a double stage pre-treatment arranged around a selection among DAF, DMF (mainly pressure filters) and UF technologies. Favourable seawater quality in the Gulf does not require Lamella settler technology.
2. Project TDS envelop are commonly 38,000-41,000 mg/l for Oman Sea and Red Sea, 39,000-42,000 mg/l in UAE and Qatar.
3. Despite WHO relaxation for Boron @2.4 mg/l:
    a. Saudi Arabia projects still implement a boron threshold of <1 mg/l, and consequently, all plants are equipped with a second partial second pass.
    b. Oman follows the relaxation and implements single-pass plants (bypass of second RO pass for existing plants); however, the last plant (Barka 4) is an exception with partial RO second pass where Suez made it competitive.
    c. UAE has no specific trend, but it is understood that decisions are taken according to the potential blending with associated thermal desalinated water (very low TDS and Boron contents): Taweela has not the second pass while Umm al Quawain includes a second pass.
4. Product water TDS is required < 500 mg/l

For further discussions, assessment of partial second pass cost is necessary, and so it is computed from GWI software and presented below.

10.3.4 Capital Cost Conclusion

The comparison of cost using 2 methods is given below in Table 60.

Table 60: Capital cost comparison with recent desalination plants elsewhere

Methods Used	Cost Description	Construction Cost, M USD	Unit Cost, USD/m^3
Voutchkov Graphs	Overall cost of the plant with 1800m Outfall pipeline	405.6	1014
	Overall cost of the plant with 750m Outfall pipeline	378	945
Other Plants Review	Average cost of 8 plants elsewhere	442	1105

Considering the high cost of marine works and 3 levels of pretreatment process units for 400 MLD Perur plant, the product cost of USD 1014/m^3 at recovery 42% looks reasonable and comparable to other plants. In case additional expenses due to reduced RO recovery (42%) is not taken, and high recovery (46%) is considered, the product cost will come down to USD 979.5 / m^3, and if the length of the intake and outfall positions from the shore is reduced to 1150m for intake and 750m for outfall as per the DPR proposal, the cost of the plant per m^3 will further reduce down to USD 912/ m^3.

The review cost is just indicative for comparison purpose and that they do not explicitly rely on the specifications/complexities of our project but the statistic approach, based on a wide number of projects.

The construction cost of USD 405.6 Million and the unit cost of USD 1014/m³ of product water for 400 MLD Perur desalination plant is undoubtedly the best describing the equipment included in the plant and the graphs used for determining cost was revised recently in 2019 (new edition).

10.3.5 Capital Cost Conclusion Capital Cost Comparison DPR, JICA, PMC

The capital cost for construction of the 400 MLD desalination plant at Perur, Chennai, estimated by DPR, JICA and PMC, are INR 2362 Crores, 2670 crores and 3077 crores, respectively. The cost estimated by DPR and JICA was in early 2017, while the PMC estimate was in early 2021. The major difference in the estimate of PMC is for the cost of the Intake system and RO system.

Table 61: Comparison of Project Capital Costs for 400 MLD SWRO Plant at Perur (CP1)

Sl. No.	Description of work	JICA	DPR	PMC
		Costs in INR Crores		
1	**Seawater Intake and Outfall System**	**376.8**	**265.1**	**665.7**
(1)-1	Seawater intake pipelines			378.4
(1)-2	Band Screen	0	0	41.3
(1)-3	Pumping System	included	included	29.6
(1)-4	Brine discharge pipeline facility	included	included	216.4
2	**Pre-treatment process**	**627**	**575.62**	**546.0**
(2)-1	Lamella	216.9	0	103.0
(2)-2	DAF	248.2	0	144.2
(2)-3	DMF	162	0	298.8
3	**RO Process**	**636.3**	**687**	**781.6**
(3)-1	RO Feed tank	9	0	0.0
(3)-2	Cartridge Filter	0	0	52.9
(3)-3	RO Building and equipment	627.3	0	728.6
4	**Post Treatment**	**134.3**	**73.23**	**63.8**
(4)-1	Mineralisation	121.8	included	57.4
(4)-2	CO_2	12.5	included	6.4
5	**Dosing System**	**42.6**	**0**	**40.7**
6	**Tanks**	**65.2**	**42.76**	**65.6**
(6)-1	Product Water Tank	55.2	included	22.4
(6)-2	Dirty Water Tank	10	included	0.0
(6)-3	Outfall Tank	0	0	5.6
(6)-4	Permeate Tank	0	0	3.7
(6)-5	Filtered Water Tank	0	0	7.5
(6)-6	All Transfer Pumps	0	0	26.4
7	**Buildings**	**11.6**	**7.702**	**51.9**

Sl. No.	Description of work	JICA	DPR	PMC
		Costs in INR Crores		
(7)-1	Administrative Building + interior	3.6	0	25.5
(7)-2	Computer Building + interior	0	0	10.2
(7)-2	Other Buildings - electrical, Fire, security	8	0	16.2
8	**Wastewater Treatment System**	**0**	**0**	**59.8**
9	**Control System**	**182.4**	**143.16**	**165.4**
(9)-1	Power distribution	144.3	143.16	135.6
(9)-2	DCS	38.1	0	29.8
10	**Electrical Sub-station**	**57.8**	**0**	**60.0**
11	**Site Development** including Earth filling to raise the level to 6.5m MSL, Retaining wall, Compound wall, Gate and Security Room, internal roads and Drains	**34.4**	**21.29**	**104.15**
12	**Erection, commissioning and Testing**	**128**	**121.24**	**165.3**
(12)-1	Erection of the plant			25
(12)-2	Dry and Wet Commissioning			5
(12)-3	Pre-commissioning test			19
(12)-4	Process Proving test			116
13	**Shipping and Transportation**	**25.6**	**0**	
14	**Overhead, Profit**	**348.30**	**424.92**	**307.43**
	Total Cost for CP1	**2670**	**2362**	**3077**

10.4 Operating Cost Evaluation

High-complexity projects typically have source water with a high membrane fouling potential which requires elaborate pretreatment and process monitoring, and have fully automated plant operations, which require very skilled staff and compliance with very stringent environmental regulations and product water quality requirements. Concentrate disposal costs include expenditures associated with plant wastewater treatment and final wastewater disposal to the outfall facilities. Annual desalination plant power costs are dependent on two key parameters the power tariff and the amount of power used to produce desalinated water. The SWRO system typically uses over 70% of the power required to operate the desalination plant. The rest of the power is consumed mainly by plant intake and pretreatment systems and the product water delivery pumps.

Apart from energy cost, other venues for operating costs are chemical, maintenance (plant replacement cost), manpower and additional essentials costs. The detailed calculations for each cost are presented below in Tables 62 to 68.

10.4.1 Manpower

Staffing the proposed desalination plant is based on 133, including helpers, security and divers, according to the following breakout.

Table 62: Manpower Cost Calculation

Year Product water 143080 ML/year — 5% Yearly Increment

S. No.	Manpower Type	Qualification	Min. Experience in Years	General Shift	No. of Personnel /Shift (8Hrs)	No. of shifts /day	Reliever	Total Nos of Persons	Salary / Month/ Person (INR)	PF/ESI/ Bonus etc (30%)	Total Salary/ Month/ Person (INR)	Total Salary /Month (INR)	Total Salary / Year (INR)	Manpower Cost / m3 product water (INR)	%
1	General Manager/Plant Head (Sr. Executive)	BS in Engg	> 15	1	0	3	0	1	115,385	34,615	150,000	150,000	1,800,000	0.013	3.6%
2	Sr. Operation Managers (Executive)	BS in Engg	> 10	1	0	3	0	1	92,308	27,692	120,000	120,000	1,440,000	0.010	2.9%
3	Operation Manager / Shift incharge (Highly Skilled) - 1 per Stream	BS in Engg	> 5	0	2	3	0	6	69,231	20,769	90,000	540,000	6,480,000	0.045	12.9%
4	Maintenance Incharge: Mechanical (Skilled)	Dip in Engg	> 5	1	0	3	0	1	38,462	11,538	50,000	50,000	600,000	0.004	1.2%
5	Maintenance Incharge: Electrical (Skilled)	Dip in Engg	> 5	1	0	3	0	1	38,462	11,538	50,000	50,000	600,000	0.004	1.2%
6	Maintenance Incharge: Instrumentation (Skilled)	Dip in Engg	> 5	1	0	3	0	1	38,462	11,538	50,000	50,000	600,000	0.004	1.2%
7	Maintenance Personnel: Mechanical (Semi-Skilled)	Dip in Engg / Sc.Graduate	> 5	0	2	3	0	6	30,769	9,231	40,000	240,000	2,880,000	0.020	5.8%
8	Maintenance Personnel: E&I (Semi-skilled)	Dip in Engg / Sc.Graduate	> 5	0	2	3	0	6	30,769	9,231	40,000	240,000	2,880,000	0.020	5.8%
9	SCADA Operator (Skilled) 1 per stream	Dip in Engg / Sc.Graduate	> 7	0	2	3	0	6	38,462	11,538	50,000	300,000	3,600,000	0.025	7.2%
10	Lab Technician (Skilled) 1 per stream	Sc. Graduate	> 7	0	2	3	0	6	23,077	6,923	30,000	180,000	2,160,000	0.015	4.3%
11	Field Operators (Skilled) - 200 MLD stream A	Sc. Graduate	> 5	0	4	3	0	12	23,077	6,923	30,000	360,000	4,320,000	0.030	8.6%
12	Field Operators (Skilled) - 200 MLD Stream B	Sc. Graduate	> 5	0	4	3	0	12	23,077	6,923	30,000	360,000	4,320,000	0.030	8.6%
13	Helper, Fitter, Rigger, Technician (Unskilled)	SSLC	> 2	12	8	3	1	37	19,231	5,769	25,000	925,000	11,100,000	0.078	22.2%
14	Administrative Staff	Graduate	> 5	2	0	3	0	2	38,462	11,538	50,000	100,000	1,200,000	0.008	2.4%
15	Safety Officer	HSE Qualified	> 5	1	0	3	0	1	38,462	11,538	50,000	50,000	600,000	0.004	1.2%
14	Security Guards	Skilled	>2	4	2	3	1	11	11,538	3,462	15,000	165,000	1,980,000	0.014	4.0%
15	Drivers	Skilled	>2	2	1	3	0	5	11,538	3,462	15,000	75,000	900,000	0.006	1.8%
16	Labour - Horticulture, Cafeteria, Etc.	Un-Skilled	> 5	6	4	3	0	18	9,231	2,769	12,000	216,000	2,592,000	0.018	5.2%
	Total							133		**Grand Total**	**Monthly Salary**	**4,171,000**	**50,052,000**	**0.350**	**100%**

10.4.2 Energy

The energy cost is based on a rate of 6.5 INR/KWh. Discharge head for RO equipment is computed for average seawater quality.

Table 63: Energy Cost Calculation

INR / kWh 6.5 3% Yearly Increment

Description	Capacity, m³/hr	Head (m)	Duty	Stand by	Total Quantity	pump Efficiency	Motor Efficiency	Drive Efficiency	Calculated Power BKW	Operating Hours	Total Power Consumed BKWhr/day	per m3 product water (kWh/m3)	Cost of Power/day (INR/day)	Yearly Power cost (INR/year)	per m3 product water (INR/m3)	%
Band Screen	9876.1	-	4	2	6	89%	93%	97%	96.3	24	2312.3	0.006	15030	5485843	0.038	0.2%
Intake Feed Pumps	6584.1	20	6	3	9	88%	93%	97%	2711.9	24	65085.6	0.163	423056	154415497	1.058	4.8%
Flash Mixer	9876.1	-	4	2	6	80%	93%	97%	86.6	24	2078.4	0.005	13510	4931095	0.034	0.2%
Flocculators			20	0	20	80%	93%	97%	144.3	24	3464.1	0.009	22516	8218492	0.056	0.3%
DAF recirculation (4 Months/y)	1481.4	70	4	0	4	80%	93%	97%	1566.1	24	37586.9	0.031	244315	89174950	0.611	2.8%
Backwash Pump - GMF	2880	15	6	3	9	88%	93%	97%	889.7	5.6	4942.6	0.012	32127	11726416	0.080	0.4%
Backwash Blower - GMF	3500	6	6	3	9	88%	93%	97%	432.5	5.6	2402.7	0.006	15617	5700341	0.039	0.2%
HP Booster pump	1064	30	16	16	32	80%	93%	97%	1927.4	24	46258.0	0.116	300677	109747144	0.752	3.4%
RO High Pressure Pumps (at average feed)	1064	581	16	2	18	88%	93%	97%	33934.2	24	814421.4	2.036	5293739	1932214872	13.234	59.8%
Booster Feed ERD	1224	30	16	16	32	85%	93%	97%	2087.1	24	50090.9	0.125	325591	118840677	0.814	3.7%
ERD Recirculation	1224	35	16	16	32	88%	93%	97%	2352.0	24	56447.1	0.141	366906	133920839	0.917	4.1%
Backwash Pumps - Lime Filter	5000	20	2	2	4	88%	93%	97%	686.5	0.2	137.3	0.000	892	325734	0.002	0.0%
Backwash Blower - Lime Filter	5000	7	2	2	4	88%	93%	97%	240.3	0.2	48.1	0.000	312	114007	0.001	0.0%
PLC/Control system			1	1	2	75%	93%	97%	3.4	24	81.2	0.000	528	192621	0.001	0.0%
Dosing System			12	12	24	95%	97%	97%	32.2	24	772.3	0.002	5020	1832260	0.013	0.1%
CIP and Flushing Pumps	2160	50	2	2	4	86%	93%	97%	758.6	0.20	151.7	0.000	986	359974	0.002	0.0%
Wastewater Treatment												0.000		0		
Sludge mixer in Balance Tank			3	0	3	80%	93%	97%	21.7	24	519.6	0.001	3377	1232774	0.008	0.0%
Sludge Transfer Pump to Thickener	1180.6	20	2	1	3	86%	93%	97%	165.9	24	3980.5	0.010	25874	9443829	0.065	0.3%
BFP Feed Pumps	106.25	20	2	1	3	86%	93%	97%	14.9	16	238.8	0.001	1552	566625	0.004	0.0%
Wastewater Transfer Pump to Outfall Tank	5640.6	20	4	2	6	86%	93%	97%	1584.9	24	38036.9	0.095	247240	90242432	0.618	2.8%
Neutralization Pumps to Outfall	2160	20	1	1	2	86%	93%	97%	151.7	0.20	30.3	0.000	197	71995	0.000	0.0%
Addl. power due to RO operation at a low recovery	10%						-		4719.05		108612.89	0.272	705984	257684079	1.765	8.0%
Addl. use at plant	10%								5460.72		123769.97	0.309	804505	293644250	2.011	9.1%
Total									**60067.9**		**1361469.7**	**3.34**	**8849553**	**3230086745**	**22.1**	**100.0%**

10.4.3 Chemicals

The chemical unit costs are based on Nemmeli and Minjur plant invoicing. Chemical dosing is computed for average seawater quality.

Table 64: Chemical Cost Calculation

Yearly output **146,000** ML/year 3% Yearly Increment

Chemical & Position	unit	% operating time	Treated Water	Ratio Treated Flow/ Product flow	Averaged rate	ppm rate of pure chemical dose rate	pure chemical per product water	Chemical conc. in commercial product	Commercial chemical per product water	Density	commercial product quantity Ton/y	Local unit price (INR/ton)	Yearly chemical cost (INR)	per m^3 product water (INR)	%
					12										
Intake															
Shock chlorination NaOCl 12° (4h/d)	g Cl_2/m^3	16.7 %	948.11	2.36	13.5	13.5	5.31	10%	53.07	1.18	7,747.6	10,000	77,476,039	0.531	7.46%
Chlorination at Intake	g Cl_2/m3	83.3 %	948.11	2.36	3.0	3.0	5.90	10%	58.96	1.18	8,608.4	10,000	86,084,488	0.590	8.29%
Lamella filters operation						-					-		-		
pH adjust acid H2SO4	g /m3	100 %	950.77	2.37	11.7	11.7	27.59	98%	28.16	1.83	4,110.8	15,593	64,099,356	0.439	6.17%
Coagulant Ferric chloride DAF	g FeCl3100%/m3	100 %	950.77	2.37	10.8	10.8	25.62	40%	64.05	1.42	9,352.0	6,816	63,743,362	0.437	6.14%
Polymere flocculation	g polymer/m3	100 %	950.77	2.37	0.3	0.3	0.77	100%	0.77	1.00	112.2	194,000	21,771,501	0.149	2.10%
DAF operation						-					-		-		
pH adjust acid H2SO4	g /m3	100 %	931.76	2.32	0.0	-	-	98%	-	1.83	-	15,593	-	0.000	0.00%
Coagulant Ferric chloride DAF	g FeCl3100%/m3	100 %	931.76	2.32	3.3	3.3	7.53	40%	18.82	1.42	2,747.6	6,816	18,727,708	0.128	1.80%
Polymere flocculation	g polymer/m3	100 %	931.76	2.32	0.2	0.2	0.37	100%	0.37	1.00	53.5	194,000	10,387,374	0.071	1.00%
RO						-					-		-		
SBM	g $NaHSO_3$/m^3	100 %	878.26	2.18	10.1	10.1	22.12	98%	22.57	1.00	3,295.5	48,000	158,183,263	1.083	15.23%
Antiscalant	g/m^3	100 %	878.26	2.18	2.3	2.3	4.92	95%	5.17	1.00	755.5	160,000	120,872,981	0.828	11.63%
pH adjust soda (boron removal)	g NaOH/m^3	100 %	878.26	2.18	5.8	5.8	12.74	48%	26.55	1.35	3,876.4	45,000	174,436,919	1.195	16.79%
Post-treatment						-					-		-		
Calcite for limestone beds	g $CaCO_3$/m^3	100 %	402.00	1.00	49.0	49.0	49.00	99%	49.49		7,226.3	5,250	37,937,879	0.260	3.79%
CO2 liquid	g CO_2/m3	100 %	402.00	1.00	21.6	21.6	21.56	99%	21.78		3,179.6	12,250	38,949,556	0.267	3.89%
pH adjust soda	g NaOH/m^3	100 %	402.00	1.00	3.0	3.0	3.00	48%	6.25	1.35	912.5	45,000	41,062,500	0.281	4.10%
Disinfection NaOCl 12°	g Cl_2/m^3	100 %	402.00	1.00	1.0	1.0	1.00	10%	10.00	1.18	1,460.0	10,000	14,600,000	0.100	1.46%
WWTP + sludge (only Lamella Clarifier + DAF)						-					-		-		
Polymere Thickener	g polymer/m3	100 %	28.36	0.07	11.5	11.5	0.81	100%	0.81	1.00	118.1	194,000	22,908,674	0.157	2.29%
Polymere sludge	g polymer/m4	100 %	2.55	0.01	121.1	121.1	0.77	100%	0.77	1.00	112.2	194,000	21,763,240	0.149	2.17%
						-							-	-	
Chemical cleaning (4 times /Y)													-	-	

Yearly output **146,000** ML/year 3% Yearly Increment

Chemical & Position	unit	% operating time	Treated Water	Ratio Treated Flow/ Product flow	Averaged rate	ppm rate of pure chemical dose rate	pure chemical per product water	Chemical conc. in commercial product	Commercial chemical per product water	Density	commercial product quantity Ton/y	Local unit price (INR/ton)	Yearly chemical cost (INR)	per m³ product water (INR)	%
Na-EDTA (0.1%)							-				56.4	87,000	4,906,800	0.034	0.49%
Caustic Soda (1%)											11.7	45,000	526,500	0.004	0.05%
The citric acid (2%)							-				225.7	72,000	16,250,400	0.111	1.62%
HCl acid (0.05%)											8.8	15,953	140,386	0.001	0.01%
neutralisation acid- HCl						-	-				33.0	15,953	526,289	0.004	0.05%
neutralisation basic - NaOH											153.2	45,000	6,894,000	0.047	0.69%
												Total	**1,002,249,214**	**6.865**	**100 %**

10.4.4 Maintenance/Renewal

The EPC contract value is estimated at INR 3077 Crores; The percentage of EPC contract related to the various items and equipment to be maintained/periodically renewed are derived from the Capex breakdown of several previous projects. The maintenance rates are assessed as per PMC operating experience.

Table 65: Maintenance/Renewal Cost Calculation

Total Asset Value 3077 Cr Excluding Membrane 2894 Cr

Year Product water 146,000 ML/year Yearly Increment 2%

Sr. No.	Consumable Assets	Asset Value %	Asset Value Amount (INR Cr)	Replacement / Year	Consumption cost (INR) per year	Maintenance Cost / m³ product water (INR)	% Consumption
1	Civil works	11.07%	320.3	0.15%	4,805,101	0.033	1.49%
2	Marine works	25.79%	746.3	0.10%	7,463,026	0.051	2.32%
3	Mechanical Works	27.74%	802.7	1.50%	120,409,665	0.825	37.43%
4	Electrical Works	10.97%	317.4	1.50%	47,616,944	0.326	14.80%
5	Instrumentation & Control Works	2.31%	66.8	2%	13,369,206	0.092	4.16%
	Others	22.12%	640.1	2%	128,020,273	0.877	39.80%
	Total				**321,684,215**	**2.20**	**100%**

10.4.5 Membrane Replacement

Table 66: Membrane Replacement Cost Calculation

	Year Product water	146,000	ML/year			Yearly Increment		2%	
Sr. No.	**Consumable Items**	**UOM**	**Installed Working Quantity**	**Rate (INR)/ UOM**	**Replacement Frequency**	**Consumption per year**	**Consumption cost (INR) per year**	**Membrane Replacement Cost / m^3 product water (INR)**	**%**
1	RO Feed Cartridges	Units	6905	350	Every 3 Months	27618.3	9666393.218	0.066	5.74%
2	RO CIP Cartridges	Units	204	350	Every 3 Months/train	13856.6	4849811.321	0.033	2.88%
3	1st Pass RO Membranes (400 USD x 1.1 for custom x 75 INR/USD): 440 ft^2 membranes	Units	32,640	33,000	Over 7 years	4,663	153879000	1.054	91.38%
	Total					**46,138**	**168,395,205**	**1.15**	**100%**

10.4.6 Other Essential Cost

Other essential costs include all administrative costs indicated in Table 67 below.

Table 67: Other Essential Cost Calculation

	Year Product water	146000	ML/year			Yearly Increment	6%	
Sl. No.	**Expense Head**	**Expense Type**	**Qty/Unit**	**Unit Rate (INR)**	**Total (INR)**	**Total Expenses/year (INR)**	**Manpower Cost / m^3 product water (INR)**	**%**
1	Vehicle Rent	Monthly	3	40,000	120,000	1,440,000	0.010	1.18%
2	Guest House, Cook, others	Monthly	1	100,000	100,000	1,200,000	0.008	0.99%
3	Uniform and PPE	Annually	1	250,000	250,000	250,000	0.002	0.21%
4	Staff welfare	Annually	1	100,000	100,000	100,000	0.001	0.08%
5	Office Stationery	Monthly	1	25,000	25,000	300,000	0.002	0.25%
6	Travelling Expenses	Monthly	1	25,000	25,000	300,000	0.002	0.25%
7	HAZOP Check	Annually	1	250,000	250,000	250,000	0.002	0.21%
8	Consent fee charges	Annually	1	25,000	25,000	25,000	0.000	0.02%
9	Telephone expenses	Monthly	1	10,000	10,000	120,000	0.001	0.10%
10	3rd party liability insurance	Annually	1	50,000	50,000	50,000	0.000	0.04%
11	**Plant Insurance** cost (Fire, Breakdown, Workmen Compensation)	Annually	1	75,000,000	75,000,000	75,000,000	0.514	61.61%
12	BG Charges	Annually	1	4,380,000	4,380,000	4,380,000	0.030	3.60%
13	Lifting tools / Forklift Renting charges	Annually	1	250,000	250,000	250,000	0.002	0.21%
14	Tank cleaning	Annually	1	250,000	250,000	250,000	0.002	0.21%
15	Cost of Certification/Calibration	Annually	1	500,000	500,000	500,000	0.003	0.41%
16	Waste cloth	Monthly	1	10,000	10,000	120,000	0.001	0.10%
17	External analysis	Monthly	1	100,000	100,000	1,200,000	0.008	0.99%
18	Disposal of Cartridges, Membranes, Sludge	Monthly	1	3,000,000	3,000,000	36,000,000	0.247	29.57%
	Total					**121,735,000**	**0.83**	**100%**

10.4.7 OPEX Summary

In addition to the 5 main opex cost items, administrative costs have been included in the Other Essential Costs.

Table 68: Estimated O&M Cost Summary for 400 MLD Perur Desalination Plant

INR/USD Conv = 75

Sl. No.	Expense Heads	OPEX Cost per Annum		Cost per m³ Product Water		O&M Cost over 20 years		
		(INR)	(USD)	(INR)	(USD)	(INR)	(USD)	
1	Chemical Cost	₹ 1,002,249,214	$ 13,543,908	6.86	0.09	₹ 27,738,736,051	$ 374,847,784	3% cost escalation per year
2	Power Cost	₹ 3,230,086,745	$ 43,649,821	22.12	0.30	₹ 89,397,449,679	$ 1,208,073,644	3% cost escalation per year
3	Manpower Cost	₹ 50,052,000	$ 676,378	0.34	0.00	₹ 1,737,767,991	$ 23,483,351	5% cost escalation per year
4	Membrane Replacement	₹ 121,735,000	$ 1,645,068	0.83	0.01	₹ 4,746,779,582	$ 64,145,670	2% cost escalation per year
5	Asset Replacement	₹ 168,395,205	$ 2,275,611	1.15	0.02	₹ 4,173,391,768	$ 56,397,186	2% cost escalation per year
6	Other Essential Cost	₹ 321,684,215	$ 4,347,084	2.20	0.03	₹ 7,972,401,948	$ 107,735,161	6% cost escalation per year
7	**Total O&M Cost**	₹ 4,894,202,378	$ 66,137,870	**₹ 33.52**	**$ 0.45**	₹ 135,766,527,019	$ 1,834,682,798	
8	Total O&M Cost	INR 489.4 Cr	USD 66.1 M			INR 13576.7 Cr	USD 1834.7 M	
9	Average O&M Cost per day	INR 1.34 Cr	USD 0.18 M			INR 1.86 Cr	USD 0.25 M	

A conservative cost of 66 M USD per year with USD 0.45/m³ product water cost is the best operation and maintenance cost evaluation undertaken for 400 MLD Perur Desalination plant. Total OPEX is about 30% higher due to high energy train configuration and high chemical usage due to high TSS and TOC.

11 MAIN DIFFERENCES BETWEEN PMC, JICA AND DPR DESIGN

Table 69 below presents a comparative summary of the plant process design by DPR, JICA and PMC.

Table 69: Summary of the Comparative Process Design for 400 MLD Perur Desalination Plant

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
Raw water (mean values)	• TDS: 36000 mg/L • pH: 8.13 • Temperature: 28.3 °C • Boron: 3.53 mg/L • Turbidity: 12 NTU • TSS: 75 mg/L • **TOC < 8mg/l**	• TDS: 35,200 mg/L • pH: 8.21 • Temperature: 27.9 °C • Boron: 3.17mg/L • Turbidity: 25 NTU • TSS: 75 mg/L • TOC not addressed	• TDS: 35,200 mg/L • pH: 8.2 • Temperature: 27.9 °C • Boron: 3.17mg/L • Turbidity: < 10 NTU • TSS: 75 mg/L • TOC not addressed
Product water	• *According to Indian Standard:* ○ *TDS ≤ 450 ppm,* ○ *Chlorides ≤250 ppm* ○ *Turbidity ≤ 1* ○ *Boron ≤ 1ppm* ○ *LSI: slightly positive* ○ *Hardness ≥ 60 mg/l as CaCO3*	• *According to Indian Standard:* ○ *TDS ≤ 500 ppm,* ○ *Chlorides ≤250 ppm* ○ *Turbidity ≤ 1* ○ *Boron ≤ 0.5 ppm (1ppm tolerance limit)* ○ *LSI: positive*	• *According to Indian Standard:* ○ *TDS ≤ 500 ppm,* *Chlorides ≤250 ppm* ○ *Turbidity ≤ 1* ○ *Boron ≤ 0.5 ppm (1 ppm tolerance limit)* ○ *LSI: positive*
RO recovery	• *Nominal RO recovery: 46% (provision for 42%)* ***(recommended for only 44% recovery)***	• *Nominal RO recovery: 46% (provision for 42%)*	• *Nominal RO recovery: 46% (provision for 42%°*
Offshore seawater intake system	• *Submerged open-intake* • *Velocity cap type* • *Horizontal velocity at 0.12m/s* • *Screen bar with 10cm spacing* • *Shock chlorination + air compressed pipes*	• *Submerged open-intake* • *Velocity cap type* • *Horizontal velocity at 0.10m/s* • *Screen bar with 30cm spacing* • *Shock chlorination + air compressed pipes*	• *Submerged open-intake* • *Velocity cap type* • *Horizontal velocity < 0.15m/s* • *Screen bar with 10cm spacing* • *Shock chlorination + air compressed pipes*
Offshore seawater intake pipes	• *2 pipes of HDPE (2500 mm OD SDR 26)* • *Length 1150 m (each line)* • *Same profile/ alignment*	• *2 pipes of HDPE (2500 mm OD SRD 22)* • *1140m length* • *Same profile/ alignment*	• *2 pipes of HDPE (2500 mm OD SRD 21)* • *Approx. 1km length* • *Two different profiles*
Brine outfall system	• *1 pipe in HDPE OD 2500 mm. SDR26* • *Total length: 1800 m (recommended).* • *Brine diffuser: >30 units diam 350mm spaced 6m.*	• *Same profile as intake pipes* • *1690 m length* • *Brine diffusers (14 nozzles spaced on 47 m)*	• *750m length* • *Other profile as intake pipes*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
Ancillary equipment for the intake system	• *Intake Well - 4 Chambers/ 4 sets Band screens* • *Air bursting and Shock chlorine dosing* • ***The two pipes are designed to be cleaned by a pigging system with a launcher/ receiver installed in the pumping station/ intake.***	• *Stop logs / 4 sets of travelling screens* • *Shock dosing pump*	• *4 + 1SB Band screens*
Seawater intake pumping station	• *6 + 3SB units of wet well vertical turbine pumps for total flow 43333 m^3/h* • *Recommended flow:* 39500 m^3/h *(948 MLD) @ average recovery of 46%* • *Discharge pressure: 18 m* • *Presence of VFD* • *Pumping station depth: 7.90m*	• *4+2SB sets of vertical turbine pumps.* • *Total flow: 45,000 m^3/h* • *Discharge pressure: 25 m* • *Presence of VFD*	• *6 + 2SB pumps.* • *Total flow: 42,252 m^3/h* • *Discharge pressure: 23m* • *Presence of VFD*

Pretreatment	• *Composed by chemical and physical processes.*
	• *Main stages:*
	  ○ *Coagulation/flocculation – Flash mixing*
	  ○ *Clarification by Lamella Settler*
	  ○ *Dissolved air flotation*
	  ○ *Dual media gravity filtrations (optional third media as needed to reduce TOC)*
	• *Cartridge filters*
		• *Composed by chemical and physical processes.*
		• *Main stages:*
		  ○ *Coagulation/flocculation*
		  ○ *Clarification*
		  ○ *Optional dissolved air flotation*
		  ○ *Dual media gravity filtrations*
		• *Cartridge filters*
			• *Composed by chemical and physical processes.*
			• *Main stages:*
			  ○ *Coagulation/flocculation*
			  ○ *Clarification*
			  ○ *Optional dissolved air flotation*
			  ○ *Dual media gravity filtrations*
			• *Cartridge filters*

Coagulation stage	• *Retention time: 20 seconds*	• *Retention time: 25 seconds*	• *Retention time: 30 seconds*
Flocculation stage	• *Retention time: 20 minutes*	• *Retention time: 10 min*	• *Retention time: 10 minutes*
Clarification stage	• *Lamella surface loading rate:* **≤1.0 $m^3/m^2.h$**		• *Lamella surface loading rate:* **1.3 $m^3/m^2.h$**
Dissolved air flotation	• *Retention time: 15.2 minutes* • *Surface loading rate with recycling: 25 $m^3/m^2.h$* • *15% recycling*	• *Surface loading rate: 15 $m^3/m^2.h$ 12% recycling*	• *Surface loading rate: 15 $m^3/m^2.h$* • *10 to 15% recycling*
Gravity dual media filters	• *Surface loading rate: < 7.5 $m^3/m^2.h$ with all filters operating* • *Top layer (Anthracite): 1.2 m* • *Bottom layer (Silica sand): 1.5 m*	• *Surface loading rate: 8 $m^3/m^2.h$* • *Top layer: Anthracite* • *Bottom layer: Silica sand*	• *Surface loading rate of 8 $m^3/m^2.h$* • *Top layer (Sand): 0.8 m* • *Bottom layer (Anthracite): 1.3 m*
Cartridge filters	• *Filtration size: 5 µm* • *Construction material GRP* • *cartridges: melt blown polypropylene*	• *Filtration size: 5 µm.*	• *Filtration size: 5 µm.*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
Chemical pretreatment	• *Ferric chloride 5 – 30 ppm as pure chemical (jar test needed for ppm level)* • *Polymer (0.1- 0.5 ppm Lamella, DAF)* • *Sodium hypochlorite (1-2 ppm disinfectant)* • *Sodium Bisulphite (~10 ppm)* • *Sodium hydroxide (pH control, 10 ppm)* • *Antiscalant dosage for SWRO (~ 1 ppm)*	• *Ferric chloride (25 ppm Lamella, 10ppm DAF)* • *Polymer (0.1 to 0.5 ppm Lamella, DAF)* • *Sodium hypochlorite (disinfectant)* • *Sodium Bisulphite (max.10 ppm)* • *Sodium hydroxide (pH control, 20 ppm)* • *Antiscalant dosage for SWRO (2 ppm)*	• *Ferric chloride (coagulant, 16ppm)* • *Polymer (0.5 ppm Lamella, 0.5 ppm DAF)* • *Sodium hypochlorite (disinfectant)* • *Sodium Bisulphite (15 to 30 ppm)* • *Sodium hydroxide (pH control, 35 ppm)* • *Antiscalant dosage for SWRO (0.7ppm)*
Filtered water tank	• *Two RCC tanks – one for each stream with interconnection proposed with 2 compartments/ tank for isolation and cleaning* • *Tank Capacity - 10000 m^3 each (30 min)*	• *2 tanks* • *Unitary volume: 2 x 3,000 m^3*	• *Capacity: 13,750 m3*
SWRO desalination lines	• *6 main lines, divided into two main streams (2x 200 MLD) – Pressure Centre Design* • *Each line comprises 5 SWRO sections (total 6x5 =30 sections of 128 PV each).* • *Single RO pass*	• *16+1SB trains (240 PV per train)* • *Single RO pass*	• *16+1SB trains (240 PV per train)* • *Single RO pass*
SWRO membranes	• *30,720 elements in operation.* • *(3 High Rejection + 5 Low energy)/PV* • *Operating flux: 13.4 l/h/m²* • *Diameter: 8”, Length: 40”, Area: 440 ft*	• *Total 4080 PV (32,640 membranes including 1,920 units in stand-by)* • *8 High rejection membranes/PV* • *Operating flux: 13.5 l/h/m²* • *Diameter: 8”, Length: 40”, Area: 440 ft*	• *Total 4080 PV (32,640 membranes including 1,920 units in stand-by)* • *8 High Rejection membranes/PV* • *Operating flux: 13.5 l/h/m²* • *Diameter: 8”, Length: 40”, Area: 440 ft*
High-pressure feed pumps (Booster RO)	• *6+2 SB units of centrifugal mono-stage horizontal type* • *Q: 17002 m3/h* • *H: 4.8 bars* • *with or without VFD*	• *16+1 units* • *Q: 16,672 m3/h* • *H: 15 bars* • *Presence of VFD* •	• *16+1 units* • *Q: 17,049 m3/h* • *H: 14.5 bars* • *Presence of VFD* •
High pressure pumps	• *6+2SB units of centrifugal horizontal split type* • *Q : 17002 m3/h* • *H : 64 bars @ high seawater TDS* • *Presence of VFD*	• *16+1 units* • *Q : 16,672 m3/h* • *H : 56 bars* • *No VFD*	• *16+1 units* • *Q: 18,115 m3/h* • *H: 55,3 bars* • *No VFD*
Energy recovery systems	• *Installed in 6 arrays.* • *Each array includes 50 ERI PX-300 units of pressure exchange type.*	• *Installed in 17 arrays.*	• *Installed in 17 arrays.* • *Each array includes 22 ERI PX units of pressure exchange type (If ERI selected)*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
			• *Each array includes 5 DWEERS units of pressure exchange type (If DWEERS selected)*
Booster pumps for energy recovery systems	• *6+2 SB units of centrifugal mono-stage horizontal type* • *Q: 19,727 m3/h* • *H: 2.5 bars* • *with or without VFD*	• *16+1 units* • *Q: 19,568 m3/h* • *H: 5 bars* • *VFD*	• *17 units* • *Q: 21,482 m3/h* • *H: 6 bars* • *VFD*
Recirculation pumps for energy recovery systems	• *6+2SB units of centrifugal MS horizontal type* • *Q: 19,727 m3/h* • *H: 2.5 bars* • *With VFD*	• *16+1SB units* • *Q: 19,568 m3/h* • *H: 5 bars* • *VFD*	• *16+1 units* • *Q: 20,991 m3/h* • *H: 5.7 bars* • *VFD*
SWRO skids	• *6 Skids* • *Each skid has 640 PV of 8 elements* • *Total 6x640= 3840 PV*	• *16+1 skids* • *Each skid has 240 PV of 8 elements* • *Total 17x240= 4080 PV*	• *16+1 skids* • *Each skid has 240 PV of 8 elements* • *Total 17x240= 4080 PV*
SWRO front permeate tank	• *2 tanks – one per stream interconnected* • *Each Tank volume: 5,000m^3 per stream*	•	• *2 tanks* • *Unitary volume: 4,250 m3*
Post-treatment	• *Composed by remineralization with CO_2 and limestone beds (only 48% permeate to be treated)* • *pH adjustments with NaOH* • *Disinfection with sodium hypochlorite*	• *Composed by remineralization with CO_2 and limestone beds)* • *pH adjustments with NaOH* • *Disinfection with sodium hypochlorite*	• *Composed by remineralization with CO_2 and limestone beds* • *pH adjustments with NaOH* • *Disinfection with sodium hypochlorite*
Limestone bed for remineralization	• *Upflow / Continuous Feeding Limestone Remineralization system.* • *Number of cells: 28 units (14 per stream).* • *Surface loading rate:* 10 m^3/m^2.h • *Contact time: 25 minutes* • *Integrated storage system for limestone with capacity for minimum 30 days* • *Air + water backwash system*	• *Made by Upflow and Continuous Feeding Limestone Remineralization system.* • *Surface loading rate: 25 m^3/m^2.h*	•
Product water tanks	• *2 metallic or RCC tanks (2 compartments/line + bypass) for each stream* • *Total capacity 30,000 m3 (2 hours)*	• *4 metallic tanks (Unitary volume: 9,000 m3)*	• *4 metallic tanks (Unitary volume: 9,000 m3)*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
Battery limit	• *2 Electromagnetic flow meters in-line to clear water reservoir* • *CWR is in scope, but transmission pumps are not in scope.*		
Cleaning (CIP) and flushing system	• *Preparation Tank: 60 m^3* • *CIP pumps flow:1152 m^3/h* • *Flushing pumps flow: 1024 m3/h*	• *Preparation tank: 800m3* • *CIP pumps: 6,250 m^3/h* • *Flushing pump flow: 2,124 m3/h*	• *Preparation tank: 600m3* • *CIP pumps: 2,160 m^3/h* • *Flushing pump flow: 2,124 m^3/h*
Wastewater treatment	• *physicochemical treatment. 1 sludge balance tank, 2 thickeners, 1 sludge holding tank, and BFP building with up to 5 BFP pumps considering average raw water TDS up to 75 mg/L.*		
Specific requirements	• *Pretreatment pilot plant* • *RO cleaning pilot plant* • *Membrane testing plant*		

12 QUESTIONS AND DISCUSSIONS WITH CMWSSB

12.1 Product water specifications

The above-described plant design is optimised for the design parameters and very sensitive to variations of product water requirement.

12.1.1 Boron level

CMWSSB is contemplating a significant reduction in Boron level from 1 ppm down to 0.50 ppm. Such modification requires redesigning the membrane arrangement. A second pass RO is mandatory to achieve such a low boron level, and the second pass means the permeate of the first pass will be pressurised through another stage of membranes. In such a case, the first pass is commonly composed of low energy membranes since the second pass is composed of brackish water membranes. The second pass requires a high pH of around 10 (by Sodium Hydroxide injection), which has a significant impact on chemical expenses (OPEX). The second pass may be designed to treat all the first pass permeate (called the full RO second pass) or only the rear of the first pass permeate, which is worse in quality (called the partial RO second pass).

Using Mr Voutchkov graphs, please see the graphs (**Annexure 7**) for construction costs for full two-pass and single pass.

The addition of a Pass 2 RO system to decrease boron level <0.5ppm in product water all the time will increase the project cost. A cost estimation for the full Pass 2 RO system using Voutchkov's graphs (given below) shows 29 MUSD (145 MUSD -116 MUSD), equivalent to INR 220 Cr.

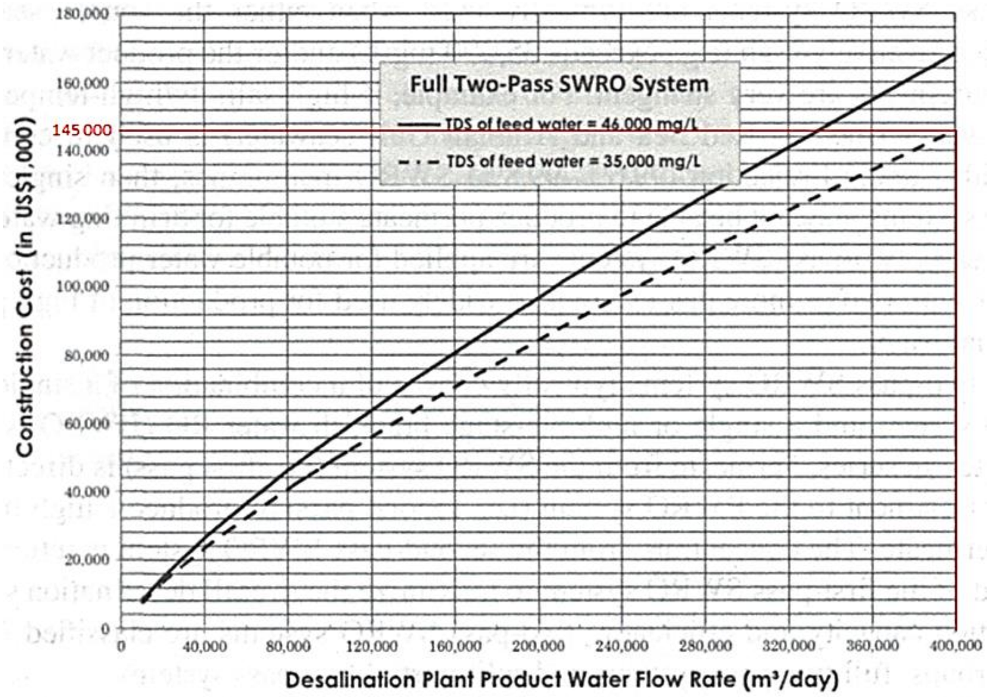


Figure 41: Construction Cost for Full Two Pass SWRO System

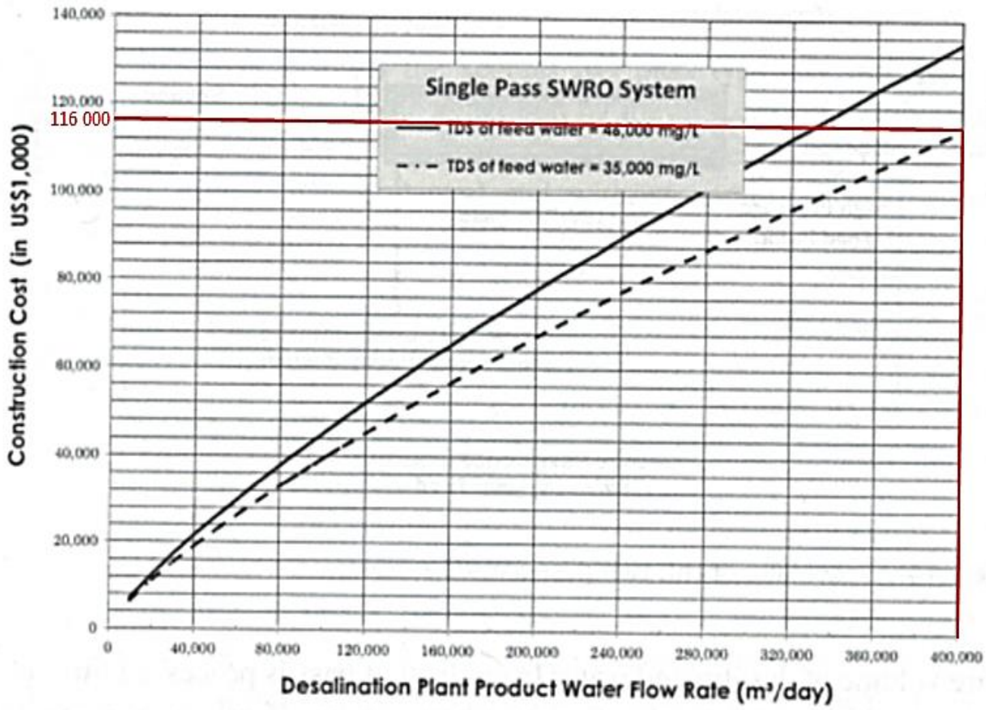


Figure 42: Construction Cost for Single Pass SWRO System

12.1.2 TDS level for product water

CMWSSB has requested to benefit from some safety margin for the TDS at the output of the plant to ensure the TDS at the tap of the consumers within the applied Indian standard of 500 ppm.

It is to be noted that:

1. There are no theoretical or practical reasons for the TDS to increase between the plant output and the consumer tap unless blending with other water of TDS> 500 ppm or leaching of pipe material in water.
2. **With a 500 ppm TDS threshold**, the Contractor's design will include a safety margin of 10-20 ppm at the worse raw water conditions (i.e. at highest water temperature + highest TDS), which is expected meeting only a few weeks per year. The TDS will be up to 50 ppm more in summer than that in the rest of the year. It is expected that the monitored TDS at the outlet of the plant will be up to **480 ppm** (375ppm in permeate +105 ppm remineralisation) **in summer** and around **430-450 ppm** (325-345 ppm in permeate +105 ppm remineralisation) **in the remaining time of the year**.
3. This 500 ppm threshold is a common desalination requirement for municipal project all over the world.

Thus, the PMC team strongly believes that the product water quality will be met with TDS < 450 mg/l most of the time and that the CMWSSB plan about distributing water at the customer tap at < 500ppm TDS water is not violated in the present design offered by PMC.

As CMWSSB maintains its requirement to decrease the TDS threshold in product water ≤450 ppm, PMC has studied the various options to reach this new goal. The options to reduce the TDS at the output of the plant are therefore as follows:

1. To “use” part of the safety margin for the temperature and reduce the operating envelop down to 31°C or 30.5°C. Refer to Figure-9 above for the recorded temperature at Nemmeli during 5 past years.

2. To lower the remineralisation target down to 60 ppm as $CaCO_3$ (saving in OPEX). As per CPHEEO guidelines, the hardness can be kept anywhere below 200 ppm as CaCO3. The mineral water available in the market has a hardness in the range of 20-50 ppm as CaCO3.

3. To replace one or several low energy membranes (SWC5max) with high rejection membranes (SWC4max), which will induce a higher energy consumption.

4. Introducing a second RO pass for Boron removal, as discussed in the previous paragraph, will replace all the above solutions by producing permeate TDS <300 ppm in all the operating conditions and meeting the product water TDS <450 ppm all the time at the maximum remineralisation level.

12.1.3 Raw water TDS increase

Increasing the range of some raw seawater parameters may have almost no impact on the CAPEX or OPEX costs. However, for some other parameters, like seawater TDS, increasing the range will impact the design and affect the CAPEX slightly but OPEX significantly, whether the extreme conditions are met or not.

The present discussion must be linked with legal and contractual considerations:

- If the raw water responsibility (risk allocation matrix) is left to the Contractor, there is no further discussion since the Contractor must deliver nominal product water whatever the raw seawater conditions)
- If CMWSSB requires to keep the raw seawater responsibility (meaning the contractor has reduced obligations when raw seawater parameters are outside the envelope), it is important to keep the raw seawater parameters envelop as realistic as possible, since CAPEX and OPEX will directly be derived from this envelope.

Increasing the TDS envelop from 38,500 ppm up to 39,000ppm will have no impact on CAPEX and restricted impact on OPEX.

According to the above discussion, it was agreed to adjust the following parameters:

- Raw water TDS envelop up to 39,000 mg/l
- Product water TDS threshold down to 450 mg/l

NB: Contemplating further increase up to 41,000 mg/l (which is not realistic since even high than the West coast of India) will oblige a full revision of the design, and it will initiate contractors to design the plant suitable for this feed water quality. This will finally increase the project cost.

However, in case there is high TDS in seawater up to 41000 mg/l for a few weeks in a year, this can be managed by reducing plant recovery from 46% to 44%. Please see Table 29 in Section 3.5.3.3, the product water TDS is very close to 500 mg/l at the maximum temperature of 31.5 ^{o}C, which can be further reduced by reducing hardness down to 60 mg/l as CaCO3. However, it is very evident that the risk of meeting feed seawater TDS values around 41000 mg/l is not expected in Chennai. Such TDS values, not even met on the coasts of Oman, are more specific to the Gulf (UAE).

Therefore, the PMC recommends the raw seawater TDS value to be kept at 39000 mg/l.

12.1.4 Hardness level

As discussed above, added hardness level will have an impact on the maximum TDS level of the product water. Common practices in desalination recommend a hardness level between 40 and 100 mg/l eq $CaCO_3$ in product water. The precise level is adjusted according to medical recommendations. For obvious cost reason, bottled mineral water is not very popular in India. According to the amount of calcium requirement in Indian food (Chennai), it could be decided to go to the higher side or the low side of the range. At the initial stage of design, the PMC team opted for a medium side of the range (60 ppm eq $CaCO_3$).

13 MINIMUM FUNCTIONING SPECIFICATIONS (MFS)

13.1 The reason for being

In a DBO (or a BOOT), an Employer is buying from Contractor product water in a determined quantity and quality against a specific unit price during a specific period (operation period).

To a certain extent, the Employer could consider the plant as a black box totally under the responsibility of the Contractor and therefore focus only on the output metering system (quantity) and at monitoring the product water quality. In such a situation, the Contractor bidder may propose a very aggressive design to win the bid or propose material that will hardly stand the term of the operation period. In certain case, the Employer may take over the Contractor after the contractual operation period.

To avoid such a situation where the Employer does not receive the expected amount of product water or product water not meeting quality requirement (despite he receives liquidated damages at the same time), and/or is transferred a plant in unacceptable conditions at the end of the operating period, the employer has the interest to properly define properly:

- “Minimum functioning specifications” for designing and erecting the plant in terms of process, availability (safety margins) and durability of plant.
- Operating and maintenance requirement to protect the asset and ensure its life expectancy.

13.2 Philosophy and Content

As discussed above, a loose MFS will procure a reasonable EPC price but a higher risk regarding the collection of product water (quantity and quality). On the other hand, if the MFS is too tight, and similarly to a construction contract, aims at specifying every piece of equipment, the Employer will not benefit from the bidder experience in optimising desalination plants.

Therefore, the MFS shall focus more on the expected performances of the plant than on the means to achieve them.

14 APPENDIX

The following appendix is furnished below in this Report:

Appendix 1: Indian Drinking Water Quality Standards

The treated water quality from the proposed Desalination plant shall meet the standards prescribed in the **IS:10500-2012 "Drinking water specification"**. However, the desalination plant is designed to achieve the total dissolved solids (TDS) in the **range of 300 mg/l** of permeate, which after remineralization would not exceed 500mg/L, complying with the TDS limit specified in IS:10500-2012. Drinking water standard for the desalination plant is furnished below the Tables.

Drinking water standards for Desalination Plant

Sl. No.	Characteristics	Unit	Treated water requirements
1.	Turbidity	NTU	≤1
2.	Colour	Pt-Co scale	≤5
3.	Taste and odour		Unobjectionable
4.	pH		7.0 to 8.5
5.	Total Dissolved Solids	mg/l	≤500
6.	Total hardness ($CaCO_3$)	mg/l	≤200
7.	Chloride (Cl)	mg/l	≤200
8.	Sulphates (SO_4)	mg/l	≤200
9.	Sulphide	mg/l	≤0.05
10.	Fluorides (F)	mg/l	≤1
11.	Nitrate (NO_3)	mg/l	≤45
12.	Ammonia (NH_3)	mg/l	≤0.5
13.	Calcium (Ca)	mg/l	≤75
14.	Magnesium (Mg)	mg/l	≤ 30
15.	Iron (Fe)	mg/l	≤0.1
16.	Manganese (Mn)	mg/l	≤0.05
17.	Copper (Cu)	mg/l	≤0.05
18.	Aluminium (Al)	mg/l	≤0.03
19.	Alkalinity	mg/l	≤200
20.	Residual Chlorine	mg/l	0.2 (Minimum)
21.	Zinc (Zn)	mg/l	≤5
22.	Boron (B)	mg/l	≤1.0
23.	Phenolic Compounds (Phenol)	mg/l	≤0.001
24.	Anionic detergents (MBAS)	mg/l	≤0.2
25.	Mineral Oil	mg/l	≤0.01
26.	Arsenic (As)	mg/l	≤0.01
27.	Cadmium (Cd)	mg/l	≤0.003
28.	Chromium (hexavalent Cr)	mg/l	≤0.05
29.	Cyanides (CN)	mg/l	≤0.05
30.	Lead (Pb)	mg/l	≤0.01

Sl. No.	Characteristics	Unit	Treated water requirements
31.	Selenium (Se)	mg/l	≤0.01
32.	Mercury (Hg)	mg/l	≤0.001
33.	Silver	mg/l	≤0.1
34.	Polynuclear Aromatic Hydrocarbons (PAH)	µg/L	≤0.0001
35.	Pesticides	mg/l	Absent
36.	Gross Alpha activity	Bq/l	≤0.1
37.	Gross Alpha activity (Bq/l)	Bq/l	≤1
38.	Trihalomethanes:	µg/L	≤0.02
39.	Bromodichloromethane (BDCM)	mg / L	≤0.06
40.	Bromoform	mg / L	≤0.1
41.	Dibromochloromethane	mg / L	≤0.1
42.	Chloroform	mg / L	≤0.2

Treated Water Quality for Bacteriological Parameters

Organism	Value
All water intended for drinking.	
E-coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample.
Treated water entering the distribution system	
E-coli or thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample.
Total coliform bacteria	Must not be detectable in any 100 ml sample.
Treated water in the distribution system	
E-coli of thermotolerant coliform bacteria	Must not be detectable in any 100 ml sample.
Total coliform bacteria	Must not be detectable in any 100 ml sample. In the case of abundant supplies, where sufficient samples are examined, they must not be present in 95% of the sample taken throughout any 12 months.

The CHENNAI 400 MLD DESALINATION PLANT is a Project being delivered by the Chennai Metropolitan Water Supply & Sewerage Board (CMWSSB) with the assistance of an Official Development Assistance (ODA) loan from the Japan International Cooperation Agency (JICA).

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