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 8 July 2020

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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 TCE 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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EXECUTIVE SUMMARY

The Project Management Consultancy (PMC) working closely with the Project Implementation Unit (PIU) of CMWSSB, commenced with the signing of the agreement on 9th January 2020. 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, M/s 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 the inferences on critical parameters for the conceptual process design of the 400 MLD Perur desalination plant. Under the current lockdown situation, PMC team in a very coordinated manner planned and completed this study. The study information already presented in the Interim 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 scheduled by the end of July 2020 depending on the post-COVID-19 lockdown situation.

The Key Areas focused in the report are:

Key Areas to Focus

- Intake structure and associate investigative works.
- Desalination Plant site – protection and costs
- Sea Water 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 & Operations)

Due to the current COVID-19 lockdown, it's proposed to organise a ZOOM/any other form net meeting to seek feedback on the actions presented in this report to continue to complete the preparation and submission of the concept design report. To facilitate this process, a presentation is planned over the next week to CMWSSB-PIU.

Site Conditions

Detailed investigation of site conditions has been done in DPR, and JICA reports. The plant site elevation is 6.5m above Mean Sea Level (MSL) which is a minimum elevation for such a large plant. Usually, an elevation over 10 m above MSL is desirable for the proposed Perur DSP. 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 for the 10 km coast in Southern and Northern directions. A recent investigation revealed one major sewage outputs ingress approx. 10 km North of the Perur site.

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 a high level 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 arose late 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 due to the presence of white fibre 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 Nemmeli DSP, the design envelops 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	10
Boron	mg/L	3.2	3.5	3.8
Algae	cells/ml	100	500	30000
Jelly fish occurrence		NA	NA	yearly

*It is assumed values. Further analysis for TOC has been recommended, which will provide the actual values.

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 rejects, 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. No brine dispersion study has been performed in DPR. PMC needs the approval of CMWSSB to carry out this task at the earliest.

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	1800 m	900 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 the reasoning for the process selection.

PMC is satisfied with the implementation of three (3) processes for the recent seawater quality of 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 process design of the pretreatment processes at optimum critical parameters is 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) and approx. 10-15% TOC – jar/pilot tests are required to verify this.
d) Due to 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 low loading rate (7- 8 m/hr) will improve the filtrate water quality.

PMC has proposed for additional analyses to confirm the content of TOC in the seawater. If the TOC content in raw seawater monitored during the proposed additional sampling period evidences persistent values higher than 8mg/l, then significant change in the pre-treatment process design must be considered.

RO System Design

RO system will be designed to operate at 46% recovery. However, in 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 cr. The provision of additional flow to the plant will increase operating cost too on a continuous basis for seldom need of RO system operation at 42% recovery. PMC recommends to eliminate the provision of reduced recovery or reduce it to 2% reduction instead of 4%, i.e. 46% to 44%. It needs PIU's consent.

The Perur 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 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.
- 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 in the report and found it suitable to be adopted in the Perur DSP.
- A cost-effective membrane selection shall be made taking into consideration of 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 96-97%. An alternative to this is a 3-Center design configuration which allows us to get 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 in this report.

The report has addressed only the major processes in the desalination plant, which may pose issues in meeting the required quantity or quality of product water. A process flow diagram (Annexure -A) is attached in the report which indicates the process units included in the plant.

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 for the preparation of 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 forbid documentation

With the view of fulfilling Task 5, a preliminary concept design report has been prepared by PMC for further discussions with the PIU team 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 ▪ Pre-treatment facility ▪ Seawater desalination facilities by Reverse Osmosis (RO) technology ▪ Post-treatment facility for remineralization and disinfection ▪ Product Water Tank (36 ML Capacity) and Potable water (3 ML Capacity) ▪ Effluent discharge pipelines ▪ Pre-treatment & wastewater treatment facility ▪ All other buildings and structures are necessary for the seawater desalination plant.

1.2.1 Design Works for CP1 Components

The Consultant have been carried out the Consulting Services through the following work items for Design works (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, which will be provided as a part of the tender document.
c) Conceptual design of the Perur DSP, which includes brine diffusion analysis using the ocean current survey data.
d) Preparation of conceptual design report, which includes a description 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 "Operation and Maintenance Requirement (including risk allocation, payment method, monitoring and evaluation method, etc.) " to be included in the bid documents.

1.3 Conceptual Design (CP1) Scope and Objectives

It should be reminded 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 which 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 prepare the following, but will not be included in the RFP package:

- An Engineering Report 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
- A cost approach for DB cost (CAPEX for Capital Expenditures) and an 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 CMWSSB aiming at:

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

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

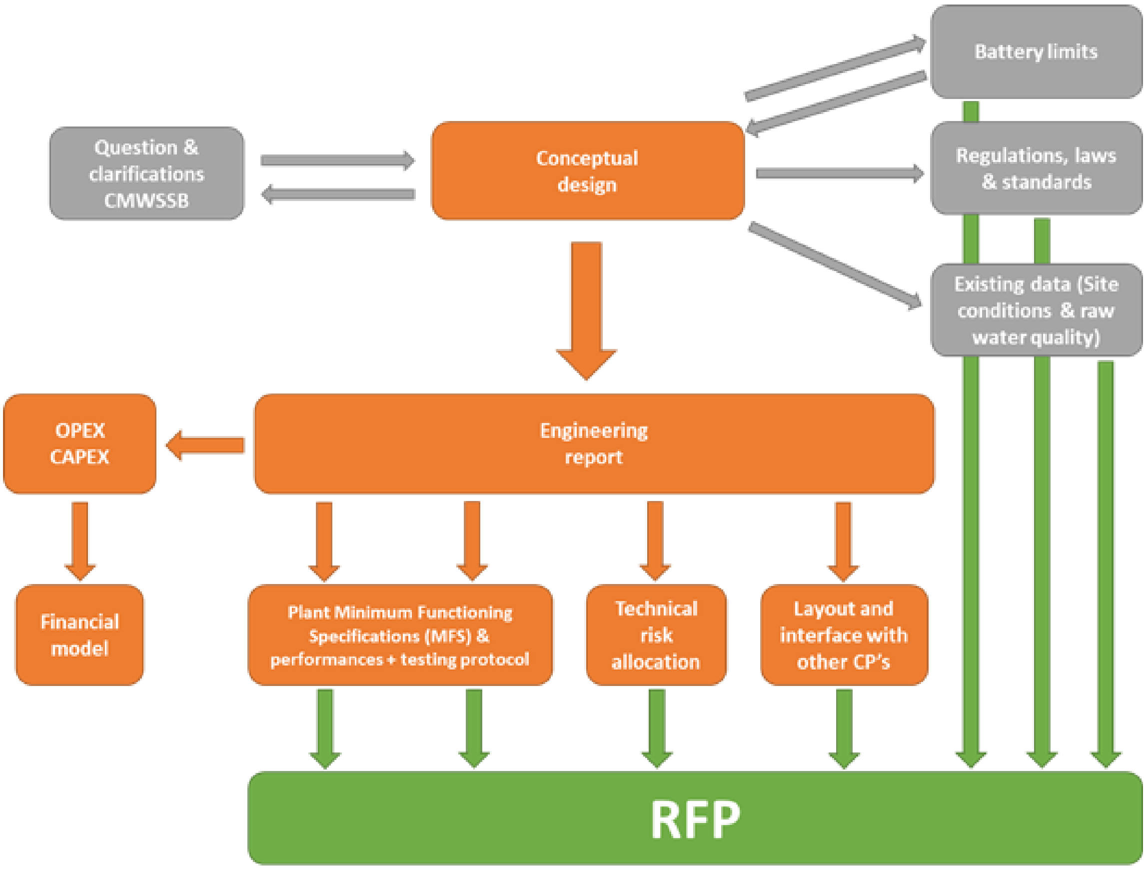


Figure 1: Functional Diagram for Conceptual Design

2 CONCPET DESIGN REPORT INPUTS

The Concept report has been prepared by duly considering the available data and data 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.

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 report covers only the major process issues of the concept design, which require early feedback from 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.

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 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 is being maintained by the PMC to monitor the status of information requests and ensure that outstanding information is actively managed.

As stated above, the present report will refer 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 have been studied and will be further carefully reviewed and evaluated if necessary. Accordingly, the design and recommendation will be 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 being experienced in Chennai.

It is noted that no external stakeholder liaison has commenced within the initial phase.

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, which will form part of the early process review activities prior to Concept Design being progressed;
iii. Project specifications for Perur DSP (CP1) – the balance between performance-based requirements and minimum technical standards will need careful consideration in the development of the Specification for this 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 government agencies approval for construction activities such as permission from TNPCB, CRZ, Tamil Nadu Forest Department etc. Therefore, it is better to communicate with the other government agencies regarding this upcoming project and required permission for the execution of works in the best interest of project progress.

The topographical surveys, bathymetry surveys, geotechnical investigations, water sample analysis and other requisite investigation activities as noted in this report will be carried out during the Final Detailed Design phase of the Services, once the issues COVID-19 resolved and also lockdown lifts in the project area.

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 Endownment Board (HR & CE) Department, Government of Tamil Nadu (GoTN). CMWSSB procures 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: Kanchepuram / 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. It is not unusual to install these large plants at one km or more from the beach, to reach elevation over 10 m above MSL. However, in this case, the plant spot has already been selected, and the required land has been taken on lease for construction of the 400 MLD Perur desalination plant.

- 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, harbor) impacting raw water quality should be investigated and assessed for the 10 km coast in southern and northern directions. A recent investigation revealed the ingress of major sewage Nallah approx. 10 km north of the Perur site.

Discussion with PIU for decision to move forward:

- Work to be undertaken for backfilling and retaining structure with cost estimates
- Raw water quality to be assessed 10 Km from intake North – South direction to assess sewage pollution.

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

Figure 2: Photo of the Proposed Site for 400 MLD Perur DSP, Water Storage Reservoir and Pumping Station

The onshore investigations and surveys will require access to the proposed Perur site (refer to Figure-3), which is understood to be restricted at present. This constraint requires urgent resolution (Enter upon permission) by the CMWSSB to avoid any potential delay to these activities.

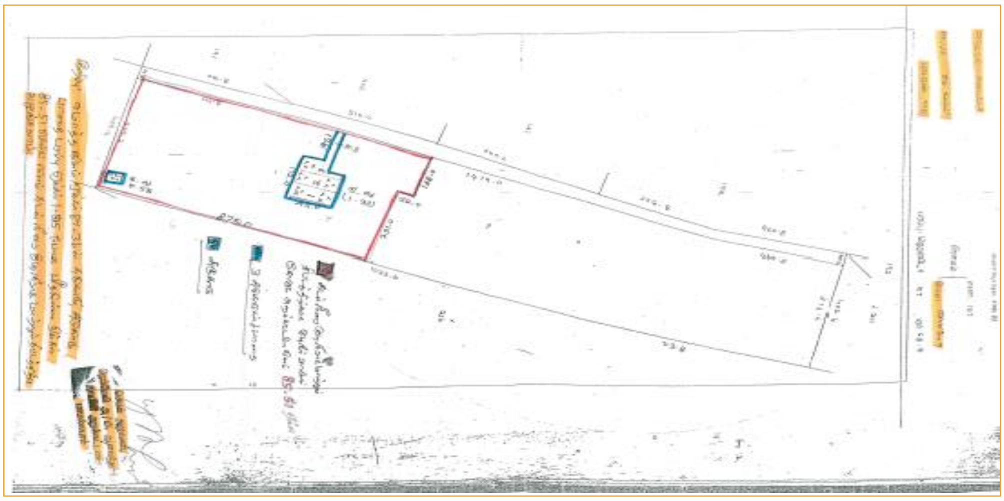


Figure 3: FMB Sketch of Proposed location of Perur DSP

4.1.2 Topography

Based on the study report, the onshore topographic survey and offshore topographic survey have been 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 +2.0m Chart Datum (CD) to + 3 m CD indicating the almost uniform site condition. The site is having tree plantation of Casuarina. The site falls under Seismic Zone III as per BIS code IS: 1893 (Part I). The topography of the proposed Perur DSP site is furnished in Figure 4.

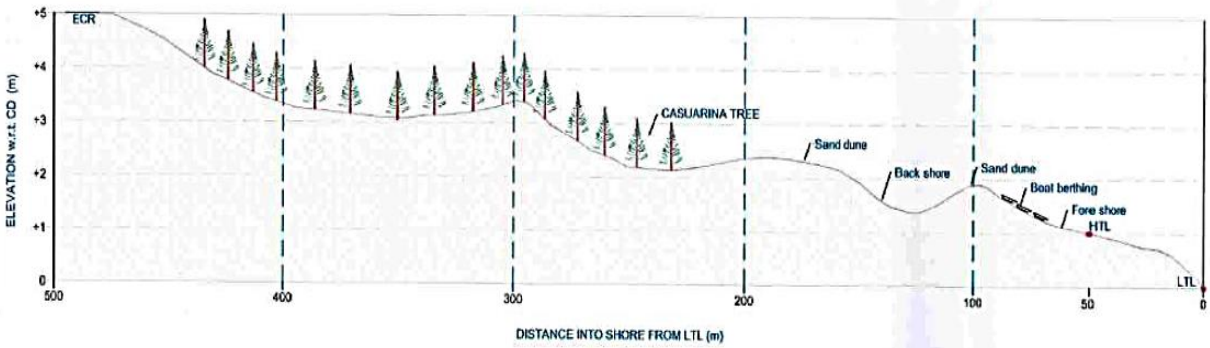


Figure 4: Typical Topography of Planned Perur DSP site

4.1.2.2 Offshore topography:

Based on the bathymetric survey, 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.

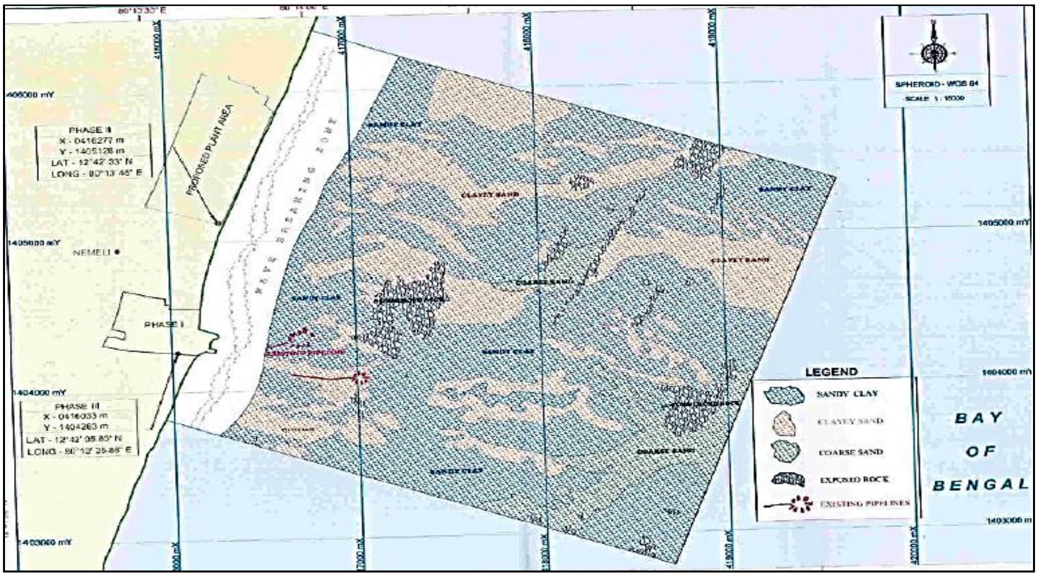


Figure 5: Seabed Map

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 report 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.

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 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 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 0.5.

4.1.5 Geotechnical data

A geotechnical survey has been carried out on behalf of CMWSSB during the year 2014. 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 – 19.0 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 is not available to analyse and recommend the essential pre-treatment processes for producing safe feed water for the extra-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. The details of the requirements in this respect are given below.

5.1.1 Requirements for a satisfactory raw water assessment

a) Raw water sampling shall be organised as close as possible of the intended location of the intake heads and at 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 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 (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) Analysis results shall be sourced from different laboratories and crosschecked. 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 (Oven 180°C then remaining salt weighting is the right method for TDS determination; deriving TDS from conductivity is acceptable for field measurement, not for 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.

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 till 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 the below 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.

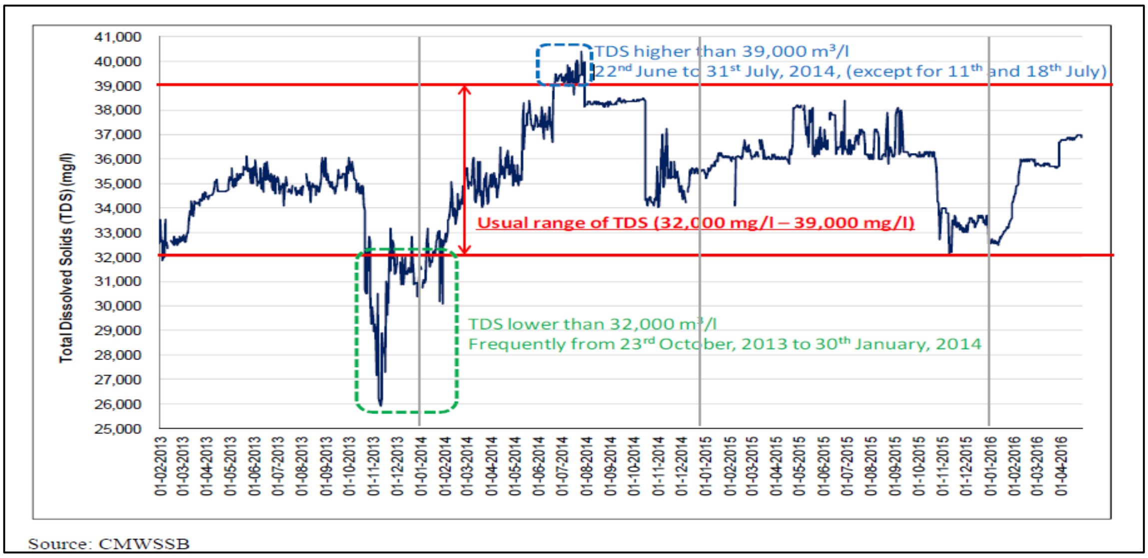


Figure 6: TDS profile over a period of 3 years (JICA Report) in the Raw Seawater of Nemmeli DSP

These data display the range of TDS values met around the year; specific events shall be "erased" not to increase too much the design and operational range. The following table procured from 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 to be 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 at RO design parameters as TDS, pH and water temperature, but not too much on pre-treatment parameters, as TSS, turbidity and TOC.

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.

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.

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 Perur plant.

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

The records from 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, ^oC	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
Sulfate, mg/L	1860	589419	2600

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

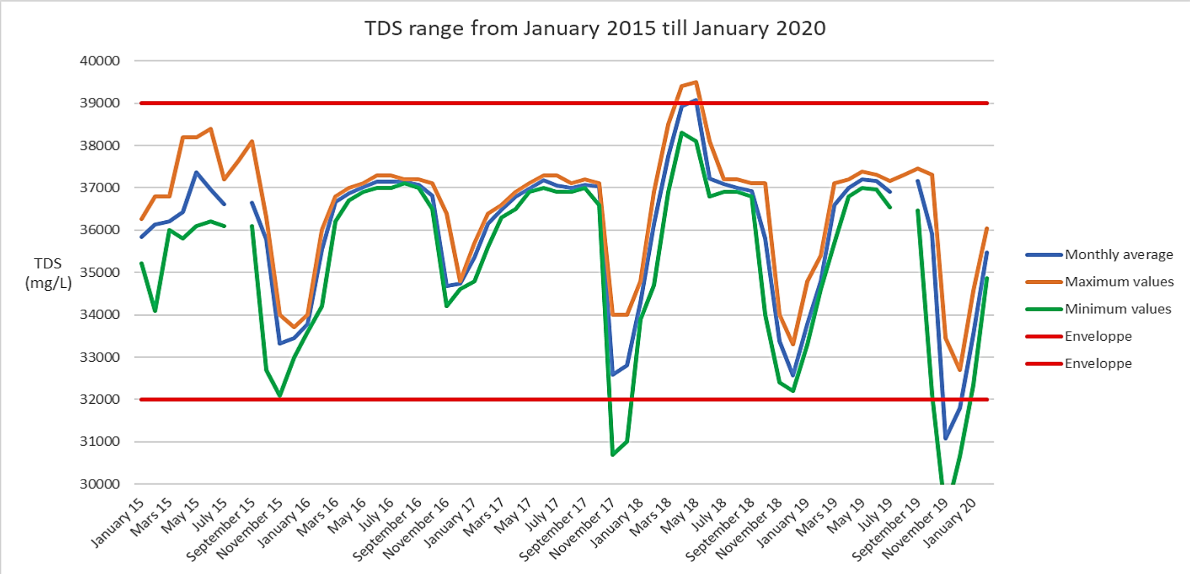
From the raw seawater quality at the Nemmeli plant that covers 5 years of data, it is possible to draw profile for the main parameters. Such profiles allow a more accurate approach to design envelop. Also, it allows us to review correlations between parameters, for instance, conductivity, TDS and TSS 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 7.

Figure 7: TDS profile over a period of 5 years (Nemmeli Data)



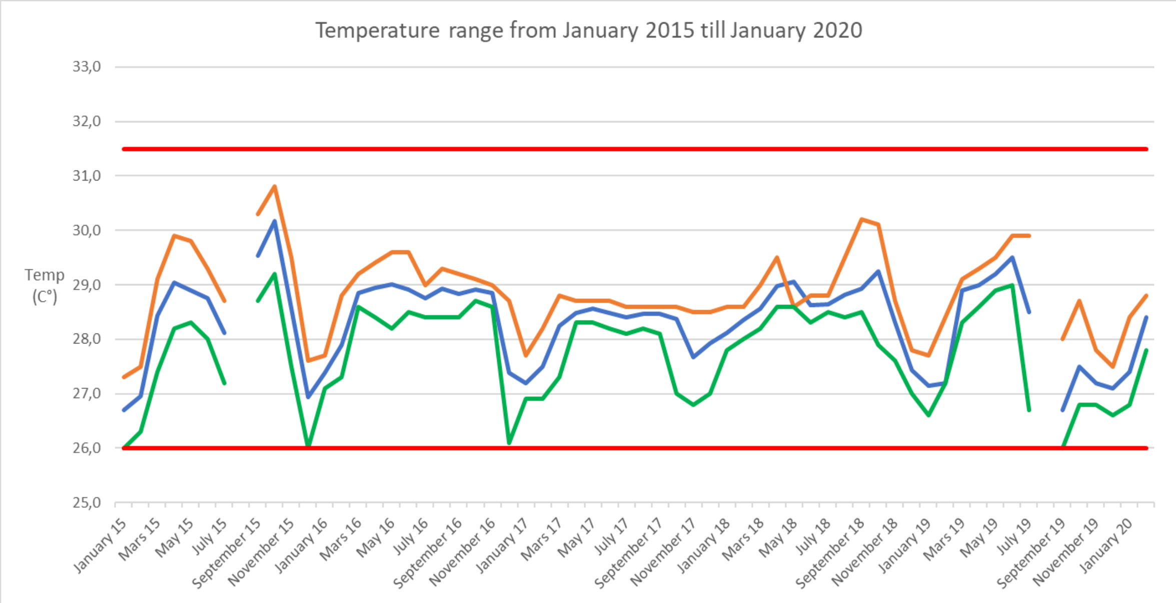
The TDS range is quite extensive due to flesh water impact during the Monsoon period. The decrease of TDS in November is repetitive, and its intensity depends on the rainfalls. Except for two restricted periods in 2015 and 2018, repeatability of TDS values below 37,500 mg/l are observed during spring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

II. Temperature

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

Figure 8: 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.

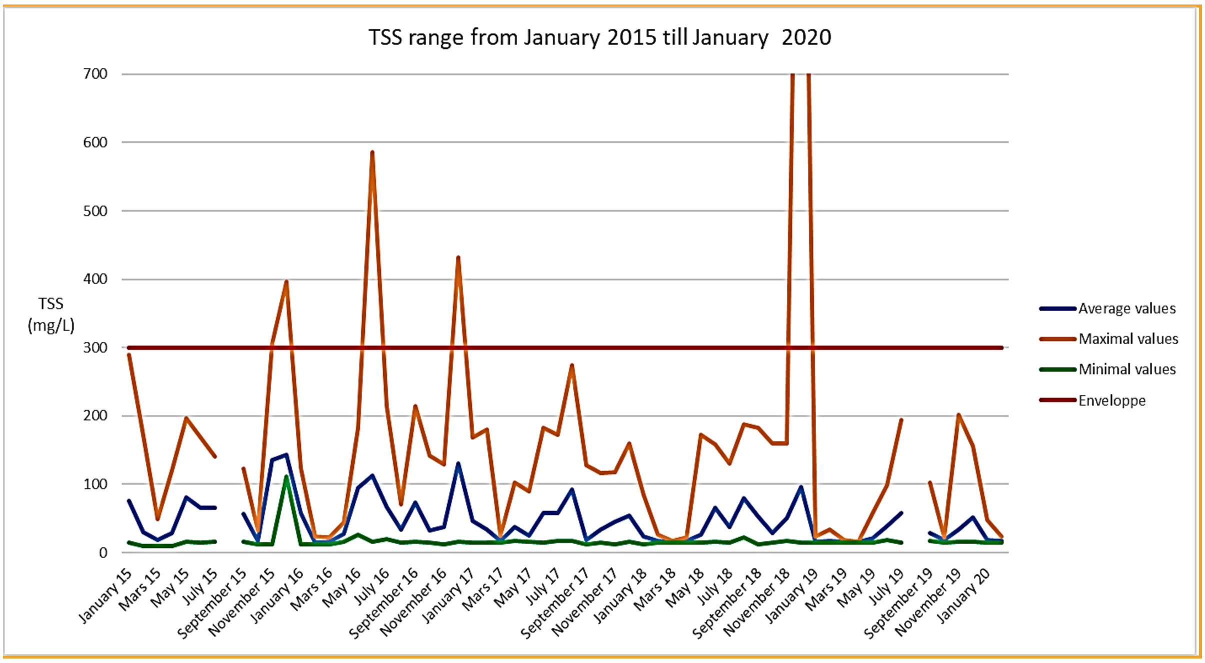
5.1.2.4 Parameters to be taken into consideration for pre-treatment design:

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)

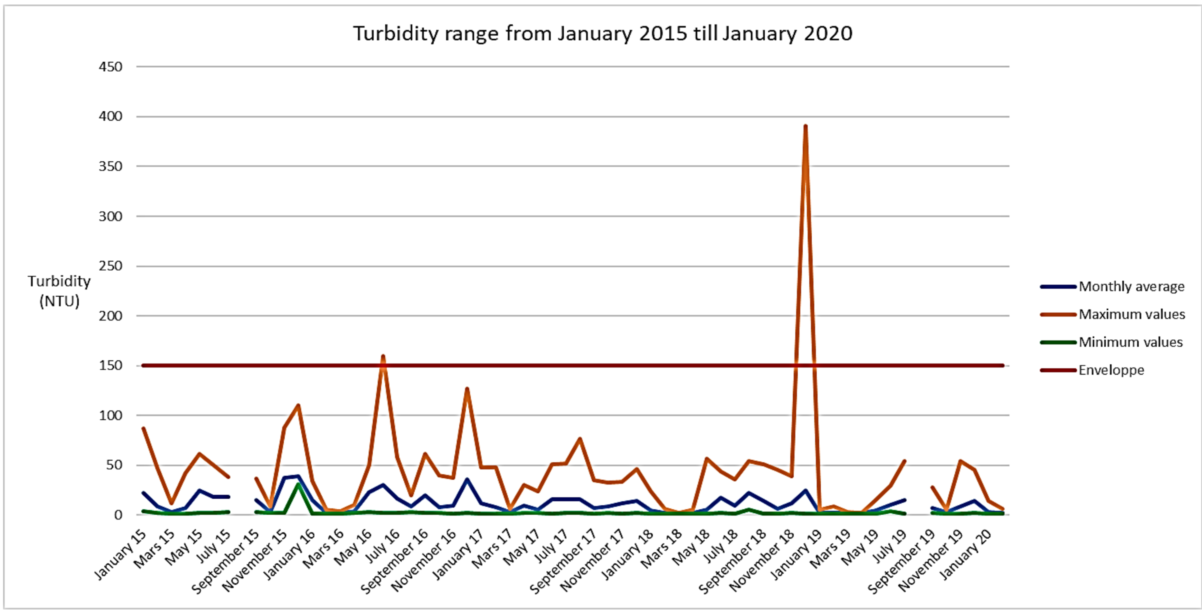
The variation of TSS over more than 5 years period is presented below in Figure 9.

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



A peak of TSS reached 1478 mg/l in December 2018. Usually, such abnormal value (one day) is considered an outlier and discarded. The maximum value of TSS in seawater has been considered at 300 mg/L for the pre-treatment design purpose.

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

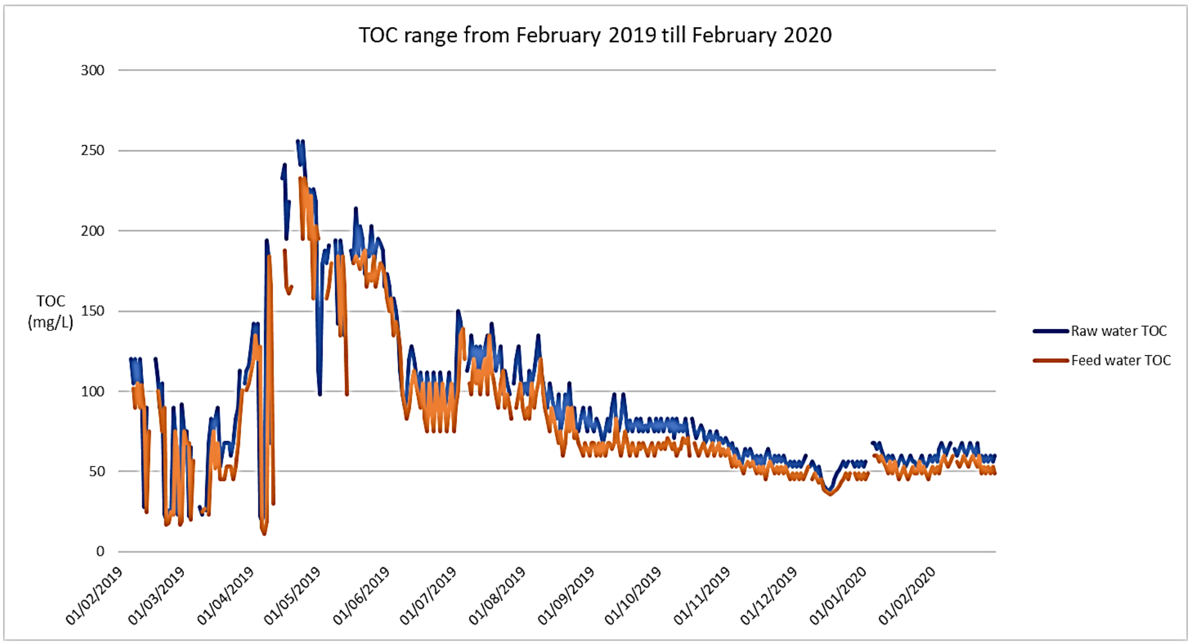


In Figure 10, turbidity displays good correlation with TSS, evidencing a quite low colloid content.

IV. <u>Total Organic Carbon (TOC)</u>

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 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 11 below.

Figure 11: TOC profile over a period of 1 year (Nemmeli Data)



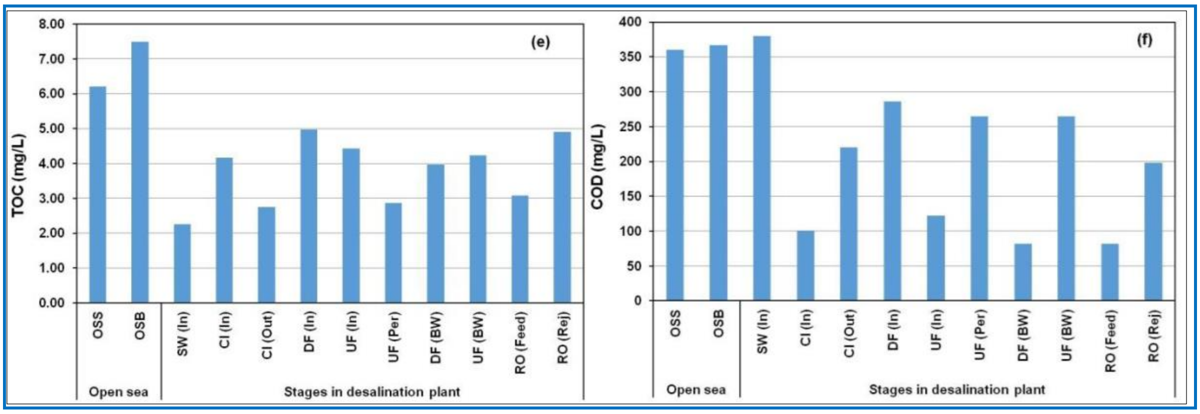
The range of TOC in seawater is ***very questionable*** and ought to be discarded until further laboratory for the following reasons:

- 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

- 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 up to **20 mg/l**, but with 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).

Figure 12: NIOT report on TOC at various stages of the Nemmeli plant



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 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 40 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 are lighter).

All these mitigation measures will have a cost impact and a delayed impact on the Project.

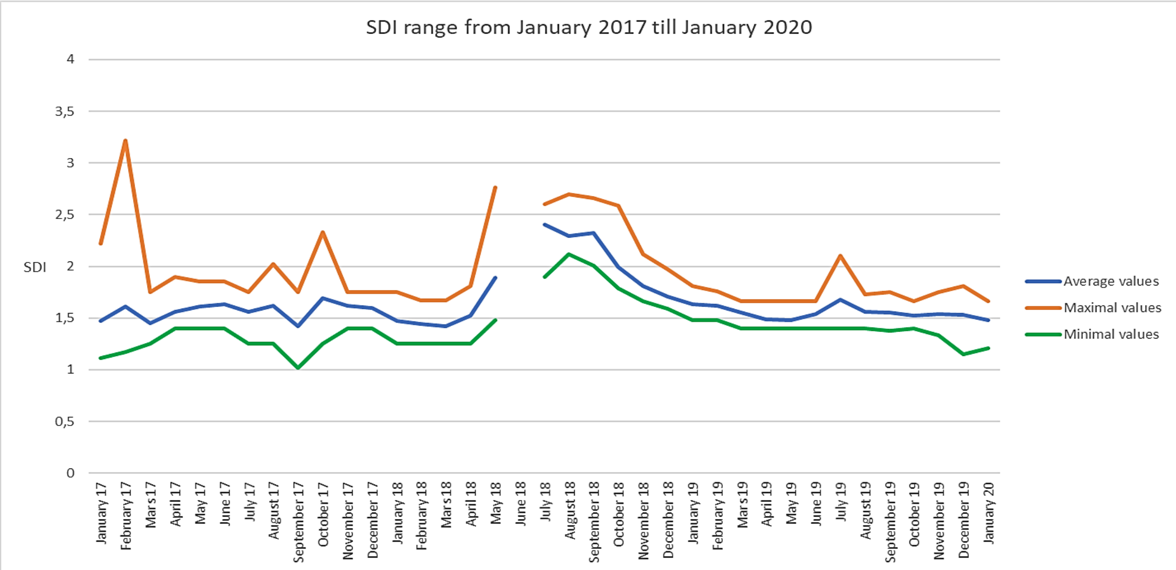
This shall be first reminded that:

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

V. Silt Density Index (SDI)

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

Figure 13: 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 all membranes issues. These excellent values confirm that most of the TOC are 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 Raw Water complementary survey

- **Reasons for additional raw water analysis campaign:**

1. PMC did not receive any third-party analysis for raw water (only single sourcing from Nemmeli plant laboratory)
2. Designing a plant of such size with only single sourcing of raw water induces a non-acceptable risk.
3. One of the main raw water parameters TOC (responsible for membrane fouling) impacting the design was not assessed by previous studies (DPR report or JICA report).
4. Confirmation of the best compromise between intake length and raw water quality (in particular in term of TOC content).
5. Procurement of a more comprehensive water profile, regarding ion content.

- **Location and conditions of sampling:**

1. Nemmeli DSP pumping station: to cross check data delivered by the plant
2. Proposed Perur desalination plant estimated intake point in the same pipe direction at 1140 m from the shore
3. Proposed Perur desalination plant estimated at present discharge location (future intake tower location) located at 1800 m of the shore
4. Keeping the same pipe direction, at 2400m from the shore.

For sampling location 2, 3, 4, the amount of bulk collected water shall be enough for three full sets of analysis. Two bulk sample shall be supplied to two different laboratories for analysis, and one bulk sample shall be kept for future verification in case needed. Sampling will be performed at 3 meter above the seabed (tower inlet depth). The selected laboratory will have to provide the following data (with related methods of the statement):

- Anions + cations contents
- TDS (not derived from conductivity)
- Water Temperature at sampling
- pH
- TOC and DOC
- Colour (before and after filtration (0.4 microns)
- COD and BOD
- Turbidity
- TSS
- Algae count (cell/ml)
- Pathogen counts

5.1.4 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 12 below.

Table 12: 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 envelop			
Turbidity	1.0	12	150
TSS	10	75	300
Total Organic Carbon (TOC)	3.0	5	8
Hydrocarbon contents			0.10
Algae count (cells per ml)	100	500	30000
Jelly fish attacks	N.A	N.A	Yearly Occurrences

5.2 Treated Water Quality (Indian Standard)

The water quality requirements shall meet the following:

1. The Indian Standards IS:10500-2012 (provided in Annexure 2).
   Main parameters relevant to 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) < 0.50 mg/l but tolerance up to 1 mg/l
   - pH 6.5<pH<8.5
   - LSI > Positive

2. Regarding remineralisation, the PMC recommends a minimum value of 80 mg/l eq $CaCO_3$ of hardness. It needs to be confirmed by CMWSSB.
3. In order to meet Indian standards at the customer tap, CMWSSB requires a safety margin 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 13.

Table 13: 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 proposed DSP are identified for the proposed Perur project and they are related to waste management and disposal and ambient noise pollution regulation and control is furnished in Table 14.

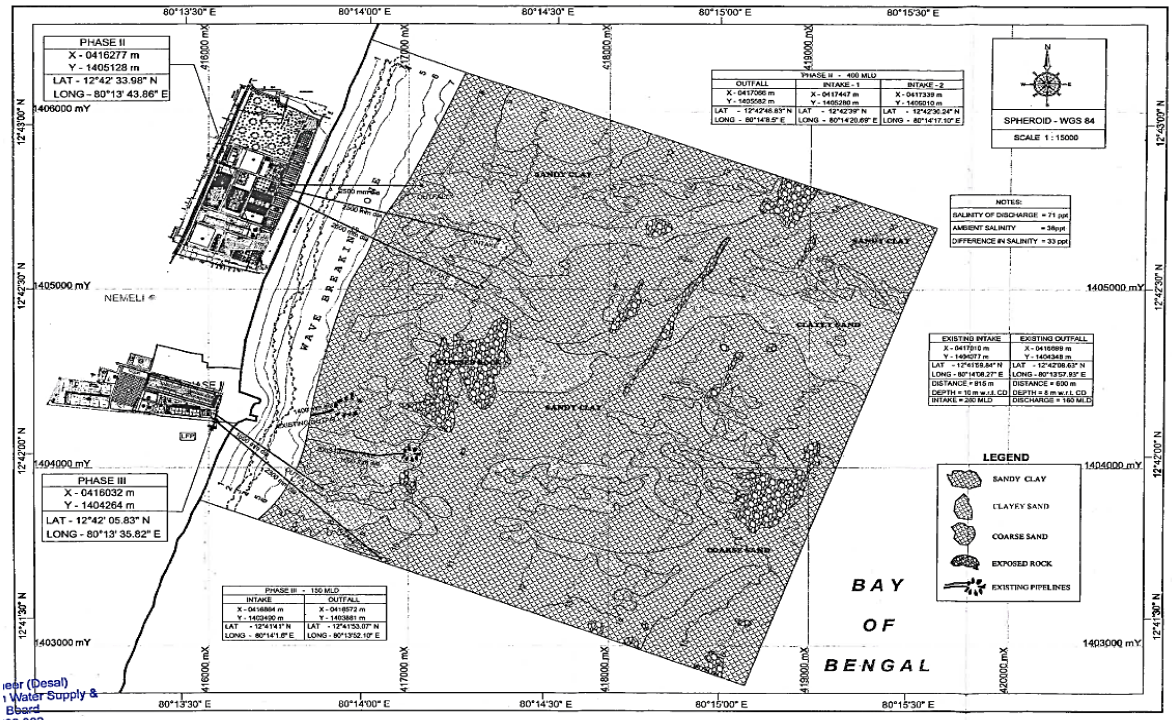
Table 14: Discharge Permit

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 needs the approval of CMWSSB to carry out this task at the earliest.

Main comments regarding this configuration are the following:

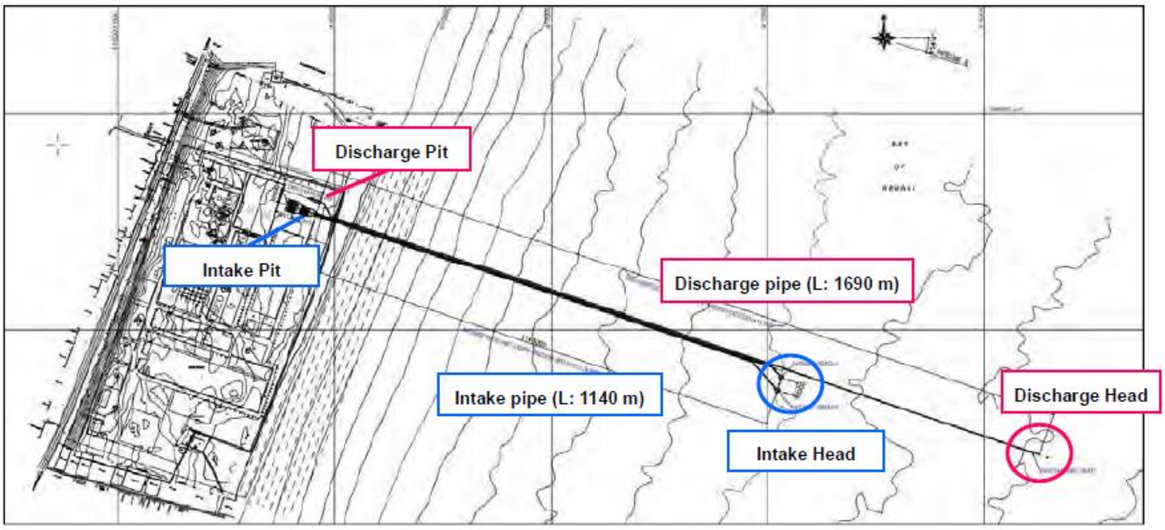
1. 3 different profiles (routes) for the 3 pipes are not of common usage in desalination practices since it implies a significant extra cost for the marine works. This is due to the additional dredging equipment required to complete works on time. As the DPR report highlights, the marine works window (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 up to 1.0 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 in 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.

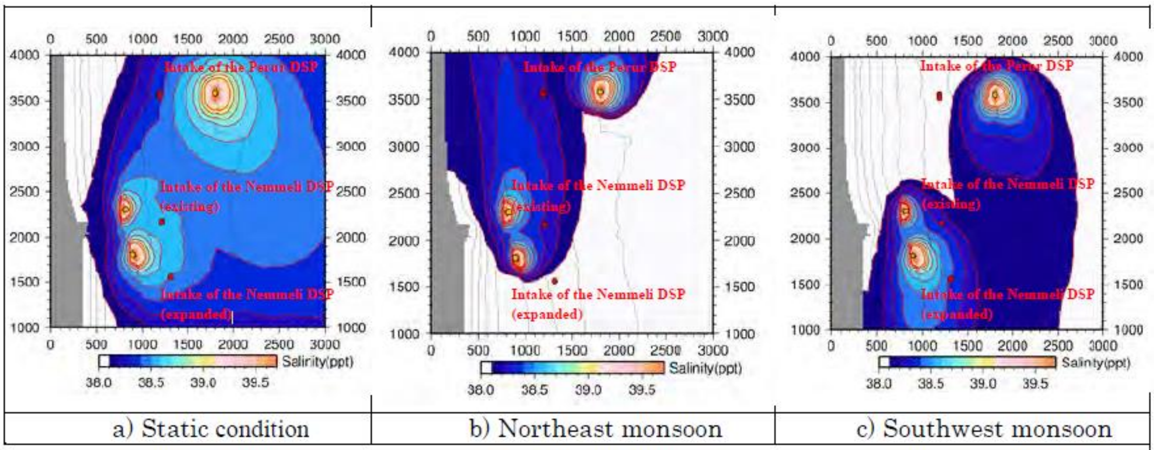
The final option proposed by JICA is a dual intake of 1140m length and a 1690 m discharge pipe, with the following implementation and dispersion plums (scenario no.3).



Source: JICA Study Team

Figure 14: 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.



Source: JICA Study Team

Figure 15: Dispersion simulation in 3rd Phase (JICA proposal)

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

Furthermore, this configuration does not leave too much room for the Perur expansion, and present intake location will be severely affected by dredging works of the Perur expansion.

Consequently, the PMC teams advised that further simulations need to be performed according to a new hypothesis:

1. Intake pipes to reach approximately 1700-1800 m (extra depth at around 12-13 m)
2. Discharge pipe to be shortened by 900 m (approximately 900 m remaining length) to achieve no recirculation in static conditions (800-900 m between intake heads and brine diffusers). This will affect slightly Nemmeli plants (less than their internal recirculation). This solution does not jeopardise quality at Perur (400 MLD and perhaps 600 MLD with expansion) and preserves only 250 MLD Nemmeli existing projects as attempted in JICA proposals.
3. Furthermore, it should be noted about 30% of marine works costs are due to mobilisation-demobilisation. Adding extra capacity to accommodate Perur expansion (say up to total 600 MLD capacity) will be relatively not very costly and can be investigated if CMWSSB and JICA allow it; approval of this extra capacity implemented with the present project will secure Perur 400 MLD operation during expansion works. In that case, the new proposed simulations for brine dispersion shall consider this option.

Such option as proposed by DPR was presented in the JICA report (Figure 16) but not optimised;

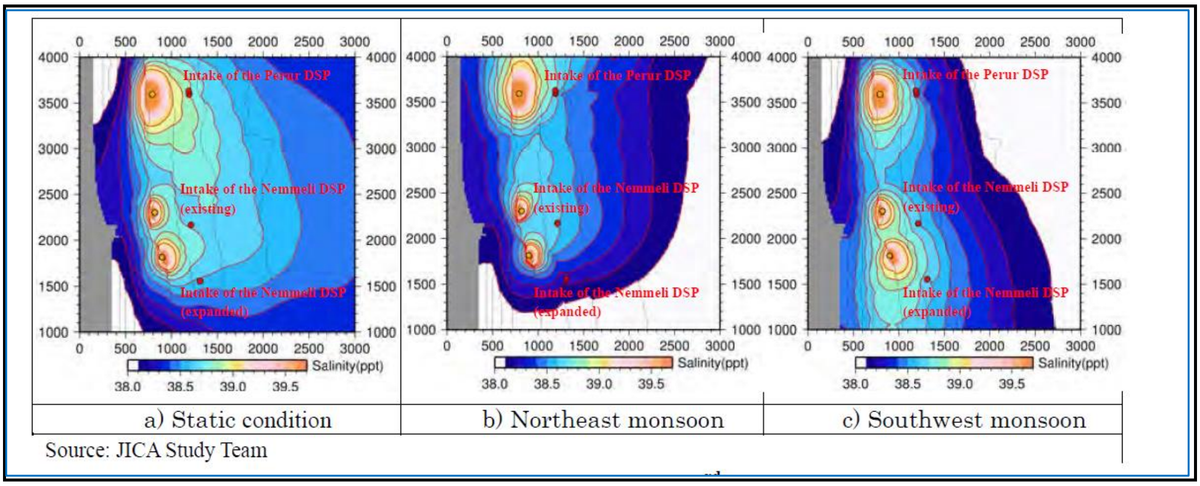
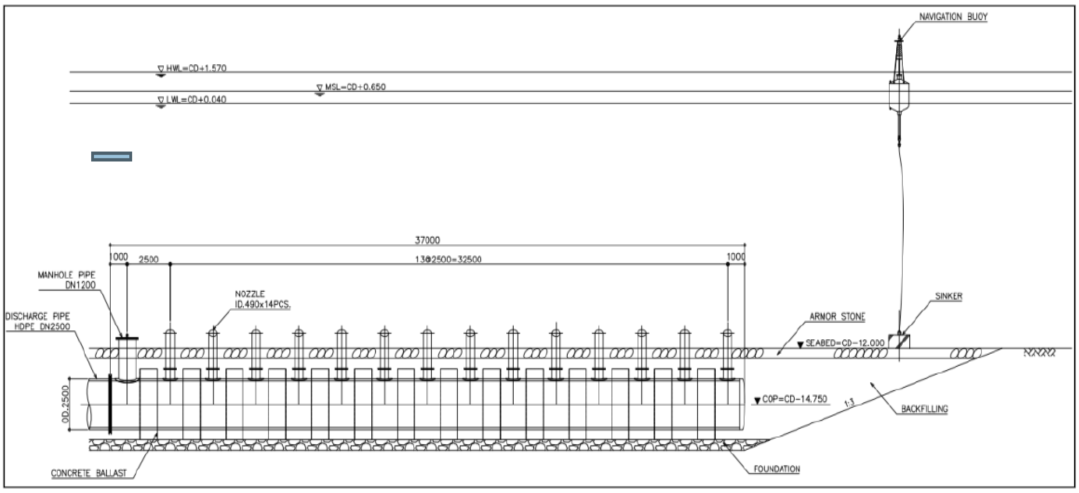


Figure 16: Dispersion simulation in 3rd Phase (DPR proposal)

Furthermore, the plum of Nemmeli plants during the Northern monsoon of phase 3 (Figure 16) is quite different from the one in Phase 3 (Figure 15): it should be quite similar since not yet impacted by Perur discharge.

4. 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 17: Design of Brine Discharge Head (JICA proposal)

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 x 0.97 = 141.62 Million m^3/year
- The aggregate stoppages of the Plant (preventive maintenance and forced outage) will amount:
  365 x 0.03 = 11 days

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 desalination Industry. While aiming at reducing the Opex, a specific focus at 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 Annexure-2**.**

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 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 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
- We should allow the contractor to demonstrate any alternative pretreatement processes to mee the RO feed water quality proposed above.

Important notice: If the raw water TOC content monitored during the additional sampling period evidences persistent values 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 higher than 40% of the feed TOC content.
2. In such the above conditions, implementation of DAF 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 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 section 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 and media rinsing for gravity filters (from 3 to 5% according to water quality)4%
- Waste drain from DAF and Lamella settlers (drain, cleaning) 3%

The below Table 15 (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 (1040 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 15: Mass balance around plant at 42% RO recovery

Process Stage	m³/day	Rate	Factor to Net Output
Intake Pumps	1,038,431		100%
Service Water	2000		0.2%
Utility and Leakage		5,192	0.5%
Lamella + DAF waste		31053	3.0%
GMF Backwash		40,442	3.9%
Pre-filtered water	961,955		92.6%
Feedwater RO+ERD	961,955		92.6%
Feed to RO	961,905		92.6%
HP pumps	404,000		38.9%
Recir. Pump	557,905		53.7%
Feed to ERD	557,955		53.7%
RO permeate	404,000		38.9%
RO Reject	557,955		53.73%
CIP & Flushing		2000	0.2%
Total plant waste discharge		636,642	61.3%
Net Plant Product Water	402,000		
Overall Plant Recovery	38.7%		

A detailed mass balance sheet is attached in Annexure-3

6.3 Marine Works

The major basic objective 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 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 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 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 to marine works design** to ensure pigs will 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 18 provides a photo of the pig from Pigtek used in the desalination plant at Ashdod, Israel and at Baraka 4, Oman and Figure 19 gives the typical hydraulic curves before/ after pigging operation.

Figure 18: Pig from Pigtek Co. (2.1 m diameter)

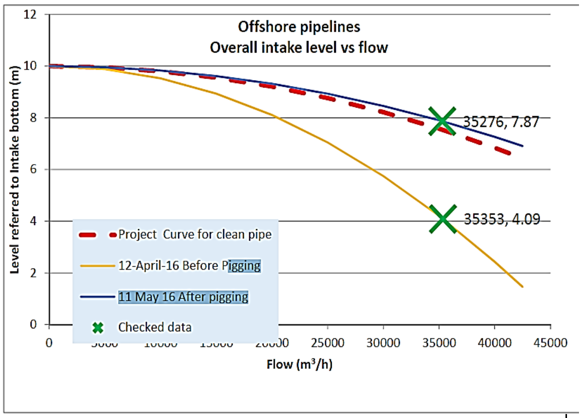
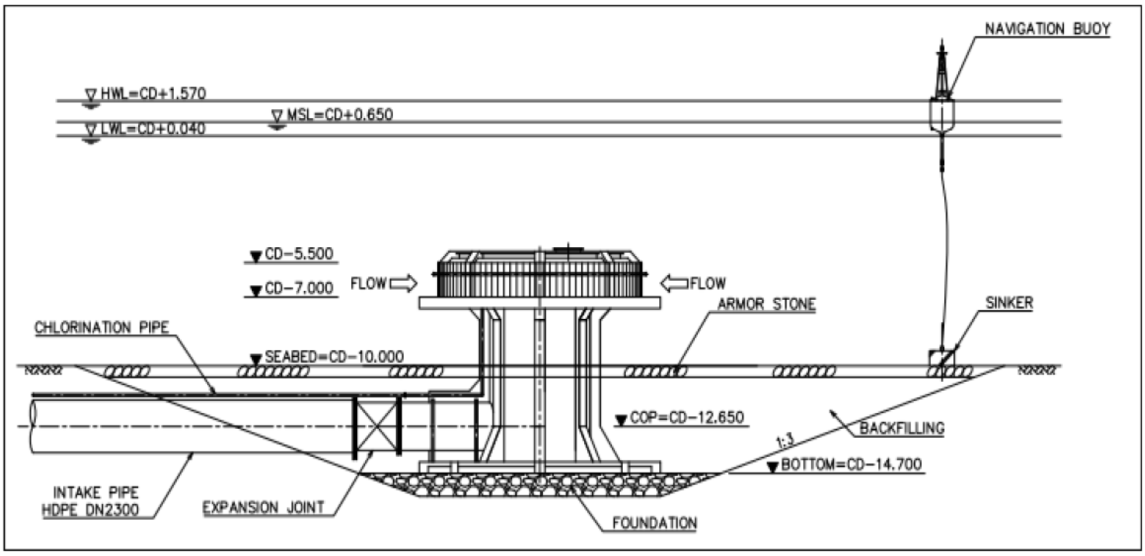


Figure 19: **Intake hydraulic curves before/after pigging operation**

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 20: 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 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 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 (1.43 m/s when clean, 1.71 m/s when clogged).

Table 16: Design of Intake Pipe

01. INTAKE PIPE	Unit	Value	Remarks
Number in operation	N	2	
Nominal flow per intake	m^3/h	21633	
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	1.44	**MFS< 1.6m/s**
Roughness coef K or C value		130	
Head loss at nominal flow (after pigging)	m	**1.10**	Using Hazen & William Eq.
Incrustation thickness	mm	100	
Reduced Diameter by Incrustation	mm	2108	
Velocity at a reduced diameter	m/s	1.72	
Roughness coef K or C value		85	
Head loss in incrusted pipe	m	**3.76**	
If intake capacity computed with a safety margin of	%	180%	**MFS**
Extended capacity	m^3/h	38940	
Diameter (ID)	mm	2308	
Velocity at extended capacity	m/s	2.59	
Roughness coef K & C value		135	
Headloss at extended capacity	m	**3.05**	

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 21.

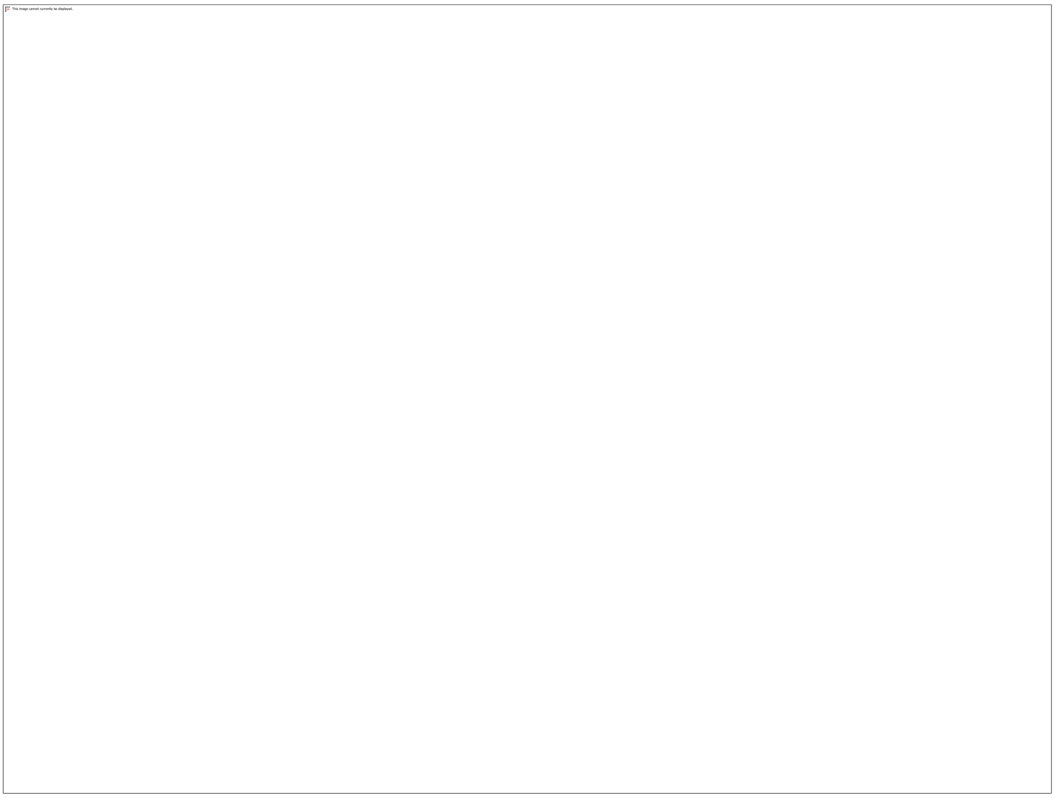


Figure 21: Presentation of head loss due to clogging of the intake pipeline

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 1.1 m and lead to **level N3 = -1.65m**
- 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 3.76 and leads to level N4= -4.31m**

- ➢ **The difference between these 2 levels (2.66 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 17.

Table 17: 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**	
Headloss at the intake head	m	0.2	
Headloss at screening bands (max when 1 under maint.)	m	0.5	
TOTAL N2	m	**-0.55**	
Head loss in intake (after pigging)	m	1.10	
TOTAL N3	m	**-1.65**	
Head loss with maximal clogging	m	3.76	
TOTAL N4	m	**-4.31**	
Minimal pump coverage	m	2	supplier data
Pump length	m	1	supplier data
Safety margin (sump)	m	1	
Pumping station depth	m	**-8.31**	
Intake depth (upper diam at pumping station)	m	**-5.56**	= N4 + 0.5diam
Intake depth (upper diam at the inlet)	m	**-14.87**	one meter 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	**7222.2**	
Design discharge pressure	m	**17.4**	
VFD		**YES**	
Pump efficiency at the design point	%	85	
Motor efficiency at design load	%	97	
VFD efficiency	%	98	

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 > 85%**
> - **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 18: Process design for shock chlorination

03. SHOCK CHLORINATION		Unit	Value	REmarks
Processed flow (total 2 intakes)		m^3/h	43267	
Commercial reagent		/	NaOCl	
Concentration		%	10.3%	
Max dosage		g/m^3	**15**	
Mass flow (100% pure)		kg/h	649	
Density		kg/L	1.18	
Volumetric flow		L/h	5339.8	
Frequency		h/week	3.5	to be adopted at an operation level
Dosing pump				
	Number in operation	n	1	
	Number in stand-by	n	1	
	Unit flow	L/h	8000	
	Capacity safety margin	%	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 19.

Table 19: Process design for moving band screen

04. BAND SCREENS	Units	Values	Comments
Processed flow (total 2 intakes)	m^3/s	12.02	
Number in operation		3	
Number in standby		**1**	
Screen size (mesh)	mm	**5**	
unit flow	m3/s	4.01	
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 >41 (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 20.

Table 20: 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 21: Process design for coagulation and flocculation

05. COAGULATION/FLOCULATION/ pH ADJUST	Unit	Value	Comments
Feedwater			
Design flow rate	m^3/d	1042000	
Design flow rate	m^3/h	43417	
Turbidity	NTU	150	
TSS	mg/l	300	
Coagulation (flash mixing)			
Contact time	s	20	Design data
Contact time	h	0.006	
Total volume of coagulation tanks	m3	241	
Nb of tank	m	4	as per modularity
Tank volume	m3	60.3	
Unit energy requirement	kW/m^3	0.7	
total energy requirement	kW	168.8	
Flocculation			
Contact time	min	15	Design data
Contact time	h	0.25	
Total volume of coagulation tanks	m3	10854	
Nb of tank	m	18	as per modularity
Tank volume	m3	603	
Unit energy requirement	kW/m3	0.01	
Total energy requirement	kW	108.5	
Ferric chloride injection			
Commercial reagent	/	$FeCl_3$	
Concentration	FeCL3	40%	
Max dosage	g/m3	**20**	
Mass flow	kg/h	2171	
density	kg/L	1.42	
Dosing pumps	n	5	
Volume flow	L/h	1528.8	
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	%	31%	
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	

05. COAGULATION/FLOCULATION/ pH ADJUST	Unit	Value	Comments
Concentration	H2SO4	98%	density
Max dosage	g/m3	**20**	design data
Mass flow	kg/h	886	
Density	kg/L	1.83	
Dosing pumps	n	5	
Volume flow	L/h	484	
Number in operation	n	2	
Number in stand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	300	
Capacity safety margin	%	24%	
Injection point			intake pumping station
Polymer			
Commercial reagent	/	Anionic Polymer	
Concentration		100%	
Max dosage	g/m³	**1**	design data
Mass flow	kg/h	43	
density		1	
Solution Concentration		0.5%	
Dosing pumps	n	5	
Volume flow	L/h	8683	
Number in operation	n	2	
Number instand by operation	n	2	
Number in workshop	n	1	
Unit flow	L/h	6000	
Capacity safety margin	%	38%	
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 22.

Table 22: Process Design for Lamella Settler

06. LAMELLA SETTLERS	Unit	Value	Comments
Design flow rate	m^3/h	43417	
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	$m3/m^2.h$	**18.7**	
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 to pre-treatment as second players after Lamella filtration. Figure 23 provides the process design for the DAF system.

Table 23: Process design for DAF

07. DISSOLVED AIR FLOTATION		Unit	Value	Comments
Feedwater				
	Design flow rate	m^3/d	1021000	
	Design flow rate	m^3/h	42542	
	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/m².h	25	MFS <25-30
	Recirculation rate	%	15%	
	Total surface flotation area	m²	1702	
	Surface Flotation per tank	m²	156	
	Number of the tank in operation		12	
	Surface contact zone area/tank	m²	40	
	Total Surface contact zone area	m²	476	
	Width	m	6	
	Depth	m	5	
	Length	m	30	
	Number of tanks		12	
	Total area		2160	
	hydraulic detention time	min	15.2	MFS >15

07. DISSOLVED AIR FLOTATION		Unit	Value	Comments
Circulation pumps				
	Number in operation	u	4	
	Number in standby	u	2	for two-stream of 200 MLD
	Discharge flow	m3/h	1595	
	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	425	
	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 as given in Figure-24. 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 pre-treatment purpose is to remove all contaminants before membrane stage, it should not generate itself 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 24: Process design for Granular Media Filtration

08. GRANULAR MEDIA FILTRATION		Unit	Value	Comments
Feedwater				
	Design flow rate	m^3/d	1011000	
	Design flow rate	m^3/h	42125	
	Turbidity	NTU	30	
	Operation cycle	h/BW Cycle	36	MFS>24h in worse conditions
	TSS removal	%	100%	
	TOC Removal	%	30%	
	Surface loading rate	$m^3/m^2/h$	**7.4**	MFS< 8
	Type		DM gravity	
	Total filtration area	m^2	5693	
	N filters in operation		80	40 for two streams of 200 MLD each
	Unit surface	m^2	71.2	Max =>40 to 100 (Gravity) 15 to 40 (Pressure)
	Unit flow	m^3/h	527	
	N-1 filters in operation		78	1 in each stream of 200 MLD
	Total filtration surface	m^2	5550	

08. GRANULAR MEDIA FILTRATION		Unit	Value	Comments
	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	5407.9	
	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	3558	
	Water flow rate	m³/h/m²	10	higher than filtration velocity
	Water flow per Filter	m³/h	712	
2-	Water only	m³/h/m²	36	MSF>30 (and<50 no loss of media)
	Water flow rate	m3/h	2562	
3-	Filter maturation	m3/h/m²	8.5	higher than filtration velocity
	Water flow rate	m3/h	605	
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	652	
	Discharge pressure	m	8	
	Pump efficiency at the design point		85%	
	Motor efficiency at design load		95%	
	VFD efficiency	100% if No VFD	100%	

08. GRANULAR MEDIA FILTRATION		Unit	Value	Comments
	Total - Step-2	N	6	
	In operation (step 2)	N	4	2 in each stream of 200 MLD
	Discharge flow	m^3/h	2562	
	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	Nm^3/h	3558	
	Discharge pressure	m	6	
	Power at design load	KW	120	To be confirmed
Backwash tank				
	% of daily backwash requirement	%	50%	
	Tank capacity	m^3	20000	
	Per half-plant	m^3	10000	

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 the below Table 25:

Table 25: 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	m^3/h	40196	
Cartridge requirement		7584	
Unit flow	m^3/h	5.3	

09. CARTRIDGE FILTERS	Unit	Value	Remarks
CF cartridge vessel			
Material		GRP	
CF vessel content	unit	250	
nb of vessel required		30.3	
nb of vessel installed		36	20% margin vs supplier max capacity
Nb of cartridges installed		9000	
Head loss when new	m	2	
Head loss when clogged	m	7	
The extra cartridge in Warehouse	50%	4500	

(Desaltis 2020)

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-26, are therefore computed for a 46% recovery ratio. The overall plant recovery (product water flow/intake water flow) is equal to 42.4%. The detailed mass balance is available in Annexure-3. The overall plant recovery (product water flow/intake water flow) is up to 42.4%.

Table 26: Mass Balance for operation at 46% RO recovery

Process Stage	Process water	Wastewater	Rate wrt Feed
Intake Pumps	948160		100.00%
Service Water	2000		0.002109349
Utility and Leakage		4741	0.50%
Lamella + DAF waste		28363	0.029913728
GMF Backwash		36938	3.90%
Pre-filtered water	878311		0.926332054
Feedwater RO+ERD	878311		92.63%
Feed to RO	878261		0.92627932
HP pumps	404000		42.61%
Recir. Pump	474261		0.500190896
Feed to ERD	474311		50.02%
RO permeate	404000		0.426088424
RO Reject		474311	50.02%
CIP & Flushing		2000	0.002109349
Total plant waste discharge		546,353	57.6%
Net Plant Product Water	402,000		
Overall Plant Recovery	42.4%		

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 saving in energy is not fully compensated by the over cost in chemicals. 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 in the 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 27. The projections have been prepared with the seawater TDS equal to 39000 mg/l, which is considered as the maximum TDS value expected for the Perur desalination plant. In case of the seawater TDS reaching more than 39000 mg/l up to 41000, the production will be maintained with required product water quality by reducing recovery down to 44% and adjusting pH in RO feed.

The details are given below.

Table 27: 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
HCO3	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 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.

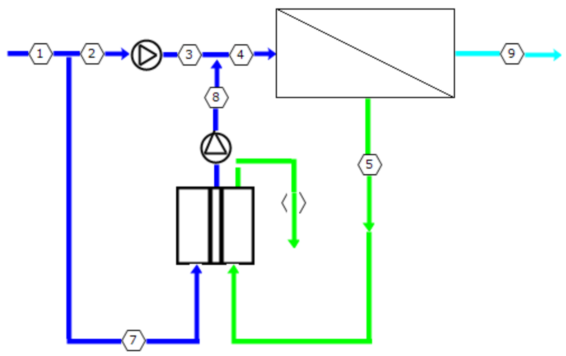
To select the best membranes or combination of membranes, Boron rejection in worse conditions (high Boron, low pH, high temperature, max average membrane life) has been first reviewed:

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.

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

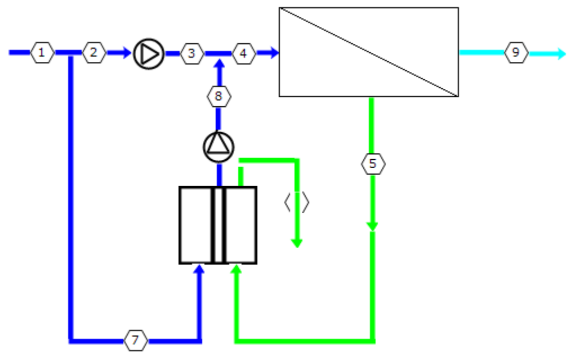


	1	2	3	4	5	6	7	8	9
Flow (m3/h)	2287	1064	1064	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	65.2	65.2	63.5	0	0	65.2	1.50
TDS (mg/l)	39010	39010	39010	39743	73276	71905	39010	40381	307
Hardness as CaCO3	6323	6323	6323	6443	11914	11690	6323	6547	12.0
Cl	21560	21560	21560	21965	40500	39742	21560	22318	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 pH of RO feed which will only bring the Boron level down while the TDS will remain high in RO permeate. So, it is clear that the use of 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-28 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 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 the 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 39000 mg/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 28: 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

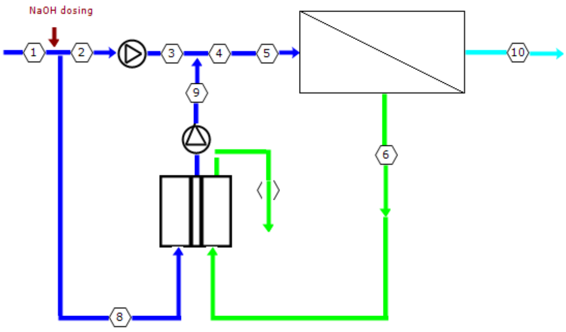
Arrangement	Condition	TDS (ppm)	Temp, °C	Avg age	Permeate Boron (ppm)	Soda dosing (ppm)	Permeate TDS (ppm)	TDS product	Test @ Hardness 80	Pressure, Bar	HP Energy Cost/year (MUSD)	Chemicals Cost/year (MUSD)	Total Cost/year (MUSD)	Saving/year (MUSD)
								Hardness -	105					
Run with RO recovery @ 46%														
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 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

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



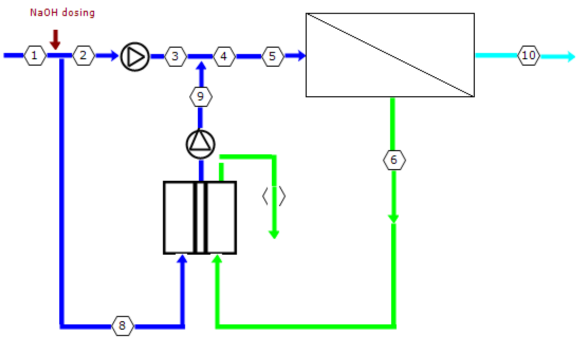
	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2287	1064	1064	2287	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	62.6	62.6	62.6	60.8	0	0	62.6	1.50
TDS (mg/l)	39010	39012	39012	39744	39744	73197	71830	39012	40380	386
Hardness as CaCO3	6323	6323	6323	6443	6443	11912	11689	6323	6547	15.1
Cl	21560	21560	21560	21964	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

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

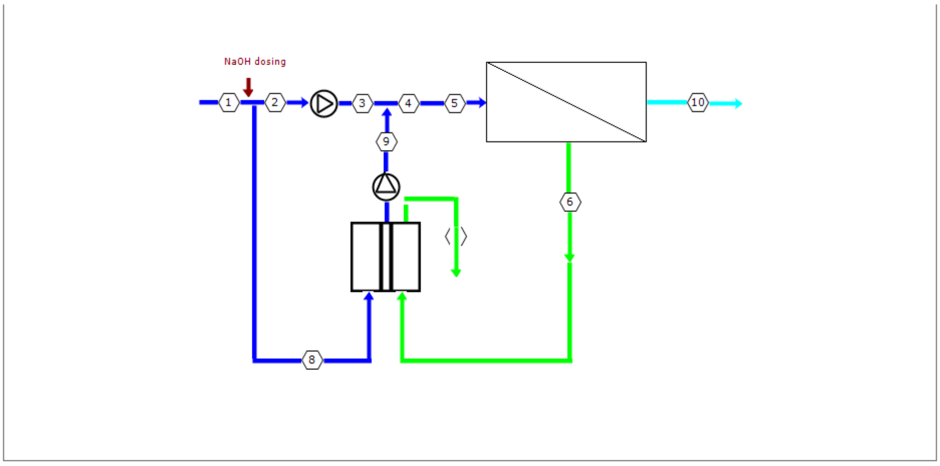


	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2338	1064	1064	2338	2338	1286	1286	1273	1273	1052
Pressure (bar)	0	0	61.8	61.8	61.8	60.0	0	0	61.8	1.50
TDS (mg/l)	39010	39012	39012	39728	39728	71864	70550	39012	40327	380
Hardness as CaCO3	6323	6323	6323	6440	6440	11694	11479	6323	6538	14.8
Cl	21560	21560	21560	21956	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

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

The details of the RO projections are given in Annexure-4.

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.

1. Seawater TDS 41000 mg/l, temperature 31.5 ºC, 46% recovery
2. Seawater TDS 41000 mg/l, temperature 31.5 ºC, 44% recovery

The projection results are presented below in Table 29.

Table 29: Projections for 3HR + 5LR membrane configurations with feed TDS 41000 mg/l

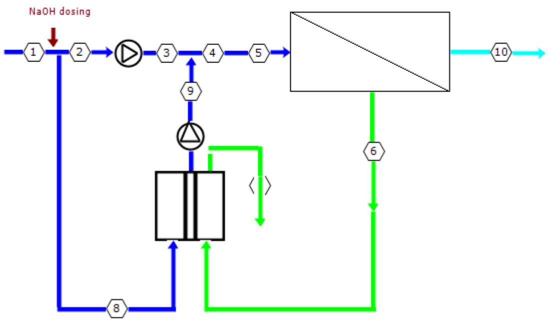
Arrangement	Condition	TDS (ppm)	Temp, ºC	avg age	Permeate Boron (ppm)	Soda dosing (ppm)	Permeate TDS (ppm)	TDS product
Recovery 46%								
3 HR + 6LE	High Max	41000	31.5	3.5	0.96	7.7	410	509
Recovery 44%								
3 HR + 6LE	High Max	41000	31.5	3.5	0.95	7.7	397	496

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 projections have been provided in Annexure-4

3 high rejection + 5 low rejection membranes @ 46% 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

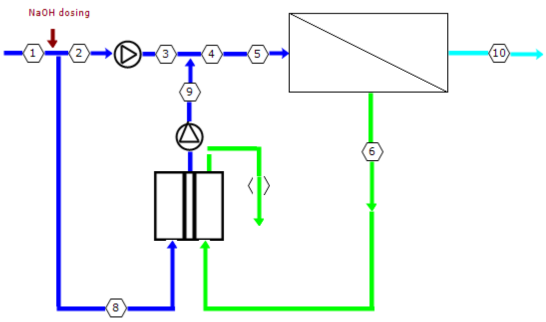


	1	2	3	4	5	6	7	8	9	10
Flow (m3/h)	2287	1064	1064	2287	2287	1236	1236	1223	1223	1052
Pressure (bar)	0	0	66.3	66.3	66.3	64.5	0	0	66.3	1.50
TDS (mg/l)	40997	41000	41000	42177	42177	77679	75479	41000	43200	410
Hardness as CaCO3	6733	6733	6733	6928	6928	12808	12443	6733	7097	16.3
Cl	22755	22755	22755	23409	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 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 oC and at the subsequent 1 oC increase in temperature up to 31.3 oC.
- 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 $CaCO_3$ has been taken into account in maintaining the product seawater hardness within 80 mg/l as $CaCO_3$.
- The projection is run at 46% recovery.
- Table 30 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 30: 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 a different temperature from average to the maximum is given below in Figure 22 and Figure 23.

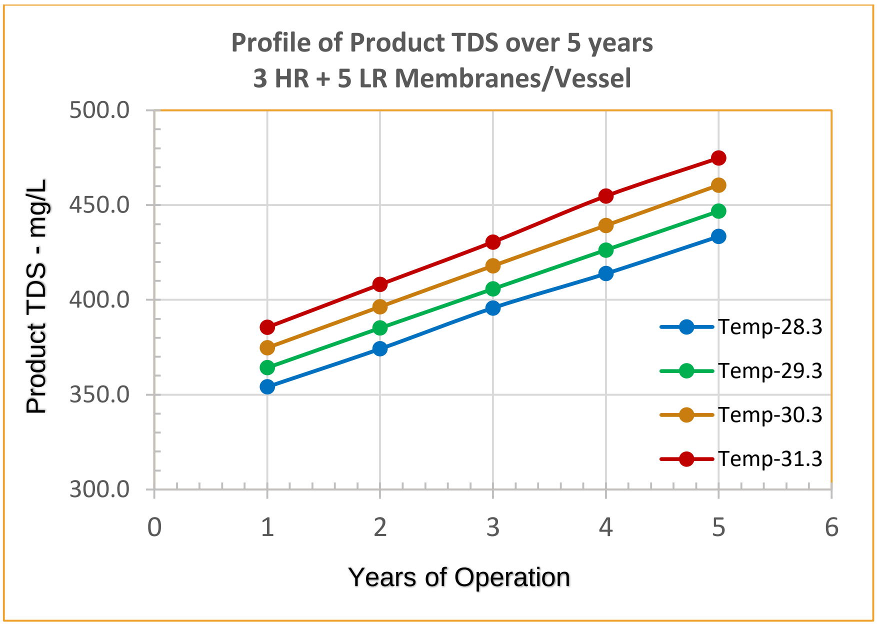


Figure 22: Trend of product TDS at various temperature and average feed seawater quality

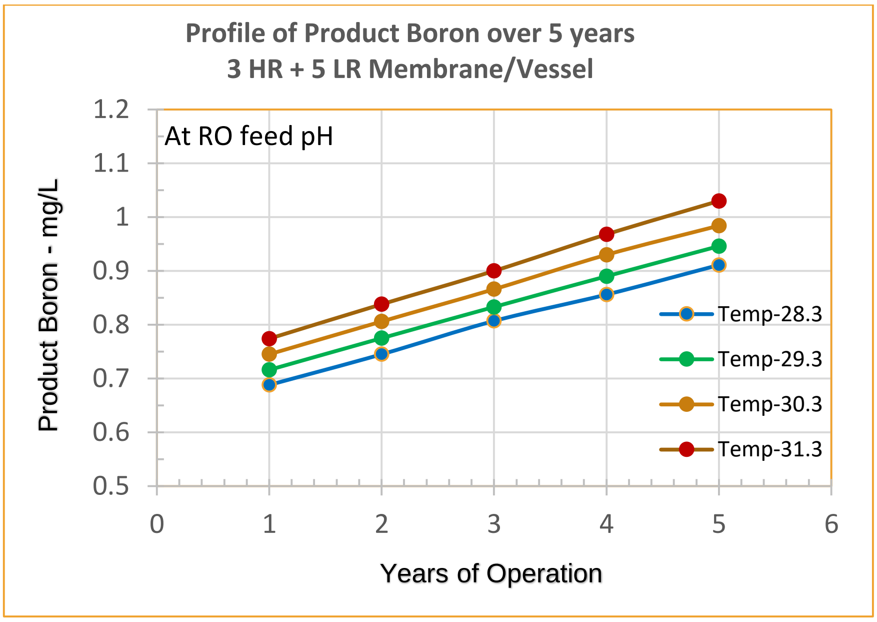


Figure 23: Trend of product Boron at various temperature and average feed seawater

The above trends presented in Table 30 and in Figures 22 & 23 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 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 24 below.

6.5.4.1 Conventional "train" configuration

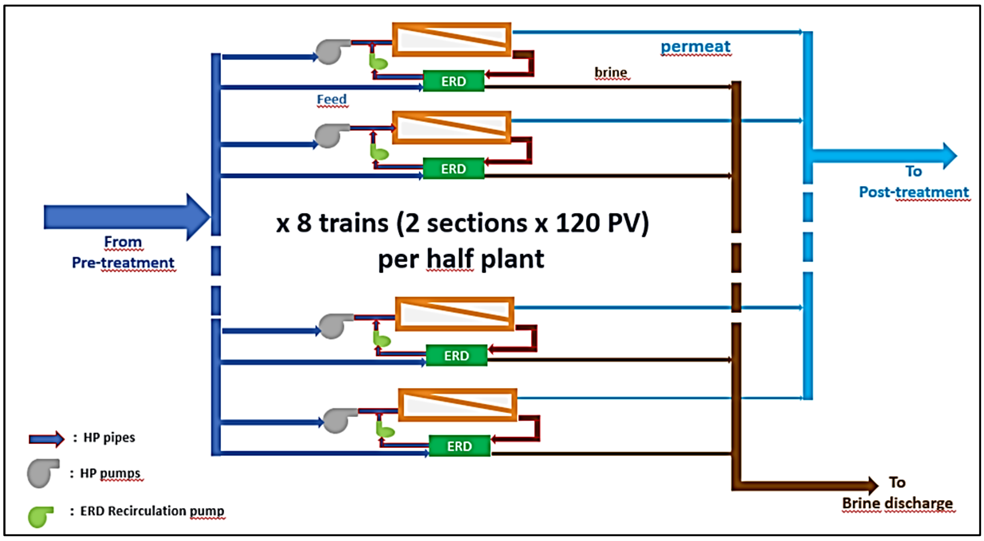


Figure 24: Train configuration option for the Perur Project (one-half plant)

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 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 25.

- **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 stand by 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 on line standby. In case of failure or preventive maintenance within the ERD or a recirculation pump, the stand by equipment can take over, and the **CAPACITY IS MAINTAINED.**

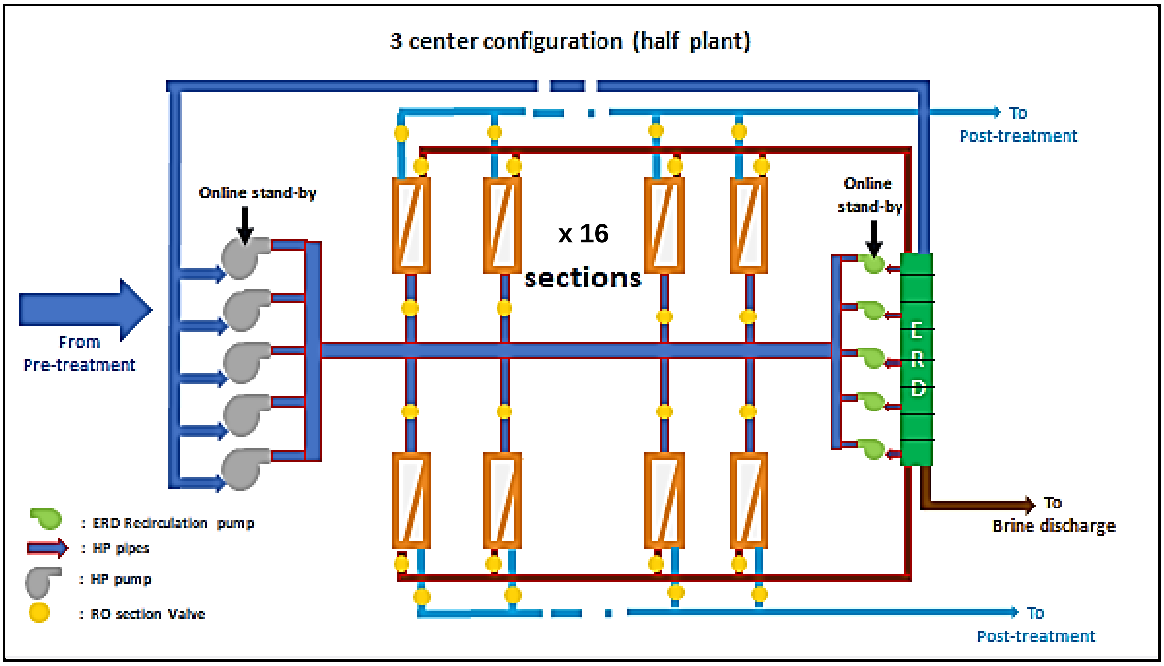


Figure 25: 3-Centre Train configuration option for the Perur Project (one-half plant)

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-31 below, issued by the Israeli Water Authority.

Table 31: Cost of water in plants with 3-Centre Design

SWRO Prices

	Ashkelon 2005	Palmahim 2007	Hadera 2009	Sorek 2013	Ashdod 2013
Mm^3/Year AFY (x 10^3)	120 97	45 36	127 103	150 122	100 81
Water Price $\text{US\$/m}^3$ $\text{US\$/Kgal}$	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 32 below.

Table 32: 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:

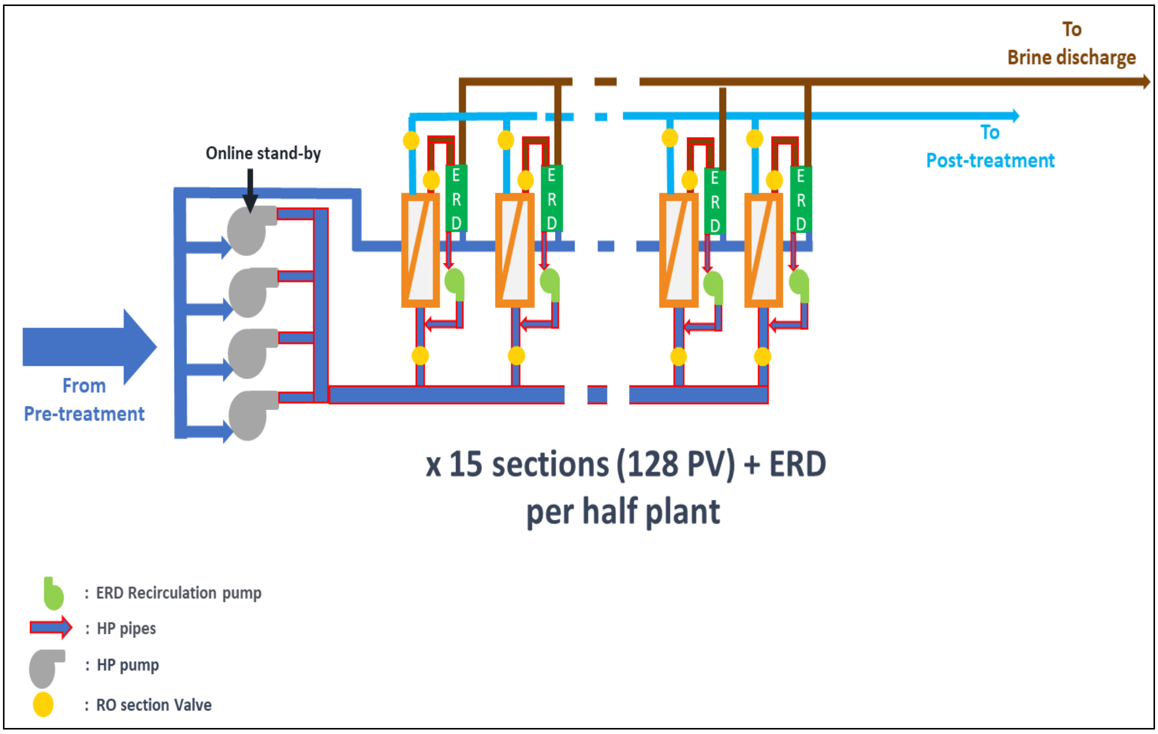


Figure 26: Pressure Centre Train configuration (one-half plant)

This design is also implemented within the large plants (Ashdod 380 MLD). The above sketch displays such 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 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 33: 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 34: 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 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 35: 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 36: 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 Cr 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 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 Perur plant.

Table 37: 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**	
						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 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 m^3/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) with implementing a risk of corrosion due to stagnant water (as frequently met with idle SB trains).

Table 38: 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**
							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 39: Capex for 6-pump – Pressure Centre Design with Standby

6-pump – Pressure 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
ERD	D-1550	60	333			81200	4.87	41.41
Membranes		30720				320	9.83	83.56
Pressure Vessels		3840				1500	5.76	48.96
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
Standby for 6 Pump Pressure-Centre Configuration (in Warehouse)								
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	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
ERD	D-1550	6	312			81200	0.49	4.14
Membranes		1536				320	0.49	4.18
Pressure Vessels		192				1500	0.29	2.45
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 the Table-40 below.

Table 40: 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 41: 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 are 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

Table 42: 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	
Design flow		m^3/h	2811	
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 the 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 43: 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	
Design flow		m3/h	2 811	
Discharge pressure		m	630	Normal feed water 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 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 the Energy Recovery Device (ERD). The feed pressure must be as low as possible while complying with the ERD design guidelines.

Table 44: 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	
Design flow		m^3/h	3 288	
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 45: 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	
Design flow		m	3288	
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	

Membranes 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 array, of course, does not affect the overall membrane flux of the plant which is kept @ 13.4 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 reduction of flux is necessary to reduce fouling. All pipe headers for each section will be provided with additional pressure vessel with available connection to reduce permeate flux.

Table 46: 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**	
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 Startup 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 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 stoke:
  HP brine enters the chamber and expelling the pre-treated seawater from the chamber while transferring it 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 stoke two).

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

- ERI Model PQ300 (capacity 68 m3/h) (2 x 2 chambers per element)
- Dweers Model Isobaric D-1550 (capacity 350 m3/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.

Both the technical documentation are provided in Annexures-5; as CMWSSB has already experience in ERI technology, only a description of Dweer technology is provided here below (Figure-27).

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 stoke.
- 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.

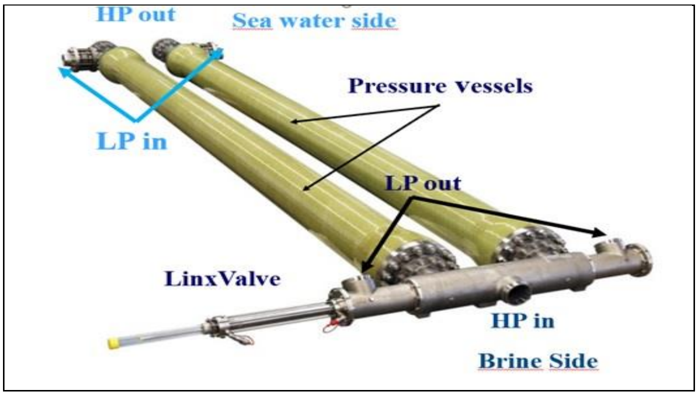


Figure 27: Typical design of Dweer ERD

➢ **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 28):

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 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).

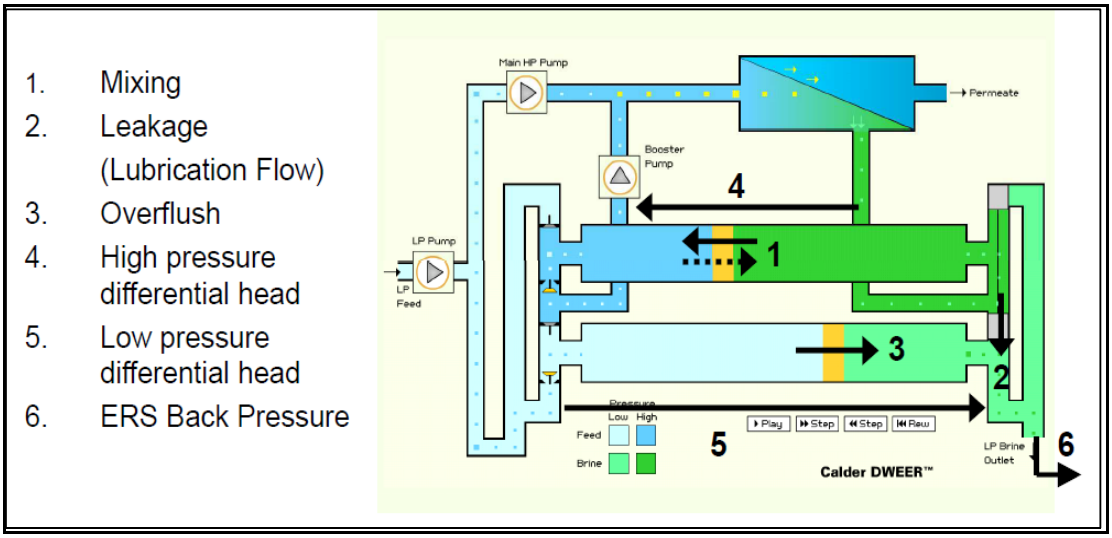


Figure 28: Illustration of defaults at isobaric devices

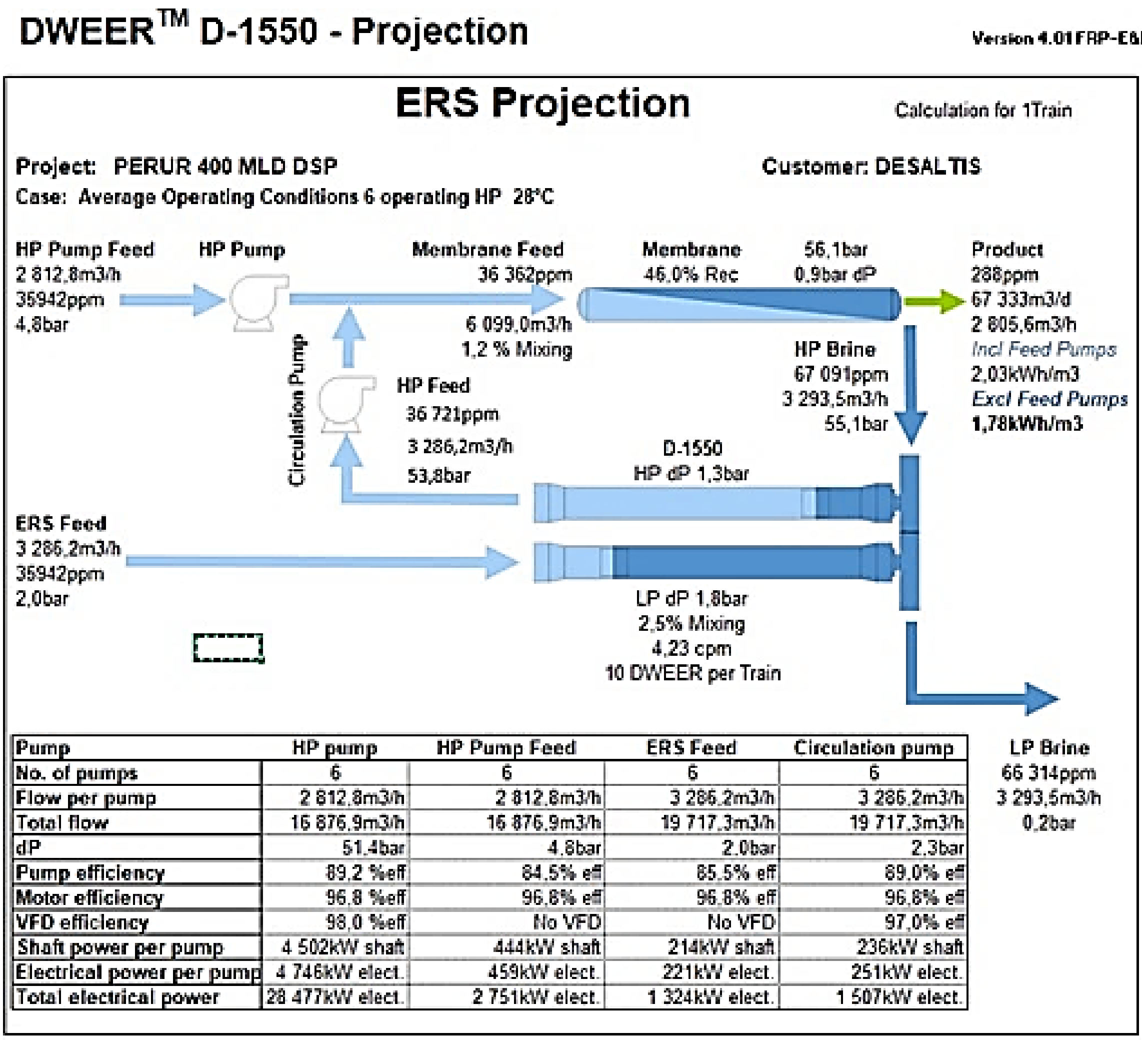
6.5.6.2 Projections

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 47: 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**	
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 29: DWEER isobaric devices projection

- **Projection for ERI (50 units per operating HP pumps)**

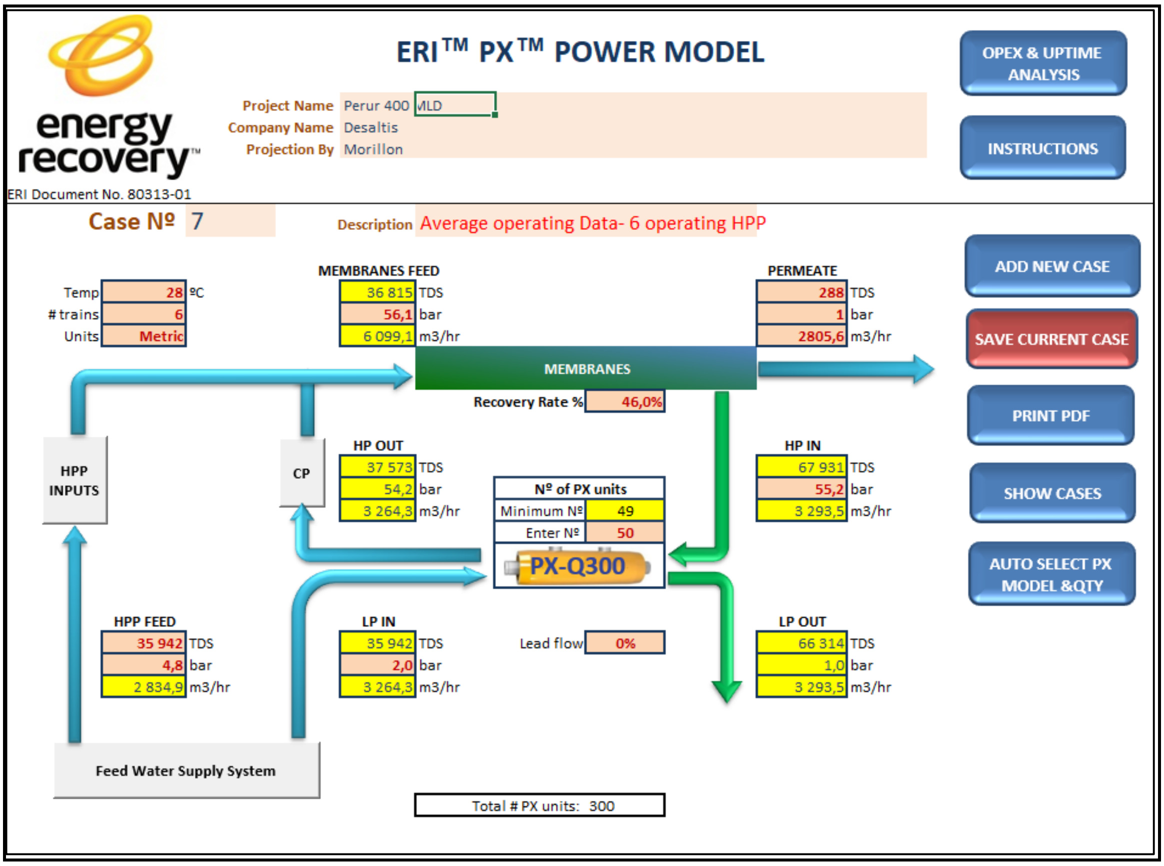


Figure 30: ERI isobaric devices projection

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 Nemmeli 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 Nemmeli 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

Advantage is for 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

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 boasts up to 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 around the world. 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

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 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 | 01.01.2020 | Worldwide | 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 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 to implement. 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 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) that 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 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 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-31 for better understanding:

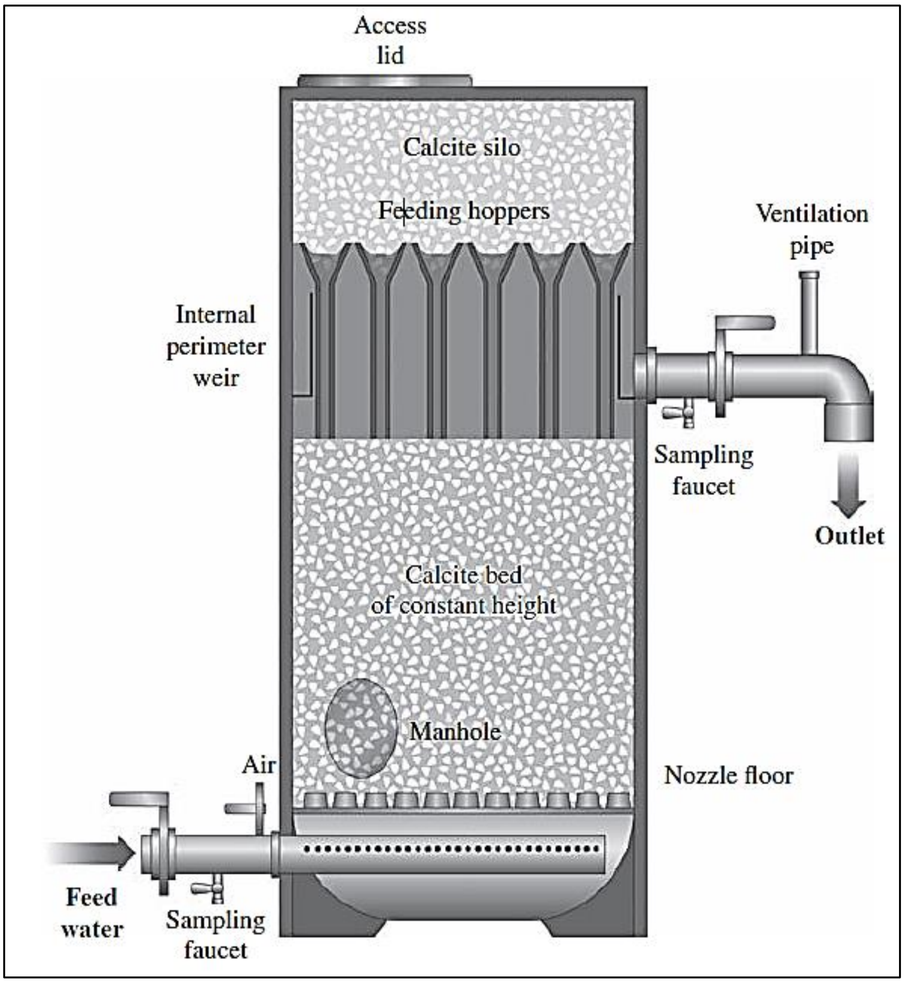


Figure 31: Cross-section of Drintec Calcite Contactor Cell

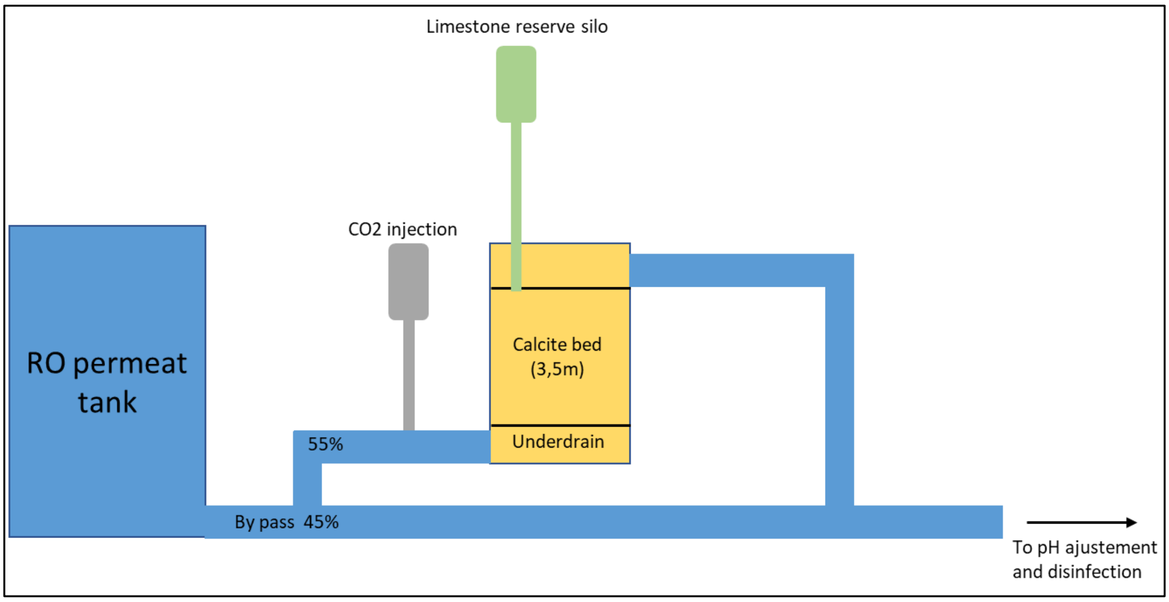


Figure 32: Illustration of Limestone Filter Process

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 48.

Table 48: 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	m^3/h	8080	
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)	U	27	
Total number of modules (half-plant)	U	14	
Module surface loading rate (actual)	$m^3/m^2.h$	9.6	MFS <10 (for turbidity purpose)
Module surface loading rate N-1	$m^3/m^2.h$	10.4	MFS <11 (for turbidity purpose)
Media contact time	min	25	MSF ≥20 min

16. POST TREATMENT: REMINERALISATION	Unit	Value	Comments
CO_2 consumption	g/m3	78	Excess CO_2 - Not Stoichiometric
CO_2 daily consumption	T/day	15.1	
Total hardness in water after remineralization	mg/l CaCO3	80	
Calcium Hardness addition in the product water	mg/l CaCO3	69	
Limestone purity	%	99%	
Calcite daily consumption	T/day	28.2	
Automatic loading storage capacity	Tonnes	844.7	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 CaCO3	69	
CO2 addition in the product water	mg/l	30	
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, 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 in 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 49.

Table 49: 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 50: 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 instand 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, this 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 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 to provide 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 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 which 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, 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 high 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 51.

Table 51: 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 m^3/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 m^3/hr - Progressive cavity pumps
	Belt Filter Press Washing Pumps	4 (3W+1S)	30 m^3/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 m^3/hr –Diaphragm metering pumps
	Dosing Pumps for Dewatering	18 (15W+3S)	0-1.5 m^3/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 33.

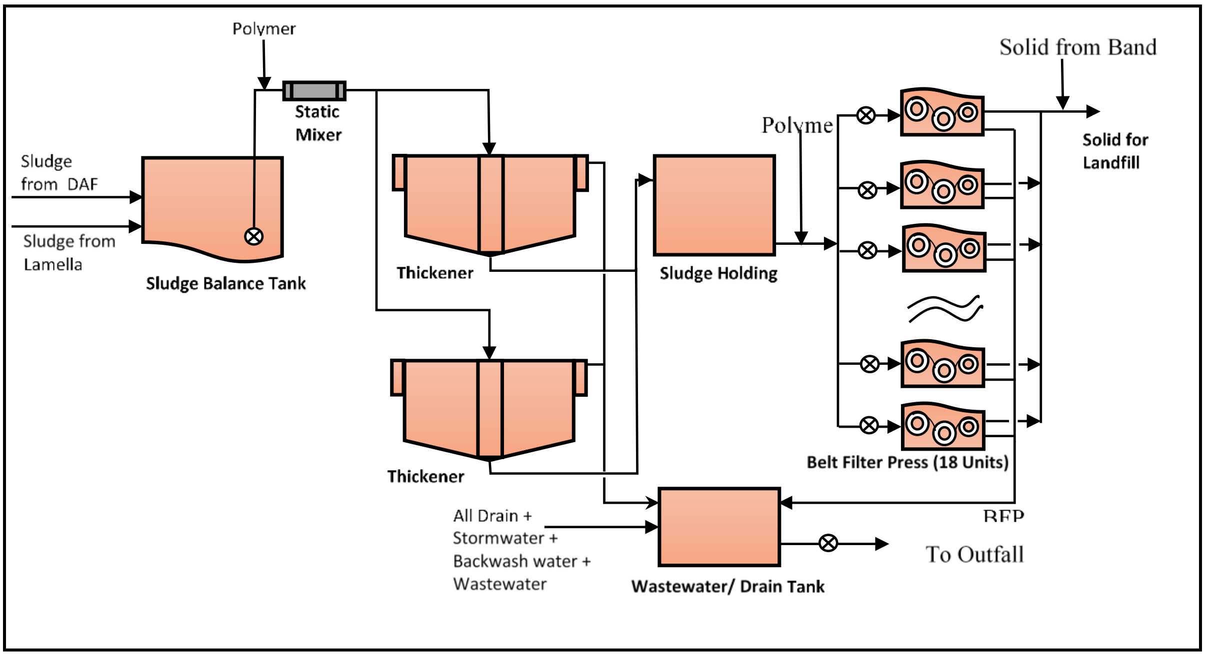


Figure 33: Sludge Treatment Flow Diagram

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 Annexure-2.

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 52 below.

Table 52: Foot Print Area of Facilities at Perur- DSP

Sl.No.	Process/ facility	JICA		PMC		Key Function
		Estimated size (m)	unit	Estimated size (m)	unit	
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 lime stone
	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 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 34. As discussed in Section 5.5.4, the two production streams will 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 which is under review by PIU. It will be worked out again after getting feedback from PIU and further discussion with them.

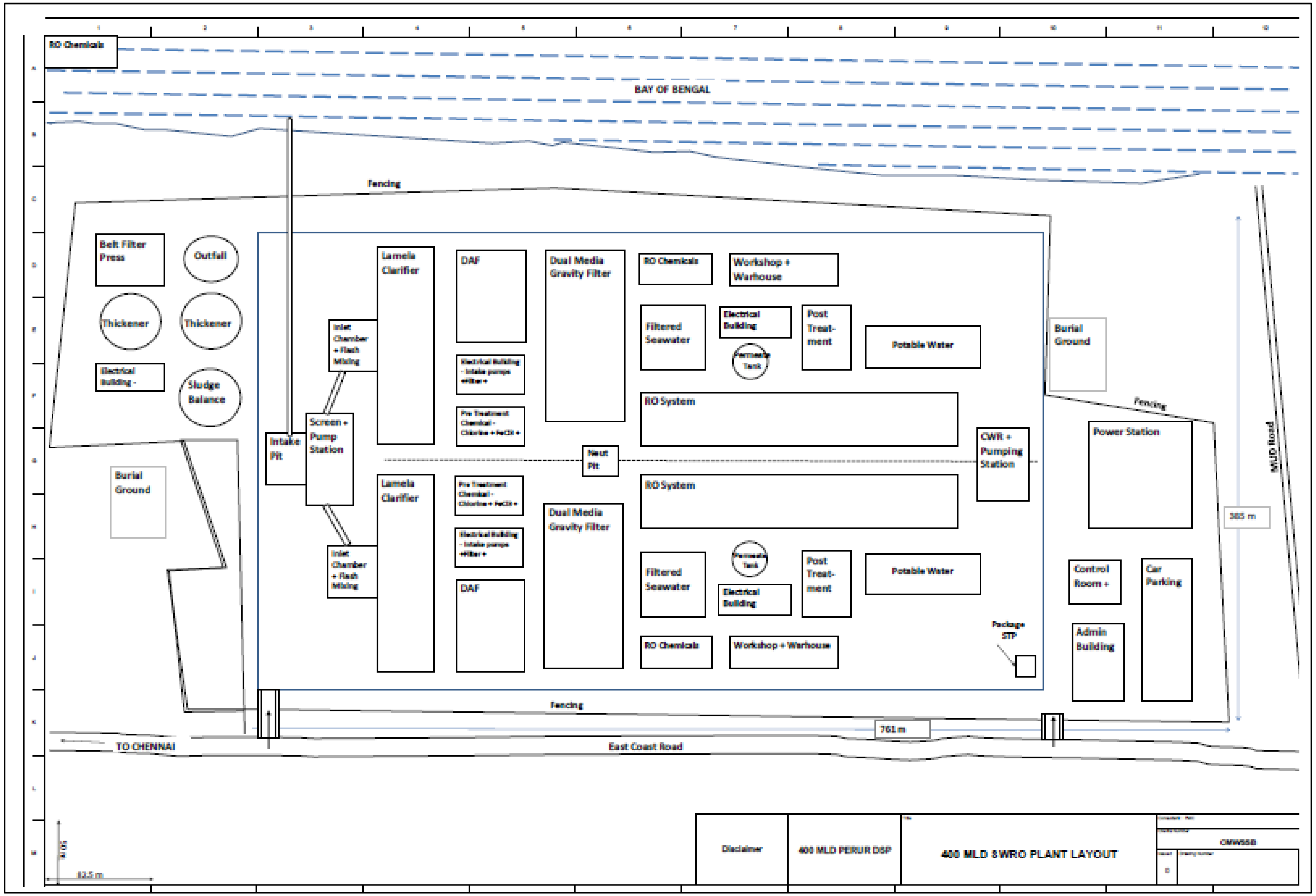


Figure 34: Tentative Plant Layout of Perur DSP

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

7.1 Battery limits

Table 53: Battery limits and CP1 interface

Sl. No.	The function of the terminal point	Description of the terminal point and relevant requirements
1.	Seawater suction Seawater intake suction heads located offshore	Point marked as "Terminal Point 1". X: Y:
2.	Product supply at the designated point (CP2 interface)	Point marked as "Terminal Point 2". X: Y:
3.	Electric supply to Project (CP5 interface)	Point marked as "Terminal Point 3".
4.	Tap water (if mandatory)	From the municipal grid. Point marked as "Terminal Point 4" X: Y:
5.	Electric supply BT (if mandatory)	From Grid
6.	Flood protection system and Area surface drainage	To the sea (beach)
7.	Communications	Connection phone and internet provider
	Any Others	

8 INSTRUMENTATION AND CONTROL WORKS

8.1 Plant Operation Control System

The entire desalination plant shall 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' feed water, 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 the field areas of the plant 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 Levels in terms of Controller, Power Supplies, Communication & Operator Work Station except IO channel Redundancy.
- Uniform operation
- Modern Object Oriented Software Structure
- Communication with external system and intelligent field equipment
- Integrated diagnosis & documentation system
- Communication support

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
- Maintenance Engineer's station
- Historical data & retrieval facility
- Alarm management system & Sequence of event recording
- Interfacing with other control systems and equipment
- External network interfaces shall be through 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 soft link as per OEM standard for Alarm logging in DCS.
- Time Synchronization with package PLC's.

8.2 Redundancy Levels of DCS system

a. **Controller Level** : Required set of Redundant Controllers have been considered as a minimum at Central Control Room
b. **IO Level**: Redundancy is not envisaged for IO level.
c. **Communication Level**:- The communication redundancy for DCS shall be applied as follows,
   i. Controller to IO Modules -Redundant (communication protocol shall be as per OEM standard)
   ii. Controller to Operator/Engineering Stations - Redundant Ethernet
   iii. DCS to third party control system - Redundant OPC/ MODBUS TCP-IP/ RS 485
   iv. Time Synchronization with GPS Master clock - Redundant through NTP
   v. DCS to MOV's - Simplex Profibus/Profinet
   vi. DCS to Intelligent Master Control Centers (I-MCC's) - Redundant Profibus/Profinet

d. Power Supply Level:-

The Redundancy shall be applicable on Power Supply modules which is located at main Controller. Bulk power supply shall be redundant. The system power supply is isolated from field device power/ interrogation supplies.

8.3 Central Control Room (CCR) System

The Central control room of Desalination plant shall be facilitated with below:

i. Operator Work Stations (OWS's):

The Redundant Operator Workstations shall be interfaced with DCS controllers by using Redundant Data Bus and the same will be proposed in Central Control Room of Desalination plant.

ii. Historical Storage and Retrieval system (HSR):

The Redundant Historical Storage stations shall be proposed for storage and retrieval facility will collect and store data and parameters including trends, alarms and events from plant unit DCS data base periodically and automatically to removable data storage devices once every 24 hours.

iii. Engineering Station & Laptop:

The Engineering station-1No and Laptop -1No shall be proposed in Central Control Room for operator's immediate updation on Logic & Graphics without affecting Real time Process monitoring & control.

iv. HART Management System (HMS):

The HART Management system-1No shall be provided for centralized configuration, maintenance, diagnostic and record keeping of electronic smart transmitter data. It is a dedicated standalone PC based HMS system shall be supplied at central control rooms of Desalination plant.

v. Printers :

The Printers shall be proposed in Central Control Room for Printing of Reports, Trends etc..and those are to be interfaced with Hot Redundant LAN so that operators can take prints from multiple stations as and when required with credentials of Administrator.

- One Number of A3- Colour Laser Jet Printer
- A-3 / A-4 Black & White Laser Jet Printer
- All in One Laser Jet Printer

vi. Large Video Screen:

Two numbers of Large Video Screens shall be proposed inside the Central Control Room for operator monitoring of entire plant screen systems.

8.4 Machine Monitoring Systems

i. Vibration Monitoring System (VMS):

The Vibration monitoring system shall have condition monitoring of bearings of all HT motor drives in 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.

ii. Temperature Monitoring System:-

The RTD sensors shall be supplied by respective Motor & Pump manufacturer for HT Drives (wherever applicable) and sensor output is integrated to Temperature Scanner for interfacing with DCS controller.

iii. Handheld Calibrator:

One number of Hand held calibrator is provided for all HART transmitters for validation of calibration setting and diagnostics on entire field instrument transmitters.

8.5 Plant Communication Protocols

The plant communication protocol is envisaged in the Desalination plant as below:

a) I-MCC's to DCS : REDUNDANT PROFIBUS/PROFINET

b) VFD to DCS : REDUNDANT PROFIBUS/PROFINET

c) For LT Drive>90kW & HT drives: : REDUNDANT IEC 61850 SOFT LINK

d) Time Synchronization with GPS Master clock: REDUNDANT

e) Intelligent MOV's to DCS : NON REDUNDANT PROFIBUS/MODBUS

f) Substation Automation system to DCS : REDUNDANT OPC

g) Compressed Air system to DCS :NON REDUNDANT MODBUS RS 485

h) Fire Protection to DCS : NON REDUNDANT MODBUS RS 485

i) Remote Input & Output (RIO) module panels: These Panels shall be applicable for field instruments communication to DCS system on redundant basis.

Note: - The **Intelligent Master Control Centres (I-MCC's)** shall be interfaced with the DCS system by using Redundant Fibre Optic Cables for effective monitoring & control on entire plant drives that leads to minimise the plant downtime and huge cost savings in terms of cables also to improve diagnostic features as well.

1. Other following Systems shall be applicable and those are:

Management Information System, GPS Clock System, Fire Detection & Alarm System, Public Address & Telephone Systems, Closed Circuit Television (CCTV)

The overall Plant control architecture is illustrated in Figure 1.

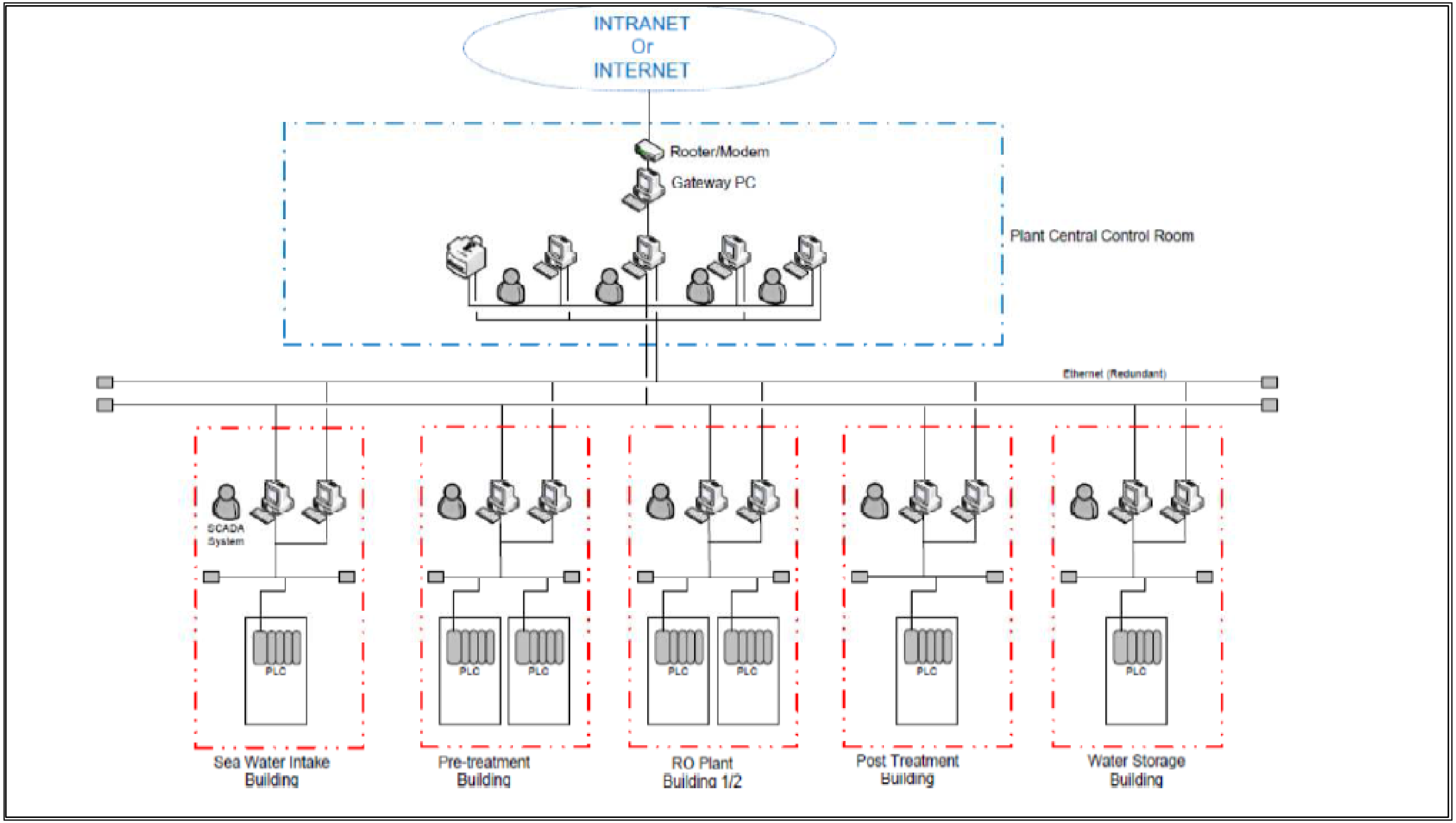


Fig 1. PLANT CONTROL SYSTEM ARCHITECTURE DIAGRAM

8.6 Instrumentation Plan

The following table presents the list of major online sensors for each process units of the Proposed Perur DSP.

Major Online Sensors for Proposed Perur DSP

Sl. No.	Location	Instruments
1.	Seawater pumping station	i. Travelling band screens - Ultrasonic differential level Sensors ii. Intake pump discharge headers – TOC/ DOC analyzer, Turbidity meter, Differential pressure sensor, Ultrasonic Insertion type Flowmeter, Oil Analyser, Residual chlorine
2.	Chemical building - Pretreatment	i. The dosing tanks will be provided with Online Non-Contact Radar Type level sensor and the dosing pumps will be provided Electromagnetic flowmeter at pump discharge headers for the following chemicals - NaOCl (Chlorination), Sulphuric acid, Ferric Chloride, Polyelectrolyte.
3.	Pretreatment – Lamella Clarifier	i. Lamella clarifier Common outlet - Turbidity meter, TOC/ DOC analyser
4.	Pretreatment – Dissolved air floatation	i. Dissolved air floatation Common outlet - Turbidity meter, TOC/ DOC analyser
5.	Pretreatment – Gravity dual media filtration	i. Gravity dual media filtration Common outlet– Turbidity meter, Online chlorine analyzer, TOC/ DOC sensor, Silt density Index analyzer, ORP analyser ii. Differential Pressure sensors at each Gravity dual media filtration unit. iii. Backwash pump discharge header- Electromagnetic meter
6.	Pretreatment – RO feed/ Backwash tank	i. Ultrasonic level sensors
7.	Chemical building for Seawater Reverse Osmosis (SWRO)	i. The dosing tanks will be provided with Online Non Contact Radar Type level sensor and the dosing pumps will be provided with Electromagnetic flowmeters at pump discharge headers for the following chemicals - Sodium hydroxide, Antiscalant and Sodium meta-bi-sulphite, Bioxide (as needed).
8.	RO building	i. RO feed pump discharge header – Online Pressure sensor ii. Micron Cartridge filter – Differential Pressure sensor iii. Micron cartridge filter outlet – Conductivity, ORP, pH, Temperature, Alkalinity, SDI Sensor iv. SWRO High-pressure pump suction – Electromagnetic flow meter, Online Pressure sensor v. SWRO High-pressure pump discharge – Online pressure sensor vi. ERD booster pump discharge – Online Pressure sensor vii. CIP dosing tanks- Online non-contact radar type level sensor viii. CIP dosing pumps discharge header – pH, Online Pressure sensor

Sl. No.	Location	Instruments
		ix. RO flushing pump discharge header – Online Pressure sensor, Electromagnetic flowmeter x. RO permeate line outlet – pH, Conductivity, Boron Electromagnetic flowmeter xi. RO pressure vessels – Online Differential Pressure Sensor in every individual Pressure vessel
9.	RO permeate water storage tank	i. Ultrasonic level sensor ii. Float type 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 outlet – pH, Electromagnetic flowmeter, Residual chlorine ii. Lime filter backwash – Electromagnetic flowmeter iii. Lime filter Backwash air blower- Online Pressure sensor iv. The dosing tanks will be provided with 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.	Potable water storage tank	i. Ultrasonic level sensor in the tank ii. Float type level sensor in the tank iii. Potable water storage tank outlet line – Electromagnetic flow meter, Boron, Conductivity, pH, Turbidity, Residual chlorine, Temperature
13.	Autosamplers	i. Seawater intake area ii. Gravity dual media filter outlet iii. Potable water analysis iv. Seawater/ Brine outfall discharge area
14.	Package sewage treatment Plant	i. Inlet Electromagnetic flowmeter and treated water flowmeter
15.	Wastewater treatment units	i. Lamella clarifier sludge discharge common line – Electromagnetic meter ii. DAF sludge discharge common line – Electromagnetic meter iii. Sludge holding tank -Ultrasonic level sensor iv. Sludge transfer pumps discharge header-Electromagnetic flowmeter, Online Pressure sensor v. The dosing tanks will be provided with 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 vi. Wastewater/ drain tank -Ultrasonic level sensor vii. Wastewater pump discharge line – Electromagnetic flowmeter, Online Pressure sensor viii. Neutralisation pit – Electromagnetic flowmeter, Online Pressure sensor. ix. Outfall tank -Ultrasonic level sensor

Notes:

i) The Instruments which will be supplied along with respective vendor package to fulfill the requirement of entire plant automation.

ii) The Vibration Monitoring System & Temperature Monitoring System shall be applicable for each HT Drive.

iii) The Drives which are operated through Variable Frequency Drive (VFD) is controlled either with Flow Feedback or Step Logic.

iv) The Dry Run Protection is mandatory for each drive.

v) The Overflow Protection is mandatory for each tank.
vi)The following systems shall also be applicable along with the DCS system like Hart Management System, Management Information System, GPS Clock System, Fire Detection & Alarm System, Public Address & Telephone Systems, Closed Circuit Television (CCTV)

8.7 Water Metering

The below table shows the overview of the proposed water metering systems and quality monitoring systems

Media to be metered	Location
Potable Water Online Quality Monitoring System	Located in the water pipelines upstream of the Potable Water Output Meter
Potable Water Output Meter	Located in the water pipeline upstream of the Clearwater reservoir
Potable Water Sample Point	Located in the water pipelines upstream of Clearwater reservoir
Operational flow measurement of seawater input	Intake piping to Stream A and Stream B

8.8 Critical Control Points

The below table shows the Critical control points for the Proposed Perur DSP.

Critical Control Points	Location	Parameter
CCP -1	RO feed line discharge	Turbidity - < 0.2 NTU, ORP- 300 mV, TOC < 2 mg/L, SDI < 3 (95% of time), SDI < 4 (100 % of time)
CCP – 2	SWRO permeate discharge	TDS - < 350 mg/L (derived value from Conductivity), Boron - < 1.0 mg/L
CCP - 3	Potable water storage tank common discharge header	TDS - < 450 mg/L, Residual Chlorine - < 1.0 mg/L, Boron - < 1.0 mg/L, Turbidity - < 1.0 mg/L
CCP - 4	Outfall tank discharge line to sea*	TSS - < 100 mg/L Iron - < 3 mg/L Residual Chlorine < 1 mg/L Temperature – Shall not exceed 5° C above receiving water temperature

Note : * - The values are discharge are based on General discharge standards of CPCB.

Dump lines are provided at the critical control points CCP-1 and CCP - 3, The following dump lines shall be included which shall be automatically operated based on signals from online analysers. The size of the automatic valves, pipes, etc. shall be for full dump of off-specification water. Online analysers, automatic valves shall be provided which shall also send signals to DCS.

Dump line No. 1 - In case of chlorine in feed water to RO (due to high ORP), a dump line shall be provided for transferring the full quantity to the Seawater pumping station Intake pit

The online sensors at CCP -1 Turbidity and ORP are duplicated as turbidity and ORP measurement being critical, in the unlikely event of failure of one turbidity meter/ ORP meter, the other meter will take over. Also in case of any one turbidity/ ORP set point was above the desired set point an alarm is annunciated and if both turbidity meters/ ORP meters desired set points are above the set value the online valves will be automatically opened for dumping.

Dump line No. 2 - In case of any parameter of potable water goes beyond the guaranteed value, a dump line shall be provided for transferring the full quantity of the potable water to the Seawater pumping station Intake pit

Similarly for dumpline No.2- The online sensors and Electromagnetic flowmeter at CCP -3 namely Boron, Conductivity, pH, Turbidity, Residual chlorine, Temperature are not duplicated as the electromagnetic flowmeter and the indicated sensors would also be provided in individual Stream A and Stream B.

Duplication of sensors would be necessary based on criticality of Process requirement.

8.9 Sampling and Monitoring Locations

The Table below indicates major sampling and monitoring locations of water quality for the proposed Perur DSP.

Major Sampling and Monitoring Locations of Water Quality

S.No.	Parameter	Raw seawater	Filtered water	Potable water	Marine Outfall
1	Silt Density Index	✓	✓	--	--
2	pH	✓	✓	✓	✓
3	Total Dissolved Solids	✓	✓	✓	✓
4	Temperature	✓	✓	✓	✓
5	Electrical conductivity	✓	✓	✓	✓
6	Turbidity	✓	✓	✓	✓
7	Residual chlorine	✓	✓	✓	✓
8	Boron content	✓	--	✓	--
9	Langelier Saturation index	--	--	✓	--
10	Oxidation–reduction potential	--	✓	--	--
11	Alkalinity	--	--	✓	--

Online monitoring of all the above parameter through Online Analysers shall be provided and the real time readings are utilised for monitoring and control through SCADA. TDS and Langelier saturation Index are computed values from online analysers.

Auto Samplers are provided at the locations indicated below to collect 24 hourly composite samples and analyzed at Laboratory in Administration building.

i. Seawater intake area
ii. Gravity dual media filter outlet
iii. Potable water analysis
iv. Seawater/ Brine outfall discharge area

9 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.

9.1 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 in Project risk in case of foreign financing) reflects the solidity of the financing entity. Utmost reputed JICA financing 80% of our project brings a comfortable situation for the Contractor, especially in case of directs payments.

Up to a certain amount, the risks are compensated by price adjustments. Beyond this maximum amount, the Contractor may renounce to bid.

9.2 Project risks

The projects risks include:

- The risk allocation between the Employer and the Contractor. For our project, the raw water quality risk will be one of the main ones
- 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).

If the tender attracts less than 6 offers, the competition will be poor, and a high level of the price shall be expected.

9.3 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 all over the world. 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 15-25% 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.**

9.3.1 Presentation and Methodology

At Concept Design stage, after the Engineering Report has confirmed the main options for processes, it becomes the 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, 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 phases of project delivery: 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 the 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 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.

9.3.2 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 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 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 D.
- The calculation of the project cost estimate has been presented in Table 54 below.

The flow rates have been taken from the mass balance flow rate presented in Annexure 2.

Table 54: 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	Local Supply
	a	b	c = 1+(1*(1-h) * (1-i) * (1-j)	d = b*c*k	e =d/400	f = d/10000 *76	g	h	i	j	k
Open offshore intake (1800m)	520	100800	1.47	118742	296.86	902.44	29.3%	30%	10%	25%	20%
Wet well pump station	520	4400	1.54	5760	14.40	43.77	1.4%	40%	10%		15%
Band intake screen	520	5200	1.80	7114	17.78	54.06	1.8%	20%			24%
Lamella filters	520	10000	1.765	13414	33.54	101.95	3.3%	15%	10%		24%
DAF	520	14000	1.77	18780	46.95	142.72	4.6%	15%	10%		24%
GMF	520	29000	1.765	38901	97.25	295.64	9.6%	15%	10%		24%
Cartridge Filters	480	4800	1.90	8664	21.66	65.85	2.1%	0%	10%		5%
RO System	200	68000	1.81	123080	307.70	935.41	30.4%	10%	10%		0%
Limestone beds + CO_2	200	9500	1.77	12743	31.86	96.85	3.1%	15%	10%		24%
Disinfection (sodium hypochlorite)	200	750	1.81	1086	2.72	8.25	0.3%	10%	10%		20%
Full 400 MLD plant outfall (800 m)	630	44800	0.47	16934	42.34	128.70	4.2%	30%	10%	25%	20%
Chemical System Building	400	4000	1.81	5792	14.48	44.02	1.4%	10%	10%		20%
Product water + wastewater + Outfall Tank with pumping	400	11500	1.77	15426	38.57	117.24	3.8%	15%	10%		24%
Administrative, control room and other infrastructure	400	3000	1.81	4344	10.86	33.01	1.1%	10%	10%		20%
Wastewater treatment system	28.5			8084	20.21	61.44	2.0%				
Startup, commissioning and acceptance test	400			5800	14.5	44.08	1.4%				
Total Cost	**400**			**404664**	**1012**	**3075**	**100%**				

1 – The EPC cost estimate is taken from the Voutchkov's graphs provided in Annexure - 7

The capital cost provided above is based on the increased size of the intake and pretreatment systems to entertain the flow rate up to 1040 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 **Million USD** for the 400 MLD plant which is **about 1012 USD/m^3** (INR 76900/m^3) at INR/USD conversion rate of 76 after taking consideration of cost reduction due to several factors including the local supply.

An explanation for 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
    - -25 % for common trench

    - 1 + (1 x (1-0.3)x(1-0.1)x (1-0.25)
    - 1 + (1 x 0.7 x 0.9 x 0.75) = 1.47

- 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 USD1012/m^3 is after the introduction of this local supply factor. Without local supply consideration, the overall construction cost will be about 476.5 **Million USD** for the 400 MLD plant which is **about 1191 USD/m^3** (INR 90500/m^3) at INR/USD conversion rate of 76.
- 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 948 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 388 Million USD for the 400 MLD plant which is about 970 USD/m^3 (INR 73700/m^3) at INR/USD conversion rate of 76.

The CAPEX difference for oversized marine works and pre-treatment for 42% RO recovery against 46% is equal to 405 - 388 = 17 Million USD (equivalent to about INR 126 Cr). 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 below USD 900/m^3 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 consideration of the increased cost, PMC recommends allowing 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 55: 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 3621.4 Cr (USD 476.5 Million)	INR 90516 / m3 (USD 1191 / m3)
Plant cost (42% recovery) with consideration of local supply	INR 3075.5 Cr (USD 404.7 Million)	INR 76900 / m3 (USD 1012 / m3)
Plant cost (46% recovery) with consideration of local supply	INR 2948.8 Cr (USD 388 Million)	INR 73700 / m3 (USD 970 / m3)
Plant cost (44% recovery) with consideration of local supply	INR 3012 Cr (USD 396.5 Million)	INR 75335 / m3 (USD 991 / m3)

9.3.3 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-56.

Table 56: Capital cost for recent Desalination Plants elsewhere

Sl. No.	Projects	Country	Contractor	Contracted in	Plant Capacity	Construction Cost	Cost/ m^3 product	
				(Year)	(MLD)	(MUSD)	USD	INR
1	Rabigh 3 IWP	Saudi Arabia	ACWA Power	2018	600	700	1167	88667
2	Barka 4	Oman	Suez	2016	281	312	1110	84360
3	Umm al Quawain	UAE	ACWA Power	2019	682	800	1173	89150
4	Taweela	Saudi Arabia	Abengoa	2019	909	870	957	72739
5	Shugaig 3 (25 years BOO)	Saudi Arabia	Acciona	2018	450	824	1831	139164

The cost of the product water per m3 for Barka 4, Rabigh 3 and Umm al Quawain is above USD 1100, and for Taweela it is less around USD 950. The cost at Shugaig 3 is high due to combined cost for 25 years of build, own and operate contract. **Average of the Construction cost for the first 4 plants is 671 M USD for average 618MLD water production and the product water cost per m3 is USD 1102/m^3.** Taking consideration of cost reduction of 15% due to local supply, the average construction cost goes to 570 MUSD for 618 MLD plant with a unit cost up to USD 937/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 (by pass of second RO pass for existing plants); however, last plant (Barka 4) is an exception with partial RO second pass where Suez was able to make 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.

The cost of partial 50% RO pass 2 is estimated at: 1325-1275 = 50 USD/m3 capacity (200 MLD); with size adjustment (10%), partial second pass for 400 MLD plant is estimated at 18 MUSD (45USD/m3 capacity)

9.3.4 Capital Cost Conclusion

The comparison of cost using 3 methods is given below in Table 57.

Table 57: Capital cost comparison with recent desalination plants elsewhere

Methods Used	Cost Description	Construction Cost, MUSD	Unit Cost, USD/m^3
Voutchkov Graphs	The overall cost of the plant	477	1191
	Cost with factor for local supply	405	1012
Review	The overall cost of the plants elsewhere	671	1102
	Cost with factor for local supply	570	937

Considering the high cost of marine works and 3 levels of pretreatment process units for 400 MLD Perur plant, the product cost of USD 1012/m^3 looks reasonable and comparable to other plants. In case, additional expenses due to reduced RO recovery (42%) is not taken into consideration, the product cost will come down to USD 970 / m^3, and if the length of the intake and outfall positions from the shore is reduced after the proposed dispersion analysis, the cost of the plant per m^3 will further reduce below USD 900/ 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 on the statistic approach, based on a wide number of projects.

The construction cost of USD 405 Million and the unit cost of USD 1012/m^3 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 were revised recently in 2019 (new edition).

9.3.5 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 3075 crores respectively. The cost estimated by DPR and JICA was in the early of 2017, while PMC estimate is in 2020. The major difference in estimate of PMC is for the cost of Intake system and RO system.

Table 58: Comparison of Project Capital Cost for Construction of SWRO Desalination 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**	**1129**
(1)-1	Seawater intake			902.4
(1)-2	Band Screen	0	0	54.1
(1)-3	Pumping System	included	included	43.8
(1)-4	Brine discharge pipeline facility	included	included	128.7
(2)	**Pre-treatment process**	**627**	**575.62**	**540.2**
(2)-1	Lamella	216.9	0	101.9
(2)-2	DAF	248.2	0	142.7
(2)-3	DMF	162	0	295.6
(3)	**RO Process**	**636.3**	**687**	**1001.2**
(3)-1	RO Feed tank	9	0	included
(3)-2	RO Building and equipment	627.3	0	included
(4)	**Post Treatment**	**134.3**	**73.23**	**96.8**
(4)-1	Mineralisation	121.8	included	included
(4)-2	CO_2	12.5	included	included
(5)	**Dosing System**	**42.6**	**0**	**52.3**
(6)	**Tanks**	**65.2**	**42.76**	**117.2**
(6)-1	Product Water Tank	55.2	included	included
(6)-2	Dirty Water Tank	10	included	included
(6)-3	Outfall Tank	0	0	included
(6)-4	Permeate Tank	0	0	included
(6)-5	Filtered Water Tank	0	0	included
(6)-6	All Transfer Pumps	0	0	included
(7)	**Buildings**	**11.6**	**7.702**	**33**
(7)-1	Administrative Building	3.6	0	Included
(7)-2	Other Buildings	8	0	Included
(8)	**Waste Water Treatment System**	**0**	**0**	**61.4**
(9)	Control System	**182.4**	143.16	Included
(9)-1	Power distribution	144.3	143.16	Included
(9)-2	DCS	38.1	0	Included
(10)	**Electrical Sub-station**	**57.8**	**0**	Included
(11)	**Site Development**	**34.4**	**21.29**	Included
(12)	**Erection and Testing**	**128**	**121.24**	Included
(13)	**Shipping and Transportation**	**25.6**	**0**	Included
(14)	**Startup, commissioning and acceptance test**			**44.1**
(15)	**Overhead, Profit**	**348.3**	**424.92**	Included
	Total Cost for CP1	**2670.3**	**2362.02**	**3075.2**

9.4 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 by 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 59 to 65.

9.4.1 Manpower

Staffing the plant is based on 133 including helpers, security and divers, according to the following breakout.

Table 59: 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 incharges (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%
													0	0.000	0.0%
													0	0.000	0.0%
	Total							133		**Grand Total**	**Monthly Salary**	**4,171,000**	**50,052,000**	**0.350**	**100%**

9.4.2 Energy

The energy cost is based on a rate of 7.5 INR/KWh. Plant availability of 98% applies. Discharge head for RO equipment is computed for average seawater quality.

Table 60: Energy Cost Calculation

INR / kWh 7.5 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 Consumped 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	9895.8	-	4	2	6	89%	93%	97%	96.3	24	2312.3	0.006	17342	6329819	0.044	0.2%
Intake Feed Pumps	9895.8	20	4	2	6	88%	93%	97%	2717.3	24	65215.4	0.166	489116	178527165	1.248	5.5%
FlashMixer	9895.8	-	4	2	6	80%	93%	97%	86.6	24	2078.4	0.005	15588	5689725	0.040	0.2%
Flocculators			20	0	20	80%	93%	97%	144.3	24	3464.1	0.009	25980	9482875	0.066	0.3%
Backwash Pump - GMF	2880	15	6	3	9	88%	93%	97%	889.7	5.6	4942.6	0.013	37070	13530480	0.095	0.4%
HP Booster pump	1029	30	16	16	32	80%	93%	97%	1865.2	24	44765.8	0.114	335744	122546439	0.856	3.8%
RO High Pressure Pumps *	1029	531	16	16	32	88%	93%	97%	30013.4	24	720322.8	1.838	5402421	1971883609	13.782	60.5%
Booster Feed ERD	1258	25	16	16	32	85%	93%	97%	1788.0	24	42912.8	0.109	321846	117473711	0.821	3.6%
ERD Recirculation	1258	35	16	16	32	88%	93%	97%	2417.9	24	58029.8	0.148	435223	158856495	1.110	4.9%
Backwash Pumps - Limestone Filter	3000	15	2	2	4	88%	93%	97%	308.9	0.2	61.8	0.000	463	169131	0.001	0.0%
PLC/Control system			1	1	2	75%	93%	97%	3.4	24	81.2	0.000	609	222255	0.002	0.0%
Dosing System			12	12	24	95%	97%	97%	32.2	24	772.3	0.002	5792	2114146	0.015	0.1%
CIP and Flushing Pumps	2160	50	1	1	2	86%	93%	97%	379.3	0.20	75.9	0.000	569	207677	0.001	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	3897	1422431	0.010	0.0%
Sludge Transfer Pump to Thickener	1181.7	20	2	1	3	86%	93%	97%	166.0	24	3984.4	0.010	29883	10907360	0.076	0.3%
BFP Feed Pumps	106.25	20	2	1	3	86%	93%	97%	14.9	16	238.8	0.001	1791	653798	0.005	0.0%
Wastewater Transfer Pump to Outfall Tank	5641.2	20	4	2	6	86%	93%	97%	1585.1	24	38041.3	0.097	285310	104138125	0.728	3.2%
Neutralization Pumps to Outfall	2160	20	1	1	2	86%	93%	97%	151.7	0.20	30.3	0.000	228	83071	0.001	0.0%
Addl. power for low recovery	10%						-				94495.92	0.241	708719	258682585	1.808	7.9%
Addl. Power consumption at the plant	10%										108234.55	0.276	811759	296292090	2.071	9.1%
Total											**1190580.1**	**3.04**	**8929351**	**3259212988**	**22.8**	**100.0%**

9.4.3 Chemicals

The chemical unit costs are based on Nemmeli and Minjur plant invoicing. Plant availability of 98% applies. Chemical dosings are computed for average seawater quality.

Table 61: Chemical Cost Calculation

Yearly output	**143,080**	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)	%
					12										
Intake															
Shock chlorination NaOCl 12° (4h/week)	g Cl_2/m^3	2 %	948.17	2.36	13.5	13.5	0.76	10%	7.58	1.18	1,084.0	10,000	10,839,944	0.076	1.35%
Chlorination at Intake	g Cl_2/m4	98 %	948.17	2.36	3.0	3.0	6.93	10%	69.30	1.18	9,914.9	10,000	99,149,358	0.693	12.31%
Pretreatment						-					-		-		
Lamella filters operation						-					-		-		
pH adjust acid H2SO4	g /m3	100 %	951.70	2.37	11.7	11.7	27.60	98%	28.16	1.83	4,029.7	15,593	62,835,594	0.439	7.80%
Coagulant Ferric chloride DAF	g FeCl3100%/m3	100 %	951.70	2.37	10.8	10.8	25.63	40%	64.07	1.42	9,167.6	6,816	62,486,619	0.437	7.76%
Polymere floculation	g polymer/m3	100 %	951.70	2.37	0.3	0.3	0.77	100%	0.77	1.00	110.0	194,000	21,342,261	0.149	2.65%
DAF operation						-					-		-		
pH adjust acid H2SO4	g /m3	100 %	932.67	2.32	0.0	-	-	98%	-	1.83	-	15,593	-	0.000	0.00%
Coagulant Ferric chloride DAF	g FeCl3100%/m3	100 %	932.67	2.32	3.3	3.3	7.54	40%	18.84	1.42	2,695.3	6,816	18,371,066	0.128	2.28%
Polymere floculation	g polymer/m3	100 %	932.67	2.32	0.2	0.2	0.37	100%	0.37	1.00	52.5	194,000	10,189,561	0.071	1.27%
RO						-					-		-		
SBM	g $NaHSO_3/m^3$	100 %	878.26	2.18	2.8	2.8	6.00	98%	6.13	1.00	876.6	48,000	42,075,240	0.294	5.23%
Antiscalent	g/m³	100 %	878.26	2.18	1.3	1.3	2.84	95%	2.99	1.00	427.5	160,000	68,394,074	0.478	8.49%
pH adjust soda (boron removal)	g $NaOH/m^3$	100 %	878.26	2.18	5.8	5.8	12.74	48%	26.53	1.35	3,796.2	45,000	170,831,051	1.194	21.22%
Post-treatment						-					-		-		
Calcite for limestone beds	g $CaCO3/m^3$	100 %	402.00	1.00	65.0	65.0	64.96	99%	65.61		9,387.7	5,250	49,285,450	0.344	6.12%
CO2 liquide	g CO2/m3	100 %	402.00	1.00	35.0	35.0	34.98	99%	35.33		5,054.9	12,250	61,922,745	0.433	7.69%
pH adjust soda	g $NaOH/m^3$	100 %	402.00	1.00	3.0	3.0	3.00	48%	6.25	1.35	893.6	45,000	40,213,678	0.281	4.99%
Desinfection NaOCl 12°	g $Cl2/m^3$	100 %	402.00	1.00	1.0	1.0	1.00	10%	9.99	1.18	1,429.8	10,000	14,298,197	0.100	1.78%
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	115.7	194,000	22,437,461	0.157	2.79%

Yearly output **143,080** 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)	%
Polymere sludge	g polymer/m4	100 %	2.55	0.01	121.0	121.0	0.77	100%	0.77	1.00	109.9	194,000	21,315,588	0.149	2.65%
						-							-	-	
Chemical cleaning (4 times /Y)					kg/m³	kg/m³							-	-	
Na-EDTA (0.1%)							-				56.4	87,000	4,906,800	0.034	0.61%
Caustic Soda (1%)											11.7	45,000	526,500	0.004	0.07%
The citric acid (2%)							-				225.7	72,000	16,250,400	0.114	2.02%
HCl acid (0.05%)											8.8	15,953	140,386	0.001	0.02%
neutralisation acid- HCl						-	-				33.0	15,953	526,289	0.004	0.07%
neutralisation basic - NaOH											153.2	45,000	6,894,000	0.048	0.86%
												Total	**805,232,263**	**5.628**	**100 %**

9.4.4 Maintenance/Renewal

The EPC contact value is estimated at INR 3200 Cr; The percentage of EPC contract related to the various items and equipment to be maintained/periodically renewed are derived from Capex breakdown of several previous projects. The maintenance rates are assessed as per PMC operating experience.

Table 62: Maintenance/Renewal Cost Calculation

Total Asset Value 3200 Cr
Year Product water 143080 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%	354.2	0.15%	5,313,600	0.037	1.24%
2	Marine works	25.79%	825.3	0.10%	8,252,800	0.058	1.93%
3	Mech Works	27.74%	887.7	1.50%	133,152,000	0.931	31.09%
4	Elec Works	10.97%	351.0	1.50%	52,656,000	0.368	12.29%
5	Inst & Control	2.31%	73.9	2%	14,784,000	0.103	3.45%
	Others	22.12%	707.8	2%	141,568,000	0.989	39.80%
6			0.0		**355,726,400**	**2.49**	**100%**

9.4.5 Membrane Replacement

Table 63: Membrane Replacement Cost Calculation

	Year Product water		143080	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 / m³ product water (INR)**	**%**
1	RO Feed Cartridges	Units	6904.566585	350	Every 3 Months	27618.3	9666393.218	0.068	5.74%
2	RO CIP Cartridges	Units	203.7735849	350	Every 3 Months/train	13856.6	4849811.321	0.034	2.88%
3	1st Pass RO Membranes (400 USD x 1.1 for custom x 75 INR/USD): 440 ft² membranes	Units	32640	33000	Over 7 years	4,663	153879000	1.075	91.38%
4						**46,138**	**168,395,205**	**1.18**	**100%**

9.4.6 Other Essential Cost

Other essential costs include all administrative costs indicated in Table 64 below.

Table 64: Other Essential Cost Calculation

	Year Product water	143080	ML/year			Yearly Increment	6%	
Sl. No.	**Expense Head**	**Expense Type**	**Qty/Unit**	**Unit rate**	**Total**	**Total Expenses/year (INR)**	**Manpower Cost / m³ product water (INR)**	**%**
1	Vehicle Rent	Monthly	3	40,000	120,000	1,440,000	0.010	1.47%
2	Guest House, Cook, others	Monthly	1	100,000	100,000	1,200,000	0.008	1.23%
3	Uniform + PPE	Annually	1	250,000	250,000	250,000	0.002	0.26%
4	Staff welfare	Annually	1	100,000	100,000	100,000	0.001	0.10%
5	Office Stationery	Monthly	1	25,000	25,000	300,000	0.002	0.31%
6	Travelling Expenses	Monthly	1	25,000	25,000	300,000	0.002	0.31%
7	HAZOP Check	Annually	1	250,000	250,000	250,000	0.002	0.26%
8	Consent fee charges	Annually	1	25,000	25,000	25,000	0.000	0.03%
9	Telephone expenses	Monthly	1	10,000	10,000	120,000	0.001	0.12%
10	3rd party liability insurance	Annually	1	50,000	50,000	50,000	0.000	0.05%
11	**Plant Insurance** cost (Fire, Breakdown, Workmen Compensation)	Annually	1	75,000,000	75,000,000	75,000,000	0.524	76.74%
12	BG Charges	Annually	1	4,380,000	4,380,000	4,380,000	0.031	4.48%
13	Lifting tools / Forklift Renting charges	Annually	1	250,000	250,000	250,000	0.002	0.26%
14	Tank cleaning	Annually	1	250,000	250,000	250,000	0.002	0.26%
15	Cost of Certification/Calibration	Annually	1	500,000	500,000	500,000	0.003	0.51%
16	Waste cloth	Monthly	1	10,000	10,000	120,000	0.001	0.12%
17	External analysis	Monthly	1	100,000	100,000	1,200,000	0.008	1.23%
18	Disposal of Cartridges, Membranes, Sludge:	Monthly	1	1,000,000	1,000,000	12,000,000	0.084	12.28%
	Total					**97,735,000**	**0.68**	**100%**

9.4.7 OPEX Summary

In addition to the 5 main opex cost items, administrative costs have been included in the Other Essential Costs.

Table 65: 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	3,259,212,988	43,456,173	22.78	0.30	90,203,561,721	1,202,714,156	3% cost escalation per year
2	Power Cost	805,232,263	10,736,430	5.63	0.08	22,285,999,220	297,146,656	3% cost escalation per year
3	Manpower Cost	50,052,000	667,360	0.35	0.00	1,737,767,991	23,170,240	5% cost escalation per year
4	Membrane Replacement	168,395,205	2,245,269	1.18	0.02	4,173,391,768	55,645,224	2% cost escalation per year
5	Asset Replacement	355,726,400	4,743,019	2.49	0.03	8,816,080,206	117,547,736	2% cost escalation per year
6	Other Essential Cost	97,735,000	1,303,133	0.68	0.01	3,810,954,142	50,812,722	6% cost escalation per year
7	**Total O&M Cost**	**4,736,353,855**	**63,151,385**	**33.10**	**0.44**	**131,027,755,049**	**1,747,036,734**	
8	Total O&M Cost	473.6 Cr	63.2 M			13102.8 Cr	1747 M	
9	Average O&M Cost per day	1.3 Cr	0.17 M			1.79 Cr	0.24 M	

A conservative cost of 63 MUSD per year with USD 0.44/m^3 product water cost is the best operation and maintenance cost evaluation undertaken for 400 MLD Perur Desalination plant. Total OPEX given in DPR is about 30% higher due to high energy (+28% - train configuration) and high chemical (+295% - overdosing) usage.

10 MAIN DIFFERENCES BETWEEN PMC, JICA AND DPR DESIGN.

Table 66 below presents below a comparative summary of the plant process design by DPR, JICA and PMC.

Table 66: 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 ≤ 0.5 ppm (1ppm tolerance limit)* ○ *LSI: slightly positive*	• *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 0.10m/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 1800 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 2400 mm. SDR26* • *Total length: 900 m, 12 meters (seabed depth).* • *Brine diffuser: 30 units diam 350mm spaced 6 m.*	• *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	• *Stop logs (3 Chambers)/ 4 sets Band screens* • *Shock dosing pump* • ***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 + 2SB units of wet well vertical turbine pumps for total flow 43333 m³/h* ***Recommended flow:* 39500 m³/h *(948 MLD)*** • *Discharge pressure: 18 m* • *Presence of VFD* • *Pumping station depth: 7.90m*	• *4+2SB sets of vertical turbine pumps.* • *Total flow: 45,000 m³/h* • *Discharge pressure: 25 m* • *Presence of VFD*	• *6 + 2SB pumps.* • *Total flow: 42,252 m³/h* • *Discharge pressure: 23m* • *Presence of VFD*
Pretreatment	• *Composed by chemical and physical processes.* • *Main stages:* ○ *Coagulation/flocculation* ○ *Clarification* ○ *Optionally dissolved air flotation* ○ *Three 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*	• *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: 15 minutes*	• *Retention time: 10 min*	• *Retention time: 10 minutes*
Clarification stage	• *Lamella surface loading rate:* ***1.0 m³/m².h.*** • *Settler tank surface loading rate:* ***18.7 m³/m².h****.*		• *Lamella surface loading rate:* ***1.3 m³/m².h.*** • *Settler tank surface loading rate:* ***21.9 m³/m².h****.*
Dissolved air flotation	• *Retention time: 15.2 minutes* • *Surface loading rate with recycling: 25 m³/m².h* • *15% recycling*	• *Surface loading rate: 15 m³/m².h 12% recycling*	• *Surface loading rate: 15 m³/m².h* • *10 to 15% recycling*
Gravity dual media filters	• *Surface loading rate: < 7.5 m³/m².h* • *Top layer (Anthracite): 1.2 m* • *Bottom layer (Silica sand): 1.5 m*	• *Surface loading rate: 8 m³/m².h* • *Top layer: Anthracite* • *Bottom layer: Silica sand*	• *Surface loading rate of 8 m³/m².h* • *Top layer (Sand): 0.8 m* • *Bottom layer (Anthracite): 1.3 m*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
Cartridge filters	• *Filtration size: 5 µm.* • *Construction material GRP* • *cartridges: melt blown polypropylene*	• *Filtration size: 5 µm.*	• *Filtration size: 5 µm.*
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 (Max.10 ppm)* • *Sodium hydroxide (pH control, 10 ppm)* • *Antiscalant dosage for SWRO (max 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 tanks with interconnection proposed for both production streams with 2 compartments:* • *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 is composed of 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 units 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* • *No 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*

PROCESS STAGE	PMC SPECIFICATIONS (2 x 200 MLD)	JICA SPECIFICATIONS (2 x 200 MLD)	DPR SPECIFICATIONS
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)* • *Each array includes 5 DWEERS units of pressure exchange type (If DWEERS selected)*
Booster pumps for energy recovery systems	• *6+2SB units of centrifugal mono-stage horizontal type* • *Q: 19,727 m3/h* • *H: 2.5 bars* • ***No 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* • *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* • *Tank volume: 5,000m³ per stream*	•	• *2 tanks* • *Unitary volume: 4,250 m3*
Post-treatment	• *Composed by remineralization with CO_2 and limestone beds (only 48% permeate 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 m³/m².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 m³/m².h*	•
Product water tanks	• *2 RCC tanks (2 compartments/line + bypass)* • *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* • *1 Sampling tap in between* • *1 drainage system in between*	•	•
Cleaning (CIP) and flushing system	• *Preparation Tank: 60 m3* • *CIP pumps flow:1152 m3/h* • *Flushing pumps flow: 1024 m3/h*	• *Preparation tank: 800m3* • *CIP pumps: 6,250 m3/h* • *Flushing pump flow: 2,124 m3/h*	• *Preparation tank: 600m3* • *CIP pumps: 2,160 m3/h* • *Flushing pump flow: 2,124 m3/h*
Wastewater treatment	• *physicochemical treatment. 1 sludge balance tank, 2 thickeners, 1 sludge holding tank and BFP building with up to 18 BFP pumps considering raw water TDS up to 300 mg/L.*	•	•
Specific requirements	• *Pretreatment pilot plant* • *RO cleaning pilot plant*	•	•

11 QUESTIONS AND DISCUSSIONS WITH CMWSSB

11.1 Product water specifications

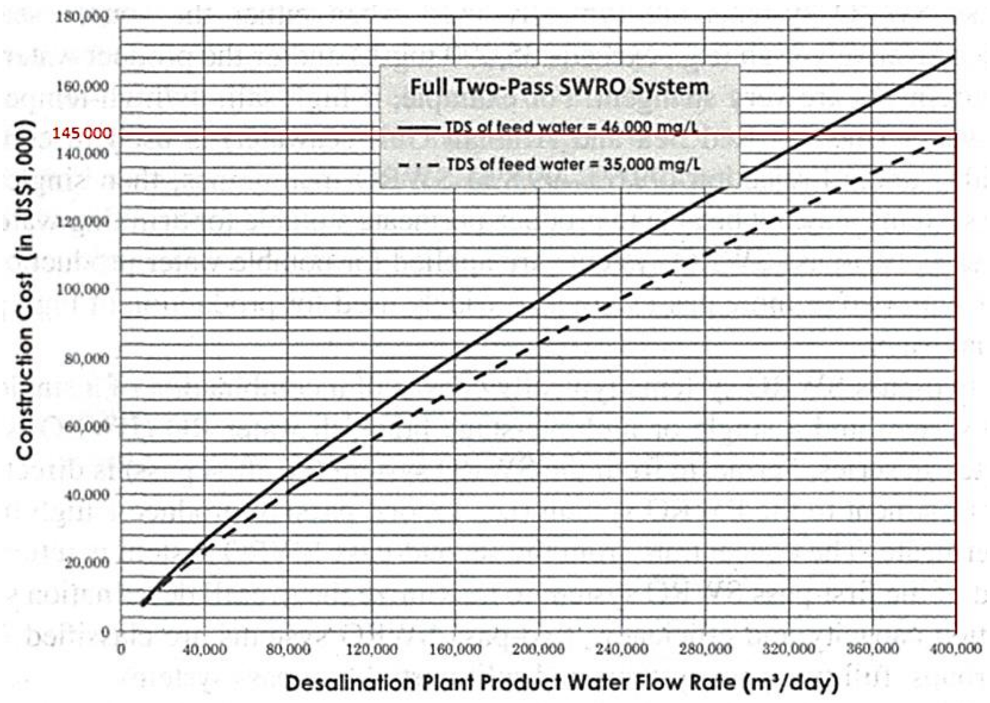
The above-described plant design is optimised for the design parameters and very sensitive to variations of product water requirement.

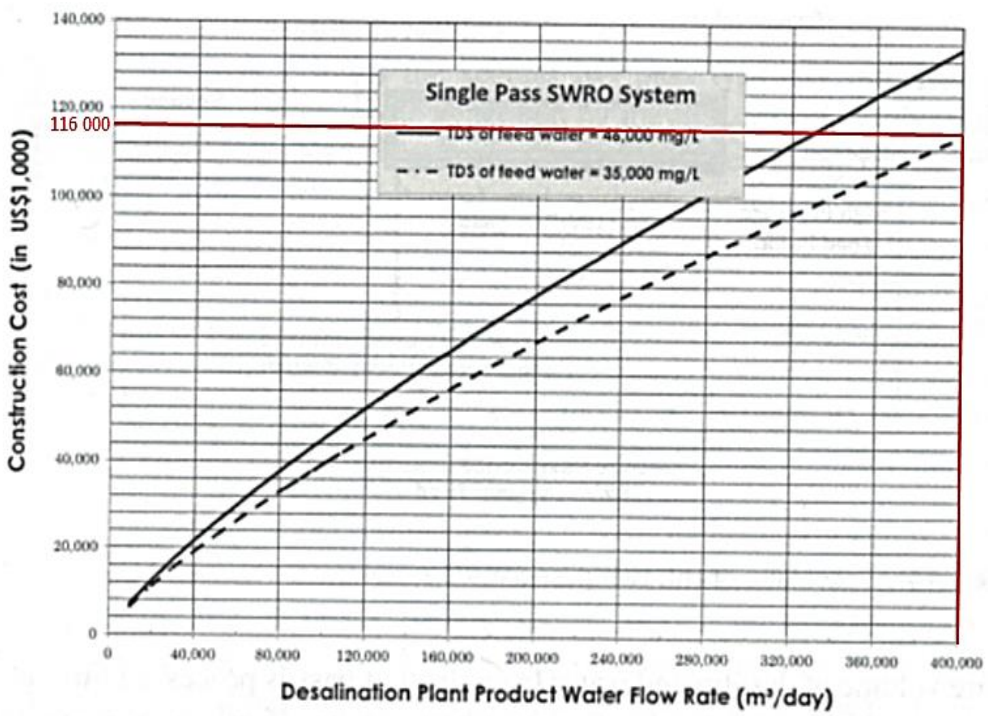
11.1.1 Boron level

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 a figure of 29 MUSD (145 MUSD -116 MUSD) which is equivalent to INR 220 Cr.





11.1.2 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.

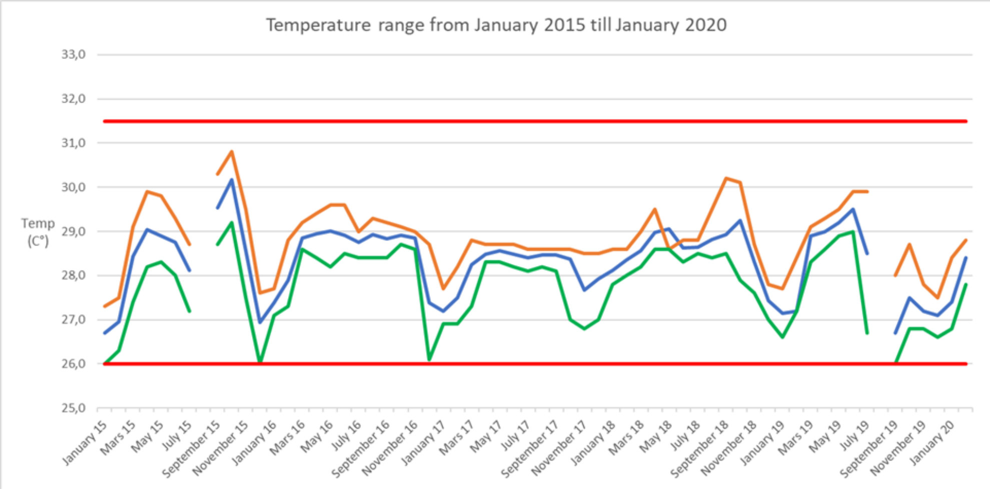
It is to be noted that:

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 for 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 the 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 is maintaining 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. Below is the recorded temperature at Nemmeli during the 5 past years.



2. To lower the remineralisation target down to 60 ppm as CaCO3 (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.

11.1.3 Raw water TDS increase

Increasing the range of some parameters of raw seawater 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 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.

11.1.4 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 CaCO3 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 (80 ppm eq CaCO3) and is expecting confirmation of CMWSSB's required level.

12 MINIMUM FUNCTIONING SPECIFICATIONS (MFS)

12.1 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 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 in 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.

12.2 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 of the bidder experience in optimising desalination plants.

Therefore, the MFS shall focus more on the expected performances of the plant than at the means to achieve them.

13 WAY FORWARD

12.1 Conceptual Design Report for CP1

On completion of this report for development of conceptual design report, the PMC team will focus on surveys and field investigations and validate the data collected so far, as a part of Conceptual Design Report preparation.

The Final Conceptual Design Report mainly focus on the following aspects:

- Fixing the TBMs and carrying out the Topographical Surveys
- Conducting Sea Water Quality Sample Analysis through a reputed laboratory
- Conducting Geotechnical Investigation, wherever required
- Preparing the block cost estimates for various proposed process units and options including Financial Analysis
- Preparing the Environmental initial screening report, Social Resettlement Action Plan and Environmental Assessment Report
- Preparing the Operation & Maintenance Plan and Operation & Maintenance Costs.

The PMC team will focus on the Final Concept Design Report for CP1 components and complete the task by the end of July 2020, if the COVID-19 situation allows carrying the field activities.

14 ANNEXURES

The following annexures are included with this Report:

14.1 Annexure 1: Indian Drinking Water Quality Standards

14.2 Annexure 2: Process Flow Diagram

14.3 Annexure 3: Detailed mass balance sheet

14.4 Annexure 4: RO design projections

14.5 Annexure 4: Sludge treatment system

14.6 Annexure 5: Deleted

14.7 Annexure 6: Detailed design of wastewater treatment

14.8 Annexure 7: N. Voutchkov's Graphs for capital cost estimation

Annexure 1: Site Visit Reports

The PMC team conducted the joint site visits with CMWSSB officials to the existing Sea Water Desalination Plants to gain additional technical information and gain current operational perspectives on the delivery and operation of major seawater desalination plant installations in Chennai:

- Minjur 100 MLD Seawater Desalination Plant (27 January 2020)
- Nemmeli 100 MLD Seawater Desalination Plant (1 and 19 February 2020)

Brief reports summarising the findings of the site visits are attached and form part of the Inception Report (submitted on 28.02.2020) – refer Annexures 2.1 and 2.2.

During the visits to the existing Nemmeli DSP, the proposed site for the Perur 400 MLD DSP was also inspected to gain familiarity with local site constraints. A photographic record of site features was assembled to complement our understanding of the site characteristics based on the review of technical/design reference reports. The visits to the Perur DSP site were however restricted to viewing from the site boundary due to current land access constraints. The site reconnaissance will be supplemented by topographic and feature surveys and geotechnical investigations as part of the Consulting Services to gain a detailed understanding of site conditions for design purposes at the Perur DSP site and key interface (tie in) points to identify integration requirements for these new water transmission and storage assets.

The PMC acknowledges and appreciates the support and guidance of the CMWSSB Project Implementation Unit (PIU) and the opportunity to meet with key stakeholders within the CMWSSB to discuss the project and its requirements during the next stage of the Project.

Annexure 2: Drinking Water Quality

The treated water quality from the proposed Desalination plant shall meet the standards as 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 desalination plant is furnished in below Tables.

Drinking water standards for Desalination Plant

Sl. No.	Characteristics	Unit	Treated water requirements
1.	Turbidity	NTU	$\leq$1
2.	Colour	Platinum cobalt scale	$\leq$5
3.	Taste and odour		Unobjectionable
4.	pH		7.0 to 8.5
5.	Total Dissolved Solids	mg/l	$\leq$500
6.	Total hardness ($CaCO_3$)	mg/l	$\leq$200
7.	Chloride (Cl)	mg/l	$\leq$200
8.	Sulphates (SO_4)	mg/l	$\leq$200
9.	Sulphide	mg/l	$\leq$0.05
10.	Fluorides (F)	mg/l	$\leq$1
11.	Nitrate (NO_3)	mg/l	$\leq$45
12.	Ammonia (NH_3)	mg/l	$\leq$0.5
13.	Calcium (Ca)	mg/l	$\leq$75
14.	Magnesium (Mg)	mg/l	$\leq$ 30
15.	Iron (Fe)	mg/l	$\leq$0.1
16.	Manganese (Mn)	mg/l	$\leq$0.05
17.	Copper (Cu)	mg/l	$\leq$0.05
18.	Aluminium (Al)	mg/l	$\leq$0.03
19.	Alkalinity	mg/l	$\leq$200
20.	Residual Chlorine	mg/l	0.2 (Minimum)
21.	Zinc (Zn)	mg/l	$\leq$5
22.	Boron (B)	mg/l	$\leq$1.0
23.	Phenolic Compounds (Phenol)	mg/l	$\leq$0.001
24.	Anionic detergents (MBAS)	mg/l	$\leq$0.2
25.	Mineral Oil	mg/l	$\leq$0.01
26.	Arsenic (As)	mg/l	$\leq$0.01
27.	Cadmium (Cd)	mg/l	$\leq$0.003
28.	Chromium (hexavalent Cr)	mg/l	$\leq$0.05

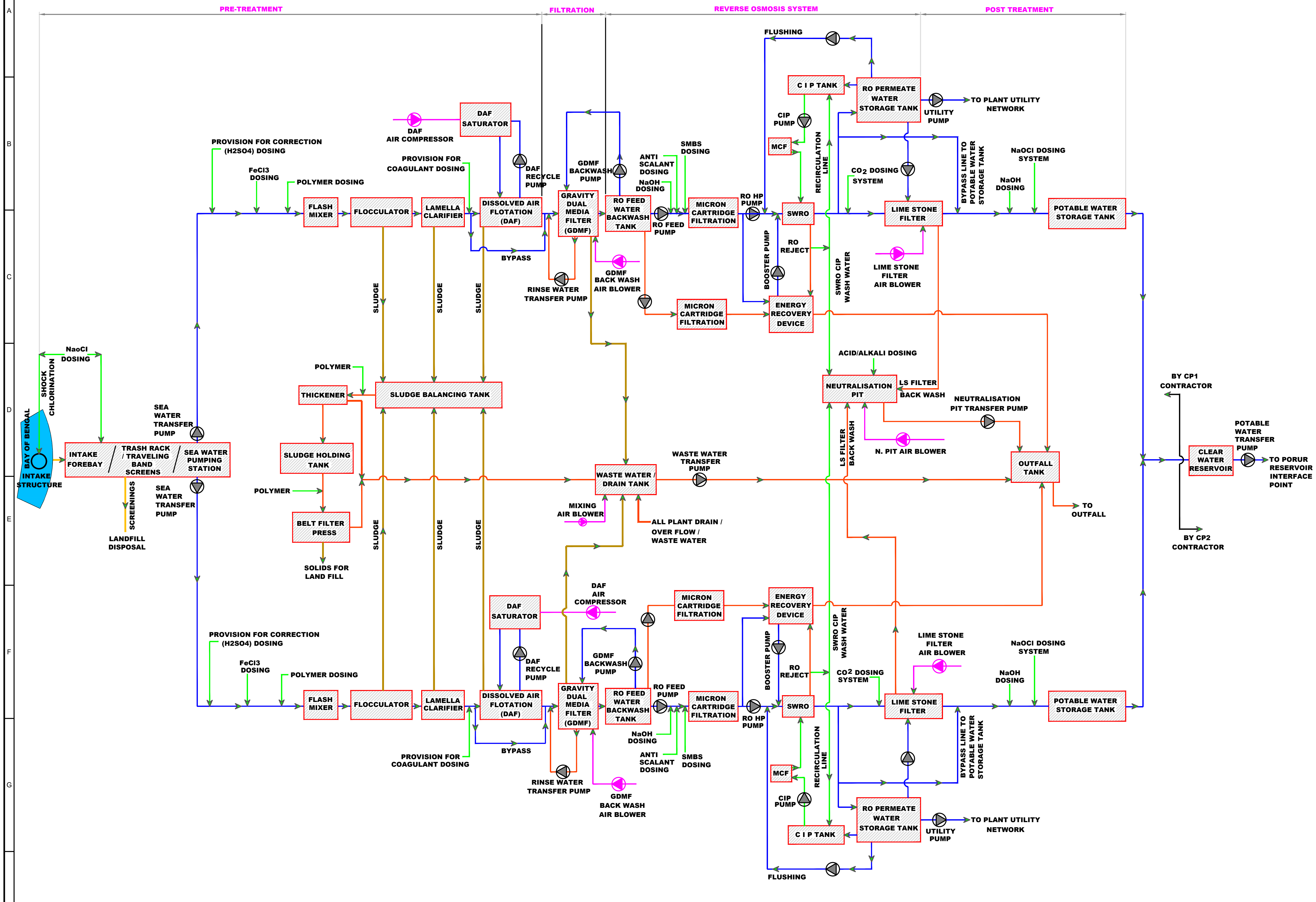
Sl. No.	Characteristics	Unit	Treated water requirements
29.	Cyanides (CN)	mg/l	≤0.05
30.	Lead (Pb)	mg/l	≤0.01
31.	Selenium (Se)	mg/l	≤0.01
32.	Mercury (Hg)	mg/l	≤0.001
33.	Silver	mg/l	≤0.1
34.	Polynuclear Aromatic Hydrocarbons (PAH)	ug/L	≤0.0001
35.	Pesticides	mg/l	Absent
36.	Gross Alpha activity	Bq/l	≤0.1
37.	Gross Alpha activity (Bq/l)	Bq/l	≤1
38.	Trihalomethanes:		
	Bromodichloromethane (BDCM)	mg / L	≤ 0.06
	Bromoform	mg / L	≤ 0.1
	Dibromochloromethane	mg / L	≤ 0.1
	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, 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).

The Project Management Consultant (PMC) for the Chennai 400 MLD Desalination Plant project is a consortium led by SMEC International Pty Ltd in partnership with Tata Consulting Engineers Limited (TCE), NJS Engineers India Pvt Ltd (NJSEI) and SMEC India Pvt Ltd.



NOTES:

1. TWO (2) STREAMS EACH OF 200 MLD CAPACITY PROPOSED

LEGEND:

- INCOMING RAW SEA WATER
- WATER LINE
- REJECT/ BACKWASH/ RINSE/DRAIN
- AIR FOR BACKWASH/ MIXING
- CHEMICAL DOSING
- SLUDGE / SCREENINGS
- BLOWER / COMPRESSOR
- PUMP
- INTERFACE POINT

SWRO	SEAWATER REVERSE OSMOSIS
MCF	MICRON CARTRIDGE FILTER
CIP	CLEAN IN PLACE
HP	HIGH PRESSURE
SMBS	SODIUM META BI SULPHATE

FOR TENDER PURPOSE ONLY

Rev	Date	Description	Drawn	Chkd	Appd
R1	24.06.2020	Conceptual Design Report for CP1	NGM	GM/MM	DD
R0	17.04.2020	Preliminary Draft Conceptual Design Report for CP1	VK	GM	DD

Client: Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB),

Project management Consultant : SMEC International Pty Ltd , Tata Consulting Engineers Limited (TCE), NJS Engineers India Pvt Ltd (NJSEI) , SMEC India Pvt Ltd.

Project Name: Consultancy for "Design, Preparation of Bid Documents & Evaluation of Bids for the Proposed Construction of 400 MLD Capacity Seawater Reverse Osmosis Desalination Plant at Perur along East Coast Road, South of Chennai, Tamil Nadu and Construction Management & Supervision for the Proposed Desalination Plant and its Product Water Conveyance Pipeline from the Plant and upto Porur and all allied works"

Project Title: PMC for Chennai Perur 400 MLD Desalination Plant and allied works

Project Code: Contract Package -1 (CP1)

Status: Conceptual Design Report for CP1

Drawing Title: PROCESS FLOW DIAGRAM FOR PROPOSED 400 MLD PERUR DSP

Drawn:	NGM	Checked:	GM / MM
Designed:	SMK	Approved:	DD
Date:	24.06.2020	Scale:	NTS

Drawing Number: 7061563/PMC400MLD/CP1/PFD/001 | Sh.No 1 OF 1 | Revision: R1

PROCESS FLOW DIAGRAM FOR PROPOSED 400 MLD PERUR DSP

Project: Construction of 400MLD DSP at Perur, Chennai
Prepared by : Dr. G. Mustafa

Annexure 3 Mass Balance and Process Flow Diagram for 400 MLD Desalination Plant at Perur, Chennai

H2SO4	mg/l	20.00
As Chemical	mg/L	20.4
	MLD	0.011
TSS	mg/L	0.00
	kg/day	0.0
Soln TDS	mg/L	1764000

Polymer	mg/l	0.20
	MLD	0.095

Coagulant

FeCl3	mg/l as Fe	4.00
As Chemica	mg/L	48.3
	MLD	0.032
TSS	mg/L	11.52
	kg/day	10922.8
Soln TDS	mg/L	568000

Flocculated Water		
Flow	MLD	951.75
pH	0	6.8
Alkalinity	mg/L as CaCO3	69.4
Boron	mg/L	3.6
TOC	mg/L	4.5
TSS	mg/L	86.7
0	kg/day	82509
TDS	mg/L	36009

Polymer	mg/l	0.10
	MLD	0.047

FeCl3	mg/l as Fe	1.00
Chemical	mg/L	12.1
	MLD	0.008
TSS	mg/L	2.88
	kg/day	2686.2
TDS	mg/L	568000

Screen Wash Water- 10L/s
3.5 MLD

Raw Seawater Feed		
Flow	MLD	948.2
	Kg/Hr	39507
pH		8.2
Alkalinity	mg/L as CaC	100.0
Boron	mg/L	3.6
Fe	mg/L	0.05
TOC	mg/L	5.0
TSS	mg/L	75.0
	kg/day	71112
TDS	mg/L	36000

Intake Well

Flocculation Tank

Lamella Clarifier

DAF

Lamella Waste Stream		
Flow	MLD	19.04
pH	0	6.8
Alkalinity	mg/L as CaC	69.4
Boron	mg/L	3.6
TOC	mg/L	2.7
TSS	mg/L	3906.9
0	kg/day	74368
TDS	mg/L	36009

Lamella Clarified Water		
Flow	MLD	932.72
pH	0	6.77
Alkalinity	mg/L as CaC	69.40
Boron	mg/L	3.60
TOC	mg/L	2.7
TSS	mg/L	10.62
0	kg/day	9901
TDS	mg/L	36009

Plant Waste to Sea		
Flow	MLD	546.352
pH	0	6.8
Alkalinity	mg/L as CaCO3	113.9
Boron	mg/L	5.7
Fe	mg/L	0.05
TOC	mg/L	3.2
TSS	mg/L	20
0	kg/day	11012
TDS	mg/L	62015

	m3/day
Washwater	1440

Wastewater Treatment Plant

Waste Stream from WWTP		
Flow	MLD	28.06
Fe	mg/L	0.9
TOC	mg/L	2.5
TSS	mg/L	303
0	kg/day	8494

Leakage
4.7

Sea Outfall Dispersion

Wastewater Tank

Mass Balance Checks		Solids due to Seawater TSS + Coagulant	Sludge due to removal of DOC	Total Solid
	Flow (MLD)	Solid Tonnes/day		
Inputs	948.49	84.721	0.0	84.7
Outputs	948.49	84.721	2.7	87.5

The following assumptions have been made based on experiences.
It is important to conduct pilot/ Jar tests to verify these assumptions.

Assemptions

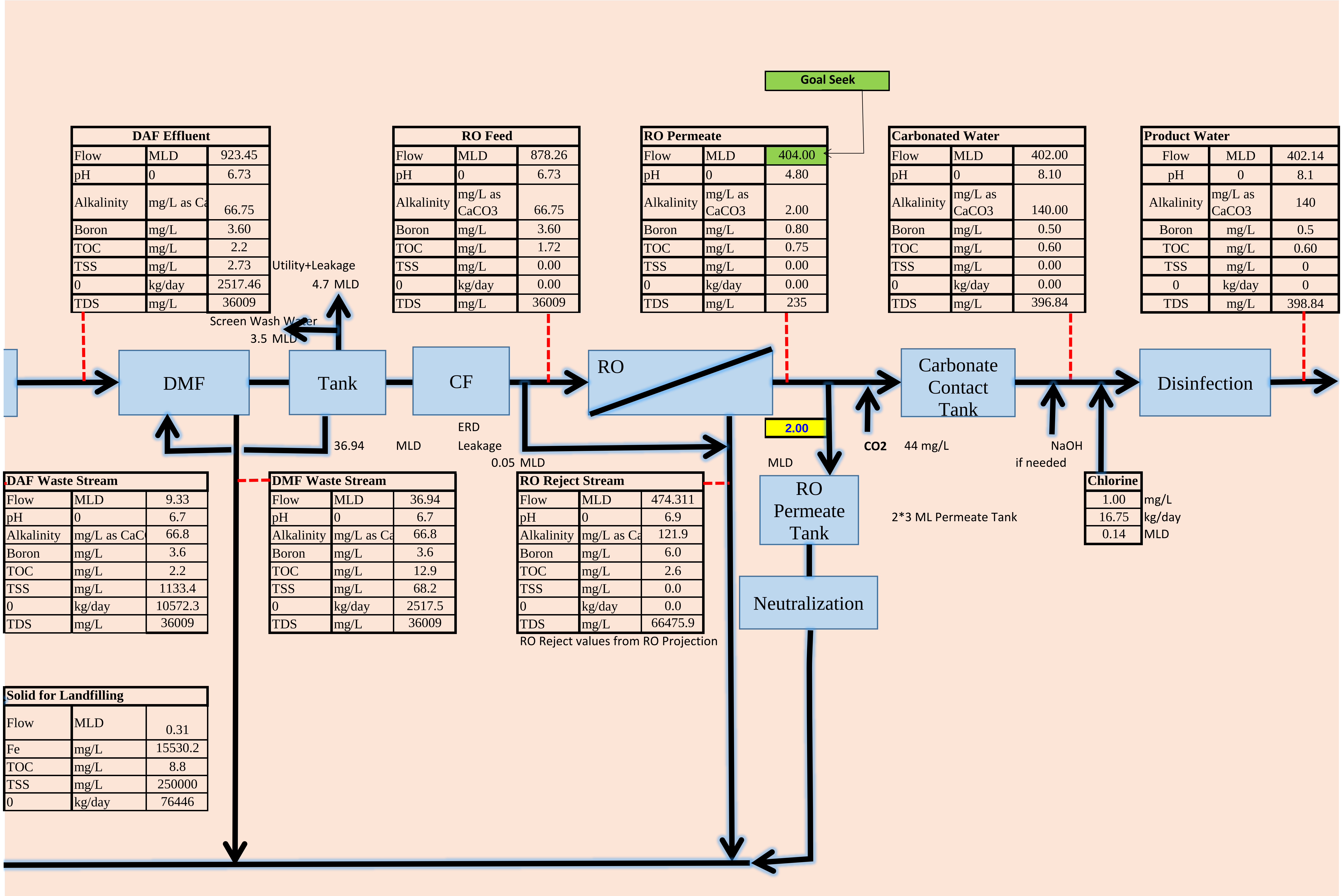
1	DOC content of total TOC	90	%
2	DOC removal in Lamella Filter	40	%
3	DOC removal in DAF	20	%
4	DOC removal in DMF	20	%
5	Lamella Clarifier recovery	98	%
6	Lamella Clarifier solid removal efficiency	88	%
7	DAF waste solid removal efficiency	80	%
8	DAF Recovery	99	%
9	DMF Recovery	96	%
10	RO Recovery	46	%
11	Poly purity	100	%
12	Poly solution concentration	0.2	%
13	Density of Poly solution	1000	kg/m3
14	DOC reduction in RO process	80	%
15	DOC reduction in Carbonate tank	20	%
16	Other Utility and Plant leakage - high feed water	0.5	%
17	Solid Recovery Rate in Thickener	90	%
18	Iron removed as solid in sludge treatment	99.5	%
19	TOC removed as solid in sludge treatment	98	%

Mass Balance at a glance - Normal Case

Process Stages	Process water	Wastewater	Rate wrt Feed
Intake Pumps	948160		100.00%
Service Water	2000		0.21%
Utility and Leakage		4741	0.50%
Lamella + DAF waste		28363	2.99%
GMF Backwash		36938	3.90%
Pre-filtered water	878311		92.63%
Feed water RO+ERD	878311		92.63%
Feed to RO	878261		92.63%
HP pumps	404000		42.61%
Recir. Pump	474261		50.02%
Feed to ERD	474311		50.02%
RO permeate	404000		42.61%
RO Reject		474311	50.02%
CIP & Flushing		2000	0.21%
Total plant waste discharge		5,46,352	57.62%
Net Plant Product Water	4,02,000		
Overall Plant Recovery	42.4%		

Chemical Addition
Waters of Hydration
Mecular Wt dehyrated
Molecular Weight (g/mol)
% Iron
% Product Strength
Specific Gravity
Dose Equivalents
Dose as Al^{3+} or Fe^{3+} (mg/L)
Dose as Active Ingredient (mg
Dose as Product (mg/L)
Alkalinity & Sludge
Alkalinity Consumed (mg CaC
Sludge Produced (mg/L)
Chemical Consumption
Feed Water Volume (MLD)
Consumption (kg/day)
Consumption (L/day)
Consumption (L/hr)

* Active Ingredient = $FeCl_3.XH$



DAF Effluent		
Flow	MLD	923.45
pH	0	6.73
Alkalinity	mg/L as Ca	66.75
Boron	mg/L	3.60
TOC	mg/L	2.2
TSS	mg/L	2.73
0	kg/day	2517.46
TDS	mg/L	36009

RO Feed		
Flow	MLD	878.26
pH	0	6.73
Alkalinity	mg/L as CaCO3	66.75
Boron	mg/L	3.60
TOC	mg/L	1.72
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	36009

RO Permeate		
Flow	MLD	404.00
pH	0	4.80
Alkalinity	mg/L as CaCO3	2.00
Boron	mg/L	0.80
TOC	mg/L	0.75
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	235

Carbonated Water		
Flow	MLD	402.00
pH	0	8.10
Alkalinity	mg/L as CaCO3	140.00
Boron	mg/L	0.50
TOC	mg/L	0.60
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	396.84

Product Water		
Flow	MLD	402.14
pH	0	8.1
Alkalinity	mg/L as CaCO3	140
Boron	mg/L	0.5
TOC	mg/L	0.60
TSS	mg/L	0
0	kg/day	0
TDS	mg/L	398.84

DAF Waste Stream		
Flow	MLD	9.33
pH	0	6.7
Alkalinity	mg/L as CaC(	66.8
Boron	mg/L	3.6
TOC	mg/L	2.2
TSS	mg/L	1133.4
0	kg/day	10572.3
TDS	mg/L	36009

DMF Waste Stream		
Flow	MLD	36.94
pH	0	6.7
Alkalinity	mg/L as Ca	66.8
Boron	mg/L	3.6
TOC	mg/L	12.9
TSS	mg/L	68.2
0	kg/day	2517.5
TDS	mg/L	36009

RO Reject Stream		
Flow	MLD	474.311
pH	0	6.9
Alkalinity	mg/L as Ca	121.9
Boron	mg/L	6.0
TOC	mg/L	2.6
TSS	mg/L	0.0
0	kg/day	0.0
TDS	mg/L	66475.9

Chlorine	
1.00	mg/L
16.75	kg/day
0.14	MLD

Solid for Landfilling		
Flow	MLD	0.31
Fe	mg/L	15530.2
TOC	mg/L	8.8
TSS	mg/L	250000
0	kg/day	76446

Assume RO CIP after every 60 days			
CIP Cleaning water per Skid =	552.960	m3/day	for two CIP
Flushing water after cleaning	720	m3/day	for two CIP
Flushing due to change in skid	360	m3/day	
Backwashing of CaCO3 Filter	2500	m3/day	
Total	**4132.96**	m3/day	
SAY	5000	MLD	
Storage of Permeate say	2*5	ML	

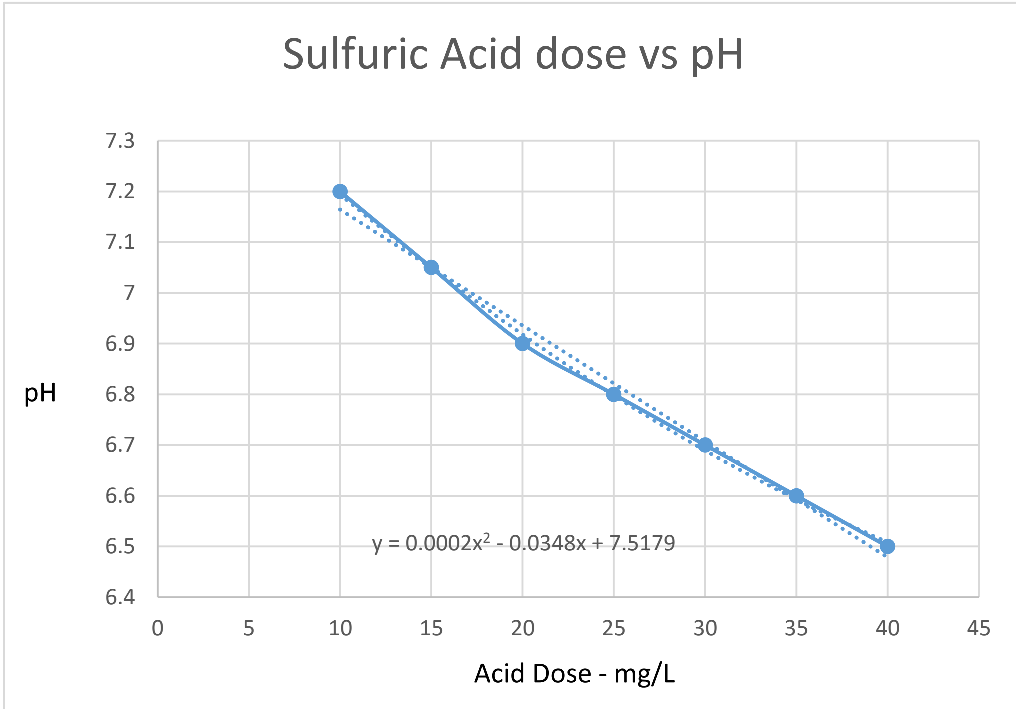
$FeCl_3$	$Fe_2(SO_4)_3$	
	6	
6	399.7	
162.4	507.7	
270.4	22.1%	
20.7%	40.0%	30/100
40.0%	1.44	30*1.42 kg/L
1.42		42.6
	4.00	426000
4.00	18.1	
19.3	45.3	
48.3		
	10.6	
10.6	11.5	
11.5		
948	42980	
45774	29848	
32235	1244	
1343		

$_2$O, or $Fe_2(SO_4)_3.XH_2O$

FeCl3 vs. pH relation after 20/25 ppm sulfuric acid dosing

Fe^{+3}	FeCl3	pH		H2SO4		Alkalinity
mg/L	mg/L	20 ppm	25ppm	mg/L		mg/L as CacO3
1	4.83	6.90	6.80	10	7.2	100
2	9.66	6.86	6.76	15	7.05	95
4	19.31	6.77	6.67	20	6.9	90
6	28.97	6.68	6.58	25	6.8	85
8	38.62	6.59	6.49	30	6.7	80
10	48.28	6.50	6.40	35	6.6	75
12	57.93	6.41	6.31	40	6.5	70
14	67.59	6.32	6.22			
16	77.24	6.23	6.13			
18	86.90	6.14	6.04			
20	96.55	6.05	5.95			

FeCl3 Fe2(SO4)3



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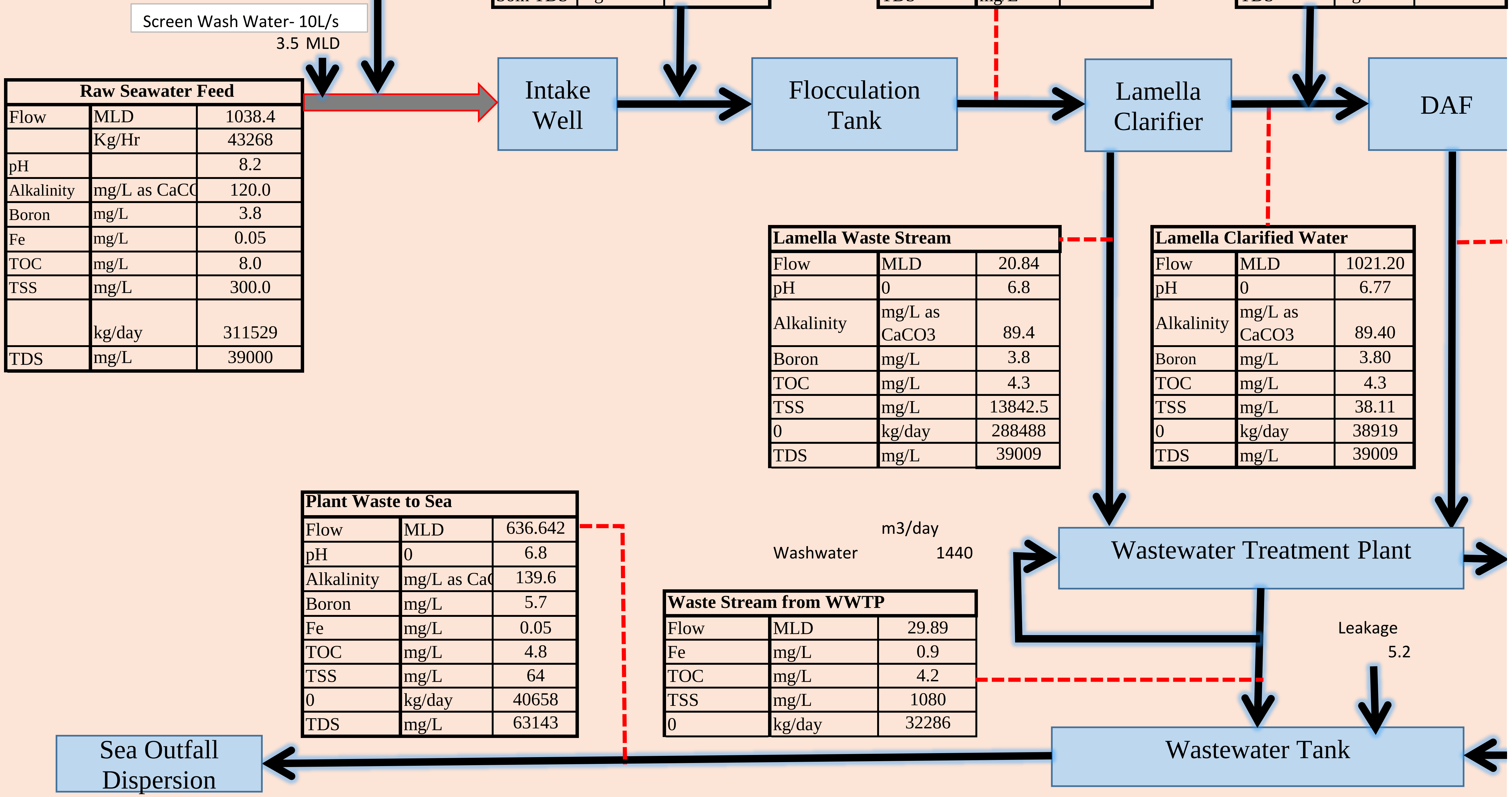
Mass Balance and Process Flow Diagram for 400 MLD Desalination Plant at Perur, Chennai



H2SO4	mg/l	20.00
As Chemical	mg/L	20.4
	MLD	0.012
TSS	mg/L	0.00
	kg/day	0.0
Soln TDS	mg/L	1764000

Polymer	mg/l	0.20
	MLD	0.104

Coagulant

FeCl3	mg/l as Fe	4.00
As Chemica	mg/L	48.3
	MLD	0.035
TSS	mg/L	11.52
	kg/day	11962.7
Soln TDS	mg/L	568000

Flocculated Water		
Flow	MLD	1042.04
pH	0	6.8
Alkalinity	mg/L as CaCO3	89.4
Boron	mg/L	3.8
TOC	mg/L	7.2
TSS	mg/L	311.2
0	kg/day	324323
TDS	mg/L	39009

Polymer	mg/l	0.10
	MLD	0.051

FeCl3	mg/l as Fe	1.00
Chemical	mg/L	12.1
	MLD	0.009
TSS	mg/L	2.88
	kg/day	2941.0
TDS	mg/L	568000

Raw Seawater Feed		
Flow	MLD	1038.4
	Kg/Hr	43268
pH		8.2
Alkalinity	mg/L as CaC(	120.0
Boron	mg/L	3.8
Fe	mg/L	0.05
TOC	mg/L	8.0
TSS	mg/L	300.0
	kg/day	311529
TDS	mg/L	39000

Lamella Waste Stream		
Flow	MLD	20.84
pH	0	6.8
Alkalinity	mg/L as CaCO3	89.4
Boron	mg/L	3.8
TOC	mg/L	4.3
TSS	mg/L	13842.5
0	kg/day	288488
TDS	mg/L	39009

Lamella Clarified Water		
Flow	MLD	1021.20
pH	0	6.77
Alkalinity	mg/L as CaCO3	89.40
Boron	mg/L	3.80
TOC	mg/L	4.3
TSS	mg/L	38.11
0	kg/day	38919
TDS	mg/L	39009

Plant Waste to Sea		
Flow	MLD	636.642
pH	0	6.8
Alkalinity	mg/L as Ca(	139.6
Boron	mg/L	5.7
Fe	mg/L	0.05
TOC	mg/L	4.8
TSS	mg/L	64
0	kg/day	40658
TDS	mg/L	63143

Waste Stream from WWTP		
Flow	MLD	29.89
Fe	mg/L	0.9
TOC	mg/L	4.2
TSS	mg/L	1080
0	kg/day	32286

Mass Balance Checks		Solids due to Seawater TSS + Coagulant	Sludge due to removal of DOC	Total Solid
	Flow (MLD)	Solid Tonnes/day		
Inputs	1038.78	326.433	0.0	326.4
Outputs	1038.78	326.433	4.8	331.2

The following assumptions have been made based on experiences.
It is important to conduct pilot/ Jar tests to verify these assumptions.

Assemptions

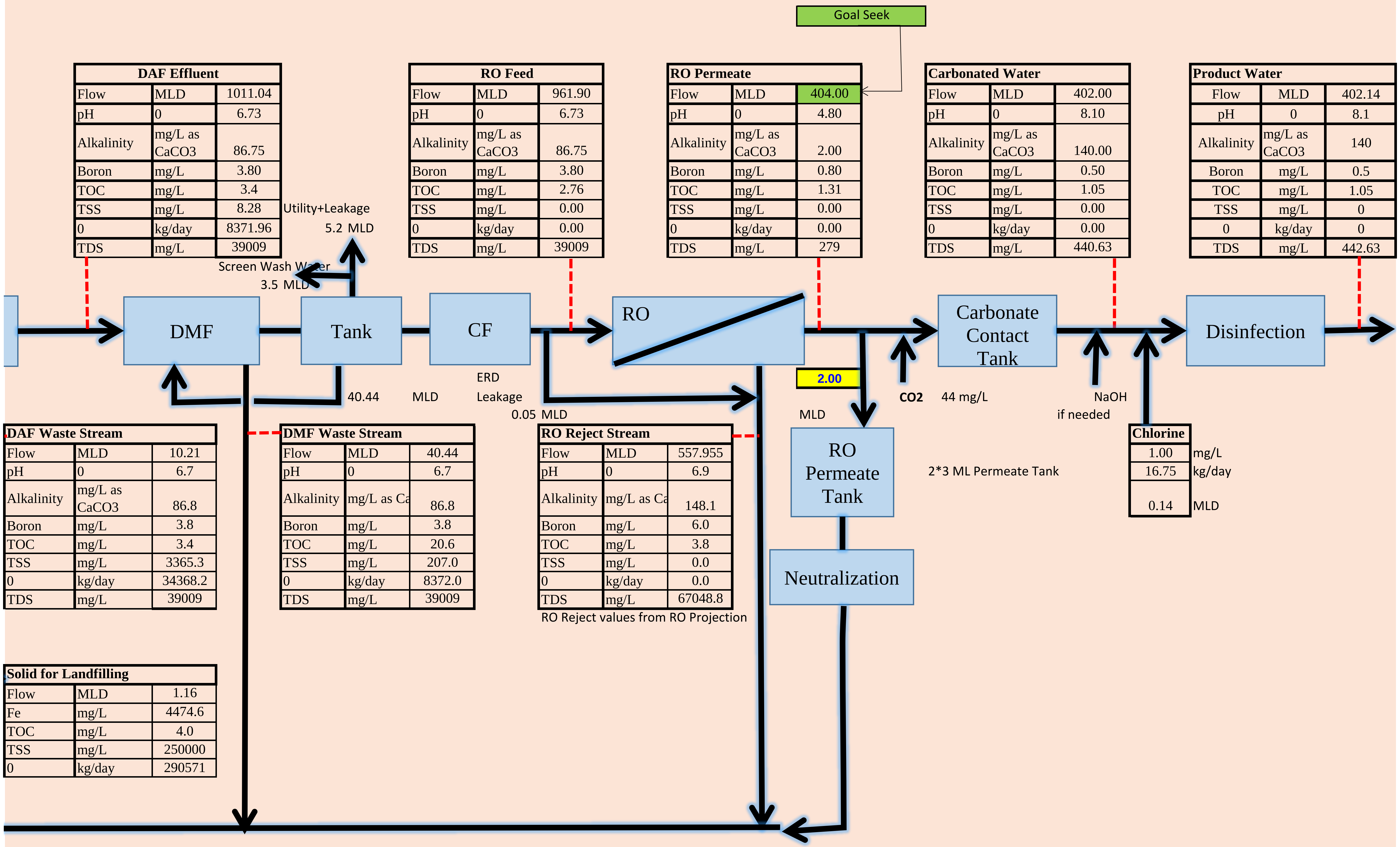
1	DOC content of total TOC	90	%
2	DOC removal in Lamella Filter	40	%
3	DOC removal in DAF	20	%
4	DOC removal in DMF	20	%
5	Lamella Clarifier recovery	98	%
6	Lamella Clarifier solid removal efficiency	88	%
7	DAF waste solid removal efficiency	80	%
8	DAF Recovery	99	%
9	DMF Recovery	96	%
10	RO Recovery	42	%
11	Poly purity	100	%
12	Poly solution concentration	0.2	%
13	Density of Poly solution	1000	kg/m3
14	DOC reduction in RO process	80	%
15	DOC reduction in Carbonate tank	20	%
16	Other Utility and Plant leakage - high feed water	0.5	%
17	Solid Recovery Rate in Thickener	90	%
18	Iron removed as solid in sludge treatment	99.5	%
19	TOC removed as solid in sludge treatment	98	%

Mass Balance at a glance - Max Case

Process Stages	Process water	Wastewater	Rate wrt Feed
Intake Pumps	1038431		100.00%
Service Water	2000		0.19%
Utility and Leakage		5192	0.50%
Lamella + DAF waste		31053	2.99%
GMF Backwash		40442	3.89%
Pre-filtered water	961955		92.64%
Feed water RO+ERD	0		0.00%
Feed to RO	961905		92.63%
HP pumps	404000		38.90%
Recir. Pump	0		0.00%
Feed to ERD	0		0.00%
RO permeate	404000		38.90%
RO Reject		557955	53.73%
CIP & Flushing		2000	0.19%
Total plant waste discharge		6,36,642	61.31%
Net Plant Product Water	4,02,000		
Overall Plant Recovery	38.7%		

Chemical Addition
Waters of Hydration
Mecular Wt dehyrated
Molecular Weight (g/mol)
% Iron
% Product Strength
Specific Gravity
Dose Equivalents
Dose as Al^{3+} or Fe^{3+} (mg/L)
Dose as Active Ingredient (mg
Dose as Product (mg/L)
Alkalinity & Sludge
Alkalinity Consumed (mg CaC
Sludge Produced (mg/L)
Chemical Consumption
Feed Water Volume (MLD)
Consumption (kg/day)
Consumption (L/day)
Consumption (L/hr)

* Active Ingredient = $FeCl_3.XH$



DAF Effluent		
Flow	MLD	1011.04
pH	0	6.73
Alkalinity	mg/L as CaCO3	86.75
Boron	mg/L	3.80
TOC	mg/L	3.4
TSS	mg/L	8.28
0	kg/day	8371.96
TDS	mg/L	39009

RO Feed		
Flow	MLD	961.90
pH	0	6.73
Alkalinity	mg/L as CaCO3	86.75
Boron	mg/L	3.80
TOC	mg/L	2.76
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	39009

RO Permeate		
Flow	MLD	404.00
pH	0	4.80
Alkalinity	mg/L as CaCO3	2.00
Boron	mg/L	0.80
TOC	mg/L	1.31
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	279

Carbonated Water		
Flow	MLD	402.00
pH	0	8.10
Alkalinity	mg/L as CaCO3	140.00
Boron	mg/L	0.50
TOC	mg/L	1.05
TSS	mg/L	0.00
0	kg/day	0.00
TDS	mg/L	440.63

Product Water		
Flow	MLD	402.14
pH	0	8.1
Alkalinity	mg/L as CaCO3	140
Boron	mg/L	0.5
TOC	mg/L	1.05
TSS	mg/L	0
0	kg/day	0
TDS	mg/L	442.63

DAF Waste Stream		
Flow	MLD	10.21
pH	0	6.7
Alkalinity	mg/L as CaCO3	86.8
Boron	mg/L	3.8
TOC	mg/L	3.4
TSS	mg/L	3365.3
0	kg/day	34368.2
TDS	mg/L	39009

DMF Waste Stream		
Flow	MLD	40.44
pH	0	6.7
Alkalinity	mg/L as Ca	86.8
Boron	mg/L	3.8
TOC	mg/L	20.6
TSS	mg/L	207.0
0	kg/day	8372.0
TDS	mg/L	39009

RO Reject Stream		
Flow	MLD	557.955
pH	0	6.9
Alkalinity	mg/L as Ca	148.1
Boron	mg/L	6.0
TOC	mg/L	3.8
TSS	mg/L	0.0
0	kg/day	0.0
TDS	mg/L	67048.8

RO Reject values from RO Projection

Chlorine	
1.00	mg/L
16.75	kg/day
0.14	MLD

Solid for Landfilling		
Flow	MLD	1.16
Fe	mg/L	4474.6
TOC	mg/L	4.0
TSS	mg/L	250000
0	kg/day	290571

Assume RO CIP after every 60 days			
CIP Cleaning water per Skid =	552.960	m3/day	for two CIP
Flushing water after cleaning	720	m3/day	for two CIP
Flushing due to change in skid	360	m3/day	
Backwashing of CaCO3 Filter	2500	m3/day	
Total	**4132.96**	m3/day	
SAY	5000	MLD	
Storage of Permeate say	6	ML	

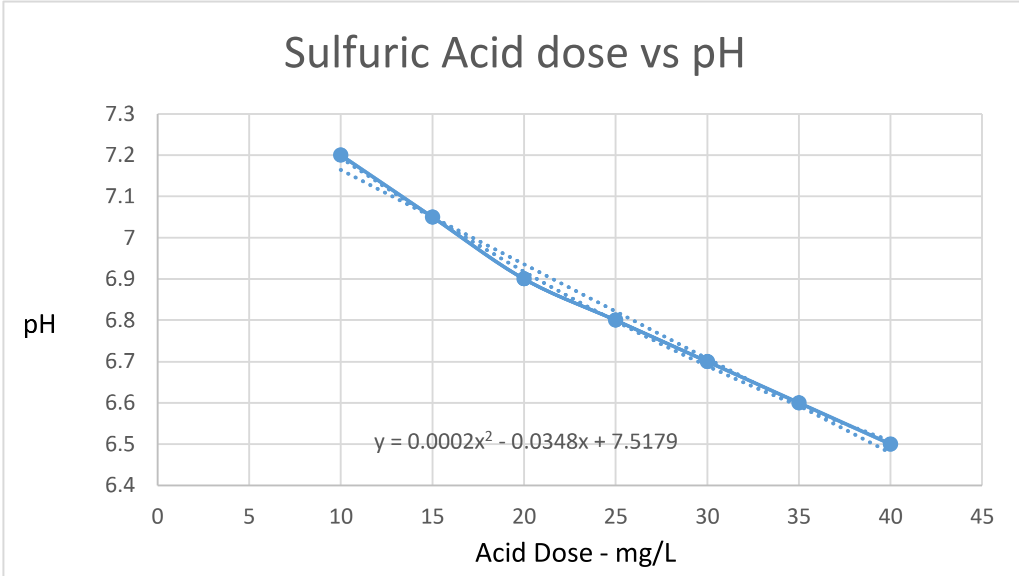
$FeCl_3$	$Fe_2(SO_4)_3$	
	6	
6	399.7	
162.4	507.7	
270.4	22.1%	
20.7%	40.0%	30/100
40.0%	1.44	30*1.42 kg/L
1.42		42.6
	4.00	426000
4.00	18.1	
19.3	45.3	
48.3		
	10.6	
10.6	11.5	
11.5		
1,038	47072	
50132	32689	
35304	1362	
1471		

$_2$O, or $Fe_2(SO_4)_3.XH_2O$

FeCl3 vs. pH relation after 20/25 ppm sulfuric acid dosing

Fe^{+3}	FeCl3	pH		H2SO4		Alkalinity
mg/L	mg/L	20 ppm	25ppm	mg/L		mg/L as CacO3
1	4.83	6.90	6.80	10	7.2	100
2	9.66	6.86	6.76	15	7.05	95
4	19.31	6.77	6.67	20	6.9	90
6	28.97	6.68	6.58	25	6.8	85
8	38.62	6.59	6.49	30	6.7	80
10	48.28	6.50	6.40	35	6.6	75
12	57.93	6.41	6.31	40	6.5	70
14	67.59	6.32	6.22			
16	77.24	6.23	6.13			
18	86.90	6.14	6.04			
20	96.55	6.05	5.95			

FeCl3 Fe2(SO4)3



400 MLD Perur DSP   Membrane – 3 SWC4MAX & 5 SWC5MAX   Max TDS-41000 mg/l, Temp 31.5C, Rec 44%

Calculated by	Dr. G. Mustafa	Permeate flow/train	25.250 mld
HP Pump flow	1064.33 m3/h	Raw water flow/train	57.386 mld
Feed pressure	64.5 bar	Permeate recovery	44.00 %
Feed temperature	31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH	8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %	7.7 NaOH	Fouling factor	0.78
Leakage	1 %	SP increase, per year	10.0 %
Volumetric mixing	6 %		
H.P. differential	0.50 bar		
Boost pressure	2.39 bar		
Specific energy	2.36 kwh/m3		
Pass NDP	19.6 bar		
Average flux rate	13.4 lmh	Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Boost bar	Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	594.2	10	7.5	20.2	0.9	24.8	1.04	1.5	0	63.6	170.9	SWC4 MAX	720	240 x 3M
1-1-h	456.8	7.5	5.6	9.3	1	16.5	1.03	1.5	0	62.7	397.6	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6732.79	6919.25	6919.25	15.741	12334.1	11998.02
Ca	480.00	493.29	493.29	1.122	879.3	855.37
Mg	1350.00	1387.39	1387.39	3.156	2473.1	2405.74
Na	12905.00	13261.49	13261.49	144.508	23549.9	22911.29
K	409.00	420.19	420.19	5.720	745.3	725.11
NH4	0.20	0.18	0.18	0.003	0.3	0.31
Ba	0.450	0.462	0.462	0.001	0.8	0.80
Sr	0.100	0.103	0.103	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	15.05	32.91	32.91	0.002	67.8	65.66
HCO3	99.41	83.92	83.92	1.498	111.7	109.99
SO4	2972.00	3054.29	3054.29	7.601	5444.0	5295.68
Cl	22755.00	23380.23	23380.23	232.326	41536.4	40409.57
F	1.63	1.67	1.67	0.033	3.0	2.88
NO3	4.00	4.10	4.10	0.301	7.1	6.90
PO4	0.10	0.10	0.10	0.000	0.2	0.18
OH	0.20	0.51	0.51	0.004	0.8	0.78
SiO2	1.38	1.42	1.42	0.011	2.5	2.45
B	3.80	3.88	3.88	0.944	6.2	6.04
CO2	0.43	0.15	0.15	0.15	0.20	0.20
NH3	0.02	0.04	0.04	0.04	0.04	0.04
TDS	**40997.12**	**42125.64**	**42125.64**	**397.23**	**74827.84**	**72798.15**

pH	**8.00**	**8.40**	**8.40**	**7.15**	**8.44**	**8.44**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	23	24	50	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1750	1805	3497	10000
SiO2 saturation, %	1	1	1	140
CaF2 / ksp * 100, %	58	63	580	50000
Ca3(PO4)2 saturation index	0.2	0.6	1.5	2.4
CCPP, mg/l	20.45	17.62	36.27	850
Ionic strength	0.80	0.83	1.47	
Osmotic pressure, bar	30.8	31.6	56.2	

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Max TDS-41000 mg/l, Temp 31.5C, Rec 44%

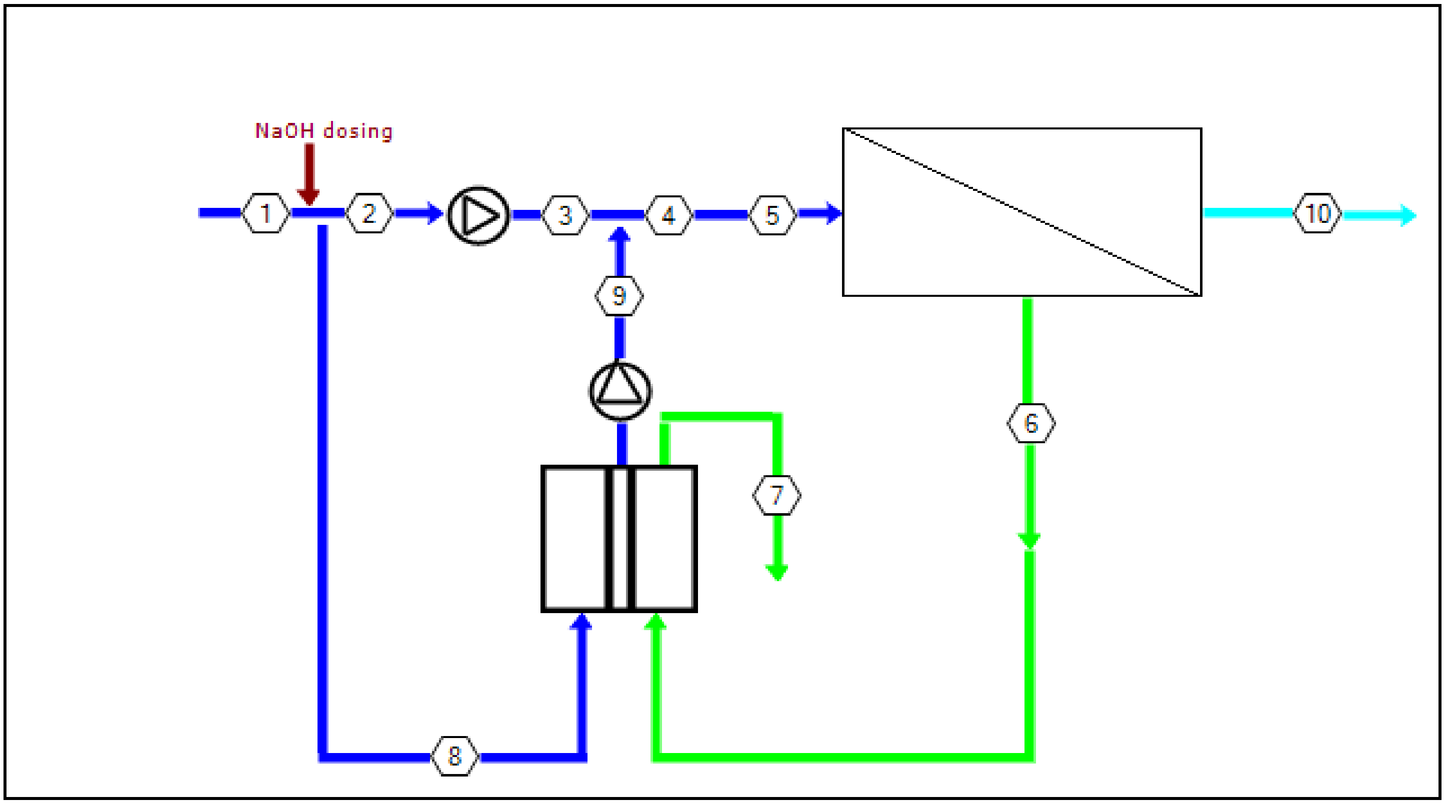
Calculated by	Dr. G. Mustafa	Permeate flow/train	25.250 mld
HP Pump flow	1064.33 m3/h	Raw water flow/train	57.386 mld
Feed pressure	64.5 bar	Permeate recovery	44.00 %
Feed temperature	31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH	8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %	7.7 NaOH	Fouling factor	0.78
Leakage	1 %	SP increase, per year	10.0 %
Volumetric mixing	6 %		
H.P. differential	0.50 bar		
Boost pressure	2.39 bar		
Specific energy	2.36 kwh/m3		
Pass NDP	19.6 bar		
Average flux rate	13.4 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	594.2	10	7.5	20.2	0.9	24.8	1.04	1.5	0	63.6	170.9	SWC4 MAX	720	240 x 3M
1-1-h	456.8	7.5	5.6	9.3	1	16.5	1.03	1.5	0	62.7	397.6	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	TDS	Ca	HCO3	Cl	NO3	B
									Permeate (Stagewise cumulative)					
1-1	1	64.5	0.36	35.2	28.7	1	24.8	1.04	126.9	0.358	0.479	74.21	0.097	0.314
1-1	2	64.2	0.31	38.7	24.6	0.8	20	1.03	147.3	0.416	0.556	86.128	0.113	0.364
1-1	3	63.9	0.27	42	20.8	0.6	15.8	1.03	170.9	0.482	0.645	99.932	0.131	0.414
1-1	4	63.6	0.24	46.1	16.6	0.7	16.5	1.03	208.5	0.588	0.787	121.935	0.159	0.521
1-1	5	63.4	0.21	49.6	12.9	0.5	11.7	1.03	250.5	0.707	0.945	146.46	0.191	0.626
1-1	6	63.2	0.18	52.4	9.8	0.3	8.3	1.02	296.5	0.837	1.119	173.397	0.225	0.731
1-1	7	63	0.17	54.5	7.5	0.2	5.9	1.01	345.7	0.976	1.304	202.149	0.262	0.838
1-1	8	62.8	0.16	56.2	5.7	0.2	4.2	1.01	397.6	1.123	1.499	232.55	0.301	0.945

400 MLD Perur DSP — Membrane – 3 SWC4MAX & 5 SWC5MAX — Max TDS-41000 mg/l, Temp 31.5C, Rec 44%

Temperature : 31.5 °C — Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2391	0	40997	6733	22755	3.80	8.00
2	1064	0	41000	6733	22755	3.80	8.40
3	1064	64.5	41000	6733	22755	3.80	8.40
4	2391	64.5	42126	6919	23380	3.88	8.40
5	2391	64.5	42126	6919	23380	3.88	8.40
6	1340	62.7	74828	12334	41536	6.18	8.44
7	1340	0	72798	11998	40410	6.04	8.44
8	1326	0	41000	6733	22755	3.80	8.40
9	1326	64.5	43029	7069	23882	3.94	8.40
10	1052	1.50	397	15.7	232	0.944	7.15

Calculated by	Dr. G. Mustafa		Permeate flow/train	25.250 mld
HP Pump flow		1064.33 m3/h	Raw water flow/train	57.386 mld
Feed pressure		64.5 bar	Permeate recovery	44.00 %
Feed temperature		31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH		8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %		7.7 NaOH	Fouling factor	0.78
Leakage		1 %	SP increase, per year	10.0 %
Volumetric mixing		6 %		
H.P. differential		0.50 bar		
Boost pressure		2.39 bar		
Specific energy		2.36 kwh/m3		
Pass NDP		19.6 bar		
Average flux rate		13.4 lmh		
			Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	594.2	10	7.5	20.2	0.9	24.8	1.04	1.5	0	63.6	170.9	SWC4 MAX	720	240 x 3M
1-1-h	456.8	7.5	5.6	9.3	1	16.5	1.03	1.5	0	62.7	397.6	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.000 mld
Specific investment	0.00 INR/mld
Investment	000.00 INR
Plant life	0.0 years
Membrane life	0.0 years
Interest rate	0.0 %
Membrane cost	0.00 INR/element
Plant factor	0.0 %
Number of elements	1920.0
Power cost	0.000 INR/kwhr
Inhibitor cost	0.00
Power consumption	2.36 kwhr/m3
Inhibitor dosing	0.0
Maintenance(as % of investment)	0.0 %
Acid cost	0.00
Acid dosing	3.83

CALCULATION RESULTS

Capital cost	0.00 INR/m3
Power cost	0.00 INR/m3
Chemicals cost	0.00 INR/m3
Membrane replacement costs	0.00 INR/m3
Maintenance	0.00 INR/m3
Total water cost	0.00 INR/m3

400 MLD Perur DSP   Membrane – 3 SWC4MAX & 5 SWC5MAX   Max TDS-41000 mg/l, Temp 31.5C, Rec 46%

Calculated by	Dr. G. Mustafa	Permeate flow/train	25.250 mld
HP Pump flow	1063.58 m3/h	Raw water flow/train	54.891 mld
Feed pressure	66.3 bar	Permeate recovery	46.00 %
Feed temperature	31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH	8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %	7.7 NaOH	Fouling factor	0.78
Leakage	1 %	SP increase, per year	10.0 %
Volumetric mixing	6 %		
H.P. differential	0.50 bar		
Boost pressure	2.21 bar		
Specific energy	2.41 kwh/m3		
Pass NDP	20.6 bar		
Average flux rate	13.4 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	615.6	9.5	7	20.9	0.9	26	1.04	1.5	0	65.4	167.9	SWC4 MAX	720	240 x 3M
1-1-h	435.6	7	5.1	8.9	0.9	16.3	1.04	1.5	0	64.5	410.7	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6732.79	6927.77	6927.77	16.265	12807.8	12443.29
Ca	480.00	493.90	493.90	1.160	913.1	887.12
Mg	1350.00	1389.10	1389.10	3.261	2568.1	2495.02
Na	12905.00	13277.56	13277.56	149.295	24446.5	23754.11
K	409.00	420.70	420.70	5.909	773.6	751.71
NH4	0.20	0.18	0.18	0.003	0.3	0.32
Ba	0.450	0.463	0.463	0.001	0.9	0.83
Sr	0.100	0.103	0.103	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	15.05	33.00	33.00	0.002	71.9	69.53
HCO3	99.41	83.92	83.92	1.546	112.9	111.09
SO4	2972.00	3058.05	3058.05	7.854	5653.0	5492.17
Cl	22755.00	23408.60	23408.60	240.024	43119.4	41897.56
F	1.63	1.68	1.68	0.034	3.1	2.99
NO3	4.00	4.11	4.11	0.311	7.3	7.14
PO4	0.10	0.10	0.10	0.000	0.2	0.18
OH	0.20	0.51	0.51	0.004	0.9	0.83
SiO2	1.38	1.42	1.42	0.011	2.6	2.54
B	3.80	3.88	3.88	0.959	6.4	6.21
CO2	0.43	0.15	0.15	0.15	0.20	0.20
NH3	0.02	0.04	0.04	0.04	0.04	0.04
TDS	**40997.12**	**42176.76**	**42176.76**	**410.37**	**77679.48**	**75478.71**

pH	**8.00**	**8.40**	**8.40**	**7.17**	**8.46**	**8.46**

Saturations	Raw Water	Feed Water	Concentrate	Limits
CaSO4 / ksp * 100, %	23	24	52	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1750	1808	3651	10000
SiO2 saturation, %	1	1	1	140
CaF2 / ksp * 100, %	58	64	683	50000
Ca3(PO4)2 saturation index	0.2	0.6	1.6	2.4
CCPP, mg/l	20.45	17.63	37.49	850
Ionic strength	0.80	0.83	1.53	
Osmotic pressure, bar	30.8	31.7	58.3	

400 MLD Perur DSP   Membrane – 3 SWC4MAX & 5 SWC5MAX   Max TDS-41000 mg/l, Temp 31.5C, Rec 46%

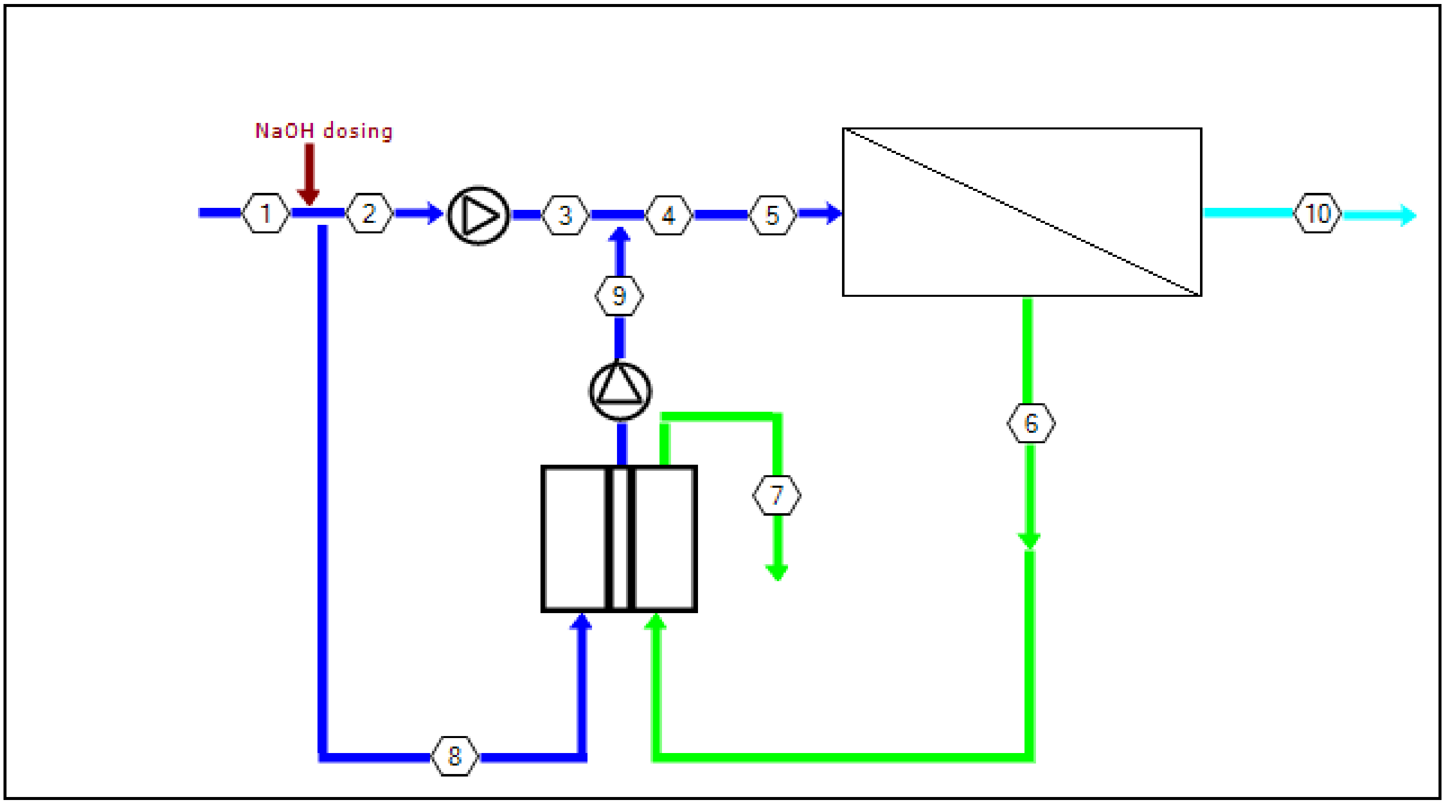
Calculated by	Dr. G. Mustafa	Permeate flow/train	25.250 mld
HP Pump flow	1063.58 m3/h	Raw water flow/train	54.891 mld
Feed pressure	66.3 bar	Permeate recovery	46.00 %
Feed temperature	31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH	8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %	7.7 NaOH	Fouling factor	0.78
Leakage	1 %	SP increase, per year	10.0 %
Volumetric mixing	6 %		
H.P. differential	0.50 bar		
Boost pressure	2.21 bar		
Specific energy	2.41 kwh/m3		
Pass NDP	20.6 bar		
Average flux rate	13.4 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Boost bar	Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	615.6	9.5	7	20.9	0.9	26	1.04	1.5	0	65.4	167.9	SWC4 MAX	720	240 x 3M
1-1-h	435.6	7	5.1	8.9	0.9	16.3	1.04	1.5	0	64.5	410.7	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	HCO3	Cl	NO3	B
1-1	1	66.3	0.33	35.6	30	1.1	26	1.04	122.4	0.345	0.462	71.58	0.094	0.302
1-1	2	65.9	0.28	39.5	25.6	0.8	20.5	1.03	143.7	0.405	0.542	84.029	0.11	0.354
1-1	3	65.6	0.24	43.3	21.7	0.7	16.3	1.03	167.9	0.474	0.633	98.157	0.128	0.405
1-1	4	65.4	0.21	47.8	16.9	0.7	16.3	1.04	208.1	0.587	0.784	121.685	0.159	0.516
1-1	5	65.2	0.18	51.5	12.8	0.5	11.2	1.03	253.1	0.715	0.954	148.01	0.193	0.626
1-1	6	65	0.16	54.4	9.6	0.3	7.6	1.02	302.6	0.854	1.14	176.94	0.23	0.737
1-1	7	64.8	0.15	56.6	7.3	0.2	5.4	1.01	355.2	1.003	1.338	207.723	0.269	0.848
1-1	8	64.7	0.14	58.3	5.4	0.2	3.7	1.01	410.7	1.16	1.547	240.19	0.311	0.96

Temperature : 31.5 °C

Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2287	0	40997	6733	22755	3.80	8.00
2	1064	0	41000	6733	22755	3.80	8.40
3	1064	66.3	41000	6733	22755	3.80	8.40
4	2287	66.3	42177	6928	23409	3.88	8.40
5	2287	66.3	42177	6928	23409	3.88	8.40
6	1236	64.5	77679	12808	43119	6.37	8.46
7	1236	0	75479	12443	41898	6.21	8.46
8	1223	0	41000	6733	22755	3.80	8.40
9	1223	66.3	43200	7097	23977	3.95	8.40
10	1052	1.50	410	16.3	240	0.959	7.17

Calculated by	Dr. G. Mustafa	Permeate flow/train	25.250 mld
HP Pump flow	1063.58 m3/h	Raw water flow/train	54.891 mld
Feed pressure	66.3 bar	Permeate recovery	46.00 %
Feed temperature	31.5 °C(88.7°F)	Element age	3.5 years
Feed water pH	8.40	Flux decline %, per year	7.0
Chem dose, mg/l, 50 %	7.7 NaOH	Fouling factor	0.78
Leakage	1 %	SP increase, per year	10.0 %
Volumetric mixing	6 %		
H.P. differential	0.50 bar		
Boost pressure	2.21 bar		
Specific energy	2.41 kwh/m3		
Pass NDP	20.6 bar		
Average flux rate	13.4 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	615.6	9.5	7	20.9	0.9	26	1.04	1.5	0	65.4	167.9	SWC4 MAX	720	240 x 3M
1-1-h	435.6	7	5.1	8.9	0.9	16.3	1.04	1.5	0	64.5	410.7	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.000 mld
Specific investment	0.00 INR/mld
Investment	000.00 INR
Plant life	0.0 years
Membrane life	0.0 years
Interest rate	0.0 %
Membrane cost	0.00 INR/element
Plant factor	0.0 %
Number of elements	1920.0
Power cost	0.000 INR/kwhr
Inhibitor cost	0.00
Power consumption	2.41 kwhr/m3
Inhibitor dosing	0.0
Maintenance(as % of investment)	0.0 %
Acid cost	0.00
Acid dosing	3.83

CALCULATION RESULTS

Capital cost	0.00 INR/m3
Power cost	0.00 INR/m3
Chemicals cost	0.00 INR/m3
Membrane replacement costs	0.00 INR/m3
Maintenance	0.00 INR/m3
Total water cost	0.00 INR/m3

400 MLD Perur DSP | Membrane – 3 SWC4MAX & 5 SWC5MAX | Avg TDS-35942 mg/l, Temp 28.3C, Rec-44%

Calculated by	Laurent MORILLON	
HP Pump flow	1064.67	m3/h
Feed pressure	56.8	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.72	bar
Specific energy	2.11	kwh/m3
Pass NDP	18.1	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Flow / Vessel Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Stagewise Pressure Boost	Stagewise Pressure Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	553.1	10	7.7	18.8	0.9	22.2	1.03	1.5	0	55.8	137.6	SWC4 MAX	720	240 x 3M
1-1-h	498.1	7.7	5.6	10.2	1	17	1.03	1.5	0	54.8	299.1	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6437.65	6437.65	12.819	11479.6	11273.31
Ca	467.00	475.45	475.45	0.947	847.8	832.59
Mg	1258.00	1280.76	1280.76	2.550	2283.8	2242.81
Na	11089.00	11288.43	11288.43	107.695	20062.5	19703.60
K	391.00	398.00	398.00	4.744	706.6	693.99
NH4	0.20	0.20	0.20	0.003	0.4	0.34
Ba	0.450	0.458	0.458	0.001	0.8	0.80
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	20.77	24.65	24.65	0.001	61.1	59.57
HCO3	126.30	124.63	124.63	1.936	183.1	180.70
SO4	2878.00	2930.06	2930.06	6.342	5224.5	5130.61
Cl	19700.00	20054.02	20054.02	173.348	35655.4	35017.21
F	1.63	1.66	1.66	0.029	2.9	2.89
NO3	4.00	4.07	4.07	0.260	7.1	6.93
PO4	0.76	0.77	0.77	0.002	1.4	1.35
OH	0.19	0.22	0.22	0.002	0.4	0.35
SiO2	1.38	1.40	1.40	0.009	2.5	2.46
B	3.53	3.58	3.58	0.979	5.6	5.53
CO2	0.44	0.37	0.37	0.37	0.49	0.49
NH3	0.02	0.02	0.02	0.02	0.02	0.02
TDS	**35942.12**	**36588.25**	**36588.25**	**298.85**	**65045.68**	**63881.56**

pH	**8.13**	**8.20**	**8.20**	**6.88**	**8.25**	**8.25**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	25	25	52	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1883	1921	3722	10000
SiO2 saturation, %	1	1	2	140
CaF2 / ksp * 100, %	54	57	468	50000
Ca3(PO4)2 saturation index	0.9	1.0	1.8	2.4
CCPP, mg/l	30.28	30.39	69.38	850
Ionic strength	0.71	0.73	1.29	
Osmotic pressure, bar	26.5	27.0	47.9	

Calculated by	Laurent MORILLON	
HP Pump flow	1064.67	m3/h
Feed pressure	56.8	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.72	bar
Specific energy	2.11	kwh/m3
Pass NDP	18.1	bar
Average flux rate	13.4	lmh

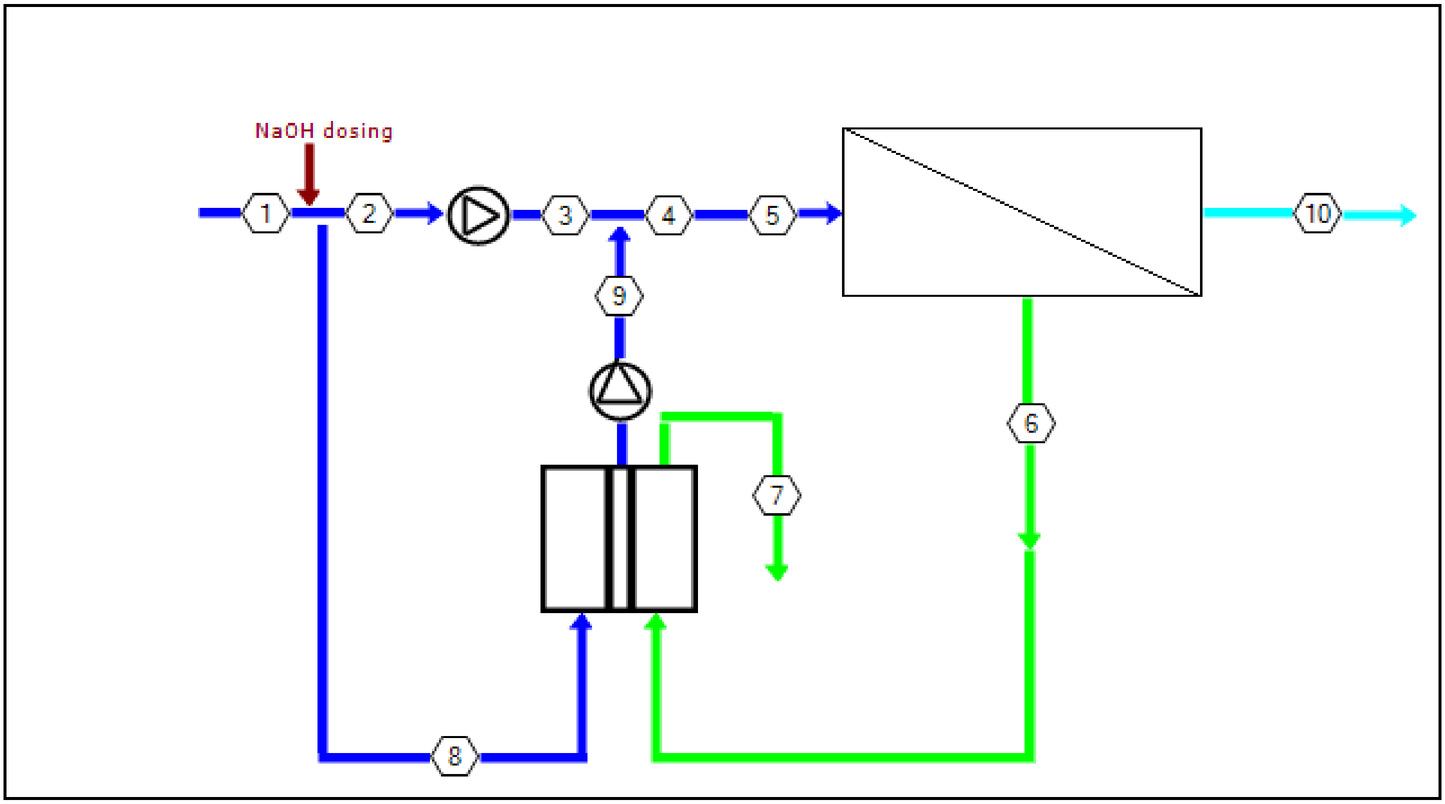
Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Flow / Vessel Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Stagewise Pressure Boost	Stagewise Pressure Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	553.1	10	7.7	18.8	0.9	22.2	1.03	1.5	0	55.8	137.6	SWC4 MAX	720	240 x 3M
1-1-h	498.1	7.7	5.6	10.2	1	17	1.03	1.5	0	54.8	299.1	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure	Pressure Drop	Conc Osmo.	NDP	Permeate Water Flow	Permeate Water Flux	Beta	TDS	Permeate (Stagewise cumulative) Ca	Mg	Na	Cl	B
		bar	bar	bar	bar	m3/h	lmh							
1-1	1	56.8	0.36	29.7	26.2	0.9	22.2	1.03	106.5	0.337	0.908	38.379	61.766	0.349
1-1	2	56.4	0.31	32.4	22.9	0.8	18.7	1.03	121.3	0.384	1.034	43.724	70.368	0.396
1-1	3	56.1	0.27	35	19.9	0.6	15.6	1.03	137.6	0.436	1.173	49.608	79.839	0.443
1-1	4	55.8	0.24	38.5	16.4	0.7	17	1.03	164	0.519	1.398	59.086	95.096	0.55
1-1	5	55.6	0.21	41.6	13	0.5	12.6	1.03	193.6	0.613	1.65	69.742	112.25	0.655
1-1	6	55.4	0.19	44.1	10.2	0.4	9.3	1.02	226.2	0.716	1.929	81.489	131.159	0.761
1-1	7	55.2	0.17	46.3	7.9	0.3	7	1.02	261.4	0.828	2.23	94.19	151.606	0.87
1-1	8	55	0.16	47.9	6	0.2	5.1	1.01	299.1	0.947	2.552	107.768	173.467	0.98

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Avg TDS-35942 mg/l, Temp 28.3C, Rec-44%

Temperature : 28.3 °C Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2391	0	35942	6323	19700	3.53	8.13
2	1065	0	35943	6323	19700	3.53	8.20
3	1065	56.8	35943	6323	19700	3.53	8.20
4	2391	56.8	36588	6438	20054	3.58	8.20
5	2391	56.8	36588	6438	20054	3.58	8.20
6	1340	54.8	65046	11480	35655	5.61	8.25
7	1340	0	63882	11273	35017	5.53	8.25
8	1326	0	35943	6323	19700	3.53	8.20
9	1326	56.8	37107	6529	20338	3.61	8.20
10	1052	1.50	299	12.8	173	0.979	6.88

Calculated by	Laurent MORILLON	
HP Pump flow	1064.67	m3/h
Feed pressure	56.8	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.72	bar
Specific energy	2.11	kwh/m3
Pass NDP	18.1	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%

Feed type Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	553.1	10	7.7	18.8	0.9	22.2	1.03	1.5	0	55.8	137.6	SWC4 MAX	720	240 x 3M
1-1-h	498.1	7.7	5.6	10.2	1	17	1.03	1.5	0	54.8	299.1	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.11	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance(as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	0.58	mg/l

CALCULATION RESULTS

Capital cost	0.00	USD/m3
Power cost	0.42	USD/m3
Chemicals cost	0.00	USD/m3
Membrane replacement costs	0.00	USD/m3
Maintenance	0.00	USD/m3
Total water cost	0.42	USD/m3

400 MLD Perur DSP | Membrane - 3-SWC4MAX & 5 SWC5MAX | Avg TDS-35942 mg/l, Temp 28.3C, Rec 45%

Calculated by	Laurent MORILLON	
HP Pump flow	1063.82	m3/h
Feed pressure	57.4	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.63	bar
Specific energy	2.12	kwh/m3
Pass NDP	18.4	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2337.78	m3/h
Permeate recovery	45.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%

Feed type: Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	561.3	9.7	7.4	19	0.9	22.6	1.03	1.5	0	56.5	136.7	SWC4 MAX	720	240 x 3M
1-1-h	489.7	7.4	5.4	9.9	0.9	16.8	1.03	1.5	0	55.6	303.7	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6440.21	6440.21	13.014	11689.4	11474.75
Ca	467.00	475.64	475.64	0.961	863.3	847.46
Mg	1258.00	1281.27	1281.27	2.589	2325.6	2282.89
Na	11089.00	11292.86	11292.86	109.325	20426.6	20053.06
K	391.00	398.16	398.16	4.815	719.4	706.27
NH4	0.20	0.20	0.20	0.003	0.4	0.35
Ba	0.450	0.458	0.458	0.001	0.8	0.82
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	20.77	24.68	24.68	0.001	63.2	61.63
HCO3	126.30	124.64	124.64	1.964	184.8	182.35
SO4	2878.00	2931.23	2931.23	6.439	5319.9	5222.27
Cl	19700.00	20061.91	20061.91	175.972	36302.9	35638.84
F	1.63	1.66	1.66	0.029	3.0	2.94
NO3	4.00	4.07	4.07	0.264	7.2	7.05
PO4	0.76	0.77	0.77	0.002	1.4	1.38
OH	0.19	0.22	0.22	0.002	0.4	0.36
SiO2	1.38	1.41	1.41	0.009	2.5	2.50
B	3.53	3.58	3.58	0.988	5.7	5.60
CO2	0.44	0.37	0.37	0.37	0.49	0.49
NH3	0.02	0.02	0.02	0.02	0.02	0.02
TDS	**35942.12**	**36602.64**	**36602.64**	**303.36**	**66226.95**	**65015.59**

pH	8.13	8.20	8.20	6.88	8.26	8.26

Saturations	Raw Water	Feed Water	Concentrate	Limits
CaSO4 / ksp * 100, %	25	25	53	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1883	1922	3800	10000
SiO2 saturation, %	1	1	2	140
CaF2 / ksp * 100, %	54	57	504	50000
Ca3(PO4)2 saturation index	0.9	1.0	1.8	2.4
CCPP, mg/l	30.28	30.40	70.78	850
Ionic strength	0.71	0.73	1.31	
Osmotic pressure, bar	26.5	27.0	48.8	

Calculated by	Laurent MORILLON	
HP Pump flow	1063.82	m3/h
Feed pressure	57.4	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.63	bar
Specific energy	2.12	kwh/m3
Pass NDP	18.4	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2337.78	m3/h
Permeate recovery	45.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%

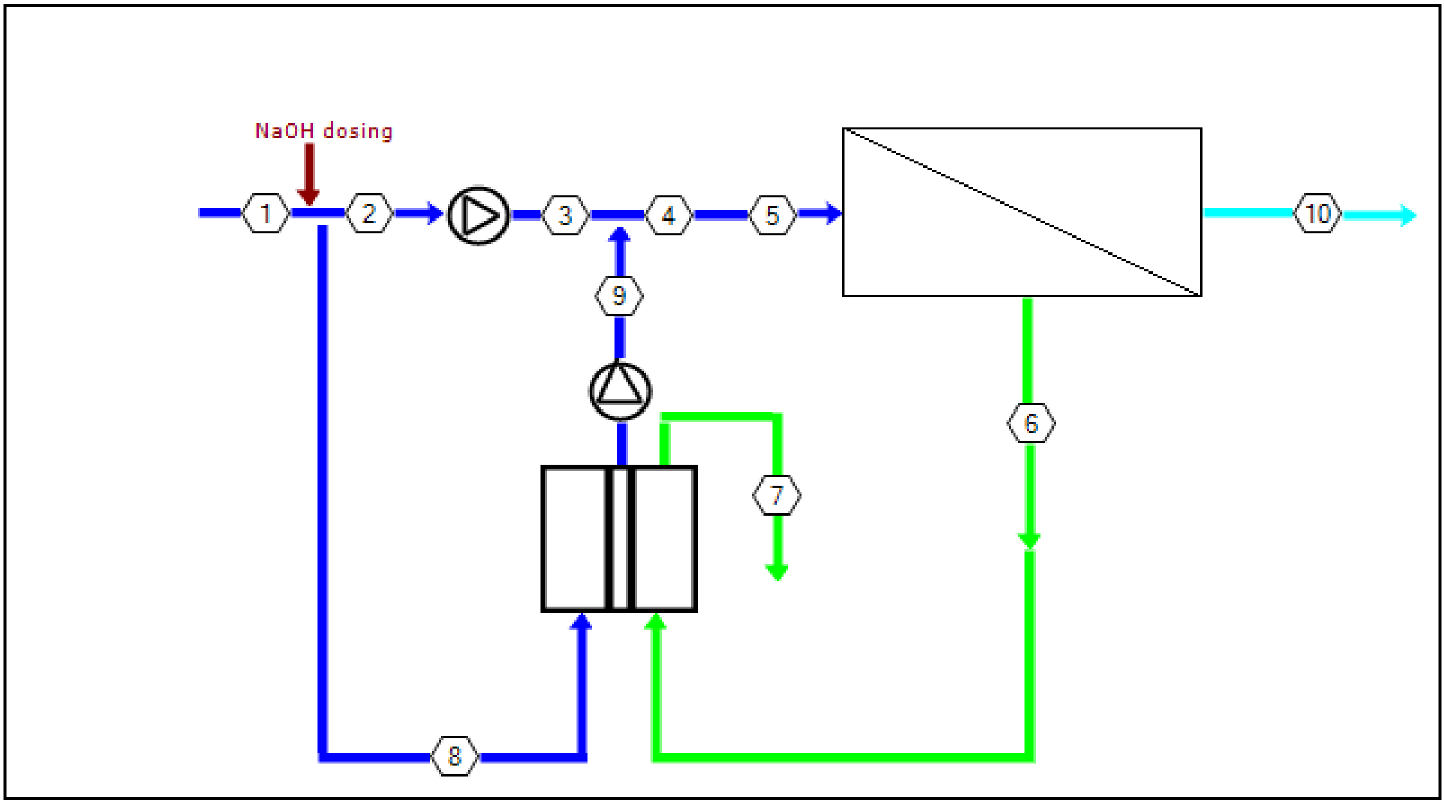
Feed type Sea Surface Conventional

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	561.3	9.7	7.4	19	0.9	22.6	1.03	1.5	0	56.5	136.7	SWC4 MAX	720	240 x 3M
1-1-h	489.7	7.4	5.4	9.9	0.9	16.8	1.03	1.5	0	55.6	303.7	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure	Pressure Drop	Conc Osmo.	NDP	Permeate Water Flow	Permeate Water Flux	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl	B
		bar	bar	bar	bar	m3/h	lmh							
1-1	1	57.4	0.35	29.8	26.7	0.9	22.6	1.03	104.9	0.332	0.894	37.812	60.852	0.343
1-1	2	57	0.3	32.6	23.2	0.8	18.8	1.03	120	0.38	1.023	43.249	69.604	0.391
1-1	3	56.7	0.26	35.5	20.2	0.6	15.6	1.03	136.7	0.433	1.166	49.28	79.311	0.439
1-1	4	56.5	0.23	39.1	16.5	0.7	16.8	1.03	163.8	0.519	1.397	59.041	95.024	0.548
1-1	5	56.3	0.2	42.3	13	0.5	12.4	1.03	194.4	0.616	1.658	70.063	112.766	0.656
1-1	6	56.1	0.18	44.9	10.1	0.4	9.2	1.02	228.2	0.723	1.947	82.229	132.352	0.765
1-1	7	55.9	0.16	47.1	7.8	0.3	6.6	1.02	264.7	0.838	2.258	95.381	153.523	0.876
1-1	8	55.7	0.15	48.8	5.9	0.2	4.8	1.01	303.7	0.962	2.592	109.433	176.146	0.989

Temperature : 28.3 °C

Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2338	0	35942	6323	19700	3.53	8.13
2	1064	0	35943	6323	19700	3.53	8.20
3	1064	57.4	35943	6323	19700	3.53	8.20
4	2338	57.4	36603	6440	20062	3.58	8.20
5	2338	57.4	36603	6440	20062	3.58	8.20
6	1287	55.6	66227	11689	36303	5.69	8.26
7	1287	0	65016	11475	35639	5.60	8.26
8	1274	0	35943	6323	19700	3.53	8.20
9	1274	57.4	37154	6538	20364	3.62	8.20
10	1052	1.50	303	13.0	176	0.988	6.88

Calculated by	Laurent MORILLON	
HP Pump flow	1063.82	m3/h
Feed pressure	57.4	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.20	
Chem dose, mg/l, 50 %	1.2	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.63	bar
Specific energy	2.12	kwh/m3
Pass NDP	18.4	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2337.78	m3/h
Permeate recovery	45.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%

Feed type Sea Surface Conventional

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Flow / Vessel Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Stagewise Pressure Boost	Stagewise Pressure Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	561.3	9.7	7.4	19	0.9	22.6	1.03	1.5	0	56.5	136.7	SWC4 MAX	720	240 x 3M
1-1-h	489.7	7.4	5.4	9.9	0.9	16.8	1.03	1.5	0	55.6	303.7	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.12	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance(as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	0.58	mg/l

CALCULATION RESULTS

Capital cost	0.00	USD/m3
Power cost	0.42	USD/m3
Chemicals cost	0.00	USD/m3
Membrane replacement costs	0.00	USD/m3
Maintenance	0.00	USD/m3
Total water cost	0.42	USD/m3

400 MLD Perur DSP Membrane - 3-SWC4MAX & 5 SWC5MAX Avg TDS-35942 mg/l, Temp 28.3C – Rec 46%

Calculated by	Laurent MORILLON	
HP Pump flow	1063.42	m3/h
Feed pressure	58.1	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.25	
Chem dose, mg/l, 50 %	2.0	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.55	bar
Specific energy	2.13	kwh/m3
Pass NDP	18.8	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	570.7	9.5	7.2	19.4	0.9	23.1	1.04	1.5	0	57.2	135.4	SWC4 MAX	720	240 x 3M
1-1-h	480.3	7.2	5.1	9.8	0.9	16.8	1.04	1.5	0	56.3	308.3	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6442.81	6442.81	13.219	11910.8	11687.32
Ca	467.00	475.83	475.83	0.976	879.7	863.16
Mg	1258.00	1281.79	1281.79	2.630	2369.6	2325.18
Na	11089.00	11297.63	11297.63	111.038	20811.1	20422.26
K	391.00	398.32	398.32	4.890	732.9	719.22
NH4	0.20	0.20	0.20	0.003	0.4	0.35
Ba	0.450	0.459	0.459	0.001	0.8	0.83
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	20.77	27.14	27.14	0.001	69.3	67.62
HCO3	126.30	122.21	122.21	1.956	180.4	178.04
SO4	2878.00	2932.42	2932.42	6.541	5420.7	5319.00
Cl	19700.00	20069.93	20069.93	178.751	36986.2	36294.73
F	1.63	1.66	1.66	0.030	3.0	2.99
NO3	4.00	4.07	4.07	0.268	7.3	7.17
PO4	0.76	0.77	0.77	0.002	1.4	1.40
OH	0.19	0.25	0.25	0.002	0.4	0.41
SiO2	1.38	1.41	1.41	0.010	2.6	2.54
B	3.53	3.58	3.58	0.955	5.8	5.72
CO2	0.44	0.33	0.33	0.33	0.44	0.43
NH3	0.02	0.02	0.02	0.02	0.02	0.02
TDS	**35942.12**	**36617.50**	**36617.50**	**308.05**	**67471.56**	**66210.43**

pH	**8.13**	**8.25**	**8.25**	**6.94**	**8.30**	**8.30**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	25	25	54	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1883	1923	3882	10000
SiO2 saturation, %	1	1	2	140
CaF2 / ksp * 100, %	54	57	545	50000
Ca3(PO4)2 saturation index	0.9	1.0	1.9	2.4
CCPP, mg/l	30.28	29.79	69.27	850
Ionic strength	0.71	0.73	1.34	
Osmotic pressure, bar	26.5	27.0	49.7	

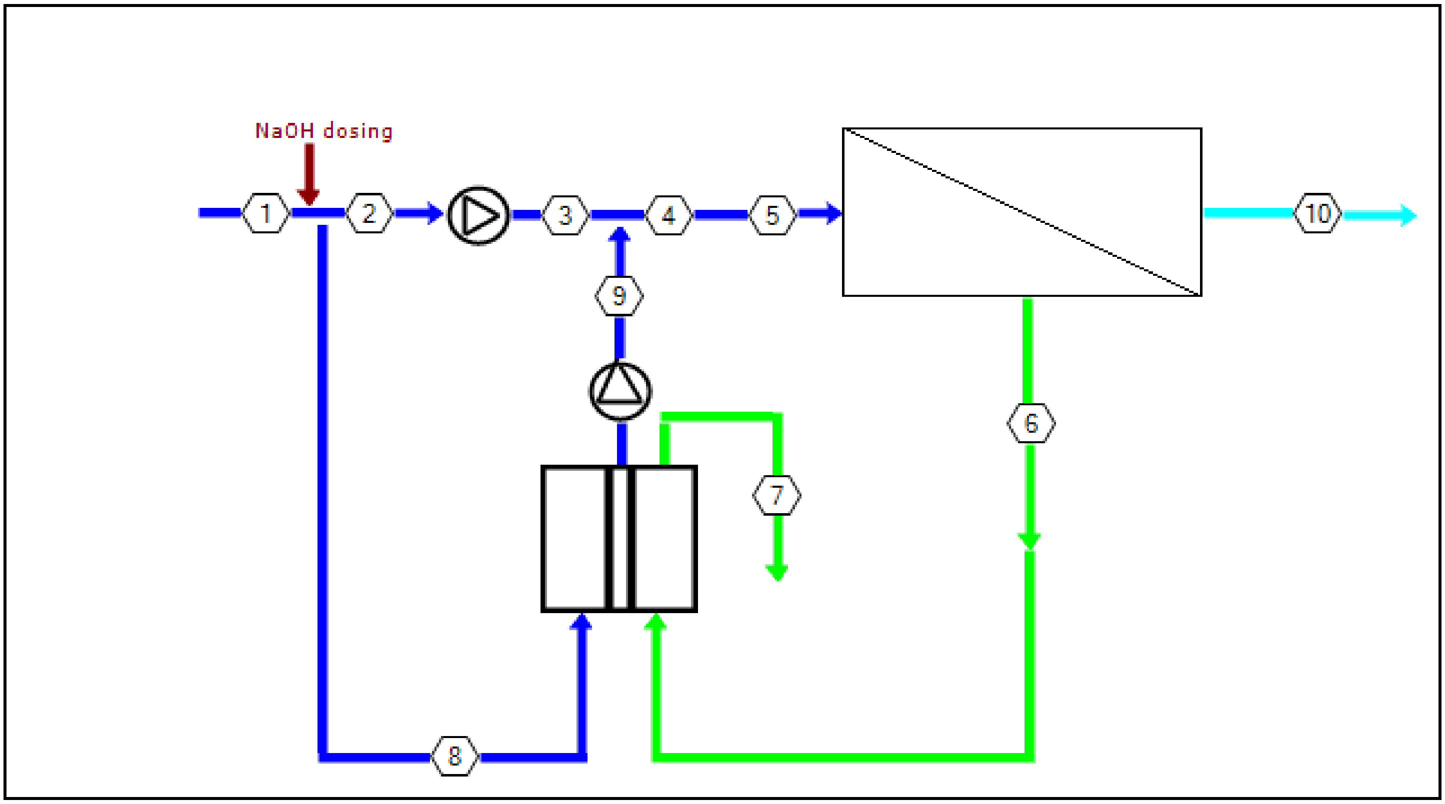
Calculated by	Laurent MORILLON	Permeate flow/train	1052.00 m3/h
HP Pump flow	1063.42 m3/h	Total product flow	16832.00 m3/h
Feed pressure	58.1 bar	Number of trains	16
Feed temperature	28.3 °C(82.9°F)	Raw water flow/train	2286.96 m3/h
Feed water pH	8.25	Permeate recovery	46.00 %
Chem dose, mg/l, 50 %	2.0 NaOH	Element age	3.5 years
Leakage	1 %	Flux decline %, per year	7.0
Volumetric mixing	4 %	Fouling factor	0.78
H.P. differential	0.80 bar	SP increase, per year	10.0 %
Boost pressure	2.55 bar		
Specific energy	2.13 kwh/m3		
Pass NDP	18.8 bar		
Average flux rate	13.4 lmh	Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	570.7	9.5	7.2	19.4	0.9	23.1	1.04	1.5	0	57.2	135.4	SWC4 MAX	720	240 x 3M
1-1-h	480.3	7.2	5.1	9.8	0.9	16.8	1.04	1.5	0	56.3	308.3	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl	B
1-1	1	58.1	0.33	29.9	27.3	0.9	23.1	1.04	103.2	0.327	0.88	37.202	59.878	0.325
1-1	2	57.7	0.29	33	23.8	0.8	19.4	1.03	118.1	0.374	1.007	42.573	68.524	0.37
1-1	3	57.4	0.25	35.9	20.4	0.6	15.8	1.03	135.4	0.429	1.155	48.821	78.581	0.418
1-1	4	57.2	0.22	39.7	16.6	0.7	16.8	1.04	163.5	0.518	1.394	58.918	94.835	0.525
1-1	5	57	0.19	43	12.9	0.5	12.2	1.03	195.2	0.618	1.665	70.343	113.23	0.63
1-1	6	56.8	0.17	45.8	10	0.4	8.8	1.02	230.2	0.729	1.964	82.962	133.546	0.737
1-1	7	56.6	0.15	48	7.6	0.3	6.5	1.02	268	0.849	2.287	96.59	155.487	0.846
1-1	8	56.5	0.14	49.7	5.7	0.2	4.6	1.01	308.3	0.977	2.632	111.137	178.91	0.956

400 MLD Perur DSP   Membrane - 3-SWC4MAX & 5 SWC5MAX   Avg TDS-35942 mg/l, Temp 28.3C – Rec 46%

Temperature : 28.3 °C   Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2287	0	35942	6323	19700	3.53	8.13
2	1063	0	35943	6323	19700	3.53	8.25
3	1063	58.1	35943	6323	19700	3.53	8.25
4	2287	58.1	36618	6443	20070	3.58	8.25
5	2287	58.1	36618	6443	20070	3.58	8.25
6	1236	56.3	67472	11911	36986	5.81	8.30
7	1236	0	66210	11687	36295	5.72	8.30
8	1224	0	35943	6323	19700	3.53	8.25
9	1224	58.1	37204	6547	20391	3.62	8.25
10	1052	1.50	308	13.2	179	0.955	6.94

Calculated by	Laurent MORILLON		Permeate flow/train	1052.00	m3/h
HP Pump flow	1063.42	m3/h	Total product flow	16832.00	m3/h
Feed pressure	58.1	bar	Number of trains	16	
Feed temperature	28.3	°C(82.9°F)	Raw water flow/train	2286.96	m3/h
Feed water pH	8.25		Permeate recovery	46.00	%
Chem dose, mg/l, 50 %	2.0	NaOH	Element age	3.5	years
Leakage	1	%	Flux decline %, per year	7.0	
Volumetric mixing	4	%	Fouling factor	0.78	
H.P. differential	0.80	bar	SP increase, per year	10.0	%
Boost pressure	2.55	bar			
Specific energy	2.13	kwh/m3			
Pass NDP	18.8	bar			
Average flux rate	13.4	lmh			
			Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	570.7	9.5	7.2	19.4	0.9	23.1	1.04	1.5	0	57.2	135.4	SWC4 MAX	720	240 x 3M
1-1-h	480.3	7.2	5.1	9.8	0.9	16.8	1.04	1.5	0	56.3	308.3	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.13	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance (as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	1.01	mg/l

CALCULATION RESULTS

Capital cost		0.00	USD/m3
Power cost		0.43	USD/m3
Chemicals cost		0.00	USD/m3
Membrane replacement costs		0.00	USD/m3
Maintenance		0.00	USD/m3
Total water cost	0.43		USD/m3

400 MLD Perur DSP | Membrane – 3 SWC4MAX & 5 SWC5MAX | Avg TDS-39000 mg/l, Temp 31.5C, Rec 44%

Calculated by	Laurent MORILLON	
HP Pump flow	1064.52	m3/h
Feed pressure	61.0	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.69	bar
Specific energy	2.25	kwh/m3
Pass NDP	18.6	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	586.1	10	7.5	19.9	0.9	24.1	1.04	1.5	0	60.1	162.8	SWC4 MAX	720	240 x 3M
1-1-h	465	7.5	5.6	9.5	1	16.6	1.03	1.5	0	59.1	374.1	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6437.60	6437.60	14.589	11476.8	11270.61
Ca	467.00	475.45	475.45	1.077	847.6	832.39
Mg	1258.00	1280.75	1280.75	2.903	2283.3	2242.27
Na	12299.00	12521.74	12521.74	135.924	22238.9	21841.42
K	391.00	397.99	397.99	5.397	706.0	693.39
NH4	0.20	0.18	0.18	0.003	0.3	0.31
Ba	0.450	0.458	0.458	0.001	0.8	0.80
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	18.46	39.90	39.90	0.002	83.0	81.24
HCO3	126.30	106.87	106.87	1.907	144.3	142.78
SO4	2878.00	2930.04	2930.04	7.288	5223.1	5129.27
Cl	21560.00	21946.88	21946.88	217.971	38994.1	38296.76
F	1.63	1.66	1.66	0.033	2.9	2.88
NO3	4.00	4.07	4.07	0.298	7.0	6.90
PO4	0.76	0.77	0.77	0.002	1.4	1.35
OH	0.19	0.49	0.49	0.004	0.7	0.73
SiO2	1.38	1.40	1.40	0.011	2.5	2.45
B	3.80	3.85	3.85	0.962	6.1	6.03
CO2	0.56	0.19	0.19	0.19	0.26	0.26
NH3	0.02	0.04	0.04	0.04	0.04	0.04
TDS	**39010.08**	**39712.11**	**39712.11**	**373.78**	**70541.61**	**69280.45**

pH	**8.00**	**8.40**	**8.40**	**7.15**	**8.42**	**8.42**

Saturations	Raw Water	Feed Water	Concentrate	Limits
CaSO4 / ksp * 100, %	23	23	48	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1771	1807	3500	10000
SiO2 saturation, %	1	1	1	140
CaF2 / ksp * 100, %	55	58	507	50000
Ca3(PO4)2 saturation index	0.8	1.3	2.1	2.4
CCPP, mg/l	29.44	25.03	50.95	850
Ionic strength	0.76	0.78	1.39	
Osmotic pressure, bar	29.3	29.8	52.9	

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Avg TDS-39000 mg/l, Temp 31.5C, Rec 44%

Calculated by	Laurent MORILLON	
HP Pump flow	1064.52	m3/h
Feed pressure	61.0	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.69	bar
Specific energy	2.25	kwh/m3
Pass NDP	18.6	bar
Average flux rate	13.4	lmh

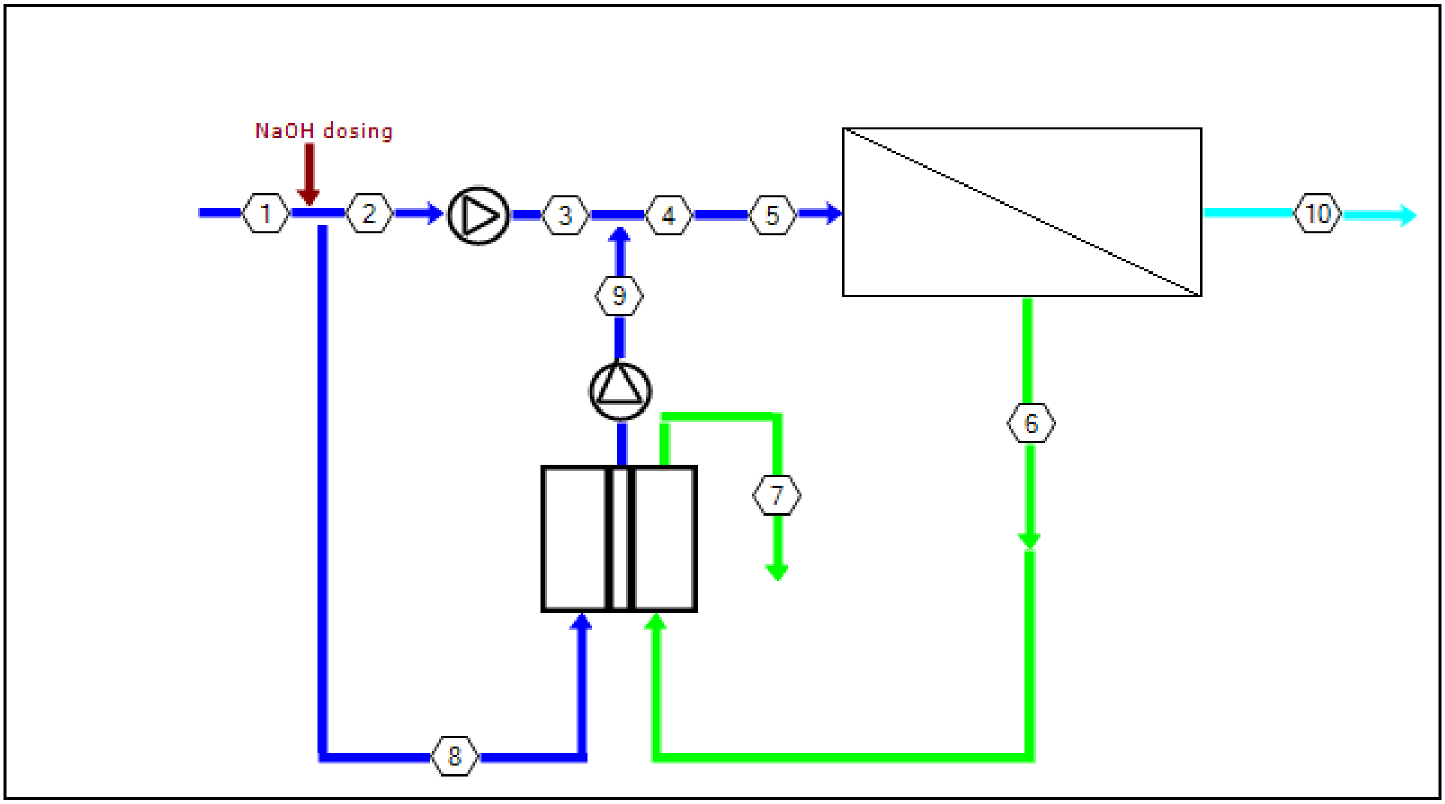
Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	586.1	10	7.5	19.9	0.9	24.1	1.04	1.5	0	60.1	162.8	SWC4 MAX	720	240 x 3M
1-1-h	465	7.5	5.6	9.5	1	16.6	1.03	1.5	0	59.1	374.1	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure	Pressure Drop	Conc Osmo.	NDP	Permeate Water Flow	Permeate Water Flux	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
		bar	bar	bar	bar	m3/h	lmh						
1-1	1	61	0.36	33	27.2	1	24.1	1.04	122.1	0.352	0.947	44.415	71.213
1-1	2	60.7	0.31	36.3	23.4	0.8	19.7	1.03	141	0.406	1.093	51.27	82.206
1-1	3	60.3	0.27	39.4	19.9	0.6	15.8	1.03	162.8	0.469	1.263	59.206	94.931
1-1	4	60.1	0.24	43.3	15.9	0.7	16.6	1.03	197.7	0.569	1.534	71.885	115.265
1-1	5	59.8	0.21	46.6	12.3	0.5	11.9	1.03	236.8	0.682	1.837	86.112	138.081
1-1	6	59.6	0.19	49.2	9.4	0.3	8.5	1.02	279.6	0.806	2.17	101.677	163.043
1-1	7	59.4	0.17	51.3	7.2	0.2	6.1	1.02	325.5	0.938	2.527	118.351	189.786
1-1	8	59.3	0.16	52.9	5.4	0.2	4.4	1.01	374.1	1.078	2.905	136.037	218.153

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Avg TDS-39000 mg/l, Temp 31.5C, Rec 44%

Temperature : 31.5 °C Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2391	0	39010	6323	21560	3.80	8.00
2	1065	0	39012	6323	21560	3.80	8.40
3	1065	61.0	39012	6323	21560	3.80	8.40
4	2391	61.0	39712	6438	21947	3.85	8.40
5	2391	61.0	39712	6438	21947	3.85	8.40
6	1340	59.1	70542	11477	38994	6.12	8.42
7	1340	0	69280	11271	38297	6.03	8.42
8	1326	0	39012	6323	21560	3.80	8.40
9	1326	61.0	40274	6529	22257	3.89	8.40
10	1052	1.50	374	14.6	218	0.962	7.15

Calculated by	Laurent MORILLON	
HP Pump flow	1064.52	m3/h
Feed pressure	61.0	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.69	bar
Specific energy	2.25	kwh/m3
Pass NDP	18.6	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2390.91	m3/h
Permeate recovery	44.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	586.1	10	7.5	19.9	0.9	24.1	1.04	1.5	0	60.1	162.8	SWC4 MAX	720	240 x 3M
1-1-h	465	7.5	5.6	9.5	1	16.6	1.03	1.5	0	59.1	374.1	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.25	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance(as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	3.86	mg/l

CALCULATION RESULTS

Capital cost	0.00	USD/m3
Power cost	0.45	USD/m3
Chemicals cost	0.00	USD/m3
Membrane replacement costs	0.00	USD/m3
Maintenance	0.00	USD/m3
Total water cost	0.45	USD/m3

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Max TDS-39000 mg/l, Temp 31.5C, Rec 45%

Calculated by	Laurent MORILLON	
HP Pump flow	1064.44	m3/h
Feed pressure	61.8	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.60	bar
Specific energy	2.27	kwh/m3
Pass NDP	19.0	bar
Average flux rate	13.4	lmh

Permeate flow/train	***1052.00***	***m3/h***
Total product flow	***16832.00***	***m3/h***
Number of trains	***16***	
Raw water flow/train	***2337.78***	***m3/h***
Permeate recovery	***45.00***	***%***
Element age	***3.5***	***years***
Flux decline %, per year	***7.0***	
Fouling factor	***0.78***	
SP increase, per year	***10.0***	***%***

Feed type *Sea Surface Conventional*

Pass - Stage	***Perm. Flow m3/h***	***Flow / Vessel Feed m3/h***	***Flow / Vessel Conc m3/h***	***Flux lmh***	***DP bar***	***Flux Max lmh***	***Beta***	***Stagewise Pressure Perm. bar***	***Stagewise Pressure Boost bar***	***Stagewise Pressure Conc bar***	***Perm. TDS mg/l***	***Element Type***	***Element Quantity***	***PV# x Elem #***
1-1-h	***595.8***	***9.7***	***7.3***	***20.3***	***0.9***	***24.8***	***1.04***	***1.5***	***0***	***60.9***	***161.6***	***SWC4 MAX***	***720***	***240 x 3M***
1-1-h	***455.8***	***7.3***	***5.4***	***9.2***	***0.9***	***16.5***	***1.03***	***1.5***	***0***	***60***	***379.9***	***SWC5 MAX***	***1200***	***240 x 5M***

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6440.24	6440.24	14.824	11693.6	11478.73
Ca	467.00	475.64	475.64	1.095	863.6	847.76
Mg	1258.00	1281.28	1281.28	2.949	2326.4	2283.68
Na	12299.00	12526.81	12526.81	138.096	22655.6	22241.39
K	391.00	398.15	398.15	5.483	719.2	706.06
NH4	0.20	0.18	0.18	0.003	0.3	0.31
Ba	0.450	0.458	0.458	0.001	0.8	0.82
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	18.46	39.93	39.93	0.002	85.5	83.63
HCO3	126.30	106.87	106.87	1.936	145.2	143.62
SO4	2878.00	2931.24	2931.24	7.405	5321.7	5223.97
Cl	21560.00	21955.77	21955.77	221.455	39725.3	38998.71
F	1.63	1.66	1.66	0.033	3.0	2.93
NO3	4.00	4.07	4.07	0.303	7.1	7.02
PO4	0.76	0.77	0.77	0.002	1.4	1.38
OH	0.19	0.49	0.49	0.004	0.8	0.75
SiO2	1.38	1.41	1.41	0.011	2.5	2.50
B	3.80	3.85	3.85	0.969	6.2	6.11
CO2	0.56	0.19	0.19	0.19	0.26	0.26
NH3	0.02	0.04	0.04	0.04	0.04	0.04
TDS	**39010.08**	**39728.20**	**39728.20**	**379.74**	**71864.15**	**70550.08**

pH	8.00	8.40	8.40	7.16	8.43	8.43

Saturations	*Raw Water*	*Feed Water*	*Concentrate*	*Limits*
*CaSO4 / ksp * 100, %*	*23*	*23*	*50*	*400*
*SrSO4 / ksp * 100, %*	*0*	*0*	*1*	*1200*
*BaSO4 / ksp * 100, %*	*1771*	*1807*	*3576*	*10000*
SiO2 saturation, %	*1*	*1*	*1*	*140*
*CaF2 / ksp * 100, %*	*55*	*58*	*549*	*50000*
Ca3(PO4)2 saturation index	*0.8*	*1.3*	*2.1*	*2.4*
CCPP, mg/l	*29.44*	*25.04*	*51.79*	*850*
Ionic strength	*0.76*	*0.78*	*1.41*	
Osmotic pressure, bar	*29.3*	*29.8*	*53.9*	

400 MLD Perur DSP | Membrane – 3 SWC4MAX & 5 SWC5MAX | Max TDS-39000 mg/l, Temp 31.5C, Rec 45%

Calculated by	Laurent MORILLON	
HP Pump flow	1064.44	m3/h
Feed pressure	61.8	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.60	bar
Specific energy	2.27	kwh/m3
Pass NDP	19.0	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2337.78	m3/h
Permeate recovery	45.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

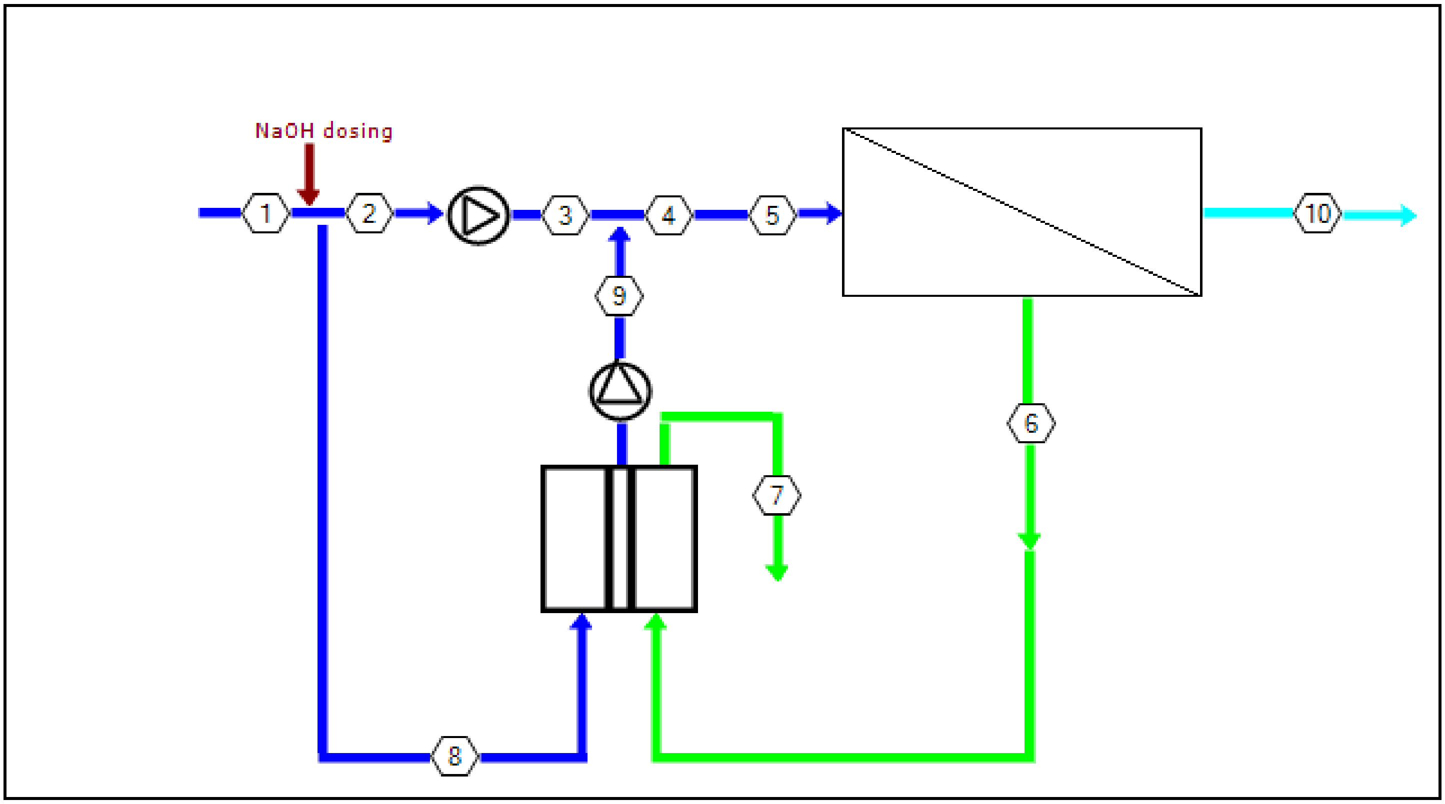
Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	595.8	9.7	7.3	20.3	0.9	24.8	1.04	1.5	0	60.9	161.6	SWC4 MAX	720	240 x 3M
1-1-h	455.8	7.3	5.4	9.2	0.9	16.5	1.03	1.5	0	60	379.9	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	61.8	0.35	33.2	27.8	1	24.8	1.04	120	0.345	0.93	43.634	69.961
1-1	2	61.4	0.29	36.6	23.9	0.8	20	1.03	139.2	0.401	1.08	50.633	81.184
1-1	3	61.1	0.26	39.9	20.2	0.7	16	1.03	161.6	0.465	1.254	58.776	94.241
1-1	4	60.9	0.23	44	16.1	0.7	16.5	1.03	197.6	0.569	1.533	71.842	115.195
1-1	5	60.7	0.2	47.4	12.4	0.5	11.7	1.03	237.8	0.685	1.845	86.471	138.656
1-1	6	60.5	0.18	50.2	9.3	0.3	8.1	1.02	282.2	0.813	2.19	102.608	164.536
1-1	7	60.3	0.16	52.3	7	0.2	5.8	1.02	329.7	0.95	2.559	119.867	192.218
1-1	8	60.1	0.15	53.9	5.3	0.2	4.1	1.01	379.9	1.095	2.95	138.151	221.544

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Max TDS-39000 mg/l, Temp 31.5C, Rec 45%

Temperature : 31.5 °C

Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2338	0	39010	6323	21560	3.80	8.00
2	1064	0	39012	6323	21560	3.80	8.40
3	1064	61.8	39012	6323	21560	3.80	8.40
4	2338	61.8	39728	6440	21956	3.85	8.40
5	2338	61.8	39728	6440	21956	3.85	8.40
6	1286	60.0	71864	11694	39725	6.21	8.43
7	1286	0	70550	11479	38999	6.11	8.43
8	1273	0	39012	6323	21560	3.80	8.40
9	1273	61.8	40327	6538	22287	3.90	8.40
10	1052	1.50	380	14.8	221	0.969	7.16

Calculated by	Laurent MORILLON	
HP Pump flow	1064.44	m3/h
Feed pressure	61.8	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.60	bar
Specific energy	2.27	kwh/m3
Pass NDP	19.0	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2337.78	m3/h
Permeate recovery	45.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Boost bar	Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	595.8	9.7	7.3	20.3	0.9	24.8	1.04	1.5	0	60.9	161.6	SWC4 MAX	720	240 x 3M
1-1-h	455.8	7.3	5.4	9.2	0.9	16.5	1.03	1.5	0	60	379.9	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.27	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance(as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	3.86	mg/l

CALCULATION RESULTS

Capital cost	0.00	USD/m3
Power cost	0.45	USD/m3
Chemicals cost	0.00	USD/m3
Membrane replacement costs	0.00	USD/m3
Maintenance	0.00	USD/m3
Total water cost	0.45	USD/m3

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400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Max TDS-39000 mg/l, Temp 31.5C, Rec 46%

Calculated by	Laurent MORILLON		Permeate flow/train	1052.00 m3/h
HP Pump flow	1063.71	m3/h	Total product flow	16832.00 m3/h
Feed pressure	62.6	bar	Number of trains	16
Feed temperature	31.5	°C(88.7°F)	Raw water flow/train	2286.96 m3/h
Feed water pH	8.40		Permeate recovery	46.00 %
Chem dose, mg/l, 50 %	7.7	NaOH	Element age	3.5 years
Leakage	1	%	Flux decline %, per year	7.0
Volumetric mixing	4	%	Fouling factor	0.78
H.P. differential	0.80	bar	SP increase, per year	10.0 %
Boost pressure	2.52	bar		
Specific energy	2.29	kwh/m3		
Pass NDP	19.4	bar		
Average flux rate	13.4	lmh		
			Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	605.4	9.5	7	20.6	0.9	25.3	1.04	1.5	0	61.7	160.6	SWC4 MAX	720	240 x 3M
1-1-h	445.9	7	5.1	9.1	0.9	16.5	1.04	1.5	0	60.8	386.2	SWC5 MAX	1200	240 x 5M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6442.81	6442.81	15.066	11912.1	11688.58
Ca	467.00	475.83	475.83	1.113	879.8	863.26
Mg	1258.00	1281.79	1281.79	2.997	2369.9	2325.43
Na	12299.00	12531.74	12531.74	140.342	23075.4	22644.45
K	391.00	398.31	398.31	5.572	732.5	718.82
NH4	0.20	0.18	0.18	0.003	0.3	0.32
Ba	0.450	0.459	0.459	0.001	0.8	0.83
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	18.46	39.97	39.97	0.002	88.1	86.11
HCO3	126.30	106.87	106.87	1.967	146.1	144.46
SO4	2878.00	2932.41	2932.41	7.526	5421.2	5319.45
Cl	21560.00	21964.42	21964.42	225.058	40462.2	39706.12
F	1.63	1.66	1.66	0.034	3.0	2.99
NO3	4.00	4.07	4.07	0.308	7.3	7.14
PO4	0.76	0.77	0.77	0.002	1.4	1.40
OH	0.19	0.49	0.49	0.004	0.8	0.78
SiO2	1.38	1.41	1.41	0.011	2.6	2.54
B	3.80	3.85	3.85	0.977	6.3	6.20
CO2	0.56	0.19	0.19	0.19	0.26	0.26
NH3	0.02	0.04	0.04	0.04	0.04	0.04
TDS	**39010.08**	**39743.83**	**39743.83**	**385.91**	**73197.09**	**71829.71**

pH	8.00	8.40	8.40	7.16	8.44	8.44

Saturations	Raw Water	Feed Water	Concentrate	Limits
$CaSO_4$ / ksp * 100, %	23	23	51	400
$SrSO_4$ / ksp * 100, %	0	0	1	1200
$BaSO_4$ / ksp * 100, %	1771	1808	3652	10000
SiO_2 saturation, %	1	1	1	140
CaF_2 / ksp * 100, %	55	59	594	50000
$Ca_3(PO_4)_2$ saturation index	0.8	1.3	2.2	2.4
CCPP, mg/l	29.44	25.04	52.65	850
Ionic strength	0.76	0.78	1.44	
Osmotic pressure, bar	29.3	29.8	54.9	

400 MLD Perur DSP   Membrane – 3 SWC4MAX & 5 SWC5MAX   Max TDS-39000 mg/l, Temp 31.5C, Rec 46%

Calculated by	Laurent MORILLON	
HP Pump flow	1063.71	m3/h
Feed pressure	62.6	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.52	bar
Specific energy	2.29	kwh/m3
Pass NDP	19.4	bar
Average flux rate	13.4	lmh

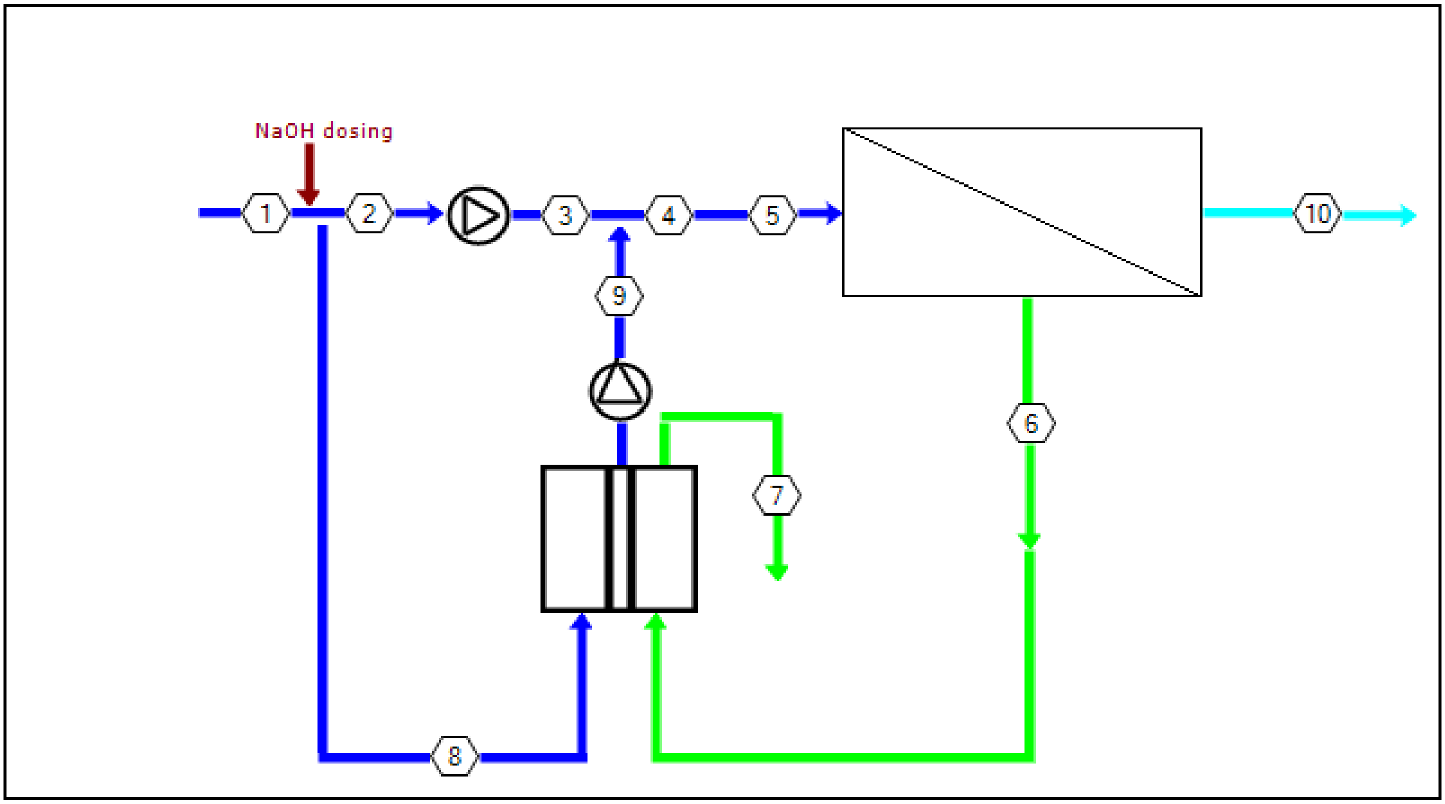
Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1-h	605.4	9.5	7	20.6	0.9	25.3	1.04	1.5	0	61.7	160.6	SWC4 MAX	720	240 x 3M
1-1-h	445.9	7	5.1	9.1	0.9	16.5	1.04	1.5	0	60.8	386.2	SWC5 MAX	1200	240 x 5M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	62.6	0.33	33.4	28.5	1	25.3	1.04	117.9	0.339	0.914	42.872	68.74
1-1	2	62.2	0.28	37	24.3	0.8	20.4	1.03	137.6	0.396	1.067	50.021	80.204
1-1	3	61.9	0.24	40.5	20.5	0.7	16.1	1.03	160.6	0.462	1.245	58.382	93.611
1-1	4	61.7	0.21	44.7	16.2	0.7	16.5	1.04	197.6	0.569	1.533	71.853	115.214
1-1	5	61.5	0.18	48.3	12.3	0.5	11.5	1.03	239.2	0.689	1.856	86.981	139.475
1-1	6	61.3	0.17	51.1	9.2	0.3	8	1.02	285.2	0.822	2.213	103.689	166.271
1-1	7	61.1	0.15	53.3	6.9	0.2	5.6	1.02	334.2	0.963	2.595	121.537	194.897
1-1	8	61	0.14	54.9	5.1	0.2	3.9	1.01	386.2	1.113	2.999	140.427	225.194

400 MLD Perur DSP Membrane – 3 SWC4MAX & 5 SWC5MAX Max TDS-39000 mg/l, Temp 31.5C, Rec 46%

Temperature : 31.5 °C Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2287	0	39010	6323	21560	3.80	8.00
2	1064	0	39012	6323	21560	3.80	8.40
3	1064	62.6	39012	6323	21560	3.80	8.40
4	2287	62.6	39744	6443	21964	3.85	8.40
5	2287	62.6	39744	6443	21964	3.85	8.40
6	1236	60.8	73197	11912	40462	6.30	8.44
7	1236	0	71830	11689	39706	6.20	8.44
8	1223	0	39012	6323	21560	3.80	8.40
9	1223	62.6	40380	6547	22316	3.90	8.40
10	1052	1.50	386	15.1	225	0.977	7.16

Calculated by	Laurent MORILLON	
HP Pump flow	1063.71	m3/h
Feed pressure	62.6	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.40	
Chem dose, mg/l, 50 %	7.7	NaOH
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.52	bar
Specific energy	2.29	kwh/m3
Pass NDP	19.4	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1-h	605.4	9.5	7	20.6	0.9	25.3	1.04	1.5	0	61.7	160.6	SWC4 MAX	720	240 x 3M
1-1-h	445.9	7	5.1	9.1	0.9	16.5	1.04	1.5	0	60.8	386.2	SWC5 MAX	1200	240 x 5M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00	m3/h
Specific investment	22,151.90	USD/m3/h
Investment	000.00	USD
Plant life	15.0	years
Membrane life	5.0	years
Interest rate	4.5	%
Membrane cost	500.00	USD/element
Plant factor	90.0	%
Number of elements	1920.0	
Power cost	0.200	USD/kwhr
Inhibitor cost	2.20	
Power consumption	2.29	kwhr/m3
Inhibitor dosing	3.0	mg/l
Maintenance(as % of investment)	3.0	%
Acid cost	1.50	
Acid dosing	3.86	mg/l

CALCULATION RESULTS

Capital cost	0.00	USD/m3
Power cost	0.46	USD/m3
Chemicals cost	0.00	USD/m3
Membrane replacement costs	0.00	USD/m3
Maintenance	0.00	USD/m3
Total water cost	0.46	USD/m3

Calculated by	Laurent MORILLON	
HP Pump flow	1063.61	m3/h
Feed pressure	65.2	bar
Feed temperature	31.5	°C(88.7°F)
Feed water pH	8.00	
Chem dose, mg/l, -	None	
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.50	bar
Specific energy	2.38	kwh/m3
Pass NDP	22.1	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1051.3	9.5	5.1	13.4	1.7	27.3	1.04	1.5	0	63.5	307	SWC4 MAX	1920	240 x 8M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6442.86	6442.86	11.959	11913.9	11690.25
Ca	467.00	475.83	475.83	0.883	879.9	863.38
Mg	1258.00	1281.80	1281.80	2.379	2370.3	2325.76
Na	12299.00	12530.00	12530.00	111.437	23094.9	22663.05
K	391.00	398.33	398.33	4.426	733.4	719.73
NH4	0.20	0.20	0.20	0.003	0.4	0.36
Ba	0.450	0.459	0.459	0.001	0.8	0.83
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	18.46	19.29	19.29	0.001	57.5	55.95
HCO3	126.30	127.78	127.78	1.867	195.5	192.76
SO4	2878.00	2932.44	2932.44	5.969	5422.1	5320.33
Cl	21560.00	21965.26	21965.26	178.552	40500.0	39742.37
F	1.63	1.66	1.66	0.027	3.1	2.99
NO3	4.00	4.07	4.07	0.245	7.3	7.19
PO4	0.76	0.77	0.77	0.002	1.4	1.40
OH	0.19	0.20	0.20	0.001	0.4	0.38
SiO2	1.38	1.41	1.41	0.009	2.6	2.55
B	3.80	3.85	3.85	0.987	6.3	6.19
CO2	0.56	0.56	0.56	0.56	0.72	0.71
NH3	0.02	0.02	0.02	0.02	0.02	0.02
TDS	**39010.08**	**39743.26**	**39743.26**	**306.79**	**73275.66**	**71905.04**

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pH	**8.00**	**8.00**	**8.00**	**6.67**	**8.13**	**8.13**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	23	23	51	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1771	1809	3653	10000
SiO2 saturation, %	1	1	2	140
CaF2 / ksp * 100, %	55	59	597	50000
Ca3(PO4)2 saturation index	0.8	0.8	1.8	2.4
CCPP, mg/l	29.44	30.32	76.10	850
Ionic strength	0.76	0.78	1.44	
Osmotic pressure, bar	29.3	29.8	55.0	

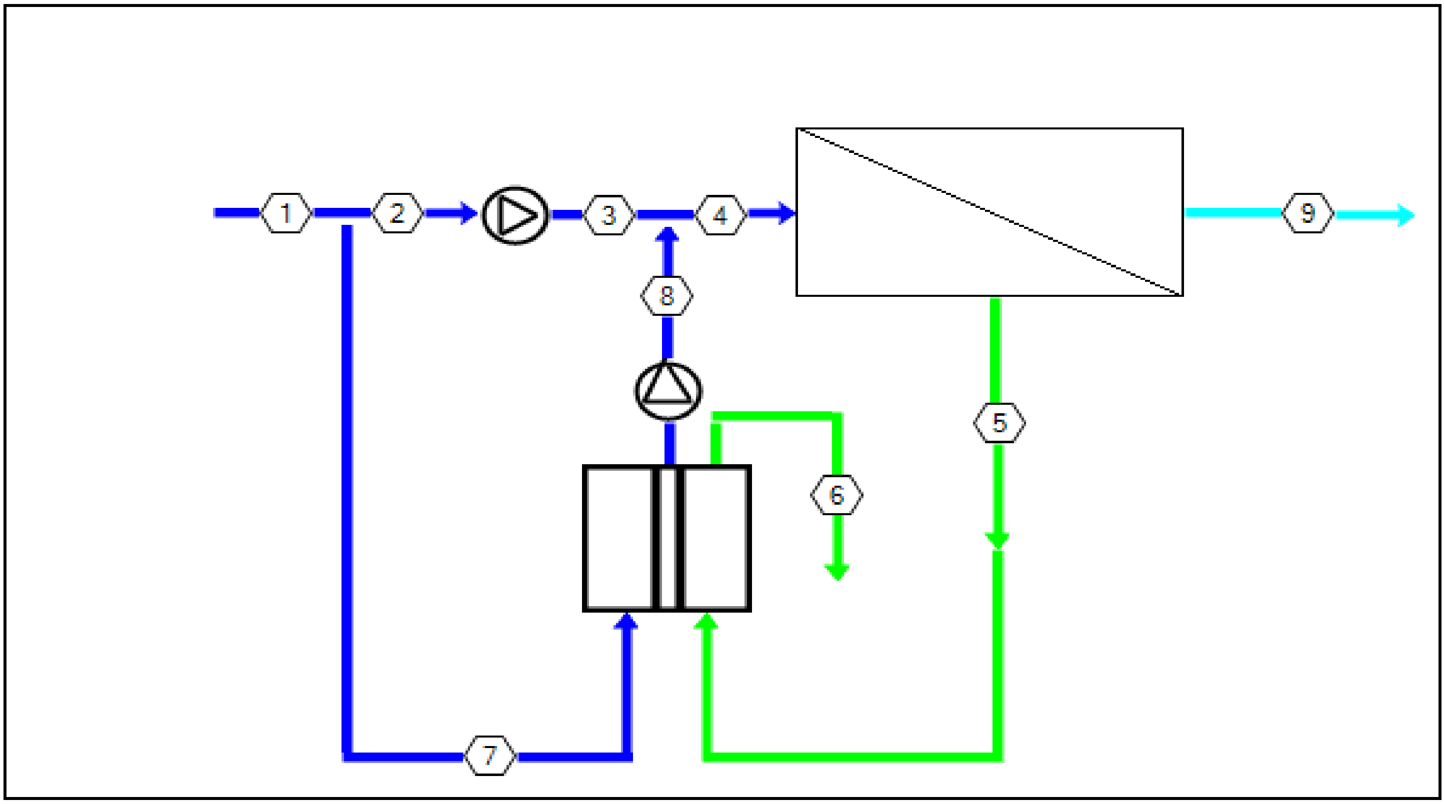
Calculated by	Laurent MORILLON	Permeate flow/train	1052.00 m3/h
HP Pump flow	1063.61 m3/h	Total product flow	16832.00 m3/h
Feed pressure	65.2 bar	Number of trains	16
Feed temperature	31.5 °C(88.7°F)	Raw water flow/train	2286.96 m3/h
Feed water pH	8.00	Permeate recovery	46.00 %
Chem dose, mg/l, -	None	Element age	3.5 years
Leakage	1 %	Flux decline %, per year	7.0
Volumetric mixing	4 %	Fouling factor	0.78
H.P. differential	0.80 bar	SP increase, per year	10.0 %
Boost pressure	2.50 bar		
Specific energy	2.38 kwh/m3		
Pass NDP	22.1 bar		
Average flux rate	13.4 lmh	Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1051.3	9.5	5.1	13.4	1.7	27.3	1.04	1.5	0	63.5	307	SWC4 MAX	1920	240 x 8M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	65.2	0.33	33.7	30.8	1.1	27.3	1.04	110.1	0.317	0.853	39.978	64.047
1-1	2	64.9	0.28	37.8	26.3	0.9	21.9	1.04	129.4	0.372	1.002	46.987	75.278
1-1	3	64.6	0.24	41.6	22.3	0.7	17.3	1.03	151.7	0.436	1.175	55.075	88.237
1-1	4	64.4	0.21	45.2	18.2	0.5	13.1	1.03	177.7	0.511	1.377	64.535	103.394
1-1	5	64.2	0.18	48.3	14.9	0.4	10	1.02	206.5	0.594	1.601	75.006	120.173
1-1	6	64	0.17	51	12.1	0.3	7.5	1.02	237.8	0.684	1.844	86.382	138.401
1-1	7	63.8	0.15	53.2	9.7	0.2	5.8	1.02	271.5	0.781	2.105	98.592	157.967
1-1	8	63.7	0.14	54.9	7.7	0.2	4.2	1.01	307	0.884	2.381	111.515	178.678

Temperature : 31.5 °C

Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2287	0	39010	6323	21560	3.80	8.00
2	1064	0	39010	6323	21560	3.80	8.00
3	1064	65.2	39010	6323	21560	3.80	8.00
4	2287	65.2	39743	6443	21965	3.85	8.00
5	1236	63.5	73276	11914	40500	6.29	8.13
6	1236	0	71905	11690	39742	6.19	8.13
7	1223	0	39010	6323	21560	3.80	8.00
8	1223	65.2	40381	6547	22318	3.90	8.00
9	1052	1.50	307	12.0	179	0.987	6.67

Calculated by	Laurent MORILLON	Permeate flow/train	1052.00 m3/h
HP Pump flow	1063.61 m3/h	Total product flow	16832.00 m3/h
Feed pressure	65.2 bar	Number of trains	16
Feed temperature	31.5 °C(88.7°F)	Raw water flow/train	2286.96 m3/h
Feed water pH	8.00	Permeate recovery	46.00 %
Chem dose, mg/l, -	None	Element age	3.5 years
Leakage	1 %	Flux decline %, per year	7.0
Volumetric mixing	4 %	Fouling factor	0.78
H.P. differential	0.80 bar	SP increase, per year	10.0 %
Boost pressure	2.50 bar		
Specific energy	2.38 kwh/m3		
Pass NDP	22.1 bar		
Average flux rate	13.4 lmh		
		Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1051.3	9.5	5.1	13.4	1.7	27.3	1.04	1.5	0	63.5	307	SWC4 MAX	1920	240 x 8M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00 m3/h
Specific investment	22,151.90 USD/m3/h
Investment	000.00 USD
Plant life	15.0 years
Membrane life	5.0 years
Interest rate	4.5 %
Membrane cost	500.00 USD/element
Plant factor	90.0 %
Number of elements	1920.0
Power cost	0.200 USD/kwhr
Inhibitor cost	2.20
Power consumption	2.38 kwhr/m3
Inhibitor dosing	3.0 mg/l
Maintenance(as % of investment)	3.0 %
Acid cost	1.50
Acid dosing	0.00 mg/l

CALCULATION RESULTS

Capital cost	0.00 USD/m3
Power cost	0.48 USD/m3
Chemicals cost	0.00 USD/m3
Membrane replacement costs	0.00 USD/m3
Maintenance	0.00 USD/m3
Total water cost	0.48 USD/m3

Calculated by	Laurent MORILLON	
HP Pump flow	1063.76	m3/h
Feed pressure	60.9	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.13	
Chem dose, mg/l, -	None	
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.53	bar
Specific energy	2.23	kwh/m3
Pass NDP	21.6	bar
Average flux rate	13.4	lmh

Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1051.4	9.5	5.1	13.4	1.7	25.3	1.04	1.5	0	59.2	245	SWC4 MAX	1920	240 x 8M

Ion (mg/l)	Raw Water	Blended Water	Feed Water	Permeate Water	Concentrate	ERD Reject
Hardness, as CaCO3	6323.24	6442.90	6442.90	10.501	11916.6	11692.88
Ca	467.00	475.84	475.84	0.776	880.1	863.57
Mg	1258.00	1281.81	1281.81	2.089	2370.8	2326.28
Na	11089.00	11297.53	11297.53	88.245	20836.1	20446.25
K	391.00	398.34	398.34	3.887	734.0	720.28
NH4	0.20	0.20	0.20	0.002	0.4	0.36
Ba	0.450	0.459	0.459	0.001	0.8	0.83
Sr	0.100	0.102	0.102	0.000	0.2	0.18
H	0.00	0.00	0.00	0.000	0.0	0.00
CO3	20.77	21.61	21.61	0.001	60.3	58.71
HCO3	126.30	127.77	127.77	1.625	194.9	192.12
SO4	2878.00	2932.46	2932.46	5.195	5423.4	5321.62
Cl	19700.00	20070.75	20070.75	142.022	37029.2	36336.05
F	1.63	1.66	1.66	0.023	3.1	3.00
NO3	4.00	4.07	4.07	0.214	7.4	7.22
PO4	0.76	0.77	0.77	0.001	1.4	1.41
OH	0.19	0.19	0.19	0.001	0.3	0.33
SiO2	1.38	1.41	1.41	0.008	2.6	2.55
B	3.53	3.58	3.58	0.748	6.0	5.90
CO2	0.44	0.45	0.45	0.45	0.59	0.58
NH3	0.02	0.02	0.02	0.02	0.02	0.02
TDS	**35942.12**	**36618.36**	**36618.36**	**244.84**	**67550.66**	**66286.34**

pH	**8.13**	**8.13**	**8.13**	**6.72**	**8.21**	**8.21**

Saturations	**Raw Water**	**Feed Water**	**Concentrate**	**Limits**
CaSO4 / ksp * 100, %	25	25	54	400
SrSO4 / ksp * 100, %	0	0	1	1200
BaSO4 / ksp * 100, %	1883	1923	3883	10000
SiO2 saturation, %	1	1	2	140
CaF2 / ksp * 100, %	54	57	548	50000
Ca3(PO4)2 saturation index	0.9	0.9	1.8	2.4
CCPP, mg/l	30.28	31.15	76.25	850
Ionic strength	0.71	0.73	1.34	
Osmotic pressure, bar	26.5	27.0	49.8	

Calculated by	Laurent MORILLON	
HP Pump flow	1063.76	m3/h
Feed pressure	60.9	bar
Feed temperature	28.3	°C(82.9°F)
Feed water pH	8.13	
Chem dose, mg/l, -	None	
Leakage	1	%
Volumetric mixing	4	%
H.P. differential	0.80	bar
Boost pressure	2.53	bar
Specific energy	2.23	kwh/m3
Pass NDP	21.6	bar
Average flux rate	13.4	lmh

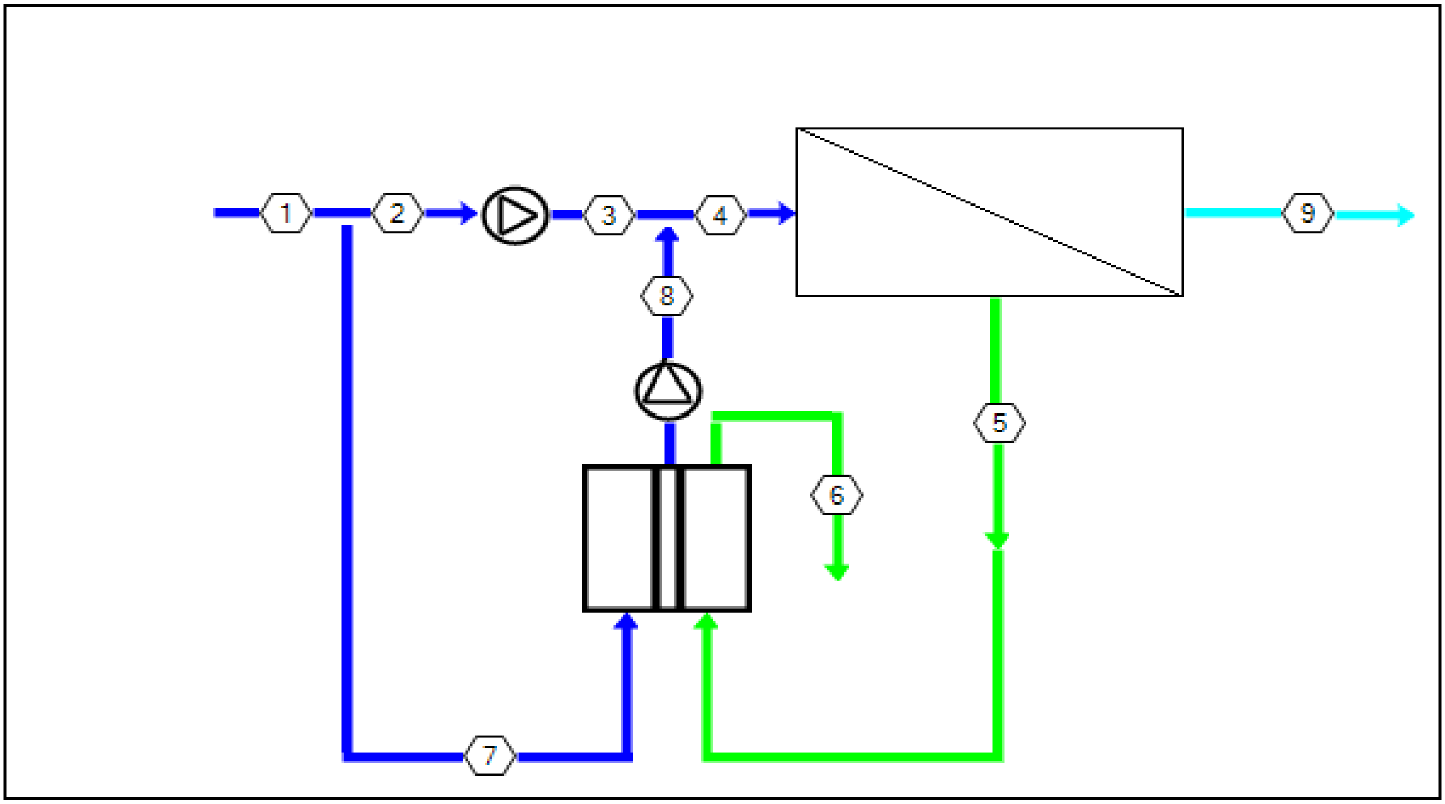
Permeate flow/train	1052.00	m3/h
Total product flow	16832.00	m3/h
Number of trains	16	
Raw water flow/train	2286.96	m3/h
Permeate recovery	46.00	%
Element age	3.5	years
Flux decline %, per year	7.0	
Fouling factor	0.78	
SP increase, per year	10.0	%
Feed type	Sea Surface Conventional	

Pass - Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Conc bar	Perm. TDS mg/l	Element Type	Element Quantity	PV# x Elem #
1-1	1051.4	9.5	5.1	13.4	1.7	25.3	1.04	1.5	0	59.2	245	SWC4 MAX	1920	240 x 8M

Pass - Stage	Element No.	Feed Pressure bar	Pressure Drop bar	Conc Osmo. bar	NDP bar	Permeate Water Flow m3/h	Permeate Water Flux lmh	Beta	Permeate (Stagewise cumulative) TDS	Ca	Mg	Na	Cl
1-1	1	60.9	0.33	30.3	29.8	1	25.3	1.04	95.3	0.301	0.812	34.329	55.243
1-1	2	60.6	0.28	33.6	26	0.9	21	1.03	109.8	0.347	0.936	39.571	63.679
1-1	3	60.3	0.24	37	22.3	0.7	17	1.03	127	0.402	1.083	45.766	73.648
1-1	4	60.1	0.21	40.2	18.9	0.6	13.6	1.03	146.4	0.463	1.248	52.767	84.916
1-1	5	59.9	0.19	43.1	15.7	0.4	10.7	1.03	168.1	0.532	1.434	60.579	97.49
1-1	6	59.7	0.17	45.7	12.9	0.3	8.3	1.02	191.9	0.607	1.636	69.141	111.271
1-1	7	59.5	0.15	47.9	10.5	0.3	6.5	1.02	217.6	0.689	1.856	78.407	126.186
1-1	8	59.3	0.14	49.8	8.5	0.2	4.9	1.01	245	0.776	2.09	88.295	142.102

Temperature : 28.3 °C

Element age, P1 : 3.5 years



Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	Hardness as CaCO3	Cl	B	pH
1	2287	0	35942	6323	19700	3.53	8.13
2	1064	0	35942	6323	19700	3.53	8.13
3	1064	60.9	35942	6323	19700	3.53	8.13
4	2287	60.9	36618	6443	20071	3.58	8.13
5	1236	59.2	67551	11917	37029	5.99	8.21
6	1236	0	66286	11693	36336	5.90	8.21
7	1223	0	35942	6323	19700	3.53	8.13
8	1223	60.9	37206	6547	20393	3.63	8.13
9	1052	1.50	245	10.5	142	0.748	6.72

Calculated by	Laurent MORILLON	Permeate flow/train	1052.00 m3/h
HP Pump flow	1063.76 m3/h	Total product flow	16832.00 m3/h
Feed pressure	60.9 bar	Number of trains	16
Feed temperature	28.3 °C(82.9°F)	Raw water flow/train	2286.96 m3/h
Feed water pH	8.13	Permeate recovery	46.00 %
Chem dose, mg/l, -	None	Element age	3.5 years
Leakage	1 %	Flux decline %, per year	7.0
Volumetric mixing	4 %	Fouling factor	0.78
H.P. differential	0.80 bar	SP increase, per year	10.0 %
Boost pressure	2.53 bar		
Specific energy	2.23 kwh/m3		
Pass NDP	21.6 bar		
Average flux rate	13.4 lmh	Feed type	Sea Surface Conventional

Pass - Stage	Perm. Flow	Flow / Vessel Feed	Conc	Flux	DP	Flux Max	Beta	Stagewise Pressure Perm.	Boost	Conc	Perm. TDS	Element Type	Element Quantity	PV# x Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	mg/l			
1-1	1051.4	9.5	5.1	13.4	1.7	25.3	1.04	1.5	0	59.2	245	SWC4 MAX	1920	240 x 8M

CALCULATION OF INVESTMENT AND WATER COST

Plant capacity as permeate	0.00 m3/h
Specific investment	22,151.90 USD/m3/h
Investment	000.00 USD
Plant life	15.0 years
Membrane life	5.0 years
Interest rate	4.5 %
Membrane cost	500.00 USD/element
Plant factor	90.0 %
Number of elements	1920.0
Power cost	0.200 USD/kwhr
Inhibitor cost	2.20
Power consumption	2.23 kwhr/m3
Inhibitor dosing	3.0 mg/l
Maintenance(as % of investment)	3.0 %
Acid cost	1.50
Acid dosing	0.00 mg/l

CALCULATION RESULTS

Capital cost	0.00 USD/m3
Power cost	0.45 USD/m3
Chemicals cost	0.00 USD/m3
Membrane replacement costs	0.00 USD/m3
Maintenance	0.00 USD/m3
Total water cost	0.45 USD/m3

Annexure: 6

Details of the Sludge Treatment System Design for 400 MLD Perur Desalination Plant

Sl.No.	Description		Value	Unit	Remarks
1	**Lamella Sludge Calculation**				
	Inflow from seawater	=	1040.00	MLD	
	TSS in Seawater	=	300	ppm	
	Sludge load from seawater	=	312000	kg/day	
	Inflow for band screen cleaning	=	3.500	MLD	
	Ferric flow rate	=	0.04	MLD	
	Poly flow rate	=	0.21	MLD	
	Total Inflow into Lamella	=	1043.75	MLD	
		=	43490	m3/hr	
	Sludge due to FeCl3 addition		14.4	ppm	2.88 times the Fe metal
	Sludge load due to FeCl3 addition	=	15030	kg/day	
	Total sludge load into Lamella	=	327030	kg/day	
	Suspended solids in Lamella inlet calculated	=	313.32	ppm	
	Recovery in Lamella assumed	=	98.00	%	
	Lamella supernant water	=	1022.877	MLD	
	TSS in Lamella supernant water	=	38.36	ppm	
	Sludge removal efficiency in Lamella		88.00	%	
	Sludge load in Lamella supernant water	=	39244	kg/day	
	Hence sludge load removed in Lamella from under flow arrived	=	287788	kg/day	
	Lamella under flow sludge flow rate arrived	=	20.88	MLD	
	Lamella under flow sludge concentration arrived	=	13784.33	ppm	
	Lamella under flow sludge consistency arrived	=	1.378	%	up to 2% as per CPHEEO sewage manual Chapter 5, page 5-55, clause No 5.7.4.2.6.1
	TSS in Lamella supernant water	=	38.36	ppm	
	Hence sludge load removed from Lamella	=	287788	kg/day	
	Total Solids load	=	11991	kg/hr	
2	**DAF Sludge Calculation**				
	Effluent of Lamella	=	1022.88	MLD	
	TSS in feed to DAF	=	38.37	ppm	
	Sludge load into DAF	=	39244	kg/day	
	Ferric flow rate	=	0.02	MLD	

Sl.No.	Description		Value	Unit	Remarks
	Poly flow rate	=	0.051	MLD	
	Total Inflow into DAF	=	1023	MLD	
		=	42623	m3/hr	
	Sludge due to FeCl3 addition		5.8	ppm	2.88 times the Fe metal
	Sludge load due to FeCl3 addition	=	5892	kg/day	0.4 times the FeCl3 consumption
	Total sludge load into DAF	=	45136	kg/day	
	Suspended solids in DAF inlet calculated	=	44.12	ppm	
	Recovery in DAF assumed	=	99.00	%	
	DAF supernant water	=	1012.716	MLD	
	TSS in DAF supernant water	=	3.57	ppm	
	Sludge removal efficiency in DAF		92.00	%	
	Sludge load in DAF supernant water	=	3611	kg/day	
	Hence sludge load removed in DAF from under flow arrived	=	41525	kg/day	
	DAF under flow sludge flow rate arrived	=	10.23	MLD	
	DAF under flow sludge concentration arrived	=	4058.88	ppm	
	DAF under flow sludge consistency arrived	=	0.406	%	
	TSS in DAF supernant water	=	3.57	ppm	
	Hence sludge load removed from DAF	=	41525.00	kg/day	
	Total Solids load	=	1730	kg/hr	
3	**Sludge Balancing Tank Design**				
	Total inflow into sludge balancing tank	=	31.10	MLD	
		=	1296.02	m3/hr	
	Sludge load into Sludge balancing tank	=	329311	kg/day	
	Tank volume considered (100% extra)	=	2592	m3	
	retention time arrived for average flow	=	2.00	hrs	
	Number of tanks	=	1	No	
	Tank depth as per contract	=	3.5	m	
	Tank area required	=	740.6	m2	
	Tank diameter arrived	=	30.7	m	
	Tank diameter considered	=	31	m	
	Tank size	**=**	**31m dia x 3.5m SWD**		
	Volume	=	2641.7	m3	
	MOC	=	RCC		
	Retention time arrived	=	2.04	hrs	
	Sludge collection pit sizing				

Sl.No.	Description		Value	Unit	Remarks
	Diameter of tank provided	=	31.00	m	
	Width provided	=	5.00	m	
	Depth provided	=	2.00	m	
	Size of sludge pit provided	=	5m x 3m x 2m Deep		
	Slope provided in spent backwash tank floor for sludge collection	=	1 in 12		As per CPHEEO Manual on Water Supply and Treatment, Cl.7.5.8, Pg. no. 230
4	**Submersible mixers**				
	No of working mixers	=	3	No	1 mixer on self
	Mixing power required	=	10	W/m3	
	Required power per mixer	=	8.8	kW	
	Motor rating considered	=	10	kW	
	Type of mixers	=	Submersible		
	Note: Details indicated above may vary based on suppliers' details.				
5	**Static mixer**				
	No of mixers	=	1	No	
	Installation	=	Pump discharge line		
6	**Thickener feed pumps**				
	Capacity of pumps required (10% extra)	=	1425.82	m3/hr	
	Pump capacity considered	=	1500	m3/hr	
	Quantity	=	2	No (1W+1S)	
	Type of pumps	=	Submersible non clog type		
7	**Thickener Design**				
	No of Thickeners	=	2	No	
	Solid loading in to Thickeners	=	329314	kg/day	
		=	13721.4	kg/hr	
	In Flow rate	=	1296.20	m3/hr	
	Design flow rate	=	1500.00	m3/hr	
	TSS in inflow of Thickener	=	9148	ppm	
	Solids recovery rate in Thickener	=	96	%	up to 90 % as per CPHEEO sewage manual Chapter 6, page 6-4, Table 6.3. Retention time is increased to achieve 96% solids recovery.
	Solid carry over in supernant of Thickener	=	548.86	kg/hr	

Sl.No.	Description		Value	Unit	Remarks
	TSS in Thickener supernant water	=	470	ppm	
	Solid loading rate	=	100-150	kg/day/m2	as per Metcalf & Eddy, table 14-19, page 1492
	Solid loading rate considered	=	86	kg/day/m2	Due to presence of high organics
		=	3.58	kg/hr/m2	
	Surface area of Thickener required	=	3829.2	m2	
	Diameter of each Thickener arrived (a)	=	34.912	m	
	Surface loading rate required	=	0.7	m3/hr/m2	
	Surface area of Thickener required	=	2142.9	m2	
	Diameter of each Thickener arrived (b)	=	26.117	m	
	Thickener diameter (max of a,b)	=	34.912	m	
	Diameter of Thickener considered	=	**35.0**	m	
	Liquid depth in Thickener	=	**4**	m	
	Type of Thickener	=	**Full bridge, central driven**		
	Size of Thickener	=	**35m dia x 4m SWD**		
	Weir load				
	Peak flow per hour into a Thickener	=	750	m3/hr	
	Flow per day per	=	18000	m3/day	
	Weir load	=	163.8	m3/day/m	
	Weir load	=	< 300	m3/day/m	as per CPHEEO page 230, Clause No 7.5.8
			Hence OK		
	Provide Thickener size - 2 x 35m dia x 4.0m SWD				
	V- Notch weir				
	Provide 90^0 V-Notch weirs at	=	175	c/c distance	
	Length of weir plate	=	109.900	m	
	No. of V-notch	=	628.00	No	
	Flow per each notch	=	0.332	lps	
		=	1.194	m3/hr	
		=	0.00033	m3/sec	
	Flow through V - Notch				
	$Q = 2.362\ C_e\ h^{2.5}$				
	Ce for head of 60 mm to 377 mm	=	0.603 to 0.686		
	Consider Ce	=	0.613		
	Consider h	=	0.035	m	
	Q	=	0.00033	m3/s	
		=	1.195	m3/hr	
	Total flow	=	750.192	m3/hr	Check for flow
	Weir plate size: 150 mm wide, 90 degree V Notch of 60 mm depth, C/C 175mm				

Sl.No.	Description		Value	Unit	Remarks
	Q	=	1.402 x 10^{-2}x $(h)^{5/2}$		
	Q	=	Flow per notch in lps		
	h	=	Water depth in cm		
	h	=	3.55	cm	
		=	4	cm	
		=	41	mm	<60 mm depth
8	**Thickened Sludge holding tank**				
	Sludge load removed in Thickener	=	13172.6	kg/hr	
	Concentration of solids in underflow	=	3 to 5	%	
	Solid concentration considered	=	5.00%		
	Formula to calculate Specific gravity of slurry				
	1/Ss	=	$(M_f/S_f) + M_v/S_v)$		
	S_s	=	Overall specific gravity of slurry		
	M_f	=	Mass of fixed solids, 0.05kg		
	S_f	=	Specific gravity of fixed solids, 2.5		
	M_v	=	Mass of volatile solids, 0.95 kg		
	S_v	=	Specific gravity of volatile solids, 1		
	Therefore Ss	=	1.0309		
	Thickener underflow slurry density	=	1030.93	kg/m^3	
	Thickener Underflow per unit	=	127.77	m^3/h	
	Total sludge from Thickener into sludge holding tank	=	255.55	m^3/h	
		=	6.13	MLD	
	Hydraulic retention time	=	4.00	hr	
	Volume of Sludge holding tank required	=	1022.19	m3	
	Depth of tank	=	3.0	m	
	Length of tank	=	28.0	m	
	Width of tank arrived	=	12.2	m	
	Width of tank considered	=	14.0	m	
	Size of tank	=	**28m L x 14.0 m W x 3.0m SWD**		
	Number of tanks	=	1	No	
	MOC	=	RCC		
9	**Agitators in Sludge holding tank**				
	No of Agitators in the tank	=	2	No	
	No of working mixers	=	2	No	

Sl.No.	Description		Value	Unit	Remarks
	Type of mixers	=	Vertical top mounted suspended type		
	Design of agitators				
A	**Power requirement**				
	Formulae for Total Power input to agitator, P	=	G^2 μ (Vol)		
	Velocity gradient (G)	=	75	s^{-1}	10-75 As per CPHEEO Manual on Water Supply and Treatment, page 213
	Absolute viscosity of water (μ)	=	0.0008	NS/m2	As per CPHEEO Manual, Table 7.4.3 of page 207
		=	0.001236	NS/m2 @ 12 deg c	
	Volume of tank (V)	=	1176.0	m3	
	Input power in water (P)	=	4.1	kW	
	Efficiency of Gear box	=	85	%	
	Efficiency of Motor	=	75	%	
	Motor rating required	=	6.41	kW	
	Motor rating for agitator considered	=	7.5	kW	
	* Motor rating for the agitator shall be finalized as per the selected vendor.				
B	**Design of No of blades**				
	Power input, (Watt)	=	1/2 x Cd x ρ x Ap $(V-v)^3$		As per CPHEEO Manual on Water Supply and Treatment, Cl.7.4.3.1 (2), Pg. no. 213
	Where, **Value considered :**				
	Cd, Newton coefficient of drag	=	1.80		0.8-1.9 As per CPHEEO Manual, Cl.7.4.3.1 (2), Pg. no. 213
	ρ, Density of water	=	1000.00	kg/m^3	
	V, Velocity of the tip of Blades	=	0.55	m/sec	0.2-0.6 As per CPHEEO Manual, Cl.7.4.3.1 (2), Pg. no. 213
	v, Velocity of water at tip of Blade	=	25% of V	m/sec	
		=	0.138	m/sec	
	Total Power input to Agitator	=	4088.07	watts	
	Hence Ap	=	64.715	m2	

Sl.No.	Description		Value	Unit	Remarks
	total area of paddles to cross section area of tank	=	19.0	%	10-25% As per CPHEEO Manual, Cl.7.4.3.1 (2), Pg. no. 213
	*The dimensions of Blades for the agitator shall be finalized as per the selected vendor.				
10	**Filter press feed pumps**				
	Sludge flow rate	=	255.5	m3/hr	
		=	6133	m3/day	
	No of hours of operation of filter presses	=	16	hours	
	Feed to filter presses	=	383	m3/hr	
	No of working pumps for filter press feed	=	15	No	
	No of stand by pumps	=	1	No	
	Capacity of each pump	=	25.6	m3/hr	
	Capacity of each pump considered	=	27.0	m3/hr	
	Type of pump	=	Progressive cavity pumps		
11	**Belt Filter Press**				
	Type of Filter press	=	Belt filter press		
	No of hours of operation of Filter presses per day	=	16	hours	
	Total sludge flow rate from Thickener	=	6133	m3/day	
		=	383	m3/hr	
	Total sludge load from Thickener	=	316142	kg/day	
		=	19759	kg/hr	
	No of working filter presses	=	15	No.	
	No of stand by filter presses	=	3	No.	
	Capacity of each filter press	**=**	**25.55**	**m3/hr**	
	Solids load to each filter press	=	1317.26	kg/hr	
	Dry solids to each filter press	=	1317	kg/h	
	Dryness of cake (Solid consistency)	=	25	%	
	Bulk density of particles	=	2500	kg/m^3	
	Formula to calculate Specific gravity of slurry				
	$1/S_s$	=	$(M_f/S_f) + M_v/S_v)$		
	S_s	=	Overall sp. gravity of slurry		
	M_f	=	Mass of fixed solids, 0.25 kg		
	S_f	=	Sp. gravity of fixed solids, 2.5		
	M_v	=	Mass of volatile solids, 0.75 kg		

Sl.No.	Description		Value	Unit	Remarks
	S_v	=	Sp. gravity of volatile solids, 1		
	Therefore Ss	=	1176.47	kg/m^3	
	Volume of cake	=	4.48	m^3/hr	
	Total sludge generated for all filter presses	=	67.2	m^3/hr	
		=	1075	m^3/day	
		=	1.075	MLD	
	Filtrate generated from all filter presses	=	316.14	m^3/hr	
			5058	m^3/day	
			5.058	MLD	
12	**Belt filter press washing pumps**				
	Total number of pumps	=	4	No	
	No of working pumps	=	3	No	
	No of stand by pumps	=	1	No	
	Capacity of each pump	=	30	m3/hr	5 m3/hr for each BFP
13	**Polymer dosing pumps for Thickener**				
	Type of polymer	=	Non-food grade		
	Solids load into Thickener	=	13721.42	kg/hr	
		=	13.72	tons/hr	
	Dosage considered for sizing	=	4.0	kg/ton SS	4 kg/ton SS as per Metcalf & Eddy, page 1496
	Quantity of chemical required	=	54.89	kg/hr	
		=	1317.26	kg/day	
	Purity of the chemical	=	100.0	%	
	Quantity of chemical required	=	54.89	kg/hr	
	Concentration of the solution	=	0.5	%	
	Pump Capacity	=	10977.14	LPH	
	No of pumps working	=	1	No	
	Capacity of pump required	=	10977	LPH	
	Capacity of pump provided	=	0-15000	LPH	
	Type	=	Diaphragm metering pump		
	Quantity	=	2	(1W + 1S)	
	Size & MOC of Poly dosing piping	=	63	HDPE / uPVC	

Sl.No.	Description		Value	Unit	Remarks
	Size & MOC of Poly dosing Valves	=	63	NB PP / PTFE	
14	**De water Polymer dosing pumps for BFP**				
	Type of polymer	=	Non Food grade		
	Solids load into BFP	=	19758.85	kg/hr	
		=	19.76	tons per hr	
	Dosage considered for sizing	=	4.0	kg/ton SS	4 kg/ton SS as per Metcalf & Eddy, page 1496
	Quantity of chemical required	=	79.04	kg/hr	
		=	1896.85	kg/day	
	Purity of the chemical	=	100.0	%	
	Quantity of chemical required	=	79.04	kg/hr	
	Concentration of the solution	=	0.5	%	
	Pump Capacity	=	15807.08	LPH	
	No of pumps working	=	15	No	
	Capacity of pump required	=	1054	LPH	
	Capacity of pump provided	=	0-1500	LPH	
	Type	=	Diaphragm metering pump		
	Quantity	=	18	(15W + 3S)	
	Size & MOC of Poly dosing piping	=	25	HDPE / uPVC	
	Size & MOC of Poly dosing Valves	=	25	NB PP / PTFE	
15	**Polymer Dosing Tanks for Sludge Treatment**				
	Storage time of chemicals	=	12	hr	
	Volume of solution required / 12 hrs	=	321411	liters	
	Volume of each tank required	=	321411	liters	
	No of tanks considered	=	2	No	
	Volume of tank required	=	321411	liters	
	Volume of tank provided	=	321411	liters	
	Quantity	=	4	(2W+2S)	
	MOC of tank	=	RCC with chemical resistant tiling		
	Volume	=	321.41	m3	
	Volume of each tank required		160.71		
	Side water depth	=	4.0	m	
	Side required	=	6.3	m	
	Side Considered		6.5	m	

Sl.No.	Description		Value	Unit	Remarks
	Size	=	6.5x 6.5m x 4m SWD+0.5m FB		
16	**Agitator for Poly Dosing tanks for Sludge Treatment**				
	Type	=	Turbine type, Motor driven		
	Agitator for chemical tank	=	60	rpm	40-125 rpm as per Metcalf & Eddy Page 356, table 5-13
	Quantity	=	4	No.	
	MOC of agitator	=	SS 316		
17	**Design of Agitator in the Poly dosing tank for Sludge Treatment**				
A	**Power requirement**				
	Formulae for Total Power input to agitator, P	=	G^2 μ (Vol)		
	Velocity gradient (G)	=	120	s^{-1}	
	Absolute viscosity of water (μ)	=	0.0008	NS/m2	As per CPHEEO Manual on Water Supply and Treatment, Table 7.4.3 of page 207
		=	0.001236	NS/m2 @ 12 deg C	
	Volume of tank (V)	=	169.0	m3	
	Input power in water (P)	=	3.0079	kW	
	Efficiency of Gear box	=	85	%	
	Efficiency of Motor	=	78.5	%	
	Motor rating required	=	4.5079	kW	
	Motor rating for agitator considered	=	5	kW	

Annexure - 7

Graphs

- **Open offshore intake and discharge pipes**

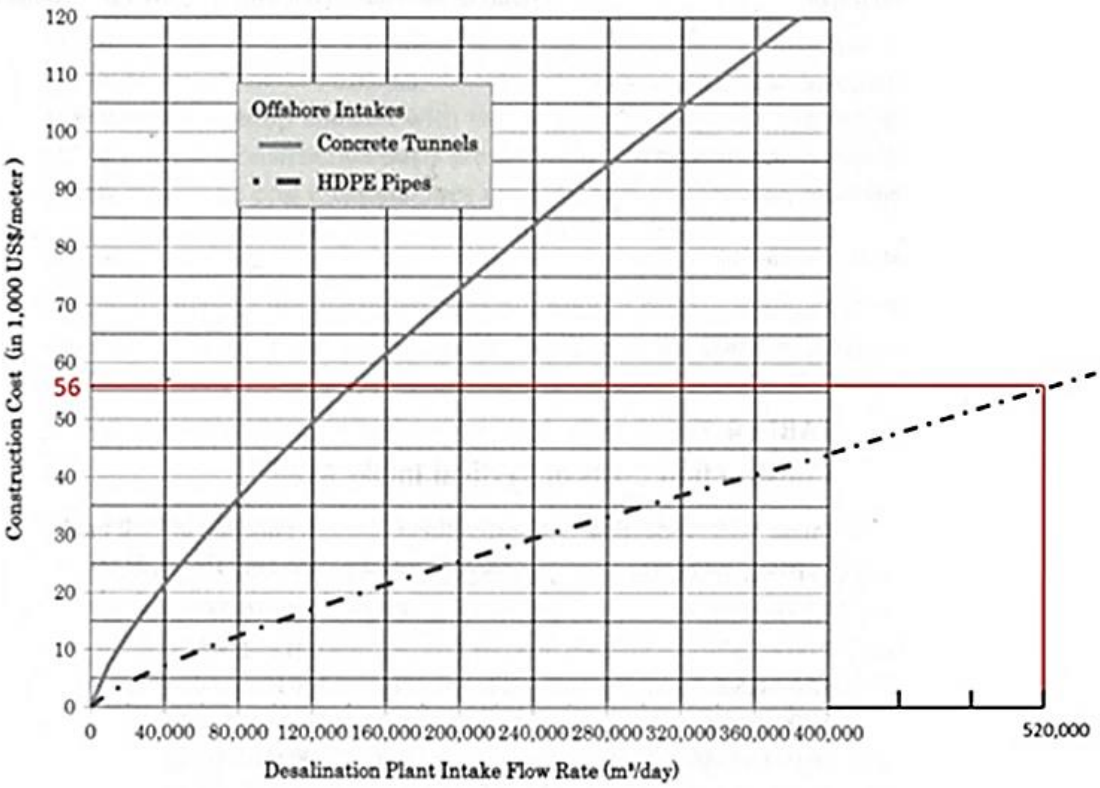


Figure 1: Construction cost for open offshore intakes

- The folowing data and coefficient are used :
    - Half plant intake flow : 520000 m3/d
    - Intake pipe length : 1800m
    - Outfall pipe length : 800m

NB The Brine pipe is not considered for 200 MLD then derived to 400 MLD plant capacity; the total plant discharge (627 MLD) will be not considered either ; since same pipe diameter than intake (2500 mm) will be implemented for discharge, the same unit cost (56,000USD/m) will be used used.

- **Intake pumping station**

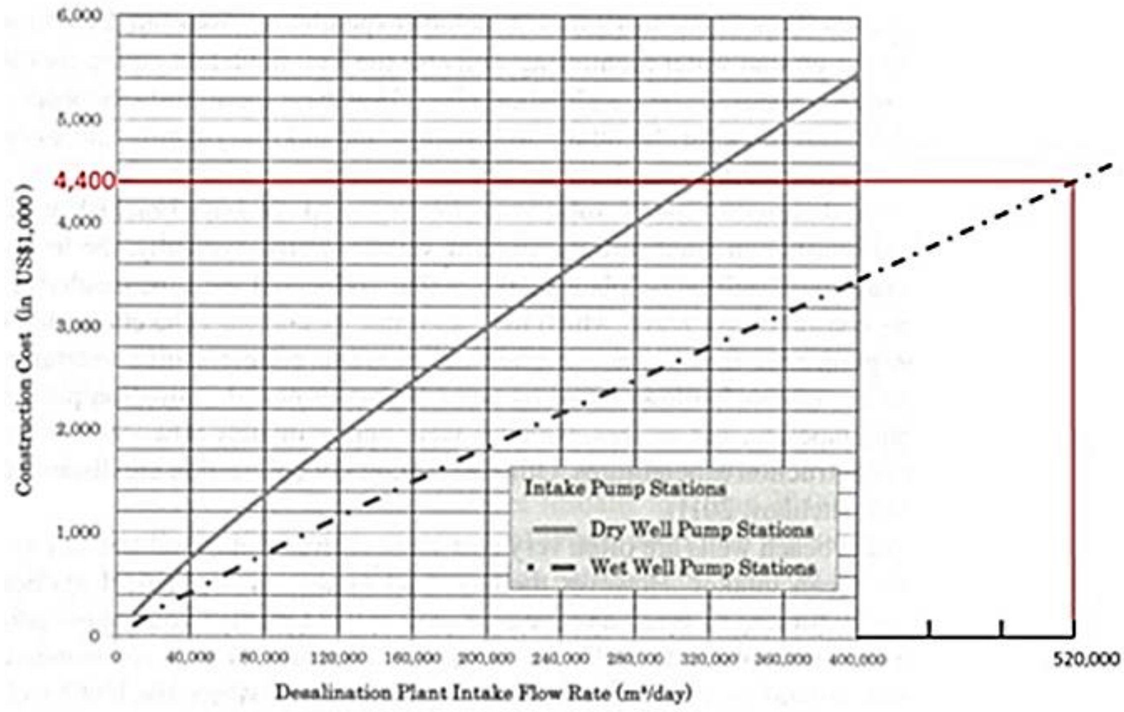


Figure 2: Construction cost for intake pump stations

- **Band screens**

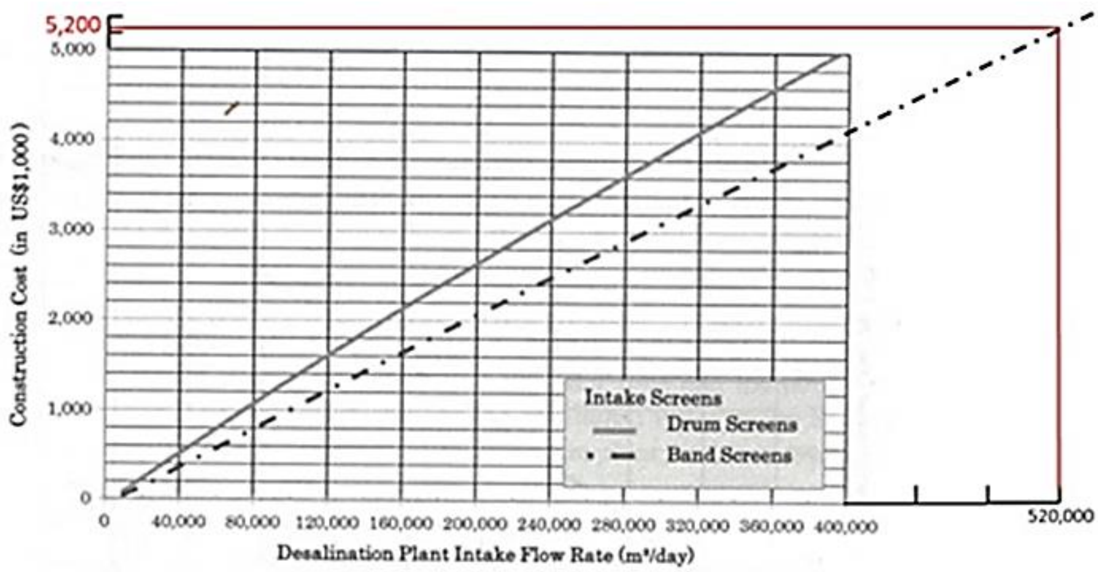


Figure 3: **Contruction cost for drum and band intake screens**

- **DAF and lamella settlers**

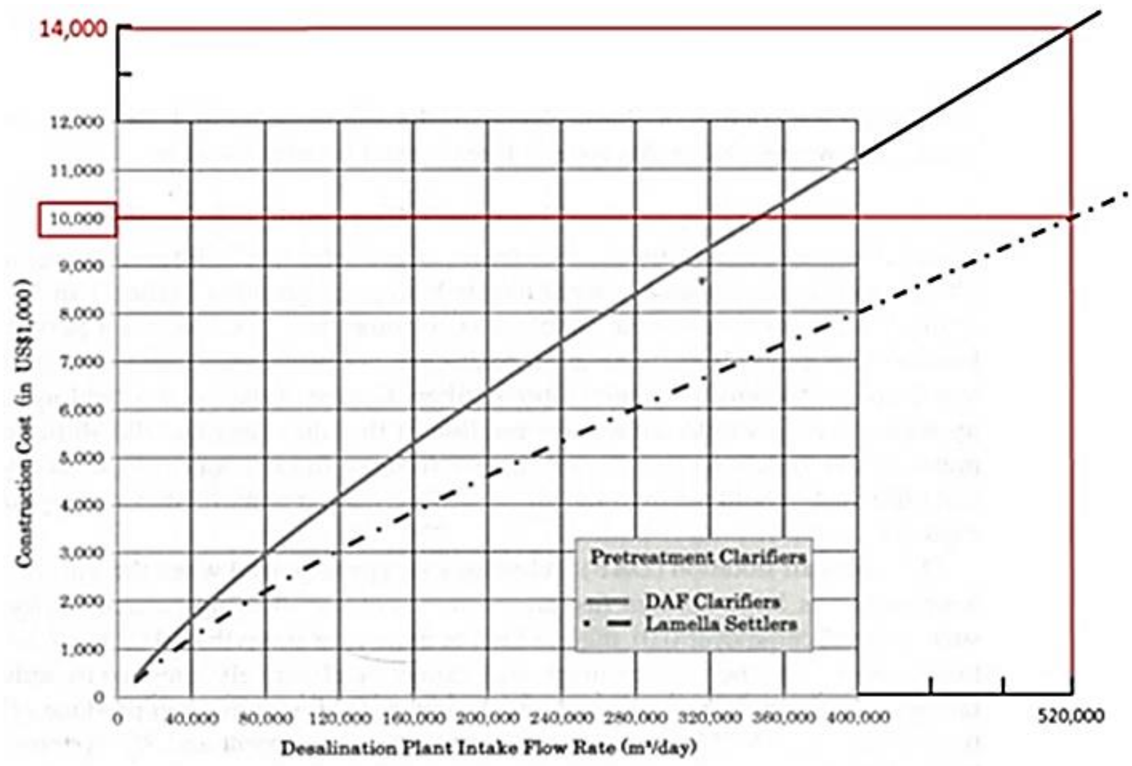


Figure 4: Construction cost for DAF and Lamella Clarifier

- **Granular Media filters**

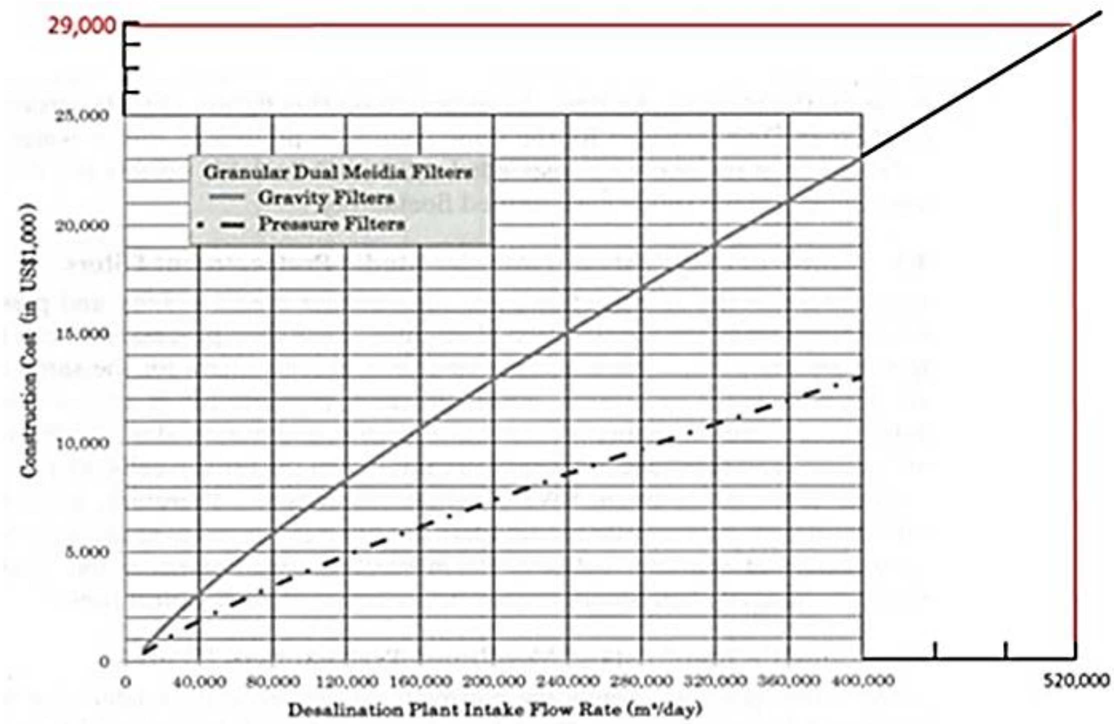


Figure 5: Construction cost for Granular Dual Media Filter

- **Cartridge filters**

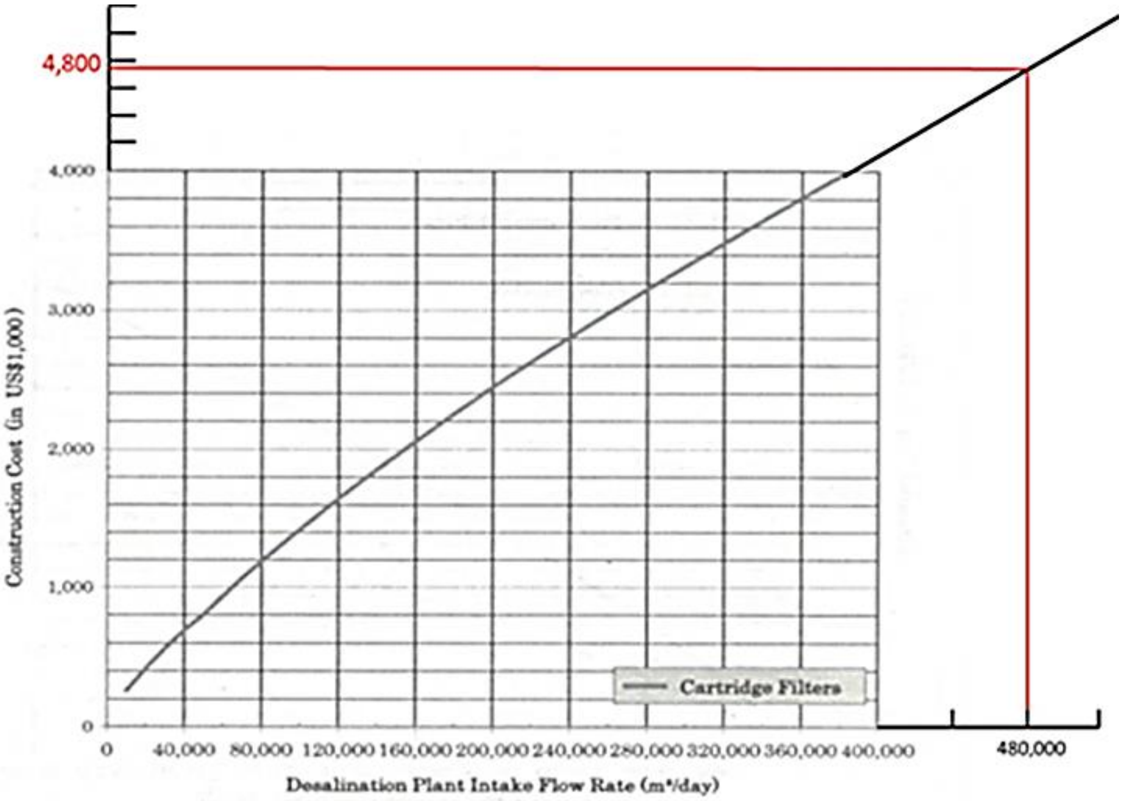


Figure 6: Construction cost for Cartridge Filters

- **Single pass SWRO**

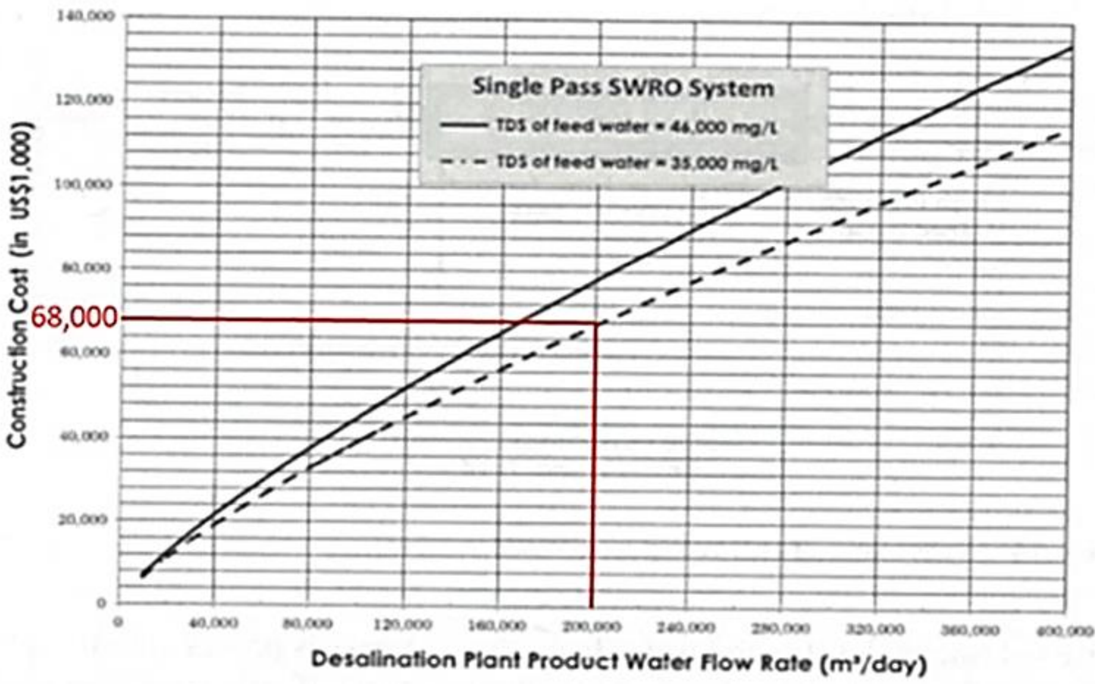


Figure 7: Construction cost for single pass SWRO system

- **Post treatment**

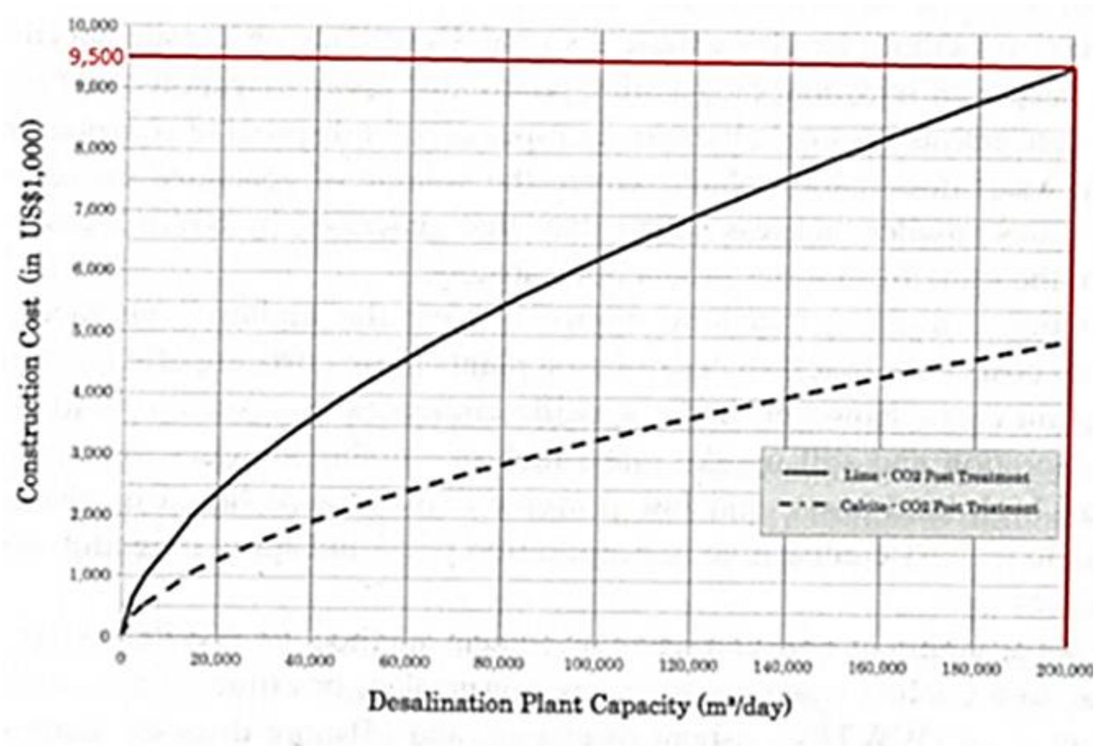


Figure 8: Constrution cost for Lime and Calcite post treatment system

- **Sodium hypochlorite disinfection**

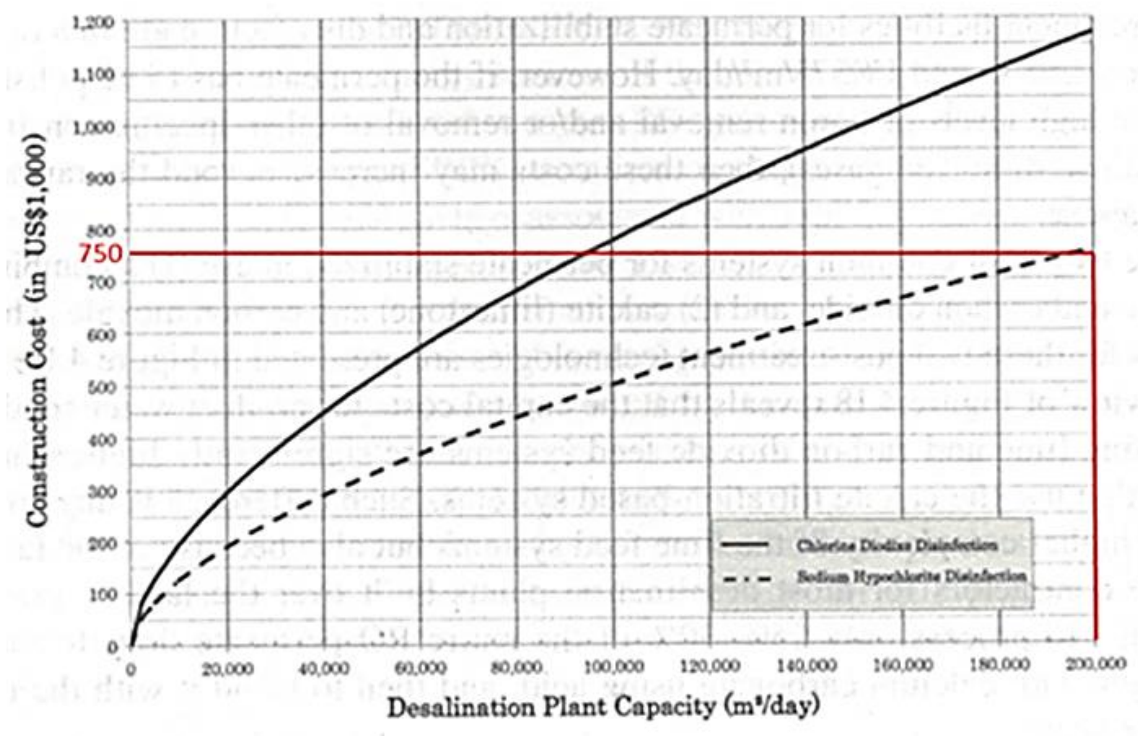
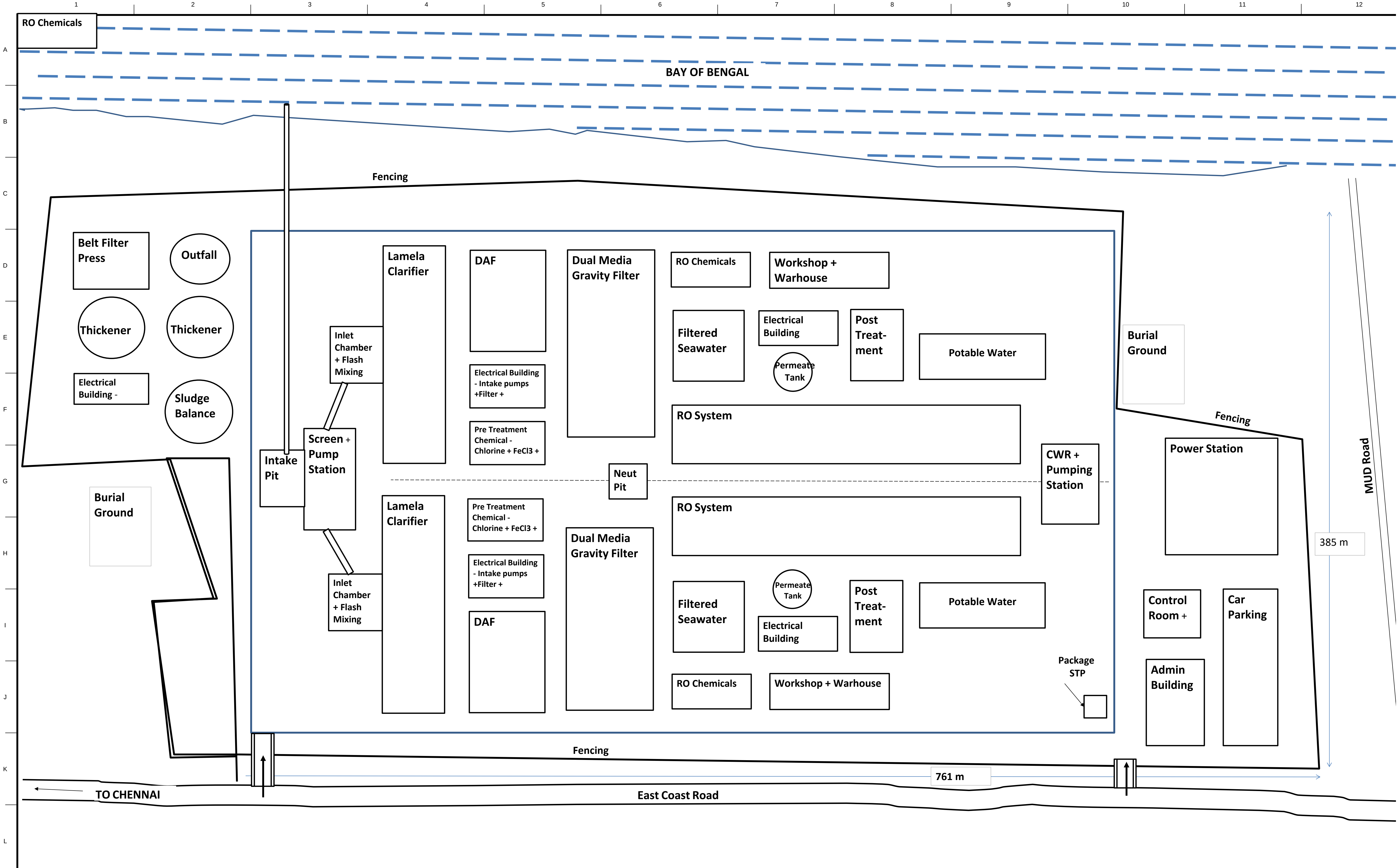


Figure 9: **Construction cost for carbon dioxide and sodium hypochlorite disinfection**



Disclaimer	400 MLD PERUR DSP	Title 400 MLD SWRO PLANT LAYOUT	Consultant:: PMC Clients Number CMWSSB Issued 0 Drawing Number

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