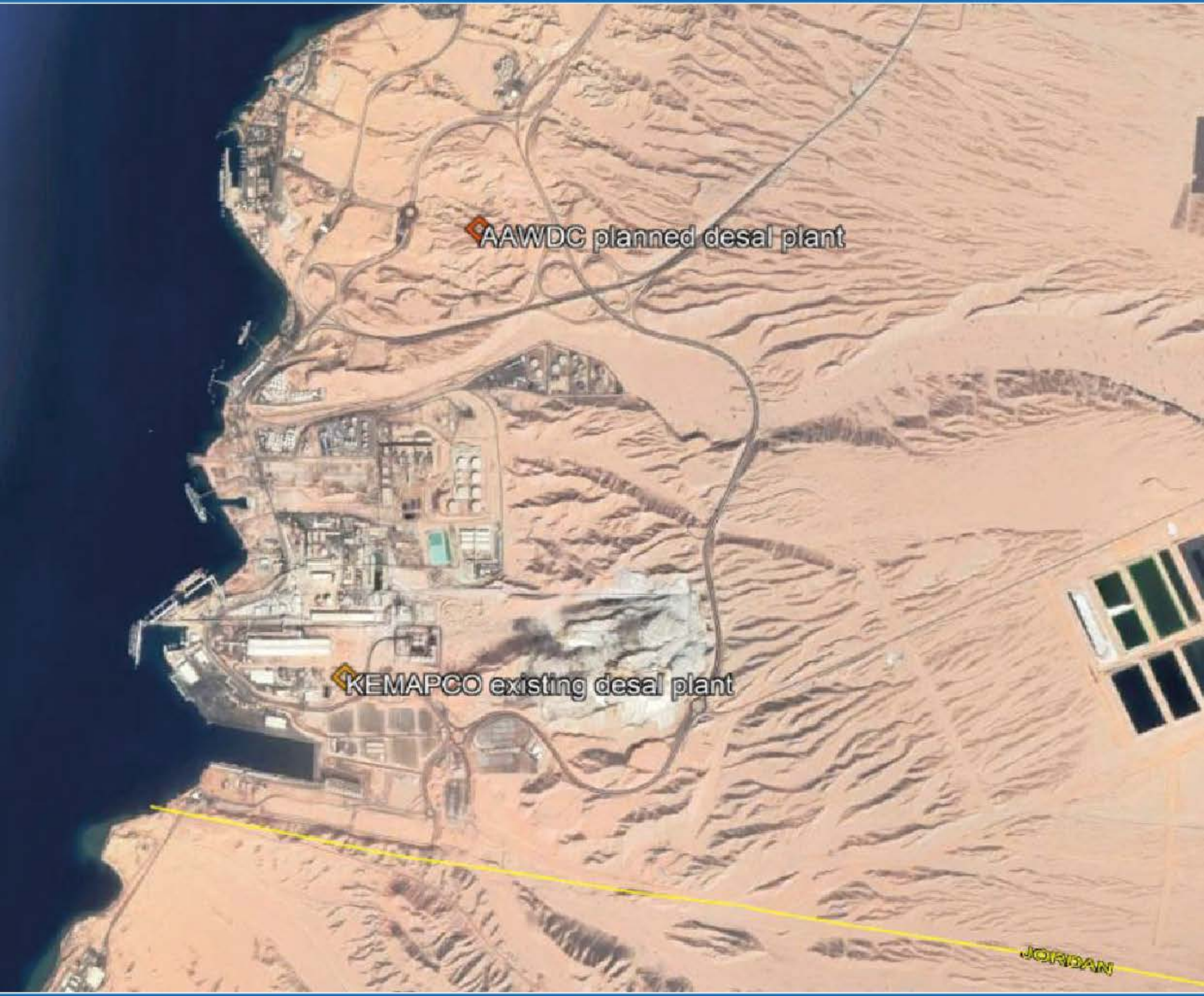
Guidelines

Planning and Management of Seawater Reverse Osmosis Desalination Plants in Jordan

Ministry of Water & Irrigation
وزارة المياه والري

سلطة المياه
WATER AUTHORITY



التعاون الألماني
DEUTSCHE ZUSAMMENARBEIT

Facilitated by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

IMPRINT

PUBLISHED BY

The Ministry of Water and Irrigation (MWI) supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

CONTACT

MINISTRY OF WATER AND IRRIGATION (MWI) & WATER AUTHORITY OF JORDAN (WAJ)

Eng. Mohammad Dweiri
Secretary General Assistant for Strategic Planning
Mohammad_Aldwairi@mwi.gov.jo

Issa Al Wer
Project Manager AAWDCP
Issa_Alwer@mwi.gov.jo

Eng. Muna Gharaibeh
Secretary General Assistant for Water Quality
muna_gharaibeh@mwi.gov.jo

45 Salem Al Hendawi Street, Amman-Jordan
I: www.mwi.gov.jo

GIZ WATER PORTFOLIO JORDAN
Mohamed Basem Al-Khammash St.13, Sweifieh
Amman 11190, Jordan
T: +962-6-5868090
E: giz-jordanien@giz.de
I: www.giz.de

DESALINATION OF SEA AND BRACKISH WATER PROJECT

PROJECT TEAM LEADER
Dr. Armin Margane
armin.margane@giz.de

AUTHORS
Report Prepared by
STEP Consulting GmbH (Aachen, Germany)
www.stepconsulting.de
Dr.-Ing. Süleyman Yüce
yuece@stepconsulting.de
Daniel Janowitz
janowitz@stepconsulting.de
Christoph Rams
Christian Kazner
Maya Stephany-Daguze
Nina Stein

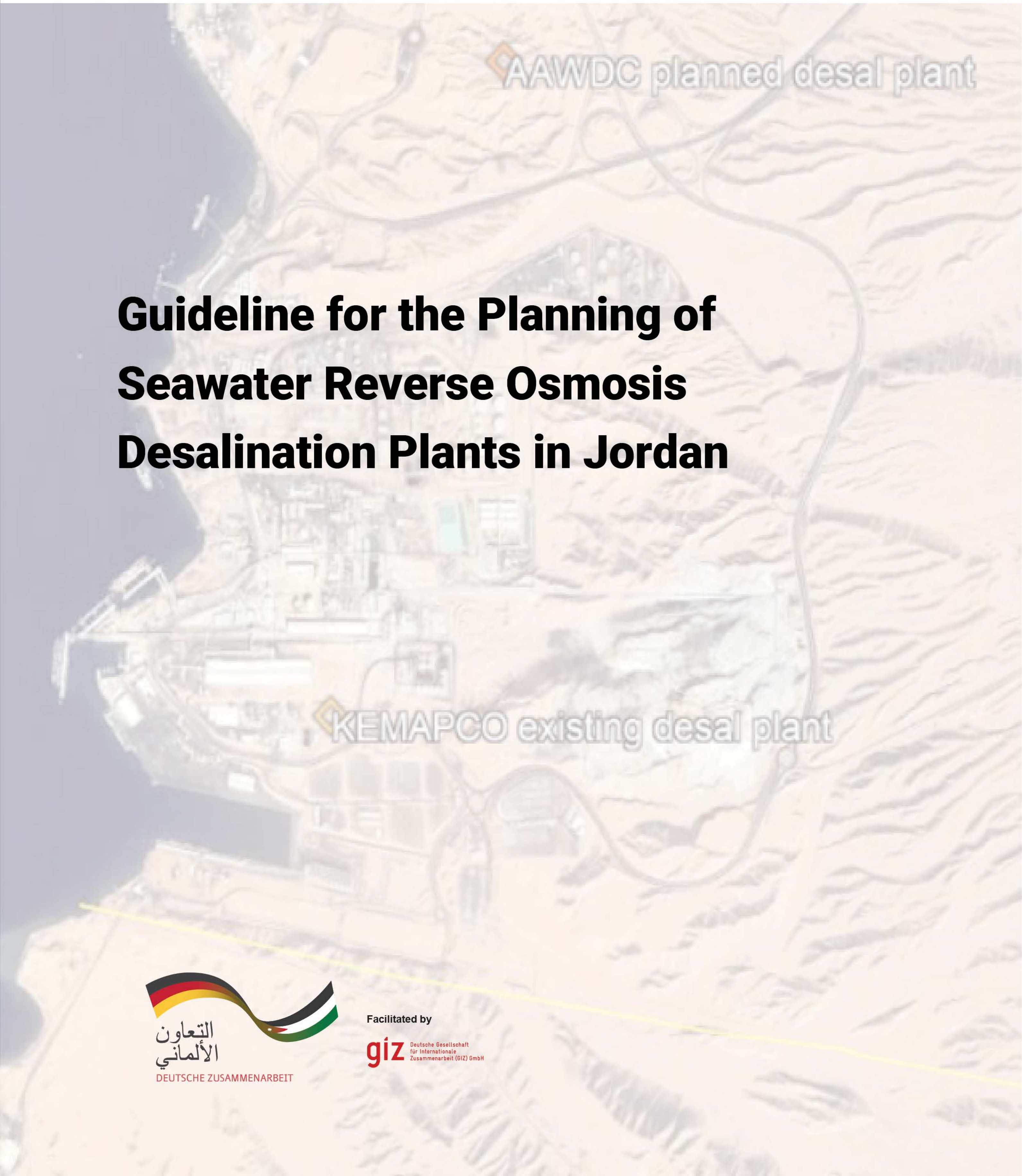
EDITORS
Christopher Claessen
Muna Gharaibeh
Dr. Armin Margane

CONTRIBUTING AUTHORS (IN ALPHABETICAL ORDER)
Ahmad Abu Hijleh
Ibtisam Al Bustanji
Christopher Claessen
Muna Gharaibeh
Mahmoud Ghneimat
Hiyam Hamedeh
Dr. Armin Margane
Firas Al Najjar
Eman Saleh
Hala Shaheen
Haitham Al Taani
Mohammad Wreikat

LOCATION AND YEAR OF PUBLICATION
Jordan, March 2022

Ministry of Water & Irrigation
وزارة المياه والري

سلطة المياه
WATER AUTHORITY



Guideline for the Planning of Seawater Reverse Osmosis Desalination Plants in Jordan

التعاون الألماني
DEUTSCHE ZUSAMMENARBEIT

Facilitated by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Table of Contents

List of Figures

List of Tables

Introduction

Several factors are hindering Jordan from harnessing seawater and brackish water for covering its ever-growing water deficit. Jordan has a very short coastline along the Red Sea near Aqaba. In addition, the salt content of the Red Sea, up to 43,000 ppm, is significantly (by ~10 %) higher than the salt content in the Mediterranean. The major demand center, Amman, is located around 350 km away from Aqaba to the north with a hydrostatic head difference of approx. 1,000 m.

The demand for drinking water is rising with population growth. The figure below shows the population distribution (2015) across the regions of Jordan[1]. It is immediately noticeable that about two-thirds of the population live in the central region, around Amman. The immediate consequence is that a large part of the drinking water requirement is in the central area. Conversely, decentralized solutions must be found for sparsely populated regions. In the central region as well as in the North and South regions in Jordan, the surface water is by far not sufficient as a source for drinking water production. Thus, groundwater resources were until now largely used to cover demand. However, groundwater overexploitation has led to significant water level declines so that the aquifers are increasingly falling dry, and extraction is becoming problematic in many areas.

Map of Jordan

ID	Governorate	Capital	Population
	Northern region		29 %
1	Irbid	Irbid	2,003,800
2	Mafraq	Mafraq	622,500
3	Jerash	Jerash	268,300
4	Ajloun	Ajloun	199,400
	Central region		63 %
5	Amman	Amman	4,536,500
6	Zarqa	Zarqa	1,545,100
7	Balqa	Al-Salt	556,600
8	Madaba	Madaba	214,100
	Southern region		8 %
9	Karak	Al-Karak	358,400
10	Aqaba	Aqaba	213,000
11	Ma´an	Ma´an	179,300
12	Tafila	Tafila	109,000
	Total population		10,806,055

Figure 1-1: Estimated population of the Kingdom of Jordan by Governate for the end of 2020[1]

Within the contract Preparation of Guidelines for Planning and Management of Desalination Plants, contract number 81266072, the following documents will be prepared:

[1] Directorate of Family and Population Surveys (2020). Estimated Population of the Kingdom by Governate, Locality, Sex and Households.

- Guideline for the Planning of Brackish Water Reverse Osmosis Desalination Plants in Jordan
- Guideline for the Management of Brackish Water Reverse Osmosis Desalination Plants in Jordan

- Guideline for the Planning of Seawater Reverse Osmosis Desalination Plants in Jordan
- Guideline for the Management of Seawater Reverse Osmosis Desalination Plants in Jordan

Objectives of the Guideline

The main objectives of this seawater desalination planning guideline are to avoid systematic deficiencies in planning that lead to poor performance, high costs and unplanned downtime. The guidelines will be used by the Jordanian water sector institutions as guiding principles for future planning and operation of seawater desalination facilities.

Objective 1: Avoidance of systematic deficiencies: Systematic deficiencies in planning can lead to critical failures in the realization and operation of desalination facilities and thus inability to meet the intended local or regional water demand requirement. During exploitation, the abstraction scheme may turn out not to be able to provide raw water of the intended quality and quantity. The planning must consider, among other aspects:

- Integration into the existing energy and piping infrastructure,
- Suitability of abstraction facility for providing constant quality and quantity of source water,
- Adequate pre-treatment as well as post-treatment,
- Measures to process monitoring and maintenance,
- Corrosion and fouling prevention according to the desalination technology,
- Brine management (disposal/mineral recovery),
- Environmental concerns & environmental management
- Health & Safety (Public & occupational).
- Adequate financial and contract management.

In addition, deficiencies in planning can lead to unspecific tendering documents that increase costs due to additional claims of the plant manufacturer and time delays.

Objective 2: Reducing costs by adequate planning and operation of desalination facilities: Planning costs make up only a small part of the total investment costs of desalination facilities. Optimized tendering documents in line with the market conditions can lead to high savings in investment costs if all necessary planning steps are conducted in the proper manner. System failures and low availability of source water lead to unstable water supply and increased costs so that sustainable and stable operation must be ensured. For obtaining a high plant reliability, large amounts of money are spent on process equipment, automation, and control systems. This will help minimize power outages, unsafe operations and damage to the plant equipment. The guidelines suggest including certain elements into tendering and contracting for targeted training of plant staff as well. The training issue will be even more beneficial in case that MWI/WAJ intends to operate desalination facilities themselves as part of their capacity-building strategy.

How to use the SW Planning Guideline

Both “seawater desalination” and “brackish water desalination” sound similar. However, there are crucial differences between both types of desalination technologies, particularly in planning, tendering, contracting, and operation issues that make it necessary to consider them in two separate planning and management guidelines. The following chapters of these guidelines are dedicated to the design, tendering & contracting of the “seawater desalination plant” in Jordan.

The Guideline for the Planning of Desalination Schemes shall review national and international planning criteria and experiences, which are illustrated in Figure 1-2.

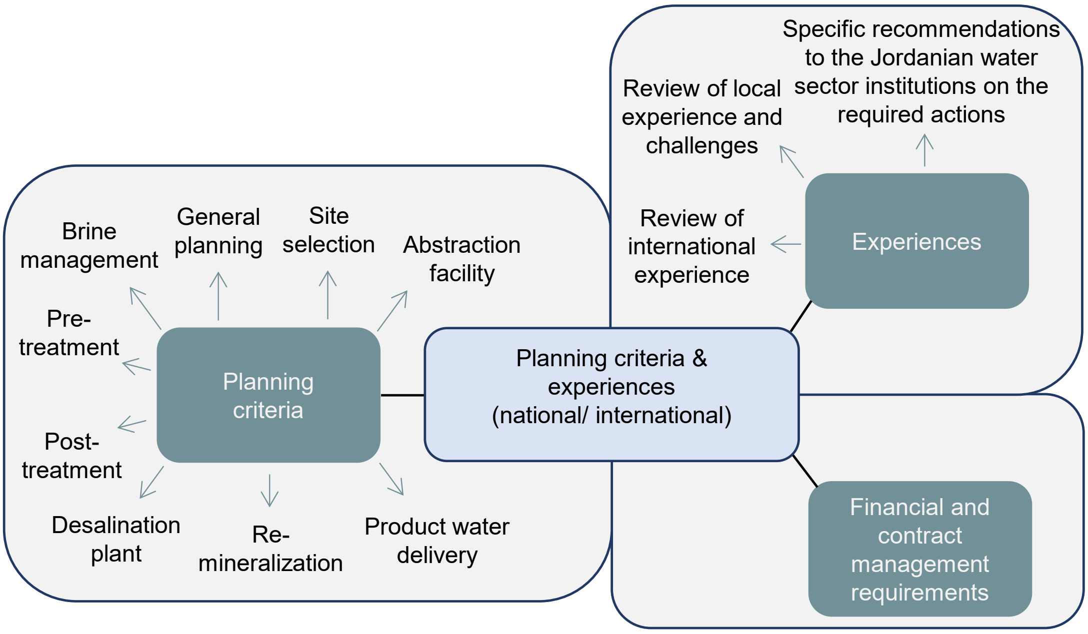


Figure 1-2: Planning steps, criteria, and experiences

The Guideline for the Planning of Desalination Plants comprises the major planning phases from basic estimates to construction management and approval. The essential planning steps are shown in Figure 1-3.

The entire planning guideline is structured according to the planning steps so that the reader can go directly to the point of interest. The planning steps are based on the “Official Order of Fees for Services by Architects and Engineers” (HOAI) and adapted to Jordan's conditions.

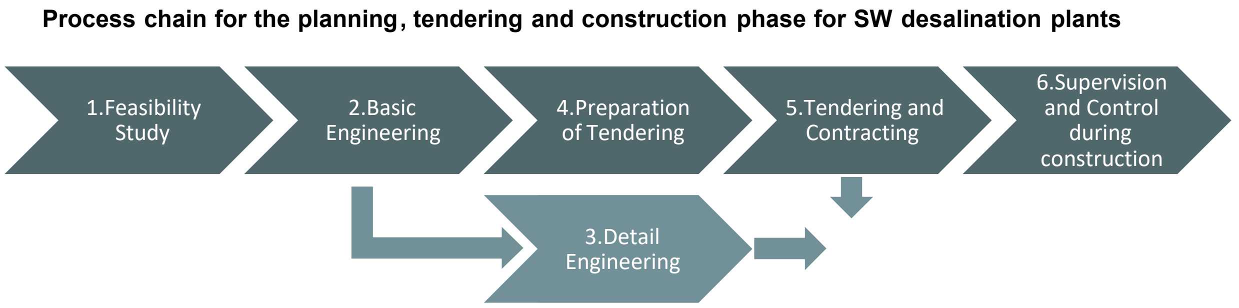
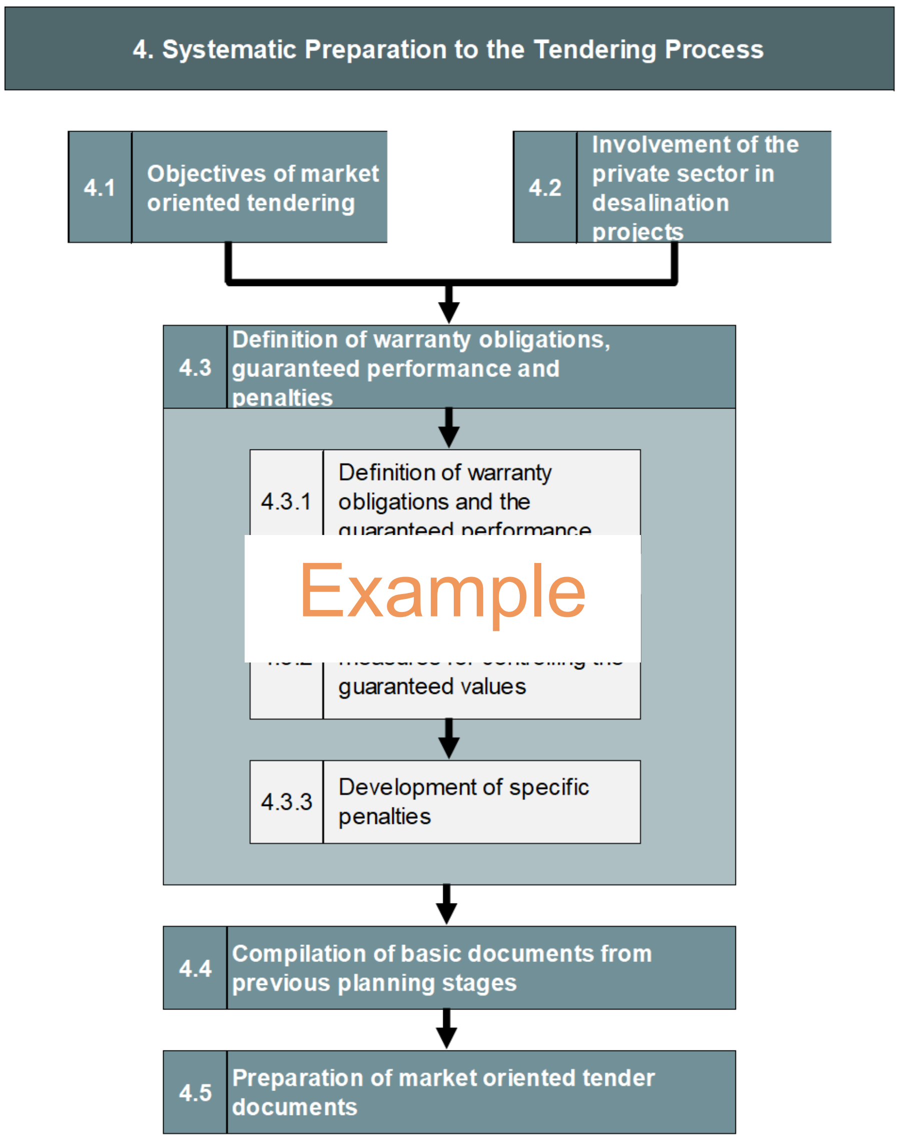


Figure 1-3: Planning phases SW treatment

Each chapter contains the following structure and elements to reinforce the understanding and application of the guidelines. Below, the elements from chapter four are exemplarily shown.

1. **The structure** that leads through the chapter:



2. **Take away messages** summarize the most important facts:

Take Away Messages – Objectives of market-oriented tendering:

- “Market orientation" must be applied to all required equipment, materials and services in all project planning phases from the feasibility study to the tendering process
- Apply the commo… and contracting processes, be aware of the … indicate that the producer compromised quality and that in the long run low prices may be more expensive..

3. **Checklist** for the application of the topics:

ITEM No.	DESCRIPTION OF ITEMS THAT NEED TO BE INCLUDED IN THE TENDER DOCUMENTS	CHECKED	REMARKS
	Preparation of tender documents	*Drawn by:*	
		Checked by:	
4.1	**Market-oriented tender**		
	a) Did you apply market-orientation to create a broad competition?		
	b) Did you apply the law of business to ensure that you get adequate quality?		
4.2	**Involvement of private sector**		
	a) Is the right contract type select… e financial risk?)		
	b) In case of B(O)OT: Is the water…		
4.3	**Warranty obligations**		
	a) Are the warranty obligations defined?		
	b) Is the warranty period of specific components realistic and on a fair level?		
	c) Did you include the essential steps until the final acceptance of the desalination plant?		
	d) Have specific penalties been developed? (Indicator, Value)		

1. Feasibility study

As shown in Figure 1-1, the feasibility study is the first step in the process of planning a SW desalination plant. The following chapter describes this step in detail.

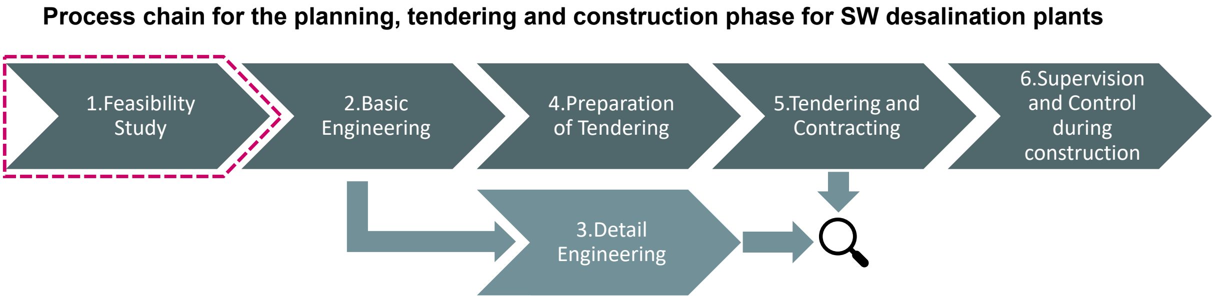


Figure 1-1: Process chain for planning, tendering, and construction phase for SW desalination plant - part 1

In the feasibility study, the technical, economic, and organizational feasibility and the project's environmental impact are closely examined. If all specified conditions are met, the best-suited desalination concept can be selected.

The aim and purpose of a feasibility study are to determine whether or not the desalination project should be advanced to the final engineering, tendering, and construction stage.

The essential steps for a successful feasibility study can be summarized as follows:

- **STEP 1: Define project targets and framework conditions**
  (→ see 1.1 Project targets and framework conditions)

- **STEP 2: Identify a suitable location considering several factors**
  (→ see 1.2 Identification of site)

- **STEP 3: Select and describe all relevant technologies according to the plant design datasheet**
  (→ see 1.3 Selection of relevant technologies)

- **STEP 4: Develop concepts and select one according to defined criteria**
  (→ see 1.4 Concept development and selection)

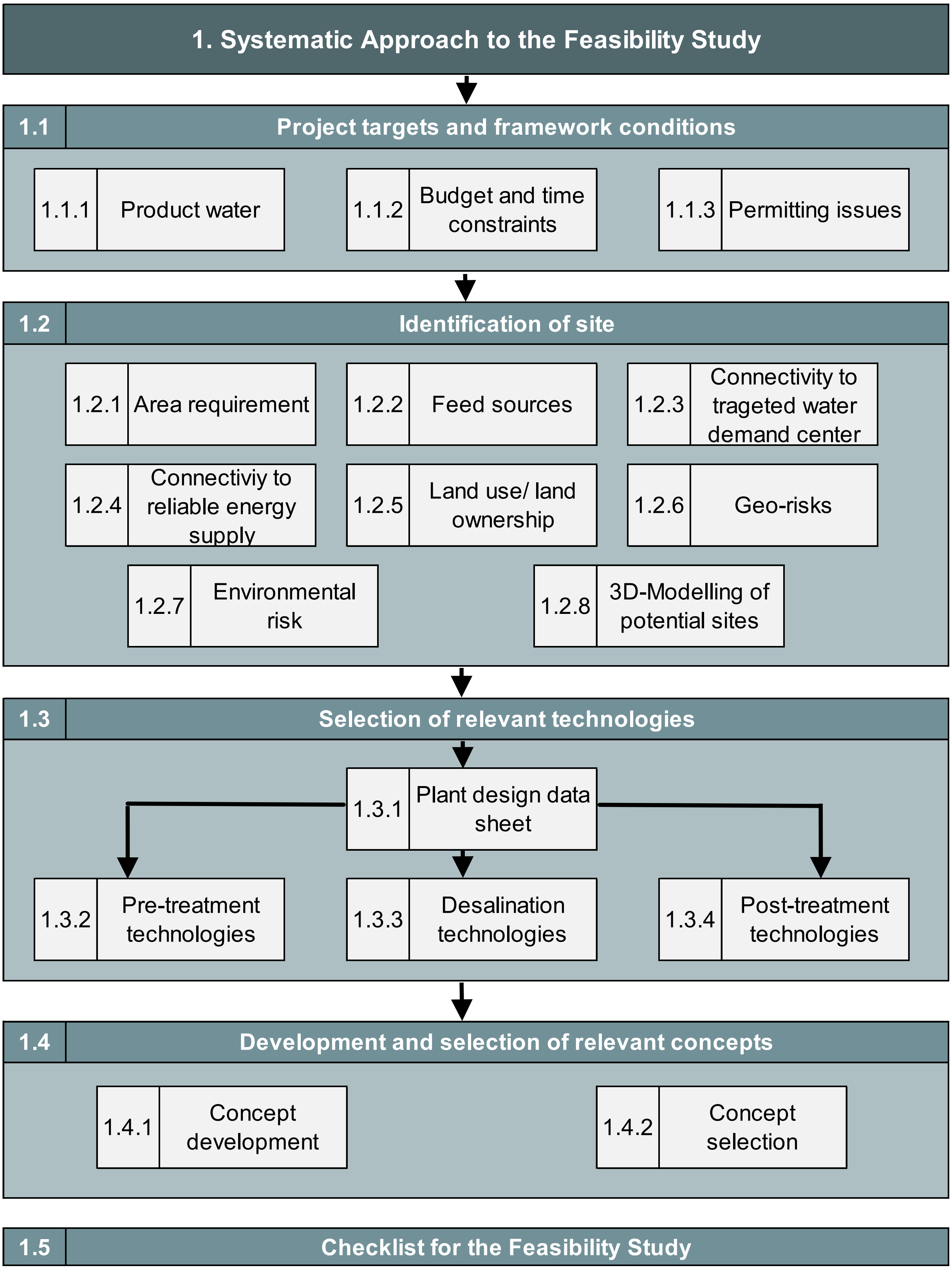


Figure 1-2: Systematic approach to the Feasibility Study

Take Away Messages – Feasibility study

- The feasibility study is of essential importance to define the goals and requirements for the conduction of a successful desalination project.
- The aim and purpose of a feasibility study is to determine whether or not the desalination project should be advanced to the final engineering, tendering and construction stage.
- The feasibility study should include at least the following main steps:

  1. Define project targets and framework conditions
  2. Identification of site
  3. Selection of relevant technolgies
  4. Development and selection of relevant concepts

- The result of the feasibility study should be capable to serve the planning concept for the further project development in the next planning steps.

1.1 Project targets and framework conditions

The first step of the feasibility study is the definition of project targets and framework conditions, as shown in Figure 1-3.

1.1	Project targets and framework conditions				
1.1.1	Product water	1.1.2	Budget and time constraints	1.1.3	Permitting issues

Figure 1-3: Overview of chapter 1.1: Project targets and framework conditions

It is essential to collect data and define the desired product water quantity and quality, the budget and time frame, among other relevant planning constraints.

1.1.1 Product water

The definition of quantity and quality of the water produced by the desalination facility has a significant influence on the scope of the whole project.

Within this context following questions have to be answered:

- What is the required quality of product water?
- How much product water needs to be produced?

Product water quality

The technology selection for desalination, including the pre-treatment and post-treatment technologies, strongly depends on the desired quality of the product water. This present guideline focuses particularly on the production of drinking water for domestic use.

Another important point regarding the product water quality is the customer acceptance of the product water. Some ingredients of the product water (for example, iron or zinc) can have negative palatability impacts (tastiness), although the product water is acceptable regarding legal standards.

According to the World Health Organization (WHO) guidelines for drinking water quality[2] as well as the Jordanian drinking water standards[3], the criteria for drinking water quality can be broken down into the following two aspects:

- Chemical
- Microbial

The following tables show the limit values of chemical and microbial parameters based on WHO and Jordanian standards. As the Jordanian drinking water standards JS 286/2015 (6th edition) are heavily based on the 4th edition of WHO guidelines, they have been combined in one column in the table below. Aesthetic parameters for drinking water are not considered. It

[2] WHO. (2017) Guidelines for drinking-water quality (4th edition).
[3] Jordanian Standards and Metrology Organization. (2015) Drinking Water JS 286:2015 (6th edition).

is the utmost task of any drinking water treatment plant to ensure these values through the use of appropriate technologies and monitor them regularly at the desalination facility and the demand center.

Table 1-1: Limit values of chemical properties

Property	WHO [mg/l]
Nitrate	50
Nitrite	3
Nickel	0.07
Copper	2
Fluoride	1.5
Chloride	500
Aluminum	0.1

Table 1-2: Limit values of microbial properties

Property	WHO [CFU/l]
Escherichia coli	0
Enterococci	-

Product water quantity

The required size of the desalination plant, including abstraction facility or intake, pre-treatment, post-treatment, brine treatment, and necessary infrastructure, highly depends on the desired target of the product water.

Thus, the product water quantity needs to be specified based on the domestic water demand at potential demand centers. For this purpose, the water demand should be determined using the historical data, if available, and expected future development.

One of the most critical factors affecting municipal water distribution is non-revenue water (NRW). NRW is defined as water being produced and distributed but not generating revenue due to water loss, e.g., through leakages. The MWI has addressed the problem of NRW in several policy changes but only with limited success. In 2020, NRW still accounted for about 50% of the water being distributed.[4]

In 2018, Jordan's total municipal water demand (supply requirement) was estimated to be around 618 MCM. According to GIZ, this number will increase to 811 MCM by 2040 due to a population increase of around 22% in the same period. In a scenario forecasting a reduction in NRW in the coming years, GIZ has estimated the water demand for 2040 to be around 721 MCM. Figure 1-4 displays these projections along with the estimated water supply. It can be seen that even considering an increased water supply due to the AAWDC project and additional water resources being considered, the water demand in Jordan still cannot be met. Due to the time Figure 1-4 was created, a recent decision to increase the water production of the AAWDC project from 250 MCM/y to 300 MCM/y by 2040 has not been considered in the graph. However, even with this in mind, there is still a gap of around 80 MCM/year between the planned water supply and the water supply requirement (NRW reduction) in 2040.

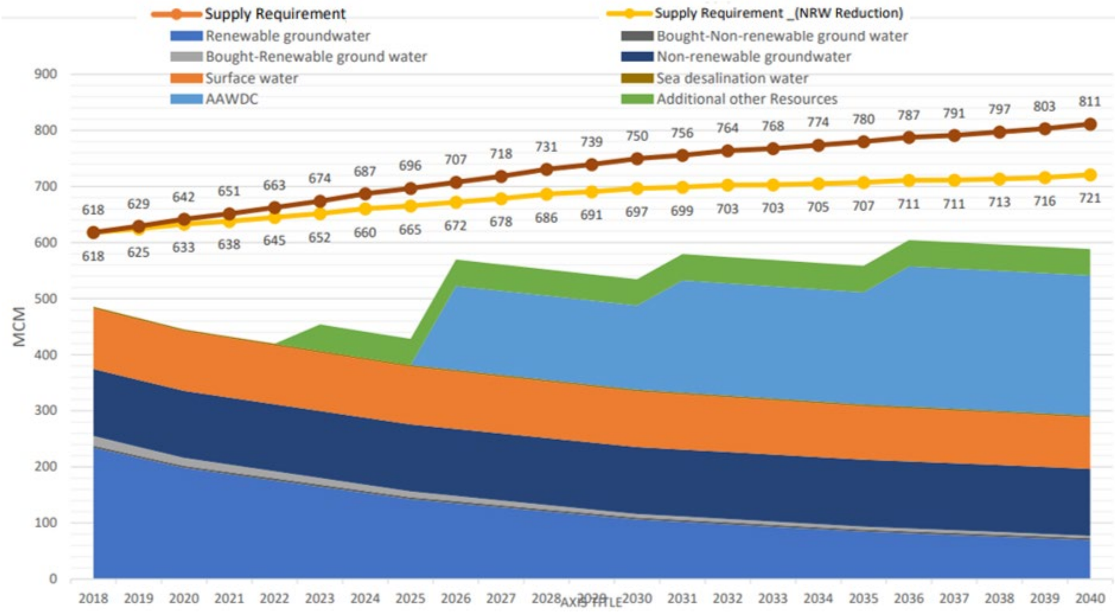


Figure 1-4: Forecast of development of water resource availability, supply requirement, and supply gap from 2018 to 2040[4]

The Water Allocation Policy from 2016 set specific targets for domestic water demand centers, which WAJ has since used as standard parameters for water supply projects. They are as follows:[4]

- 120 l/c/d (43.8 m^3/c/y) for Amman,
- 100 l/c/d (36.5 m^3/c/y) for other cities and
- 80 l/c/d (29.2 m^3/c/y) for villages in rural areas (<5,000 inhabitants).

Based on these numbers, if a town in Jordan of around 27,500 inhabitants is to be supplied with fresh water, the corresponding brackish water desalination plant must produce at least 36.5 m^3/c/y * 27,500 person = 1 MCM/y of product water.

Take Away Messages – Product water

[4] GIZ project Management of Water Resources (2020). Rapid Assessment of the Consequences of Declining Resources Availability and Exploitability for the Existing Water Supply Infrastructure.

- Define the required quality of product water.
- Comply with the JDWS/ WHO limit values through the use of appropriate technologies and to monitor them regularly at the desalination facility and at the demand centre.
- Calculate the needed product water quantity according to around 40 m³ per inhabitant per year or according to own measured or estimated consumption data, use software, if available (like WEAP).

1.1.2 Budget and time constraints

The project budget and the time frame are the most critical factors to establish at the beginning of project development.

In this stage of the feasibility study, the main goal is to get a rough overview of the budget to be raised and the time needed to plan, construct, and commission the desalination project.

Before going on with the next project steps, the following questions must be answered:

- How high is the needed budget?
- What is the time frame of the project?

Project budget

The accuracy of costs estimation for plant engineering depends on the progress of the design of plan components. Figure 1-5 shows this dependency.

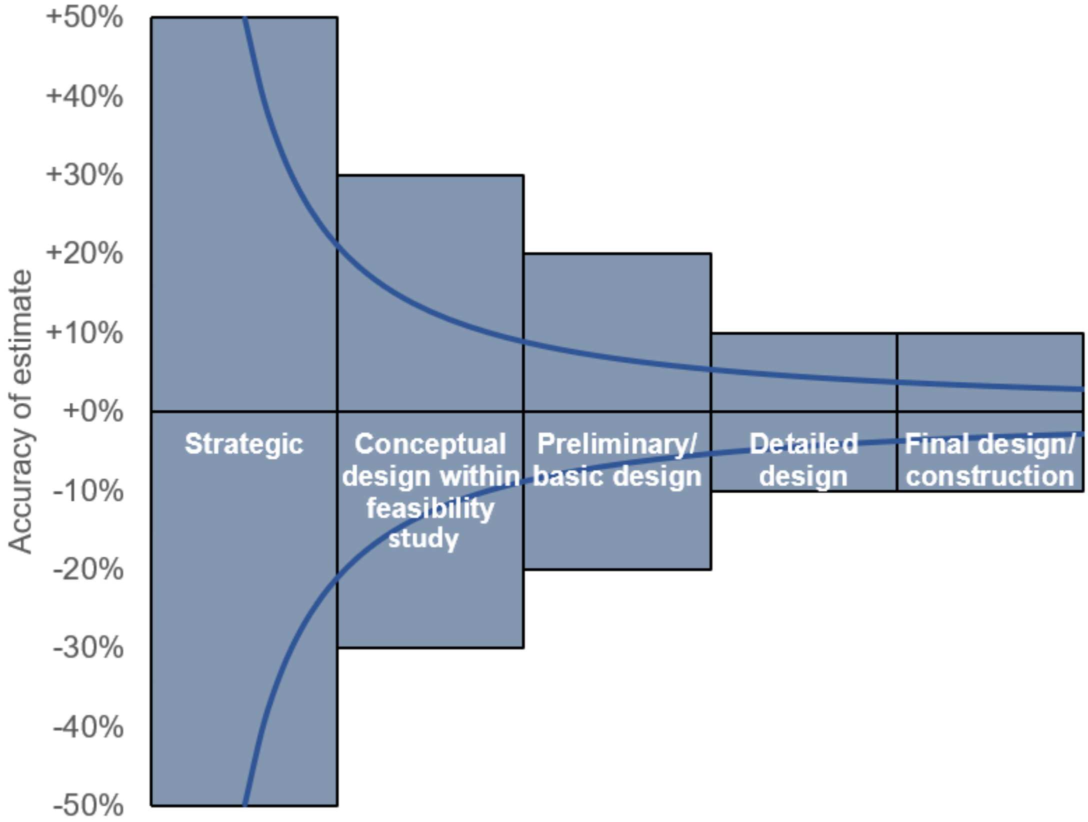


Figure 1-5: Accuracy of cost estimation in plant engineering depending on the planning phases

Within the feasibility study, the cost estimation for the planning concept should be in the range of ± 30% accuracy. By advancing through the planning stages, the accuracy is increased. The highest accuracy is reached through the evaluation of the pricing of plant components from potential bidders.

For the cost estimation in the feasibility study, it is sufficient and recommended to compare the cost data from projects comparable with the considered concept. Own projects and international projects can be included in the consideration here. For this, existing project data must be assessed to get relative plant investment costs. Distinction criteria can be:

- Water production quality
- Water production capacity
- Type of pre-treatment
- Type of RO system
- Other criteria should be added if necessary

Project time constraints

Besides the project budget, it is essential to make an appropriate assumption of the time frame of the overall desalination project.

The time frame of desalination projects is mainly, but not limited to, dependent on:

- Legal clarifications including necessary time for approvals,
- Clarification of land ownership and land acquisition
- Well drilling, well piloting, and well construction
- The appropriate time frame for the engineering design, the preparation of tender documents, the tendering process itself as well as the construction phase
- Buffer time for unforeseen events

The time-influencing factors are highly dependent on the complexity and the scale of the planned desalination project.

Table 1-3 shows the length of each project period that can be expected for a 100 MCM/a SWRO desalination project. These values are to be seen as guidelines only and can vary depending on the project specifics. A more detailed time schedule can be found in chapter 3.2: Time schedule.

Table 1-3: Typical length of desalination project implementation

Period	Time span
1. Feasibility study	4 months
1.1 Project targets and framework conditions	2 months
1.2 Site identification	2 months
1.3 Preparation of report	1 month
2. Basic engineering	2 months
3. Approval authority: approval time	6 months
4. Preparation of tendering	3 months
5. Tendering & contracting	3
6. Construction phase	24 months

1.1.3 Permitting Issues

If approval issues are not defined and clarified at an early stage of the project, it can lead to a severe project delay, cost expenditures, or even project failure. All necessary permits shall be available before awarding the desalination plants to the supplier.

Necessary permits can include environmental permits (beach wells/offshore intakes/conveyances/outfall systems/emissions), water quality-related permits, and construction permits. It is recommended to comply with the national regulations in obtaining approvals from the relevant authorities on time. If there are no specific national regulations available, internationally applicable regulations should be applied that are valid in countries with outstanding experience in desalination projects.

Take Away Messages – Budget and time constraints

- Budget:
  - Collect detailled technical and cost relevant data of already existing desalination projects in the region and internationally, document the data from future projects within Jordan.
  - Identify key parameters to make a cost comparison such as:
    - Feed water quality
    - Product water quality,
    - Type of pre-treatment technologies,
    - Type of RO System
  - Estimate CAPEX roughly from comparison of existing desalination projects with the budgetary prices from market, that are comparable by the identified key parameters.
- Time schedule:
  - The timeframe is highly dependent on the size and the type of the desalination projects.
  - Allow enough buffer time for unforseeable factors.

1.2 Identification of site

The identification of the site is the next step to be elaborated after the clarification of the project targets and framework conditions.

Figure 1-6 shows the steps necessary to identify a suitable site for the erection of the desalination facility.

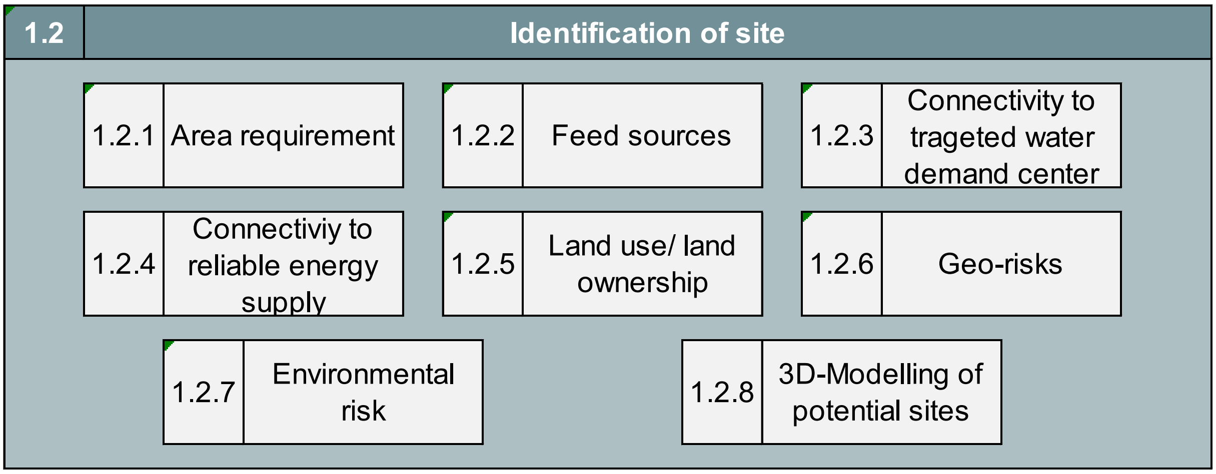


Figure 1-6: Overview of chapter 1.2: Identification of site

1.2.1 Area requirement

The site on which a SWRO desalination plant is built needs to fulfill certain requirements to make the project technically and economically feasible while meeting environmental standards. These criteria differ for each of the components, which make up a SWRO desalination plant. These eight different sub-systems, which are displayed in Figure 1-7, are described in the following section.[5]

[5] Tsiourtis (2007). Criteria and procedure for selecting a site for a desalination plant. Desalination.

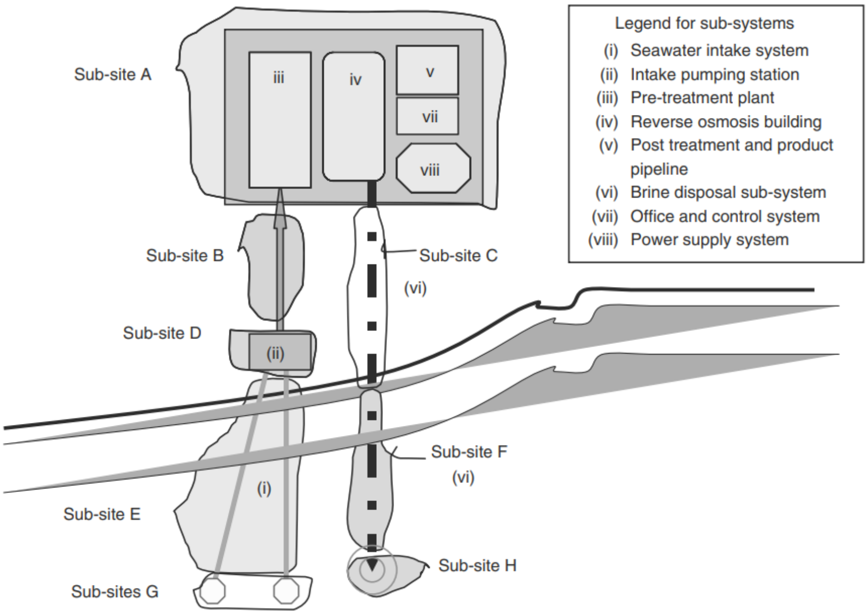


Figure 1-7: Sub-site components of a SWRO desalination plant[6]

(1) Sub-site A: This is the location of the main components of the facility including pre-treatment, RO, post-treatment, chemical tanks, office and control system and, if required, the power supply system. The plot size varies depending on the production capacity of the plant. Additionally, the location of the plot should be chosen with environmental factors in mind. As such, it should not include conservation areas or any rare species of flora. It should also be as far away from inhabited areas as possible to minimize noise pollution. This also applies to all the following sub-sites.

(2) Sub-site B: In this location is the seawater piping connecting the main facility and the pumping station. For desalination plants which are collocated with power stations, the intake piping is sometimes connected to the water return flow circuit of the power station.

(3) Sub-site C: The brine pipeline from the RO to the brine disposal outlet is located here. For desalination plants which are collocated with power stations, the outlet piping may lead to the discharge outlet of the power station.

(4) Sub-site D: This is the land on which the intake pit and the pumping station is located. It is usually adjacent to the seashore line. During the construction phase, a pit with a depth of between 10 and 12 m has to be accounted for. The geology of the plot needs to be examined in preparation of deep excavation, sheet or concrete wall piling and dewatering.

(5) Sub-site E: This is a strip of seabed on which the marine intake pipeline is located. Geological conditions of the seabed need to be examined to allow for the excavation

[6] Tsiourtis (2007). Criteria and procedure for selecting a site for a desalination plant. Desalination.

of pipeline trenches to protect the piping. It is of great importance that the excavations are done in accordance with strict marine environmental guidelines.

(6) Sub-site F: On this strip of seabed the marine brine pipeline is located. The same statements as for sub-site E apply.

(7) Sub-site G: This area includes one or more plots at the bottom of the sea on which the intake structure is located. The geological conditions should allow for a stable and secure concrete intake structure. The water in this area should be of good quality.

(8) Sub-site H: This sub-site includes the marine plot on which the brine outfall structure is located. The water conditions here should be suitable for quick mixing of the brine. High dilution and diffusion rates are important to avoid pockets of water with an abnormally high salinity.

The total area required differs depending on the capacity of the SWRO plant. Figure 1-8 displays the land requirements based on a conventional SWRO plant layout. Compact plants, which for example stack RO modules horizontally, may require less surface.[7]

Typical Plant Site Land Requirements	
Plant Capacity (m^3/day)	m^2
1.000	800 - 1.600
5.000	2.000 - 3.200
10.000	4.500 - 6.100
20.000	10.100 - 14.200
40.000	18.200 - 24.300
80.000	22.200 - 30.500
100.000	26.300 - 34.400
150.000	33.000 - 42.000
200.000	36.400 - 48.600
300.000	58.700 - 83.000
400.000	81.000 - 100.000

Figure 1-8: SWRO desalination plant land requirements[7]

[7] Voutchkov (2019). Desalination Project Cost Estimating and Management.

1.2.2 Feed sources

As a first step, the feed source of the potential raw water source needs to be defined.

The following questions must be answered:

- Are there any available seawater sources in the vicinity of the demand center?
- What is the quality of water, including temperature, that is planned to be abstracted?
- Are constant qualities of raw water provided, or do variations have to be considered?

The available water sources must be analyzed qualitatively. Having access to reliable water quality data is crucial in determining the treatment requirements of the plant. The following steps should be taken to ensure sufficient water quality assessment:

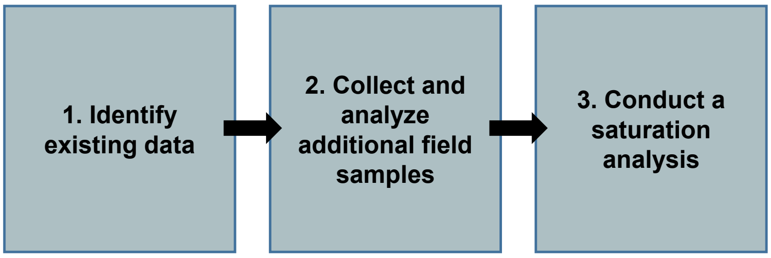


Figure 1-9: Steps for water quality assessment

Existing data can often be found to get an idea of seawater parameters in the area. However, field samples still need to be taken and analyzed to verify and fill in potential gaps in the data. Furthermore, a saturation analysis can provide additional information on water quality. The goal is to identify the minerals near their saturation limit, which are likely to precipitate out during treatment and cause fouling, taste, or odor issues. This can be achieved by calculating the Langelier Saturation Index (LSI) or performing a saturation index analysis using computer programs such as PHREEQC.

Example: Feed source analysis for Red Sea water near the Jordanian coast

This section will provide an example for a feed source analysis using Red Sea water data. The water quality analysis for these samples provides valuable information on the water parameters of the Red Sea and is therefore of utmost importance for choosing the appropriate treatment options for the desalination plant.

1. Identify existing data

The Red Sea water data stems from five different sample locations along the Jordanian Red Sea coast. They were collected by, among others, the College of Natural and Health Sciences of the Zayed University in Abu Dhabi in September of 2017 in the scope of performing an evaluation of the Gulf of Aqaba coastal water.[8]

[8] Al-Taani et al (2020). Evaluation of the Gulf of Aqaba Coastal Water, Jordan.

The results of the sample analyses are depicted in Table 1-4 and Figure 1-10. The pH values indicate basic coastal waters. The salinity of the water is comparably high which is shown by the average TDS level of 41.91 g/L. The concentrations of inorganic nutrients are relatively low, while the concentration of most metals is higher compared to other seawater coastal regions.[9]

Table 1-4: Gulf of Aqaba water quality data from 5 different sample points[9]

Parameter	Unit	Sample Nr. 1	Sample Nr. 2	Sample Nr. 3	Sample Nr. 4	Sample Nr. 5	Mean	Min	Max
pH	-	8,3	8,3	8,2	8,2	8,3	8,3	8,2	8,3
EC	mS/cm	52,3	52,5	52,4	51,9	51,4	52,1	51,4	52,5
Total Dissolved Solids (TDS)	mg/L	41.970,0	42.740,0	42.150,0	41.410,0	41.280,0	41.910,0	41.280,0	42.740,0
Total Alkalinity (TA)	mg/L	130.000,0	136.000,0	140.000,0	142.000,0	160.000,0	141.600,0	130.000,0	160.000,0
Chloride (Cl^-)	mg/l	24.592,7	25.392,1	25.192,2	22.253,1	23.152,8	24.116,6	22.253,1	25.392,1
Nitrate (NO_3^-)	mg/l	15,3	14,3	14,0	12,4	14,1	14,0	12,4	15,3
Sulphate (SO_4^{2-})	mg/l	382,3	381,3	401,1	380,6	390,2	387,1	380,6	401,1
Phosphate (PO_4^{3-})	mg/l	0,3	0,3	0,3	0,3	0,2	0,3	0,2	0,3
Ammonium (NH_4^+)	mg/l	16,6	15,4	15,5	13,7	15,9	15,4	13,7	16,6
Calcium (Ca^{2+})	mg/l	442,5	487,0	468,8	432,6	425,1	451,2	425,1	487,0
Magnesium (Mg^{2+})	mg/l	2.295,7	2.355,9	2.320,9	2.258,9	2.249,7	2.296,2	2.249,7	2.355,9
Sodium (Na^+)	mg/l	11.165,8	11.736,9	11.610,5	10.065,4	9.681,4	10.852,0	9.681,4	11.736,9
Potassium (K^+)	mg/l	591,8	602,3	570,2	558,1	581,5	580,8	558,1	602,3
Strontium (Sr)	mg/l	9,9	10,4	10,0	9,4	9,2	9,8	9,2	10,4
Cadmium (Cd)	mg/l	0,0002	0,0004	0,0004	0,0005	0,0007	0,0004	0,0002	0,0007
Chromium (Cr)	mg/l	0,0010	0,0010	0,0014	0,0013	0,0019	0,0013	0,0010	0,0019
Copper (Cu)	mg/l	0,0009	0,0012	0,0013	0,0013	0,0019	0,0013	0,0009	0,0019
Iron (Fe)	mg/l	0,0009	0,0008	0,0008	0,0013	0,0019	0,0012	0,0008	0,0019
Manganese (Mn)	mg/l	0,0008	0,0008	0,0009	0,0009	0,0012	0,0009	0,0008	0,0012
Lead (Pb)	mg/l	0,0002	0,0003	0,0003	0,0002	0,0008	0,0004	0,0002	0,0008
Zinc (Zn)	mg/l	0,0039	0,0052	0,0055	0,0051	0,0083	0,0056	0,0039	0,0083

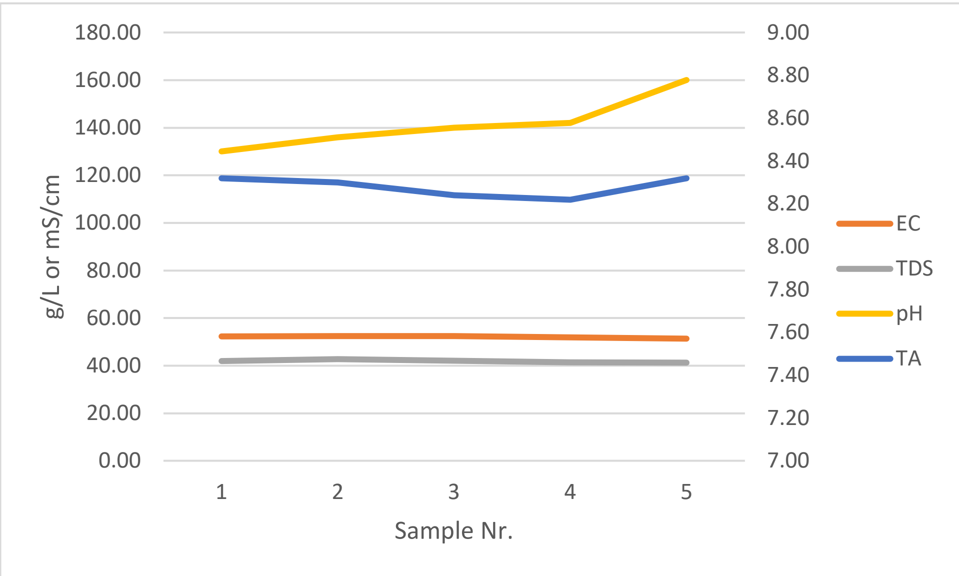


Figure 1-10: Value comparison of electrical conductivity (EC), total dissolved solids (TDS), pH and total alkalinity (TA) for five sample numbers[9]

[9] Al-Taani et al (2020). Evaluation of the Gulf of Aqaba Coastal Water, Jordan.

2. <u>Collect and analyze additional field data</u>

Experience indicates that, high levels of Boron have posed issues for Jordanian SW desalination plant operators and have required special membrane configurations. Considering the lack of data on Boron in the collected data, collecting and analyzing additional water samples is recommended. However, due to the scope of these guidelines, this was not done in this example. Collecting additional data can also confirm or refute abnormally high or low concentrations.

3. <u>Conduct a saturation analysis</u>

As part of the saturation analysis, the Langlier Saturation Index (LSI) should be calculated. The LSI uses pH as the main variable to estimate the likelihood of precipitation of calcium carbonate (calcite)[10]. The saturation index value is negative when a mineral may be dissolved, positive when precipitated, and zero when the solution and mineral are at an equilibrium. If the LSI is higher than 2, precipitation is likely, and the mineral is at risk of causing membrane fouling or other damages during treatment. The solubility limit of calcium carbonates as well calcium sulfate and other compounds can be increased by using an appropriate antiscalant to protect the RO membrane. The plant operator must consult with the antiscalant manufacturer to verify all necessary solubility limits. Antiscalants are covered in more detail in chapter 1.3.2: Pre-treatment technologies.

The pH values indicate basic coastal waters. The salinity of the water is comparably high which is shown by the average TDS level of 41.91 g/L. The concentrations of inorganic nutrients are relatively low, while the concentration of most metals is higher compared to other seawater coastal regions.

Take away messages of feed sources

- The feed water should to be analyzed qualitativly to identify key water parameters which need to be treated in order to avoid corrosion, scaling and fouling issues
- Water samples should be taken over a long period of time at different locations and depths to be able to detect changes in the SW
- Red Sea water in the sample areas is generally characterized by a comparitivly high salinity and metal content as well as low inorganic nutrients

[10] Alsaqqar A. et al (2014). Evaluating Water Stability Indices from Water Treatment Plants in Baghdad City. Scientific Research.

1.2.3 Connectivity to targeted water demand center(s)

In the feasibility study, it is necessary to investigate the connectivity of the product water to possible water demand centers. The effort for potential integration into the existing infrastructure needs to be checked.

The following questions must be answered:

- Is there an existing infrastructure to which the new plant can be connected?
- To what extent do new pipelines have to be installed?
- Are there any obstacles that prevent the easy installation of new pipelines?

Water distribution system

A water distribution system consists of pipelines, storage facilities, pumps, and other accessories.

It must be investigated whether existing distribution systems have the capacity to transport the additional amount of product water to the demand center that the new desalination plant will produce. If this is not the case, the existing distribution system must be refurbished, or a new supply line must be planned. This will have an influence on the CAPEX, OPEX, and thus the resulting water costs.

Pipelines:

- Primary feeders: water mains for the connection between the desalination plant and the demand center area
- Secondary feeders: water mains for the connection between primary feeders and distributors
- Distributors: water mains which are located near the water users
- Service lines: small diameter pipes for the connection of a water main to the individual user's location

Storage facilities (distribution reservoirs):

- To provide clean drinking water storage
- To ensure a sufficient water supply in fluctuating demands
- To equalize the operating pressure
- To serve firefighting demands (temporarily)

Types of storage facilities:

- Underground storage reservoir or covered finished water reservoir: Underground storage facility or large ground excavated reservoir that is fully covered. The walls and the bottom of these reservoirs should be lined with impermeable materials to prevent groundwater intrusion.
- Uncovered finished water reservoir: large ground excavated reservoir with adequate measures or lining to prevent surface water runoff and ground water intrusion but does not have a top cover. This type of reservoir is less desirable as the water will not be further treated before distribution. Still, it is susceptible

to contaminants such as bird waste, animal and human activities, algal bloom, and airborne deposition.

- Surface reservoir (also known as ground storage tank and ground storage reservoir): Storage facility built on the ground with walls lined with concrete, shotcrete, asphalt, or membrane. A surface reservoir is usually covered to prevent contamination. They are typically located in high elevation areas that have enough hydraulic head for distribution. Booster pumps will be required if a surface reservoir at the ground level cannot provide a sufficient hydraulic head to the distribution system.
- Water tower (elevated surface reservoir): Elevated water tank. A few common types are spheroid elevated storage tank, a steel spheroid tank on top of a small-diameter steel column; composite elevated storage tank, a steel tank on a large-diameter concrete column; and hydropillar elevated storage tanks, a steel tank on a large-diameter steel column.
- Standpipe: A water tank that is a combination of a ground storage tank and water tower water. It is slightly different from an elevated water tower in that the standpipe allows water storage from the ground level to the top of the tank.
- Sump: This is a contingency water storage facility that is not used to distribute water directly. It is typically built underground in a circular shape with a dome top above ground. The water from a sump will be pumped to a service reservoir when it is needed.

Storage facilities are typically located at the center of the service locations. Being at the central location reduces the length of the water mains to the services locations.

Take away messages

- Clearly define how the water will be transported from the desalination plants to the demand centers
- Investigate whether existing distribution systems have the capacity to transport the additional amount of product water to the demand center that the new desalination plant will produce. A water distribution system consists of pipelines, storage facilities, pumps, and other accessories
- If an extension or new construction of the supply infrastructure is required, this planning must take place in parallel with the planning of the desalination plant

1.2.4 Connectivity to reliable energy supply

Within the feasibility study, the source and other related issues of the energy supply must be clarified for the conceptual purpose. In this context, the following questions must be answered:

- How much electrical power is needed for the desalination plant?
- What is the cost of electricity?
- How much electrical power needed for pumping the product water to the demand center?
- How can the availability of electrical energy be secured?

Determination of the electrical power needed for SW desalination

Desalination, regardless of which technology, thermal or membrane-based, is still an energy-intensive process to produce drinking water from salty raw water sources. The higher the salt content in the raw water, the higher is the energy requirement for producing freshwater from this source. This statement may not apply to thermal (MED), and membrane-based (RO) processes equally. In this context, thermal processes are, in principle, less sensitive to the salt content in the raw water since they work on the basis of phase change. Membrane-based processes (RO), on the other hand, require energy depending on the water salinity to counteract the osmotic pressure, which increases linearly with the feedwater salinity.

Let's compare seawater desalination with higher feed salinity (TDS 30,000 - 45,000 ppm) with a lower feed salinity brackish water desalination plant (TDS 1000 - 15,000 ppm). It becomes immediately clear that the high osmotic pressure in SW makes the use of RO-technology more energy intensive than in BW applications. For a qualitative impression, the specific electrical energy requirement of a standard SW-MED system can be quantified independently of the salt content at about 1.5 kWh/m². In comparison, the specific energy requirement of a SWRO system is around 3 kWh/m³. In addition, a MED system needs very high thermal energy, around 65 – 70 kWh/m³, the provision of thermal energy is fundamentally decisive for its selection. Suppose the required thermal energy is inexpensive, e.g., waste heat from a nearby power plant or another energy source. In that case, MED is considered an eligible desalination process for SW applications.

At this point, we can now summarize that for seawater desalination, RO has excellent advantages from an energy point of view compared to thermal processes such as MED. In addition, it can more easily be combined with renewable energy sources since the required energy is pure electrical.

The specific energy demand values given in the present chapter can be used for preliminary conceptual considerations of power needed by seawater desalination plants. Further details of the required power calculations and the aspects regarding energy saving and energy recovery are given in chapter 2, Basic Engineering.

Determination of the electrical power needed for water transport

For the planning of desalination facilities, the topography of the area has to be taken into consideration. Particularly, the energy consumption imposed by pumping stations can be reduced by the correct placing of this technical equipment. To estimate the power needed by well pumps and transport pumps, the topography data of the wellfield and demand center area are required. The topography of the relevant area should include recording the terrain, the three-dimensional nature of the surface, and the identification of specific landforms. In modern use, elevation data is generated in digital form (DHM) that can be used for energy and power demand calculations. Considerable energy can be saved by choosing the optimal location for well fields and pumping stations.

Coupling the desalination process with renewable energy

As mentioned above, desalination is an energy-intensive technology. Thus, its economic viability is strongly dependent on the cost and availability of a reasonable energy supply at the desalination plant site. In such a sun-rich country like Jordan, the technical concepts dealing with the coverage of the energy demand of seawater desalination plants should take the solar options into close consideration. The recent market development for PV is highly encouraging to harvest solar power for viable water desalination.

Technological advancement led to a significant reduction in the energy demand of RO desalination plants. A stable energy supply is essential for proper plant operation. Two options are possible:

- PV can meet the energy demand during sunshine hours
  If the plants run longer than sunrise hours, electricity storage in the form of batteries or a supplemental connection to the grid must be considered

Large thermal desalination plants are mostly coupled with a power plant as a so-called “dual-purpose” plant. In such cases, the desalination takes advantage of the improved thermodynamics of the total complex by exploiting the “waste heat” from the adjacent power plant. Even at lower seawater temperatures, the required thermal energy for the LT-MED can be covered by low-cost, flat collectors, whereas PV panels supply electricity during the daytime. Another advantage of the LT-MED is that the required thermal energy for its operation during the night can be stored in the feed water tank. Figure 1-11 depicts such a solar energy mix with a hybrid MED-RO seawater desalination.

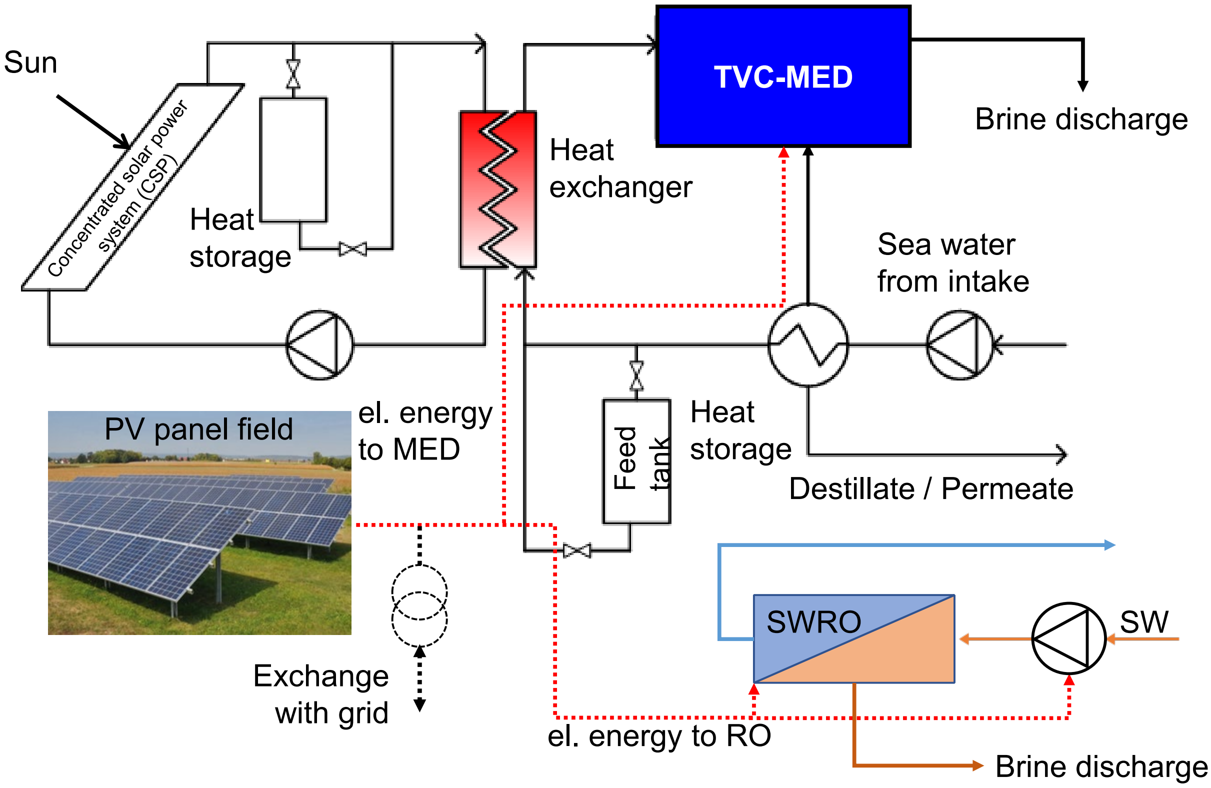


Figure 1-11: Option for an optimal renewable energy mix for a hybrid SWRO desalination plant

Take away messages of connectivity to reliable energy supply

- Mostly, wherever water is scarce, the availabilty of solar energy is high
- Advances in solar technologies will continue to improve efficiency
- Thus, it is worth condsidering the solar energy options for seawater desalination
- The exchange of solar power with the public grid increases the availability of the installed seawater desalination

1.2.5 Land use/land ownership

The current land use and the land ownership need to be specified before the final selection of the plant location. The land acquisition must be completed before tendering for the desalination plant to avoid delays in the further contracting and erection phase. The following two questions must be considered:

- What is the actual land use?
- Who is the landowner of the possible location of the desalination plant, or of the area needed to build water transport pipelines?

All land in a country either entirely belongs to the state, or its ownership is distributed to (possibly) many different parties. Thus, after identifying a proper site for a desalination plant, it is necessary to figure out the current owners of the land needed for the realization of the new plant. This must be agreed with the responsible organization, the Department of Land and Survey in Jordan. To ensure that the construction of the plant goes smoothly and successfully, it is important to consider all the elements and the footprint you need. This includes the feed water source, the plant's location, pipelines for water transportation, infrastructure for energy supply, and other infrastructure like roads.

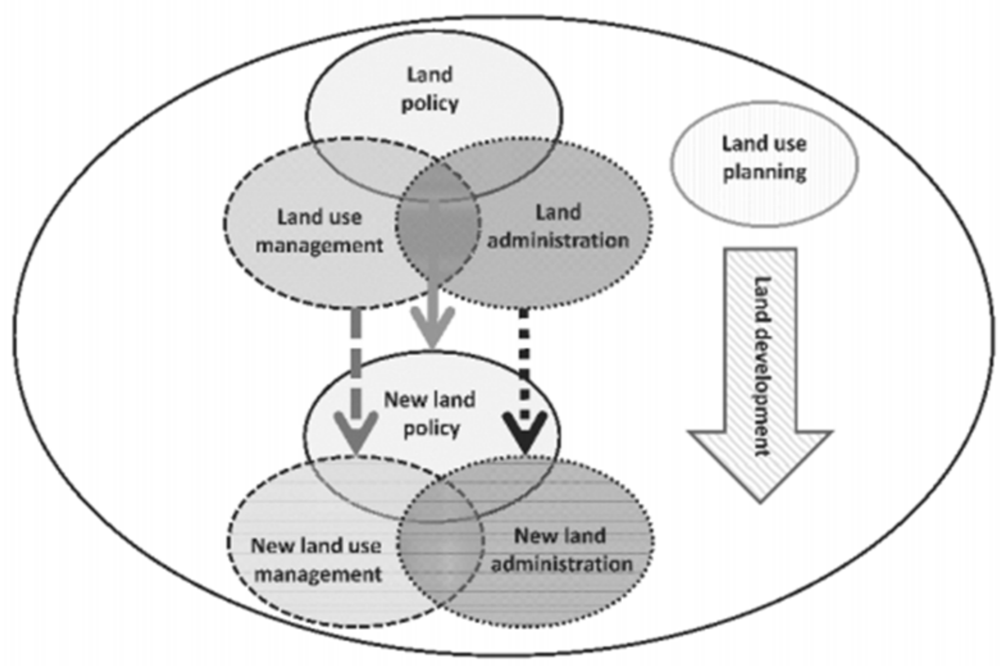


Figure 1-12: Principal of the land governance system[11]

Figure 1-12 shows a typical land governance system, including proper land policy, land (use) management, and land administration that enhances the selection and the acquisition of land for the realization of desalination plants. The explanation of the elements is listed below:

- Land governance is the government's complex task to guide, overlook and steer the land sector by the creation of action space for promoted activities

[11] Hepperle E. et al (2017). Land Ownership and Land Use Development. VDF.

- Land policy is the creation of guiding principles for land use
- Land (use) management is the work related to the use of land resources within current policy guidelines taking into consideration the legal framework for a specific land area
- Land administration embraces legal rules for land use related to a certain area. As information (site, value, etc.) about such an area is essential, the tools for assessing, documenting, and mapping this information are parts of land administration
- Land development is the bundle of methods to change land use, including land rights. There can be a need for minor and/or radical changes in land policy, land use management and/or land administration
- Land use planning is the process to predict and decide future land use or formulate a proper sequence for the implementation of a plan

Changes in land use and land ownership are dynamic factors that need to be supported to enhance investments in land development, taking into account the legal conditions applicable at the site. Methods are needed to regulate the ownership and other rights to the land, as shown in Figure 1-13.

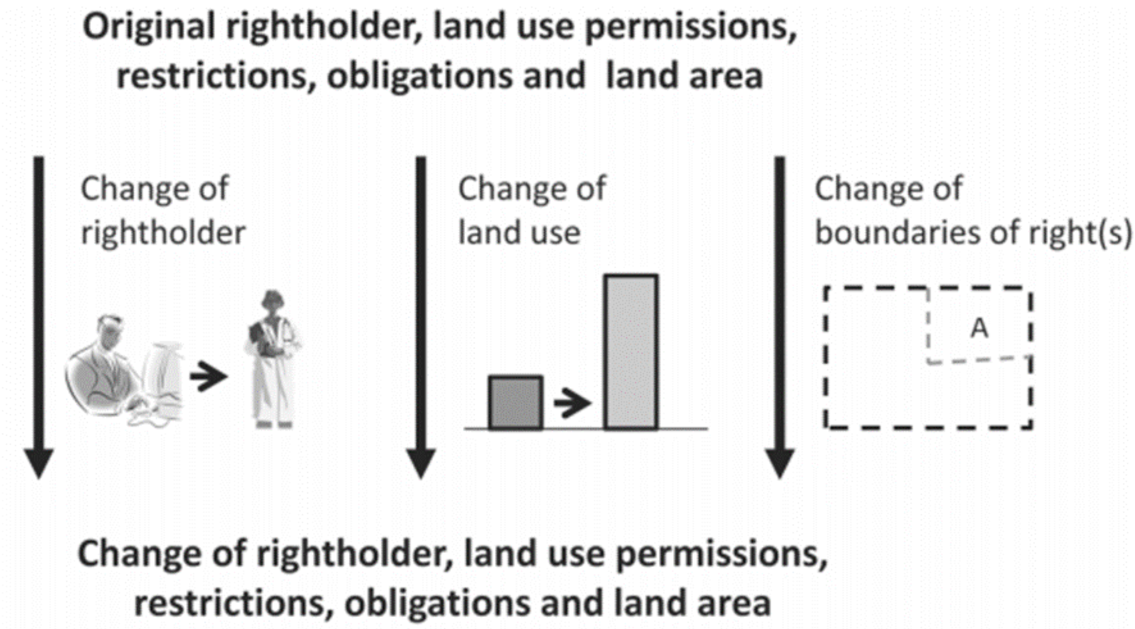


Figure 1-13: Need for methods that regulate ownership and other rights to the land[11]

A desalination project also includes the realization of the supporting infrastructure like roads, piping, pumping stations, or power lines that must be considered in addition to the construction of the well field and the desalination plant itself.

For the realization of desalination projects, the land use permissions need to be checked first. There could be archaeology excavation sites or military areas, so construction in these areas must also be carefully planned. If the land use permit for the construction of the desalination project is approved, only then the question of land ownership should be clarified as soon as possible. It is possible to change the land use and land use permissions, but this process takes, in most cases, very long.

Please consider that there could be multiple landowners, so the land acquisition process takes a long time. Also keep in mind that there is a possibility to gain the right on the land for the construction of pipelines through monetary compensation without changing the land ownership.

We recommend that in any case, the SWRO project owner clarify the ownership issue before the tendering phase and independently of the contracting structure. The risk of time-consuming ownership clarifications and the acquisition can be minimized by using this approach. The SWRO project owner could lease the land to the BOT contractor within BOT projects or exclude this point from the contracts. In any case, the land ownership must be clearly defined in law by contracts until the end of the lifespan of the total project (well field as well as desalination plant).

Take away messages of Land use/land ownership

- Start with the clarification of the issues regarding land ownership as early as possbile, in any case within the feasibility phase
- The realization of the supporting infrastructure like roads, piping, pumping stations or power lines in addition to the construction of the well field and the desalination plant itself must also be considered in the clarification of land use and land ownership
- The ownership issues must be solved prior to the tendering of the desalination project and must be clearly defined in law by contract stipulations until the end of the lifetime of the total project

1.2.6 Geo-risks

The next topic in the feasibility study is to collect data concerning geo-risks at the potential desalination site. The potential of the occurrence of hazardous events needs to be known, and risk mitigation strategies need to be developed and executed. The hazards and indications at the planned sites must be pointed out in the tendering documents, and the supplier must implement the mitigation strategies. Typical geo-risks at the designated sites are listed in Figure 1-14 below.[12]

[12] ThinkHazard. Jordan. https://thinkhazard.org/en/report/130-jordan

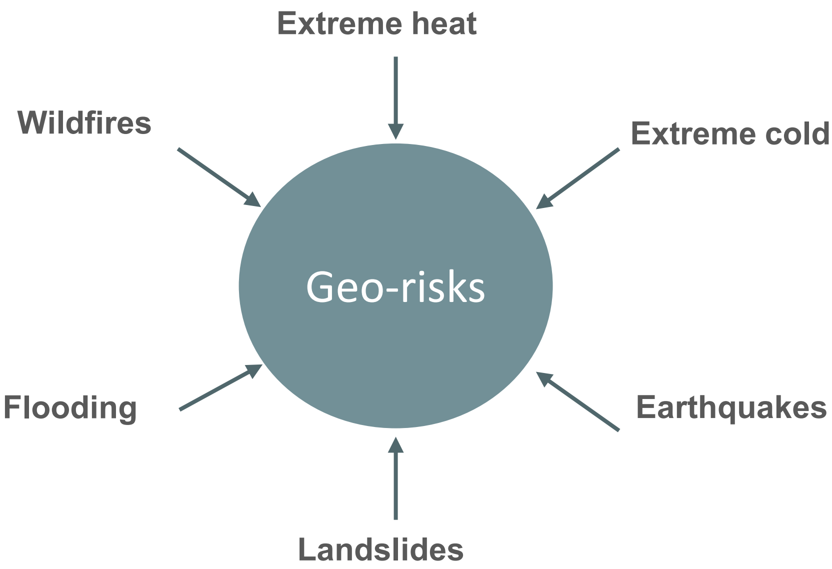


Figure 1-14: Typical geo-risks for Jordanian conditions

- Extreme heat

In Jordan, extreme heat hazard is classified as high. This means that prolonged exposure to extreme heat, resulting in heat stress, is expected to occur at least once in the next five years. Project planning decisions, project design, and construction methods must take into account the level of extreme hazard. Cooling systems in the desalination plants need to be installed to ensure suitable working conditions for the plant personnel and a stable operating temperature, especially for electrical system components.

- Extreme cold

During the coldest months of the year, December and January, the temperatures can drop to around 5 degrees. In areas with an altitude of 1000 meters and above, the is even a chance of snowfall. A minimum design temperature should be defined. This number needs to be considered when planning the desalination plant.

- Earthquakes

In Jordan, earthquake hazard is classified as a medium according to the information that is currently available. This means that there is a 10% chance of potentially damaging earthquake activity in the next 50 years.[12] Based on this information, the earthquake's impact should be considered in all phases of the project, particularly during design and construction. Project planning decisions, project design, and construction methods should consider the level of earthquake hazard. A seismic risk assessment study is highly recommended.

- Landslides

In some areas of Jordan, landslide susceptibility is classified as high. This means that this area has rainfall patterns, terrain slope, geology, soil, land cover, and (potentially) earthquakes that make localized landslides a frequent hazard phenomenon. Landslides occur mostly in hilly areas in Jordan, especially along roads during periods of intense rainfalls. Based on this information, planning decisions such as project siting, project design, and construction methods must take into account the potential for landslides. Landslides causing an increase in the project cost and delay in its completion must be expected as well.[13]

- Flood

In Jordan, the river flash flood hazard is classified as high based on modeled flood information currently available. Flash floods can occur periodically in the Jordan valley as well as most residential and desert areas throughout the country. Flash floods produce large amounts of water in very little time and are therefore especially damaging. According to GIS-based hydrology assessments, peak discharge rates of 5 MCM in the Jordan valley and 65 MCM in the W. Hammad basin must be expected.[14] Flash floods of such magnitude must be taken into account in the project planning decisions, project design, and construction methods.

The Rahma BWRO plant is located directly in the main course of the wadi (see Figure 1-15). The 4-5m high floor barrier is used as a storage basin for surface water and does not adequately protect from flooding damage. For BWRO desalination plants in the direct vicinity of a wadi it is recommended to construct a strong, at least 1.5 m high and 3 m wide, flood protection barrier in the immediate upstream area of the plant. This should also be applied to SWRO desalination plants, where applicable.

Figure 1-15: Rahma BWRO plant

- Wildfire

In Jordan, the wildfire hazard is classified as high. This means that there is greater than a 50% chance of encountering weather that could support a significant wildfire that is likely to result in both life and property loss in any given year. Based on this information, the impact of wildfire must be considered in all phases of the project, in particular during design and construction. Project planning decisions, project design, construction, and emergency response planning methods should consider the high level of wildfire hazard. Further detailed information specific to the location and planned project should be obtained to understand the hazard level adequately.

Take away messages of Geo-risk

[13] Masannat, Y. (2014). Landslide Hazards: Geotechnical Aspects and Management Policies.
[14] Al-Mahasneh, L. (2020). Assessment and mapping of flash flood hazard severity in Jordan.

- Project planning decisions, project design, and construction need to implement measures against possible hazards from all mentioned geo-risks.
  - These measures must be based on collected data to the occurrence of the hazardous events
  - It is crucial to carry out a risk analysis of the occurrence of the cases and also to specify the measures in the tender documents.

1.2.7 Environmental risk

The last step in data collection for the feasibility study is to find data about the possible environmental impacts of a new desalination plant. A thorough environmental impact assessment must be done based on this data to ensure environmental protection.

The following questions must be answered:

- What quality and amount of brine can be disposed of?
- Are there any possible environmental impacts caused by the operation of the future desalination plant (e.g., exhaust gas emissions or noise emissions)?
- What are the environmental impacts caused by the construction of the future desalination plant (e.g., impact on wildlife or pollution)?

Major environmental impacts

An environmental impact is defined as any change to the environment, whether adverse or beneficial, resulting from a facility's activities, products, or services. Ideally, a positive environmental impact of desalination is the conservation of limited natural water resources through ensuring a sustainable supply of drinking water and adapting to climate change.

In SW desalination, negative impacts can occur, for example:

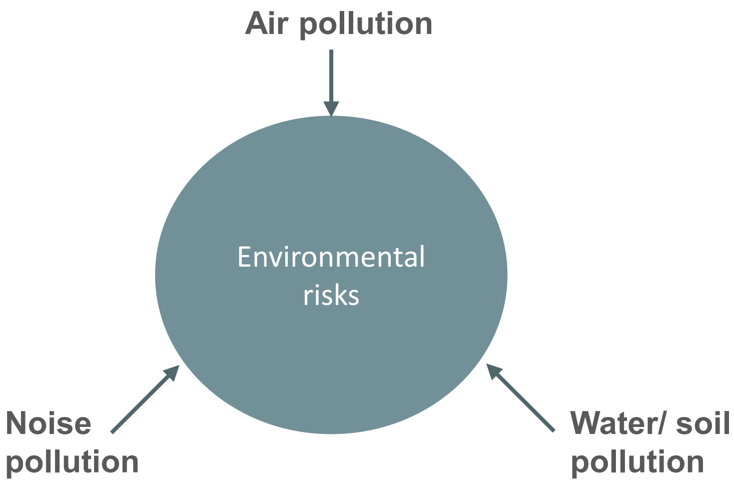


Figure 1-16: Display of typical environmental risks

- Air pollution

By using SWRO there are no exhaust gases caused by the desalination at the site. If thermal desalination technologies are preferred, there will be exhaust gases close to the site if the necessary steam is produced at the site. Changes in air quality as a result of the emissions by gas engines of machinery during the construction phase of the plant must be considered.

- Water pollution/soil pollution

Finding appropriate brine disposal methods represents an inevitable and essential part of planning the construction of new desalination plants. Properly configurated discharge structures can greatly reduce the negative impact on the environment. In the case of a SWRO plant in Jordan this means minimizing the impact of brine discharge into the Red Sea on marine organisms. Previous experiences with SWRO in the area indicate that the environmental impact of brine discharge can be satisfactorily reduced with appropriate diffuser designs based on a thorough environmental impact analysis. This analysis needs to be done in the scope of the feasibility study.

To avoid accidental spilling of chemicals, which can pollute groundwater or soil, it is necessary to have a chemical containment area in the desalination plant, with a ground that is impervious to chemicals. A sustainable method of disposing with waste products, during construction as well as operation, is a necessity.

- Noise pollution

Reverse osmosis plants generate noise because of the use of high-pressure pumps or turbines (ERT). If located near population centers or other public facilities, plans should include measures to mitigate noise pollution, such as canopies or acoustical planning. The impact of the noise does not allow for the operation of a large desalination plant in the vicinity of a population center without the use of technological means. Means for decreasing the noise level include the building of canopies over the pumps and the appropriate acoustical planning of the plant.

The data collection for the feasibility study should contain the distance between the desalination plant and the nearest habitations. Furthermore, it is necessary to estimate the future noise level of the plant. Noise generated by the machinery during the construction phase must be considered as well.

Take away messages of environmental risk

- Possible negative impacts of SW desalination are:

Air pollution: non-existent at site if SWRO is used
Water pollution / soil pollution: Brine discharge to Sea
Noise pollution: Identification of plant noise level and emissions

1.2.8 3D-Modelling of potential sites

Services of modeling potential sites comprise the preparation of land-use and development plans for new or existing facilities.

Potential sites for desalination plants can be captured by GPS in detail using CAD software like Autodesk Recap® or Autodesk Infraworks®.

A real-world context model can be created to visualize and analyze the infrastructure design concepts; an example of a 3D model is shown in the figure below. Thereby corresponding infrastructural framework conditions can be considered and improved.

Figure 1-17: Satellite view of the coast of Aqaba with Google Earth

3D-Laserscanning

With 3D laser scanning software, the physical world can be transformed into a digital asset (point cloud) to understand and verify existing and as-built conditions. The figures below illustrate point cloud models.

Figure 1-18: Autodesk Recap® 3D laser scanning view of a building

The digitization of potential sites or existing facilities may offer advantages to gain insights and make better decisions; some advantages are listed below.

- Compact overall view of the considered area

- Pre-planning of optimization improvements in the 3D model
- Possibility to integrate changes in the plant equipment into the existing infrastructure
- Precise measurement of all scanned components like pipe diameters etc.

Figure 1-19: Autodesk Recap® 3D laser scanning view of a pipe route

Inclusion of infrastructure

Within the feasibility study framework, potential sites can be automatically created with Autodesk Infraworks®; examples of a generated 3D model are shown in the figures below.

Figure 1-20: Autodesk Infraworks® example model of a crossroad

Existing interfaces can be captured, discussed, and evaluated by modeling a potential site for a desalination plant.

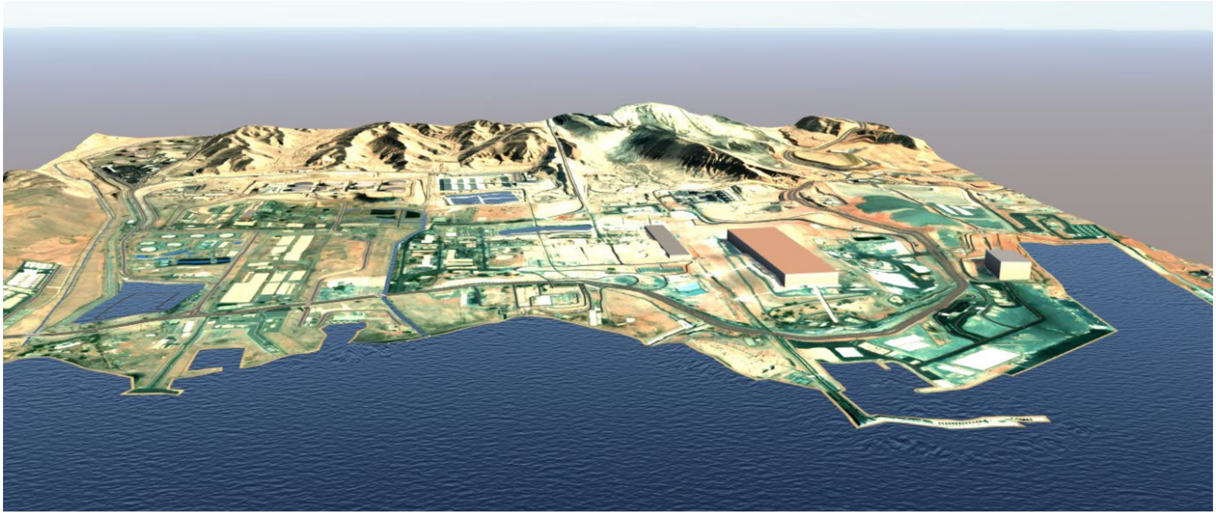


Figure 1-21: Autodesk Infraworks® model of the Industrial Terminal Jordan

The point cloud (3D laser scanning) can be implemented into the context model of Autodesk Infraworks® as well.

1.3 Selection of relevant technologies

After completing the first two steps of the feasibility study, the data collection for project targets and framework conditions for the site's identification, the "Selection of relevant technologies" has to be conducted. All data collected according to Chapter 1.1 need to be considered and evaluated.

Figure 1-22 shows a scheme for the third step in a feasibility study where possible technologies for the relevant treatment steps are described.

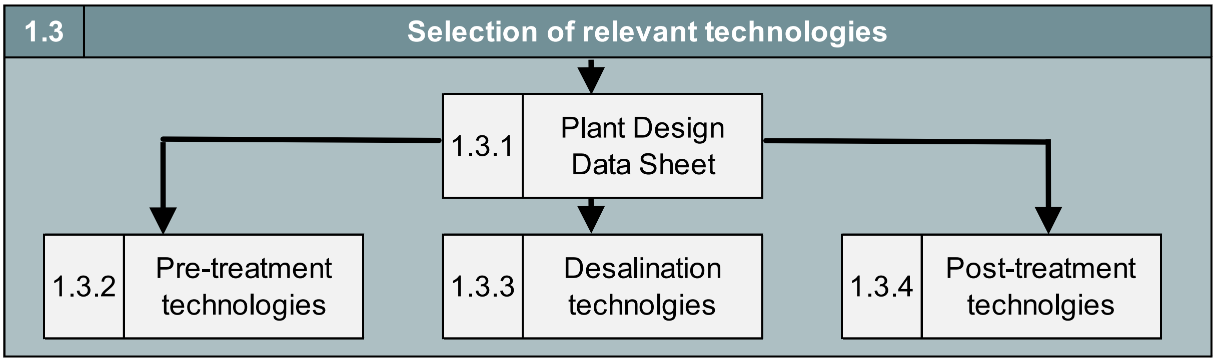


Figure 1-22: Overview of chapter 1.3: Selection of relevant technologies

As visible from Figure 1-22, it is necessary to develop a Plant Design Data Sheet, which contains the basic information for planning the future desalination plant.

After finishing the Plant Design Data Sheet, the different technologies for the necessary treatment processes must be investigated.

Following possible questions occur in this step of the feasibility study:

- What is the feed source technology within the project (Beach wells/offshore intake)?
- Which pre-treatment technology is suitable for bringing the feed water to the necessary quality suitable for reverse osmosis application?
- Which desalination principle is the best choice for the new plant?
- Which post-treatment technology can be used to reach the required water quality?

1.3.1 Plant Design Data Sheet

The Plant Design Data Sheet (PDDS) summarizes the most important data for defining the necessary performance of a desalination plant. The PDDS contains all information about the desired plant performance regarding water production, water qualities, and necessary plant performances (i.e., yield or rejection ratio). These data need to be collected in the first chapters of the feasibility study.

The Plant Design Data Sheet should contain the following design data:

- Feed water flow rate
- Design data for physical, chemical, biological key design parameters
- Targeted product water parameters
- The necessary rejection rate for each parameter

Adaptation to Jordanian conditions

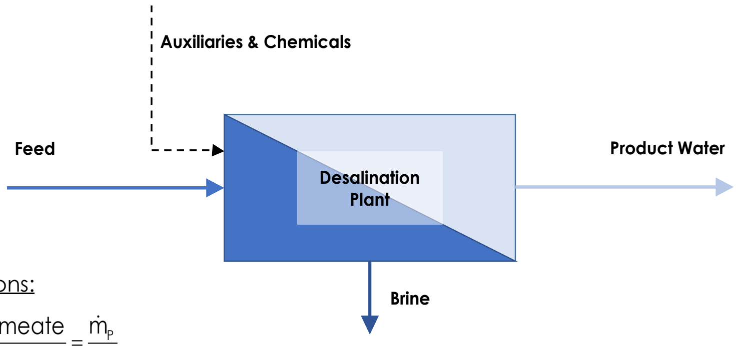
Figure 1-23 and Table 1-5 show a possible Plant Design Data Sheet as an example. It has been divided into two parts to improve the readability.

The flow rate values in the table are possible values for a new desalination plant. The annual amount of product water is determined as 100 MCM/a, leading to a targeted availability of 95% and a recovery rate of 45%, to a necessary feed amount of 222.22 MCM/a. The amount of brine is calculated to be 122.22 MCM/a.

Basic Data RO Desalination Plant

Amount of Product:	$\dot{V}_P$	=	100.00	MCM/a
Availability:	f	=	95	%
Annual operating hours:	oh	=	8322	h/a
Recovery rate RO	φ	=	45	%
Feed (TDS):	$ß_F$	=	42,000	mg/l
Permeate (TDS):	$ß_P$	=	300	mg/l

Simplified Flowsheet:



Feed		
[m³/h]	[m³/d]	[MCM/a]
26,703	640,872	222.222

Product Water		
[m³/h]	[m³/d]	[MCM/a]
12,016	288,392	100.000

Brine		
[m³/h]	[m³/d]	[MCM/a]
14,687	352,479	122.222

Equations:

$$\varphi = \frac{\text{Permeate}}{\text{Feed}} = \frac{\dot{m}_P}{\dot{m}_F}$$

Figure 1-23: Plant Design Data Sheet, part 1

Table 1-5: Plant Design Data Sheet, part 2

Parameter	Unit	SW Feed	Product Water	Necessary Reduction [%]
pH	-	8.3	6.5 - 8.5	-
Total Dissolved Solids (TDS)	mg/l	41,910	500	98.8
EC	µS/cm	52,100	500	99.0
Ammonium (NH_4^+)	mg/l	15.4	0.2	98.7
Cadmium (Cd^{2+})	mg/l	0.0004	0.003	-
Calcium (Ca^{2+})	mg/l	451.2	20	95.57
Chromium (Cr^{3+})	mg/l	0.0013	0.005	-
Copper (Cu^{2+})	mg/l	0.0013	0.02	-
Iron (Fe^{3+})	mg/l	0.0012	0.01	-
Lead (Pb^{2+})	mg/l	0.0004	0.005	-
Magnesium (Mg^{2+})	mg/l	2,296	10	99.56
Manganese (Mn^{2+})	mg/l	0.0009	0.06	-
Potassium (K^+)	mg/l	580.8	5	99.1
Sodium (Na^+)	mg/l	10,852	200	98.2
Zinc (Zn^{2+})	mg/l	0.0056	0.3	-
Chloride (Cl^-)	mg/l	24,116	50	99.8
Nitrate (NO_3^-)	mg/l	14	0.5	96.4
Phosphate (PO_4^{3-})	mg/l	0.3	0.05	83.3
Sulphate (SO_4^{2-})	mg/l	387.1	20	94.8

The SW feed data in this example is taken from the mean SW feed data in Table 1-4 in chapter 1.2.2: Feed sources. The product water quality data in the PDDS tables are based on the requirements according to the Jordan Drinking-water standards (JDWS).

The necessary reduction rate [%] is calculated as the ratio between the necessary absolute reduction [for example, in mg/l] and the feed value of the corresponding parameter.

$R_{Nec} = ((c_{Feed} - c_{Product\ Water}) / C_{Feed})*100\%$ where R = reduction %age and C= parameter concentration

Table 1-6 shows the main parameters for the design of the desalination plant. Several parameters are exceeding and violating their threshold values, and thus, they must be reduced for reaching the desired product water quality. LSI can be mentioned here, but it is not a necessity. For some parameters, e.g., iron and lead, the concentration in the seawater does not need to be reduced because the feedwater concentration is already below the given limits according to JDWS. Other constituents, like calcium, magnesium, etc., need to be reduced. Some feed water parameters, e.g., ammonia, carbon dioxide or turbidity have not been analyzed because the information is missing. These parameters are presented in Table 1-6. In these cases, specific analyses must be carried out. Or, at least, the product water needs a complete analysis to prove that the requirements according to JDWS are met. The parameters must then be added to the Plant Design Data Sheet.

Table 1-6: Missing parameters from the Plant Design Data Sheet - Seawater

Parameter	Unit	Product Water	Parameter	Unit	Product Water
Temperature	°C	25 - 30	Arsenic (As^{3+})	mg/l	0.005
Total Suspended Solids (TSS)	mg/l	0	Barium (Ba^{2+})	mg/l	1
Turbidity	NTU	5	Boron (B^{3+})	mg/l	0.15
			Lithium (Li^{+})	mg/l	-
Total Hardness ($CaCO_3$)	mg/l	60	Mercury (Hg^{2+})	mg/l	0.006
Alkalinity (as $CaCO_3$)	mg/l	40	Molybdenum (Mo^{3+})	mg/l	0.09
Ammonia (NH_3)	mg/l	-	Nickel (Ni^{2+})	mg/l	0.01
Silica (SiO_2)	mg/l	-	Selenium (Se^{4+})	mg/l	0.005
Carbon Dioxide (CO_2)	mg/l	-	Silver (Ag^{+})	mg/l	0.1
Residual Chlorine	mg/l	0.2 - 0.4	Strontium (Sr^{2+})	mg/l	-
			Tin (Sn^{3+})	mg/l	-
Total Coliform	MPN/100 ml	0	Carbonate (CO_3^{2-})	mg/l	0
E-Coli	MPN/100 ml	0	Bicarbonate (HCO_3^{-})	mg/l	50
Alpha Radionuclides excluding Radon-222	Bq/l	0.5	Bromide (Br^{-})	mg/l	0.2
Beta Radionuclides excluding Tritium and Carbon-14 and	Bq/l	1	Cyanide (CN^{-})	mg/l	0.05
			Fluoride (F^{-})	mg/l	0.1
Aluminum (Al^{3+})	mg/l	0.01	Hydroxide (OH^{-})	mg/l	-
Antimony (Sb^{3+})	mg/l	0.02	Nitrite (NO_2^{-})	mg/l	3

1.3.2 Pre-treatment technologies

Pre-treatment is the essential part to secure stable operation of a seawater reverse osmosis (SWRO) desalination plant. Without proper selection, design and operation of the pre-treatment, RO membranes will quickly foul and deteriorate limiting the life of the RO elements, impairing the performance of the plant in terms of productive capacity and quality of the RO product water, and leading to increased operational efforts and costs.

Figure 1-24: Used reverse osmosis spiral wound modules and cartridge filters pile up outside a RO plant

Both in seawater RO as well as in brackish water RO pre-treatment aims at the removal of particles and the prevention of fouling and scaling. Due to the differences in source water composition the approaches to pre-treat the RO feed water are tailor-made to the specific water characteristics. While brackish water is typically characterized by low organic content and moderate to high salinities, seawater has high contents of bulk organics, (micro)organisms, particles and colloids, alongside minerals in different concentration ranges.

In Jordan, brackish water has total dissolved solids (TDS) concentrations between 3000 ppm and 7000-8000 ppm, whereas the TDS concentration in seawater in the Gulf of Aqaba is about 5-10 times higher than brackish water at about 42,000 ppm. Furthermore, the mineral composition and the type of potential scalants of seawater and organic and microbial pollutants are very different from brackish water.

Pre-treatment requirements

The main operational issues and reasons for pre-treatment in SWRO plants arise from fouling. The types of fouling are characterized as particulate fouling by suspended particles, biofouling by microorganisms, organic fouling by dissolved organic matter, scaling by sparingly soluble inorganic compounds, in addition to oxidation and halogenation by residual chlorine reaching the membrane.

Table 1-7: Typical foulants in SWRO[15]

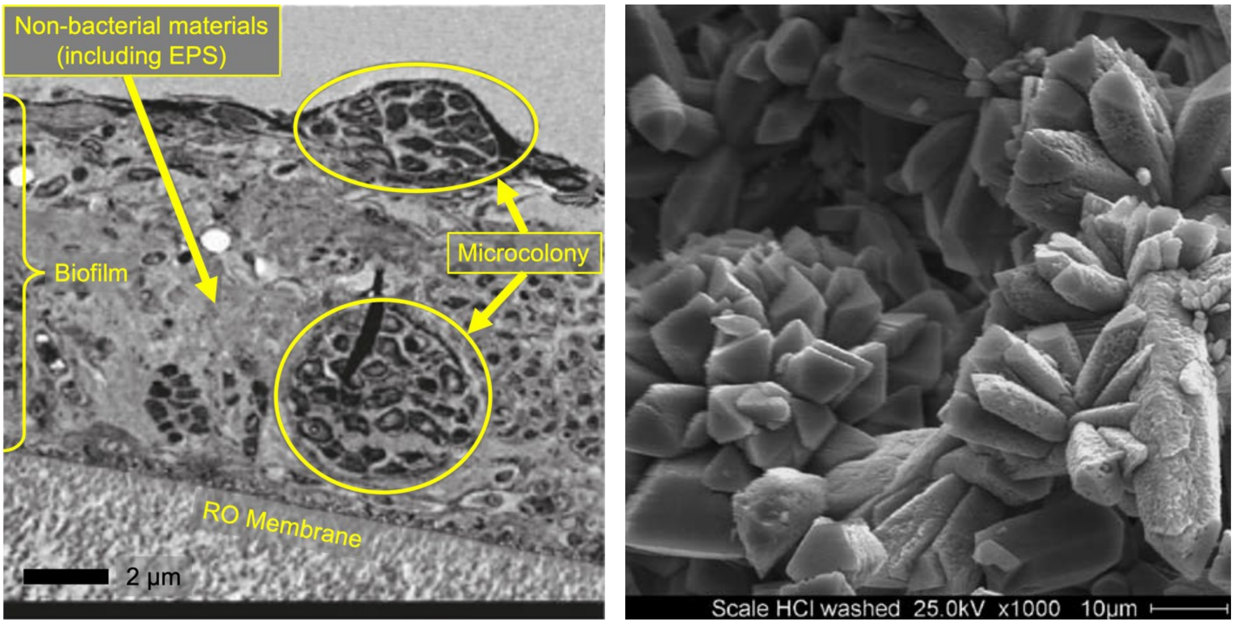
Fouling	Cause	Appropriate Pre-treatment
Biological fouling	Bacteria, microorganisms,	Chlorination

[15] Lenntech (2022) Desalination Pretreatment. https://www.lenntech.com/processes/desalination/pretreatment/general/desalination-pretreatment.htm

Fouling	Cause	Appropriate Pre-treatment
	viruses, protozoan	
Particle fouling	sand, clay (turbidity, suspended solids)	Filtration
Colloidal fouling	Organic and inorganic complexes, colloidal particles, micro-**algae**	Coagulation + Filtration Optional: Flocculation / sedimentation
Organic fouling	**Natural Organic Matter** (NOM): humic and fulvic acids, biopolymers	Coagulation + Filtration + Activated carbon adsorption Coagulation+ Ultrafiltration
Mineral fouling	**Calcium**, magnesium, barium or strontium sulfates and carbonates	Antiscalant dosing Acidification
Oxidant fouling	**Chlorine**, ozone, $KMnO_4$	Oxidant scavenger dosing: Sodium (meta)bilsulfite Granulated Activated Carbon

Table 1-7 presents the typical foulants with the main causes and appropriate pre-treatment solutions to reduce the foulants present in seawater:

- **Particulate foulants.** These are mainly suspended solids and silt/sand.
- **Colloidal foulants.** Compounds of relatively small size (0.2 to 1.0 µm) that are not in fully dissolved form, which may coalesce and precipitate on the membrane surface.
- **Mineral scaling foulants.** Inorganic compounds (i.e., Ca, Mg, Ba and Sr salts) which may precipitate and form a scale on the membrane surface (such as calcium carbonate and sulfate or magnesium hydroxide) or may block the membrane diffusion layer (e.g. Fe and Mn).
- **Organic foulants.** Organic matter (natural or anthropogenic) that can attach to membranes.
- **Microbial foulants.** Aquatic organisms and soluble organic compounds that can serve as food to the microorganisms which inhabit the source water and can form a fouling biofilm that reduces membrane transport.



Biofilm on the surface of an RO membrane

Crystalline scale on the surface of an RO membrane

Figure 1-25: Biofouling and scaling of RO membranes[18]

Another critical aspect in the design and operation of SWRO plants arises from harmful algal blooms (HAB), which may lead to severe operational issues. Variable and high turbidity combined with HAB may occur in the northern Red Sea, particularly in spring and summer [16].

The main types of phytoplankton responsible for HAB events were found to be dinoflagellates, raphidophytes, and cyanobacteria. Key factors in HAB development are nutrients such as nitrogen, phosphorus, silicon, and some trace metals from natural or anthropogenic sources including wastewater of different sources and aquaculture. The operational challenges for SWRO plants during algal blooms include contamination of product water with algal toxins, clogging and fouling of the pre-treatment system, and fouling of RO membranes.

Monitoring

Source water quality and associated fouling risks need to be thoroughly assessed using long-term data sets and a set of appropriate parameters (cf. Table 1-8). Reliable approaches to monitoring the quality of the raw and pre-treated water are essential to prevent and diagnose membrane fouling and develop effective control strategies.

[16] Eyal G. et al (2019). The Red Sea: Israel. In: Y. Loya et al. (eds.), Mesophotic Coral Ecosystems, Coral Reefs of the World 12, doi.org/10.1007/978-3-319-92735-0_11

Table 1-8: Parameters and indicators to monitor the membrane fouling in SWRO membranes[17]

Particulate matter and fouling	Organic fouling	Biofouling	Others
Turbidity	**Total organic / dissolved organic carbon (TOC / DOC)**	**Transparent exopolymer particles (TEP)**	**Algal cell concentration**
Particle counters	Liquid chromatography organic carbon detection (LC-OCD)	Assimilable organic carbon (AOC)	Chlorophyll-a concentration
Silt density index (SDI)	UV_{254}	Bacterial growth potential (BGP) based on flow cytometry or based on adenosine triphosphate (ATP)	
Modified fouling index ($MFI_{0,45}$)	Fluorescence excitation and emission matrix (FEEM)	Membrane fouling simulator (MFS)	
Modified fouling index ultrafiltration (MFI-UF)	Fourier transform infrared spectroscopy (FTIR)		

State of the art pre-treatment systems

The pre-treatment system in SWRO desalination plants combines a series of unit processes to remove all detrimental constituents of the source water for smooth, cost-efficient, and trouble-free operation of the reverse osmosis system. Initially, SWRO pre-treatment copied the traditional drinking water treatment train, which consisted primarily of coagulation/flocculation followed by media filtration. It merely replaced the treatment objective of drinking water quality with RO feed water quality. Nowadays, two main pre-treatment approaches are applied:

- **Conventional pre-treatment** using granular media filtration as the core process or
- **Membrane pre-treatment** relying on ultrafiltration or microfiltration.

Besides the required RO feed water quality, source water quality along the intake type defines the pre-treatment requirements. In SWRO plants with an open intake, pre-treatment consists of primary and secondary systems to guarantee RO feed water quality and stable operation during all conditions, in particular algal blooms. **Primary pre-treatment** typically removes large suspended materials (greater than 50 µm) by sieving and then addresses smaller particulates, silt, sand and colloids by coagulation and sedimentation or dissolved air flotation. It is followed by the **secondary pre-treatment** that typically includes granular (dual) media filtration or membrane filtration, i.e. UF or MF.

[17] Salinas-Rodriguez S.G., Schippers J.C. (2021) Introduction to desalination. Ch 1 in: 2021. Salinas Rodriguez, S. G., Schippers, J. C., Amy, G. L., Kim, I. S. & Kennedy, M. D. (Eds.) *Seawater Reverse Osmosis Desalination: Assessment and Pre-treatment of Fouling and Scaling.* IWA Publishing, London, Doi: 10.2166/9781780409863_0001

Ideally, the only constituents left in the pre-treated water would be dissolved minerals. As long as the desalination system is operated to prevent these minerals from precipitating, the plant can be operated without frequently membrane cleanings.

Practical experience shows that for desalination plants with good source-water quality and a well-designed pre-treatment system, the RO membranes may not need to be cleaned for one or more years. Their useful life could extend beyond ten years.[18] In general, for any type of source water, the following pre-treatment steps can be taken into consideration:

- Chlorination
- Screening
- Coagulation / Flocculation
- Sedimentation
- Granular media filtration
- Dissolved air flotation (DAF)
- Cartridge filtration
- Microfiltration / Ultrafiltration
- Nanofiltration
- Antiscalant dosing
- pH adjustment
- Scavenger dosing (oxidant removal)

The following table presents an overview of the unit processes used in SWRO desalination with their general concept and treatment objectives.

[18] Voutchkov (2017). Pretreatment for reverse osmosis desalination. Elsevier.

Table 1-9: Unit processes used in pre-treatment of SWRO desalination

Unit process	Description
Chlorination	Chlorination entails adding chlorine or chlorine compounds such as sodium hypochlorite to the seawater. This method is used to kill bacteria, viruses, and other microbes present in the source water or growing in the water treatment system, on the walls of water pipes, and in storage tanks.
Coagulation / Flocculation	Coagulation and flocculation are important processes in water treatment, with coagulation aimed to destabilize and aggregate particles through chemical interactions between the coagulant and colloids, and flocculation to sediment the destabilized particles by causing their aggregation into floc.
Sedimentation	Sedimentation is the tendency for particles in suspension to settle out of the fluid in which they are entrained and come to rest against a barrier. This is due to their motion through the fluid in response to the forces acting on them: these forces can be due to gravity, centrifugal acceleration, or electromagnetism. Sedimentation is typically used upstream of granular media and membrane filters when the membrane plant's source water has average daily turbidity higher than 30 NTU or experiences turbidity spikes of 50 NTU.
Granular media filtration	Granular media filtration (e.g. dual-media filtration, DMF) uses types of filters with a bed of sand, anthracite, crushed granite, or other material to filter water. In cases where the saline source water contains large amounts of algal particulates and/or oil and grease, and space is at a premium, dissolved air flotation (DAF) and granular media filtration processes can, when economically viable, be combined in one structure.
Dissolved air flotation	The dissolved air flotation (DAF) process uses very small air bubbles to float light particles and organic substances (oil, grease) contained in the source water. The floated solids are collected at the top of the DAF tank and skimmed off for disposal, while the low-turbidity source water exits near the bottom of the tank. In SWRO, it is used to remove floating particulate foulants such as algal cells, oil and grease (e.g. associated with shipping-channel impacts), or other light solid contaminants that cannot be effectively removed by sedimentation or filtration, producing effluent turbidity of < 0.5 NTU.
Microfiltration	Microfiltration is a type of physical filtration process where the feed is passed through a special pore-sized membrane to separate micro-organisms and suspended particles from the feed water. Microfiltration usually serves as a pre-treatment for other separation processes and a post-treatment for granular media filtration.

Unit process	Description
Ultrafiltration	Ultrafiltration is not fundamentally different from microfiltration. Both of these are separate based on size exclusion or particle capture. Ultra-filtration can be used to remove particulates and macromolecules from raw water as a step to produce potable water. It has been used either to replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. When treating water with high suspended solids, UF is often integrated into the process, utilizing primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages. UF has been shown to be HAB-resilient through adapted operation, such as the addition of coagulant, lowering the flux, or increasing the backwash frequency.
Nanofiltration	Nanofiltration is a membrane-based filtration method that uses nanometer-sized pores. Nanofiltration membranes have pore sizes from 1-10 nano-meters, smaller than microfiltration and ultrafiltration but larger than that in reverse osmosis. In the case of desalination plants, nanofiltration will be considered an advanced treatment step since NaCl passes through the membranes while scalants i.e. multivalent ions such as Ca^{2+} and Mg^{2+} are rejected, and bulk organics are retained.
Cartridge filtration	Cartridge filters are simple, modular filter elements inserted into a housing and can be used to remove particles from the water. Solid material suspended in the water gets trapped in the cartridge filter element. The filter will be rated to remove particles of a specific size. Some cartridge filter systems allow back-washing and come with a CIP design. Others must be removed from the housings and replaced. Corrosion products from feedwater pipelines can cause premature replacement of cartridges, significantly increasing the pre-treatment costs.
Antiscalant dosing	An antiscalant agent acts on the crystal formation to prevent nucleation or slow progress below the critical limit. It is a chemical additive put into saline water feed to reduce the scale formation on the membranes.
pH adjustment	pH adjustment via acid dosage (to lower pH) is performed to prevent scaling by pH-sensitive ingredients in the water, for example, $CaCO_3$. Caustic adjustment is also used, generally in a 2nd pass RO, to increase boron rejection.
Scavenger dosing	RO membranes can be damaged by free chlorine. The use of a so-called scavenger, a chemical that disarms the free chlorine, can be necessary if the free chlorine is not entirely consumed in the process steps upstream of the RO.

Chemical demand for pre-treatment

SWRO desalination requires a range of chemicals for different purposes. Chemicals are used

- to prevent scaling via acid addition and antiscalant dosage,
- to remove solids and colloids by coagulant and polymer dosage with subsequent removal of the flocs by different methods, and
- to prevent biofouling and clogging, for example, of the intake.

Chemicals, such as weak acids, are further used for the chemical cleaning of membrane plants and are selected on the specific cleaning objective.

Figure 1-26 gives an overview of the general intake and pre-treatment concepts with a dosage of chemicals along with the treatment trains. Table 1-10 lists the main chemicals used in SWRO pre-treatment.

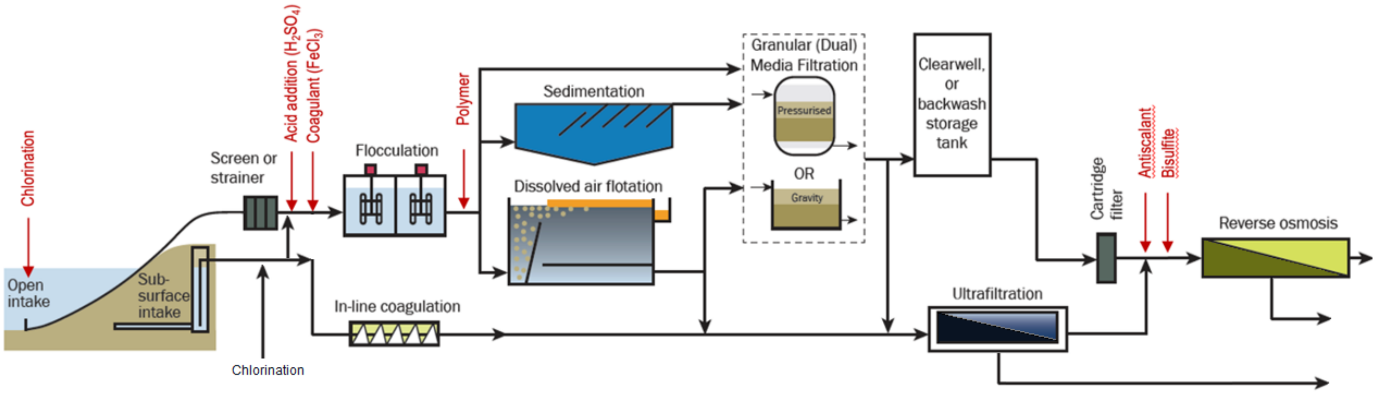


Figure 1-26: Overview of intake and pre-treatment concepts with related chemical dosage

Table 1-10: Chemicals used in SWRO and their purposes

Chemicals	Purposes of the use of chemicals
Sodium hypochlorite	Preventing screens and pipes used for water intake from becoming clogged by marine organisms, including shellfish
Sodium bisulfite	Preventing inflow of chlorine which damages the RO membrane through the reduction reaction
Coagulants (mainly ferric chloride)	Facilitating removal of substances that cause fouling of the RO membrane, incl. silt, suspended solids and organic materials in the pre-treatment
Sulfuric acid	Enhancing the effects of coagulants and preventing the generation of scale on the RO membrane
Antiscalant	Preventing formation of membrane scaling

1.3.3 Desalination technologies

The following chapter gives an overview of commercial desalination processes. A simple classification of the processes is illustrated in Table 1-11. A differentiation is made between processes with a phase change and processes without a phase change.

Table 1-11: Classification of desalination processes

Ref#	Desalination principles with phase change		Desalination principles without phase change
Principle	Distillation	Freezing / Hydrate forming	Membrane separation
Process	▪ Multi-Stage-Flash evaporation (MSF) ▪ Multiple Effect Distillation (MED)	▪ With organic refrigerant ▪ Vacuum freeze / Vapor compression	• Reverse Osmosis (RO) • Electro Dialysis (ED)
Products	Vapor / Condensate	Ice crystals / Melt	Permeate (RO) / Dilute (ED)

Within the processes, with a phase change, a differentiation can be made between the phase change “liquid → gas” and “liquid → solid”. That is to say, between evaporation processes and freezing processes. Both processes have the purity of the end-product achieved by a physical principle. As a result of the low vapor pressure of salt, the distillate of evaporation is pure water. As a result of the selective crystallization, process ice contains no salt crystals.

None of the freezing processes has been able to establish itself in the desalination market due to the several disadvantages, which will not be described in these guidelines. Thus, evaporation, particularly MSF and MED, is the market-dominating principle among the desalination processes with a phase change.

The processes without phase change are dominated by reverse osmosis. Electrodialysis, driven by an electric field for the separation of the salt ions, is suitable in principle for the desalination of brackish water, but its market share is relatively small.

There is no thermal desalination plant in operation in Jordan. All units are working as RO desalination plants. This is primarily due to investment and operational cost, but also with respect to the necessary energy input. The availability of thermal energy plays a decisive role for thermal desalination units. Thus, most MED plants worldwide are installed at a thermal power plant site utilizing waste heat.

A short overview of the most common desalination technologies MED and RO are presented below, knowing very well that RO is very likely the choice of seawater desalination technology in Jordan.

Multiple-Effect Distillation (MED):

The MED Process representing Multiple-Effect-Desalination is based on the idea that distillate is produced due to multiple effects. Generated steam coming from an external source condenses inside the pipes of the first stage and delivers its latent energy to a falling film of brackish water or seawater evaporating on the outside of the tubes. Steam is produced in the first chamber and finds its way through the pipes of the second chamber, while the condensed steam is recovered in the form of salt-free distillate. This process is repeated through all stages and leads to total distillate production. Overall, the initial energy input in the form of vaporized steam coming from an external source remains in the adiabatic system, as presented below.

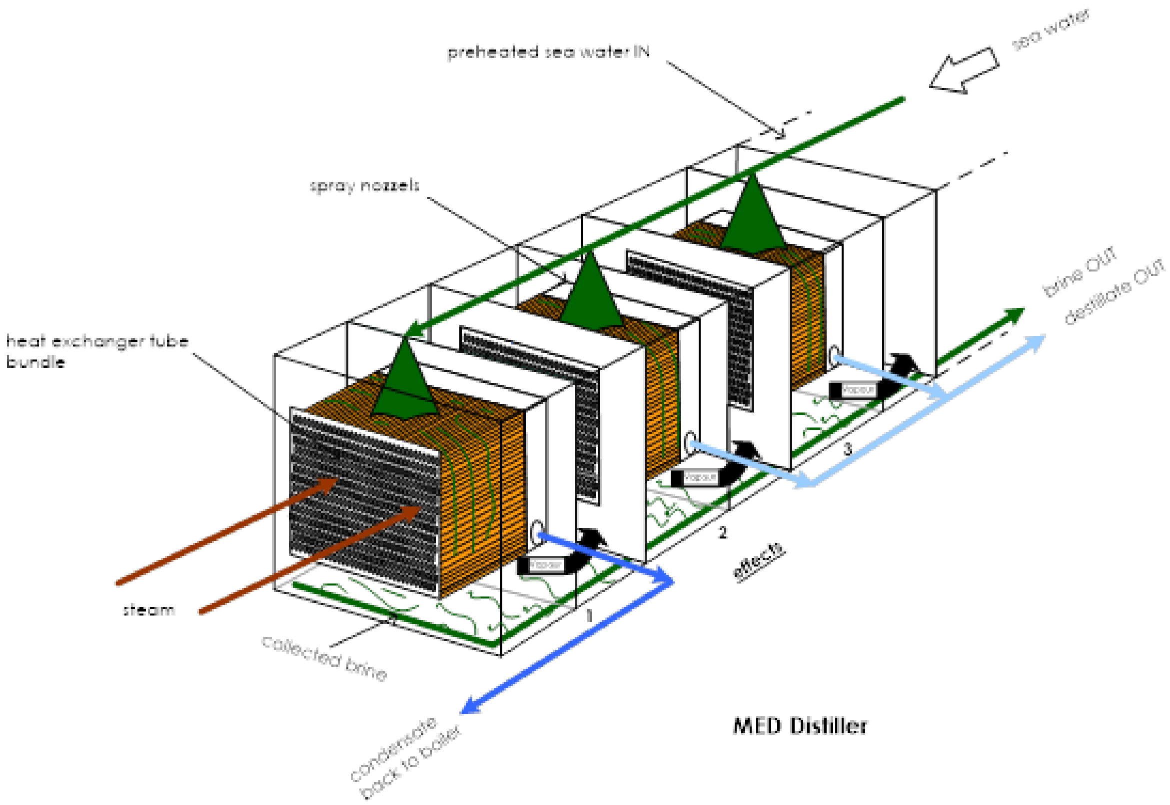


Figure 1-27: Illustration of a MED evaporation plant

Well-designed MED-Evaporation Plants are combined with 'flash evaporation' in every chamber. As well as brine, the distillate gets flashed in order to provide additional heating steam for the following stages. MED has, besides the effect of flash evaporation, the effect of direct evaporation. While MSF-distillation is based on the ineffective 'flashing' caused by non-equilibrium losses in the stages, the MED distillate production is increased by thermal energy input, and thus, it proves of a higher Gained Output Ratio (GOR) per effect.

Scaling risk is directly related to the temperature increase, particularly concerning $CaSO_4$, the maximum allowable temperature in MED plants is 70°C. A top brine temperature below 70°C causes only a small risk of scaling salts like (CaCO3 and CaSO4). Thus, the heating steam needed can be provided at the adjusted conditions, which is typically saturated steam at a temperature around 75 °C and at pressures around 0,4 bar_{abs}.

An extension of this MED process consists of the implementation of thermal vapor compression (TVC) into the whole concept. The TVC process helps to 'recycle' the steam produced by 'flash evaporation' and thus increases the GOR (Gained Output Ratio) by the same stage number given as for a 'simple' MED Process.

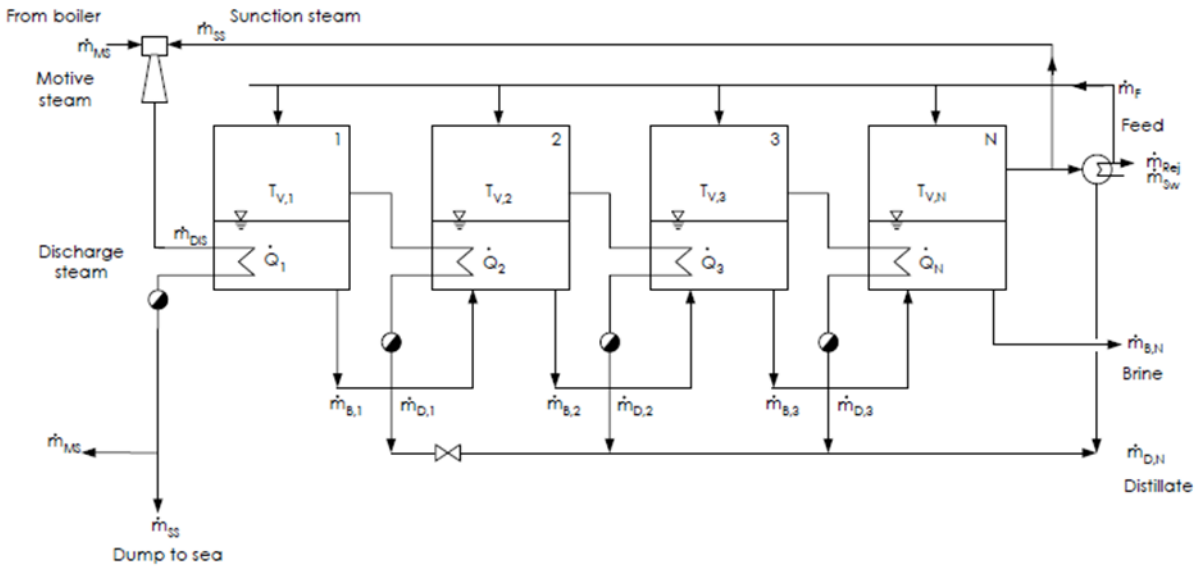


Figure 1-28: Flow sheet of a MED evaporation plant with thermal vapor compression

Reverse Osmosis (RO):

In this chapter, the desalination process reverse osmosis will be dealt with. It differs from thermal processes as they require only mechanical (=electrical) energy.

The mechanical energy necessary to build up the pressure for the desalination process is provided in most cases by electrically driven pumps. Thus, the so-called “mechanical desalination processes” are supplied with electrical energy. Energy recovery devices (ERD) allow the recovery of mechanical energy from the concentrate, thus reducing the electrical energy demand for bringing the feed on the operating pressure.

To be able to achieve a high yield by the RO desalination plant, without violation of the module design parameters given by the membrane module manufacturer, several modules have to be placed in series after each other. As shown in Figure 1-29, the concentrate of the first stage is transported to the second stage as a feed. The permeate of the individual stages is collected in a common line. The resultant typical structure of an RO-plant is known as a “Christmas Tree Structure”.

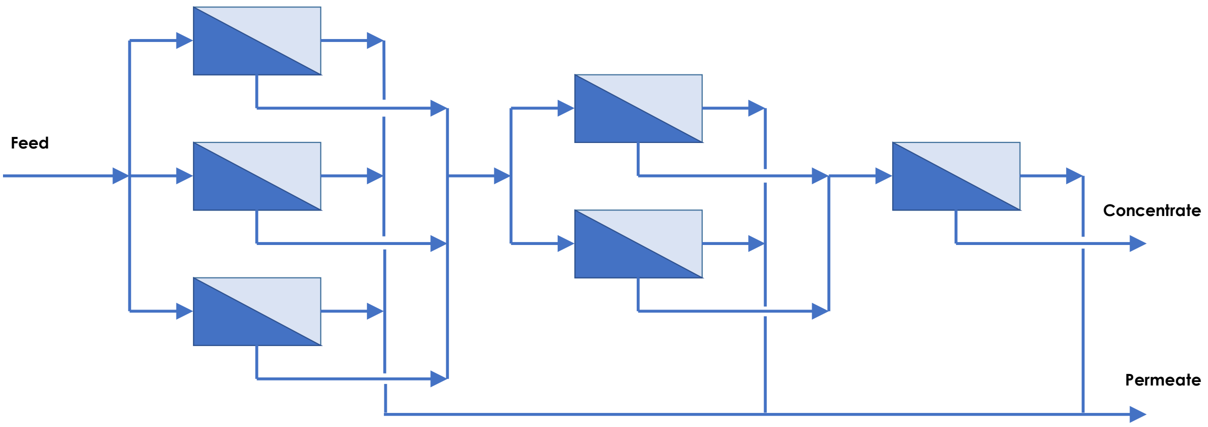


Figure 1-29: Typical staged structure of an RO plant train (Christmas Tree Structure)

1.3.4 Post-treatment technologies

Product water from desalination plants is characteristically low in mineral content, hardness, alkalinity, and pH. Therefore, desalinated water must be post-treated prior to final distribution and use. Post-treatment of freshwater produced by desalination has the following key components:

- Remineralization
- Disinfection
- Enhanced post-treatment

Remineralization:

Three main groups of technologies typically complete remineralization of desalinated water:

- Direct addition of chemicals containing calcium and magnesium:

  Most seawater and brackish water desalination plants typically add calcium to the desalinated water in the form of lime or calcite by using a sequential feed of calcium hydroxide (hydrated lime) and carbon dioxide to supply hardness and alkalinity to the product water to protect the distribution system from corrosion.

  In some desalination plants, magnesium is added as a commercially available food-grade product of magnesium sulfate or magnesium chloride to enhance the water quality regarding human health protection and achieve a higher agricultural value.

- Mixing of desalinated water with a portion of the source water or with other freshwater sources with high calcium and magnesium content

  Minerals including calcium and magnesium can be added to desalinated water by blending it with the pre-treated feed of the desalination plant. This practice is acceptable when the blend meets all applicable water quality standards.

- Addition of calcium and/or magnesium by dissolving naturally occurring minerals (for example, limestone or dolomite)

Limestone is a natural mineral made of calcite (calcium carbonate). Processing water through limestone contactors dissolves this calcium source and, in reaction with carbon dioxide, adds calcium hardness and bicarbonate alkalinity to the product water. pH adjustment of the produced water is necessary (lowering pH prior to re-mineralization and eventually raising the pH value after remineralization).

Dolomite is a natural mineral that contains calcium and magnesium carbonate. Passing desalinated water through a dolomite contactor, similar in configuration and design to calcite contactors, adds both minerals to the finished product water.

Remineralization has the following impacts on the product water quality:

- Increase in Alkalinity and Hardness
- Increase in Total Dissolved Solids
- Increase in Turbidity, caused by limestone filters

<u>Disinfection:</u>

Chlorine in various forms (e.g., sodium hypochlorite, calcium hypochlorite, and chlorine gas) is typical for disinfection of desalinated water because of its pathogen inactivation efficiency and a low level of disinfection by-products (DBPs) generation in desalinated water.

However, other disinfectants, such as chlorine dioxide and chloramines as well as ultraviolet (UV) light irradiation, could also be used for desalinated water disinfection.

The two most common types of chlorine-based disinfectants in post-treatment are:

- Chlorine gas or its derivatives (HOCl and OCl_-),

  Chlorination with chlorine gas and sodium hypochlorite is the most widely used disinfection method for disinfection of desalinated water. The typical target chlorine dosage that provides adequate disinfection depends on two key factors: desalinated water temperature and contact time. Usually, the chlorine dosage used for disinfection is 0.5 to 2.5 mg/l.

- Chloramines

  Chloramination includes the sequential addition of chlorine and ammonia to the product water to form chloramines. It is widely used principally as a secondary disinfectant because of its lower biocide potency and higher stability.

<u>Enhanced post-treatment:</u>

While RO membranes reject most of the organics contained in the source water, they are not as effective in rejecting DBPs, which are already formed when chlorine is used for source water pre-treatment. SWRO membranes have a 50 to 80 per cent rejection of disinfection by-products (DBP); therefore, the desalinated water quality may need to be polished by enhanced post-treatment.

Water quality polishing is used for enhanced treatment of specific compounds (e.g., boron, silica) when these compounds must be removed from the water to meet water quality targets. Possible post-treatment technologies are:

- Ion exchange
- Granular activated carbon filtration
- Additional multistage/multi-pass membrane RO treatment
- Air stripping
- Advanced oxidation
- A combination of the above treatment processes

1.4 Concept development and selection

After the selection of relevant technologies for seawater desalination, the next steps in the feasibility study are the development of eligible desalination concepts and, finally the selection of the best concept according to the given conditions. Figure 1-30 shows the overview of this chapter.

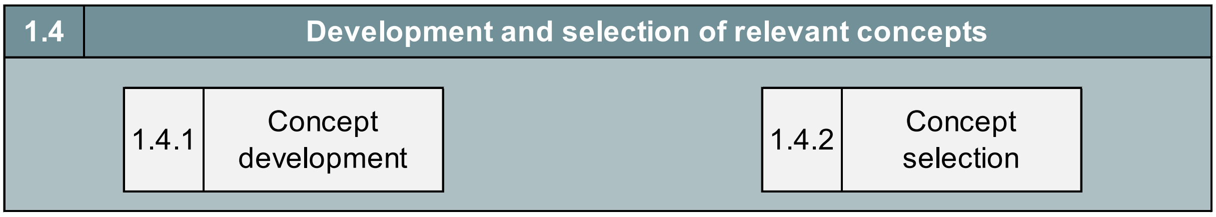


Figure 1-30: Overview of chapter 1.4: Development and selection of relevant concepts

1.4.1 Concept development

At the beginning of the concept development, the following points need to be clarified at least:

- Project targets and framework conditions (see chapter 1.1)
- Identification of site (see chapter 1.2)
- Identification of possible pre-treatment technologies (see chapter 1.3)
- Identification of possible desalination technologies (see chapter 1.3)
- Identification of possible post-treatment technologies (see chapter 1.3)

After clarification of these points, the concept development can be conducted.

All possible concepts need to fulfil the requirements according to the Plant Design Data Sheet:

- Production of the specified amount of water
- Compliance with the specified limit values and other properties of product water

To develop a desalination concept, the introduced treatment technologies for abstraction/ intake, pre-treatment, desalination, post-treatment and brine treatment need to be combined appropriately.

For the exemplary concept development, the following assumptions have been made:

- The site identification is completed.
- The chosen site is suited for thermal and membrane desalination (for this example).
- The site area is sufficient for the selected technologies.
- The desalination plant will have a sufficient thermal and electrical energy supply

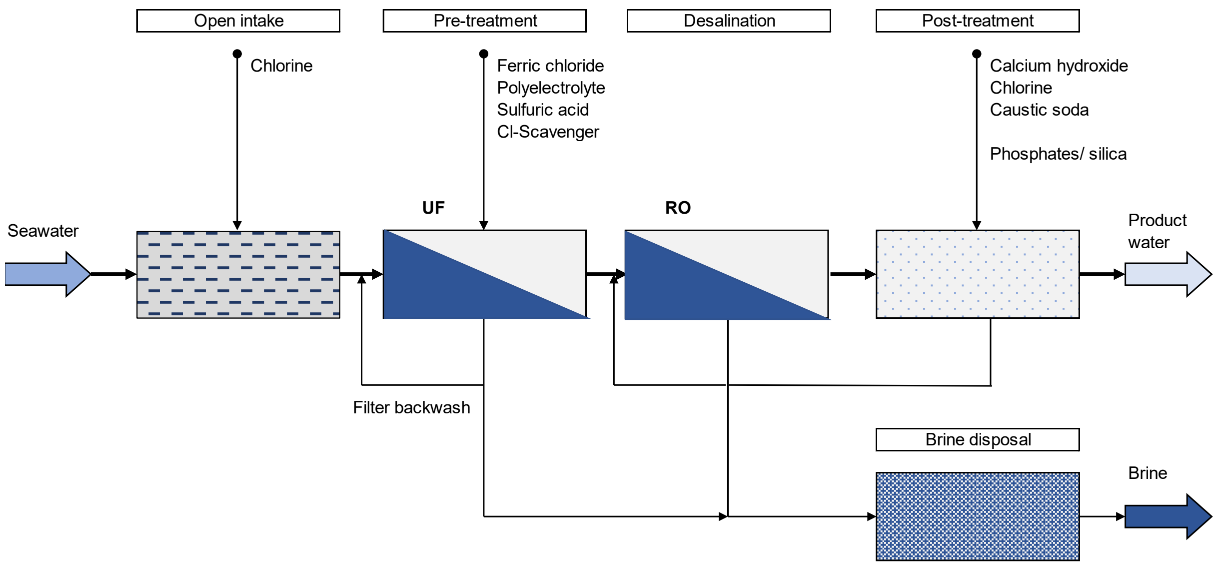
In the following example, two different concepts for seawater desalination are developed:

- Concept 1: Ultrafiltration and reverse osmosis desalination (UF-RO) with standard technologies for abstraction, pre-and post-treatment, and brine treatment

- Concept 2: Multimedia filtration and reverse osmosis desalination (MMF-RO) with standard technologies for abstraction, pre-and post-treatment, and brine treatment
- Concept 3: Thermal desalination (MED) with all necessary technologies for abstraction, pre-and post-treatment, and brine treatment

<u>Concept 1: UF-RO</u>

- Intake including pumping/piping, screening, and chlorination
- Pre-treatment including sedimentation, ultrafiltration, coagulation/flocculation (ferric chloride and polyelectrolyte), as well as the dosage of antiscalant (sulfuric acid) and chlorine scavenger
- RO desalination
- Post-treatment including remineralization/ corrosion protection (calcium hydroxide), disinfection (chlorine), pH adjustment (caustic soda) and the addition of phosphates/ silica
- Brine disposal via surface discharge



Open intake
- [x] Pumping/Piping
- [x] Screening
- [x] Chlorination

Pre-treatment
- [x] Sedimentation
- [x] Flocculation
- [ ] Media filtration
- [x] Cartridge filtration
- [x] Ultrafiltration
- [x] Anti scalant dosing
- [ ] Anti foam dosing
- [x] pH adjustment
- [ ] Chlorination
- [x] Scavenger dosing

Desalination
- [ ] MED
- [x] RO

Post-treatment
- [x] Remineralization
- [x] Disinfection
- [x] pH adjustment
- [ ] Aeration
- [x] Phosphates/ silica dosing

Brine disposal
- [x] Surface discharge

Figure 1-31: Concept 1 (UF-RO)

<u>Concept 2: MMF-RO</u>

- Intake including pumping/piping, screening, and chlorination

- Pre-treatment including sedimentation, multimedia filtration, flocculation (ferric chloride and polyelectrolyte) as well as the dosage of antiscalant (sulfuric acid) and chlorine scavenger
- RO desalination
- Post-treatment including remineralization/ corrosion protection (calcium hydroxide), disinfection (chlorine), pH adjustment (caustic soda) and the addition of phosphates/ silica
- Brine disposal via surface discharge

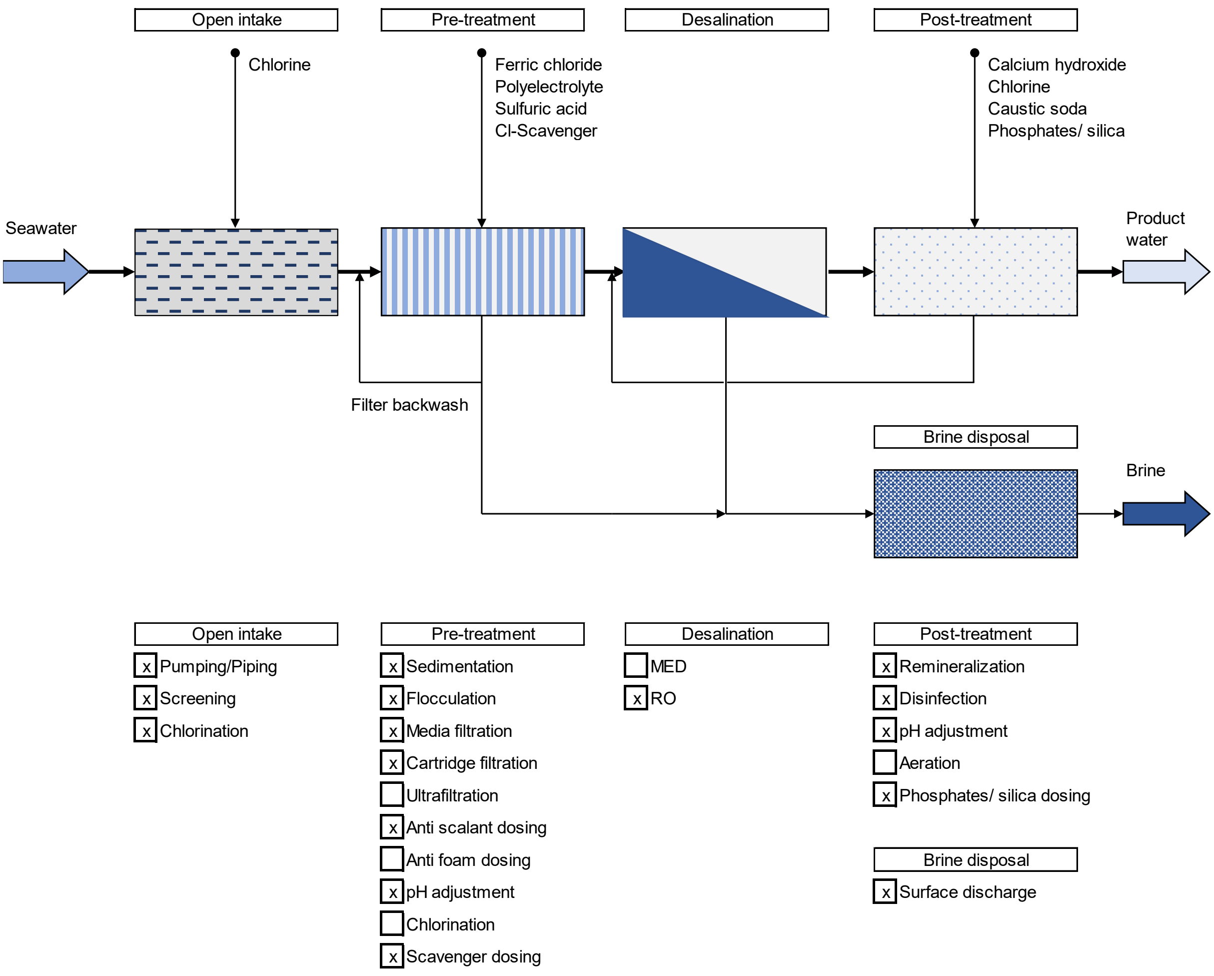


Figure 1-32: Concept 2 (MMF-RO)

Concept 3: MED

- Intake including pumping/piping, screening, and chlorination
- Pre-treatment including the dosing of antiscalants and antifoam
- MED desalination
- Post-treatment including remineralization (limestone & dolomite), disinfection (chlorine), pH adjustment (caustic soda), aeration and the addition of phosphates/ silica for corrosion protection
- Brine disposal via surface discharge

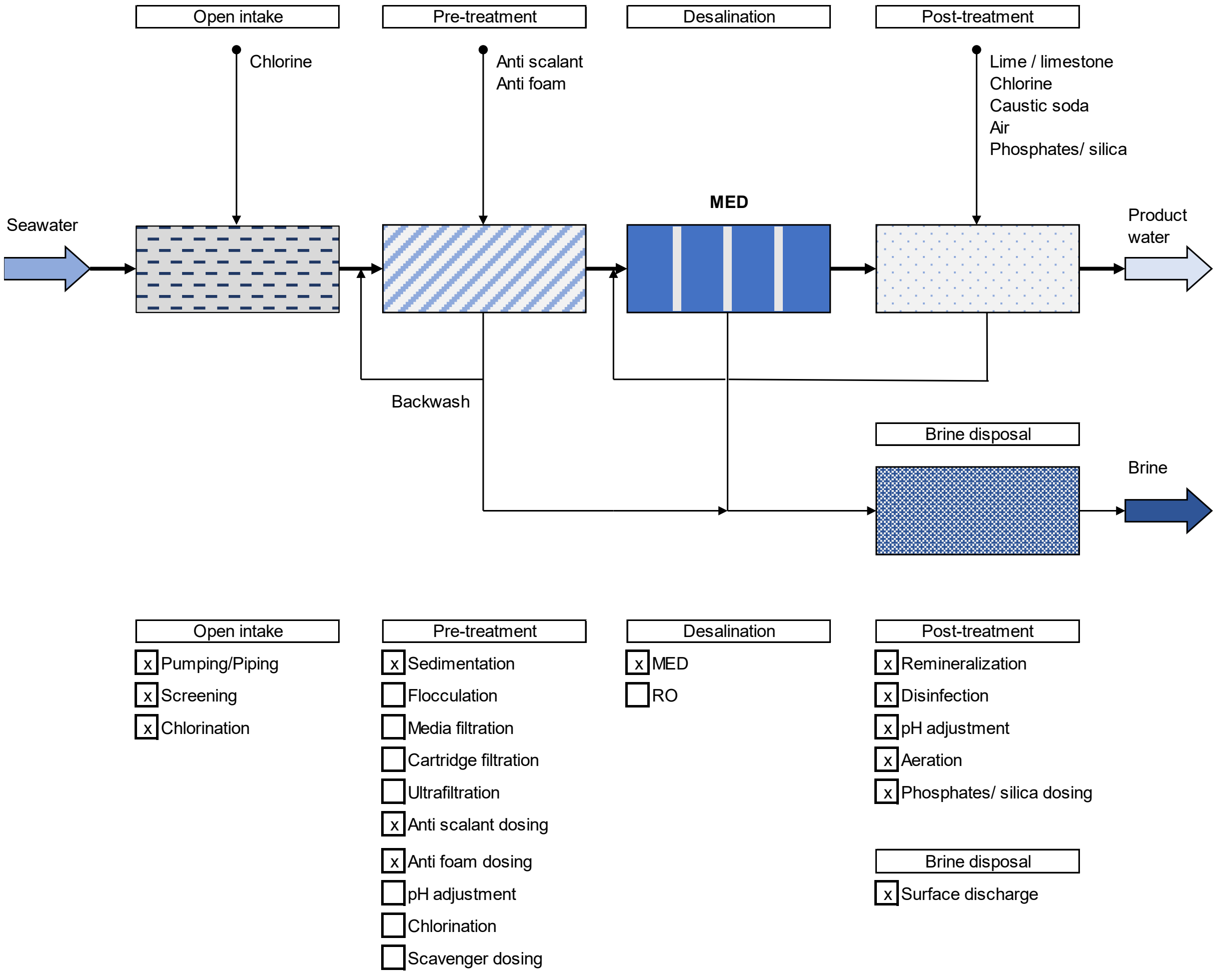


Figure 1-33: Concept 3 (MED)

1.4.2 Concept selection

In most cases, CAPEX and particularly OPEX determine the final decision on the selection of a desalting technology. However, several other criteria must be taken into consideration to select the best suitable concept.

Every process comparison takes this path in the end: question → answer → evaluation. The greatest difficulty lies in asking the correct questions, finding the right answers to them, and being also able to correctly evaluate the result. The more complex the subject – and desalination may well be seen in its entirety as being truly complex -, the more difficult it will be to be able to judge the significance of individual questions for the whole. And because this subject is complex, people tend towards drastic simplifications and ask: “How much does it cost then?”

The question regarding the price is a quantitative means of making a comparison between the concepts. However, the concepts can have other quantifiable factors that cannot be expressed only by their costs. There are also other parameters such as, e.g., “the complexity of the plant” or “references” of the technology, etc. How can such parameters be taken into account?

One method which may be used to solve this dilemma is the so-called cost-benefit analysis, a “decision making under multiple goals”. The cost-benefit analysis contains the following three essential steps:

1. Establishment of the assessment criteria
2. The weighting of the assessment criteria
3. Comparison of the available options relative to one selected option as a reference point (state-of-the-art)

1. <u>Establishment of the assessment criteria</u>

The following assessment criteria, listed in Table 1-12, can be established for a sea water desalination plant. The list may be extended or modified, depending on the specific case. But most important is that all points which are relevant for the selection of the process are taken into account. We can see, in this case, the close tie with the project aims. No single criterion should be eliminated at this stage. If the significance of the criterion is low, this is automatically taken into account by the following weighting.

Table 1-12: List of assessment criteria for a desalination plant

No.	Criteria	Keywords
1	OPEX	Desalination plant, civil works, energy supply, intake, pre-treatment, post-treatment, brine treatment, brine disposal, infrastructure
2	CAPEX	Depreciation, interest, energy, chemicals, additives, personnel, water transport, brine disposal, waste disposal, spare parts
3	Operating behaviour	Normal mode, start-up, shutdown, malfunction, overhaul, standstill period
4	Availability	Reliability, robustness, complexity, redundancy, susceptance to failure
5	Quality of the product	Boiler feed water, drinking water, process water, irrigation, dangerous chemicals
6	Dependance on supplier	Tubes, membranes
7	Staff	Number, necessary qualification
8	Environmetal impact	Coloured rejects, brine, wastes
9	References	Large, medium and small units, test plants

2. <u>The weighting of the assessment criteria</u>

The weighting of the assessment criteria must be discussed and determined by the client in consultation with the planner of the desalination plant.

The following Table 1-13 shows an example, which has been created with the help of STEP experience in several desalination projects. For a new desalination project in Jordan, these weighting factors must be discussed and adjusted to the actual conditions at the planned construction site.

Table 1-13: Weighting of assessment criteria

No.	Criteria	Weighting factor	Possible assessment points	Max. available points
1	Capital costs	0.20	from 0 to 100	20
2	Operating costs	0.50	from 0 to 100	50
3	Operating behaviour	0.06	from 0 to 100	6
4	Availability	0.05	from 0 to 100	5
5	Quality of the product	0.06	from 0 to 100	6
6	Dependance on supplier	0.03	from 0 to 100	3
7	Staff	0.05	from 0 to 100	5
8	Environmetal impact	0.02	from 0 to 100	2
9	References	0.03	from 0 to 100	3
	Summation	**1.00**	**-**	**100**

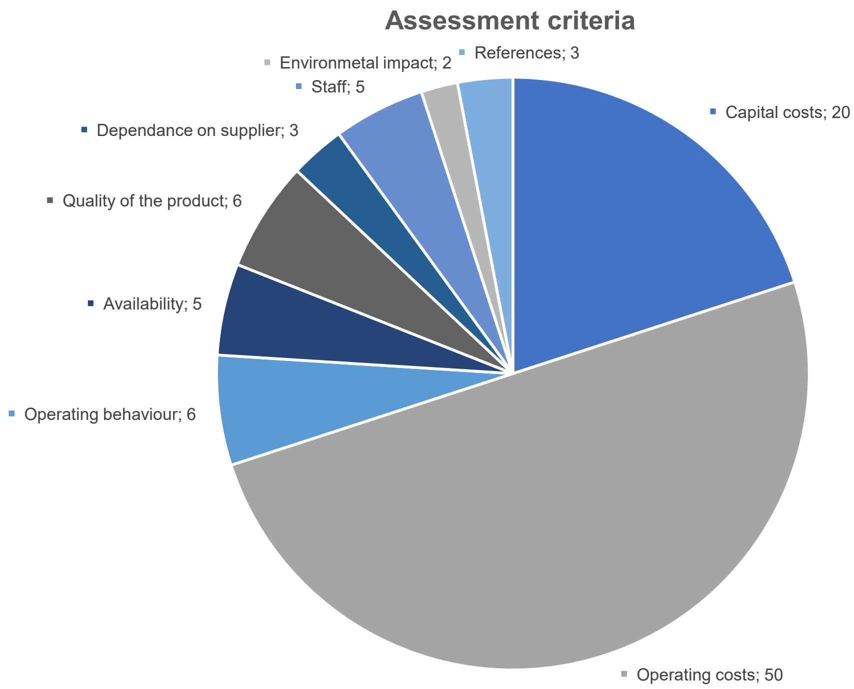


Figure 1-34: Weighted assessment criteria

By entering the derived weightings into a pie-chart (see Figure 1-34), it may be recognized that Capital Costs and Operating Costs positions comprise 70% of the total points.

3. <u>Comparison of the available options relative to one selected option as a reference point (state-of-the-art)</u>

It is now a question of assessing the individual processes in relation to each criterion and then of entering the evaluation into a matrix to obtain a general survey.

In the next chapters, the calculation of capital and operating costs will be performed for the different concepts, followed by evaluating the other criteria. The assessment of the various concepts will be concluded with a final assessment.

Investment costs (CAPEX) for the concepts

The estimation or calculation of capital costs of a seawater desalination plant is a highly complicated task. It is vital to be aware of the goals of the estimation or calculation and what battery limits must be taken into consideration. It is known from the experience of successfully completed projects in the chemical industry that the accuracy of the estimates depends on which project phase you are looking at. Figure 1-35 gives some indications of this. During the concept specification phase, the costs can deviate by as much as ± 60-100% from those actual costs calculated after the completion of the project. The accuracy improves with every step in the planning process. If a P&I diagram is used, the deviations are only ± 20-30%. After the start of construction, the uncertainty drops to ± 5-10%.

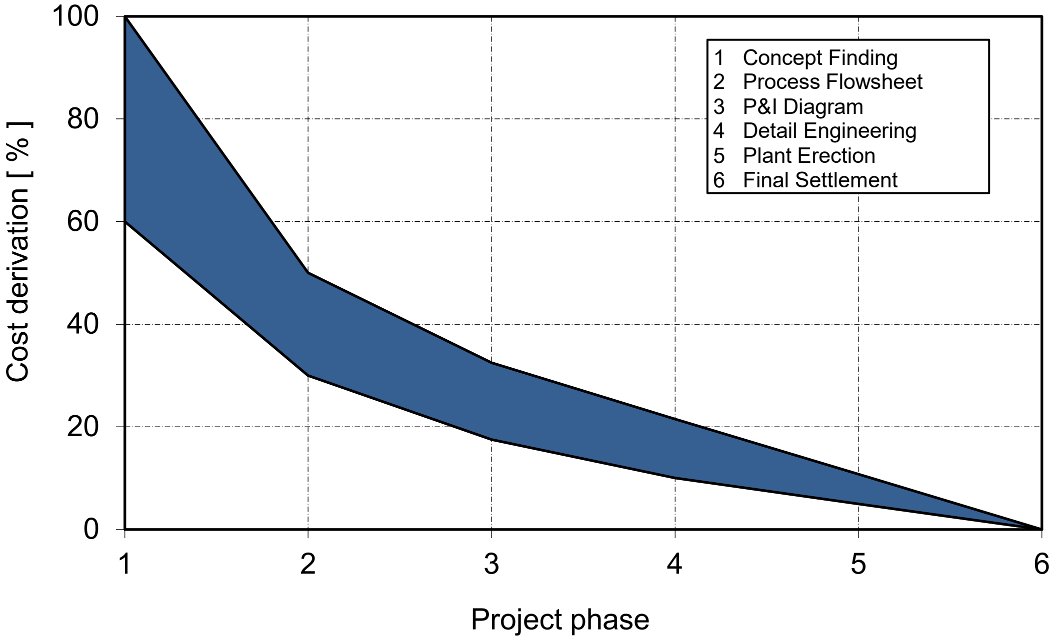


Figure 1-35: Cost derivation vs. project phase

The cost accuracy can be significantly improved, particularly in the early planning phases where data from existing plants may be referred to.

Comparison of the total annual costs for the developed concepts

The total annual costs arising during the operation of a desalination plant may be divided into fixed and operating costs. The fixed costs are incurred whether the plant is in operation or not, whereas the operating costs are coupled to the number of hours of plant operation and the water production.

A technical basic design calculation for the three, in chapter 1.4.2: Concept selection developed concepts, is presented in Table 1-14.

Table 1-14: Cost comparison of the concepts

Parameter	Unit	Concept 1+2+3
Product water (Permeate)	m³/h	12,016.3
	m³/a	100,000,000
Yield	%	0.45
Salt content feed	ppm	42,000
Max. salt content permeat	ppm	300
Availability	%	0.95
Operating hours	h/a	8,322
Energy mix renewable/grid	%	25
Funding period	a	25
Total interest rate and repayment rate	%	5

		Concept 1: UF-RO	Concept 2: MMF-RO	Concept 3: MED	
Annual capital costs					
Specific total investment costs	$/(m³/d)	1280	1150	1350	
Total annual capital costs	$/a	26,191,534.35	23,531,456.64	27,623,883.88	
Specific capital costs of the investment (product water)	**$/m³**	**0.262**	**0.235**	**0.276**	
Annual operating costs					
Maintenance & repair	$/a	11,074,260.99	9,949,531.36	11,679,884.64	
		3	3	3	% of investment
Insurance	$/a	1,845,710.17	1,658,255.23	1,946,647.44	
		0.5	0.5	0.5	% of capital costs
Staff	$/a	1,500,000.00	1,500,000.00	1,500,000.00	
		20,000	20,000	20,000	$/person/a
		75	75	75	persons
Chemicals and additives	$/a	3,000,000.00	3,000,000.00	4,000,000.00	
		0.03	0.03	0.04	$/m³ product water
Replacement of membranes and cartridge filters	$/a	2,000,000.00	2,000,000.00	0.00	
		0.02	0.02	0.00	$/m³ product water
Specific electrical energy (product water)	kWh/m³	3	3	1.5	
Electrical energy from renewable energy	$/a	2,250,000.00	2,250,000.00	1,125,000.00	
		0.03	0.03	0.03	$/kWh
Electrical energy from grid	$/a	27,000,000.00	27,000,000.00	13,500,000.00	
		0.12	0.12	0.12	$/kWh
Waste disposal/others	$/a	2,000,000.00	2,000,000.00	2,000,000.00	
		0.02	0.02	0.02	$/m³ product water
Total operating costs	**$/a**	**50,669,971.16**	**49,357,786.59**	**35,751,532.08**	
Specific operating costs (product water)	**$/m³**	**0.507**	**0.494**	**0.358**	
Annual capital and operating costs	**$/a**	**76,861,505.51**	**72,889,243.23**	**63,375,415.96**	
Specific fixed and operating costs (product water)	**$/m³**	**0.769**	**0.729**	**0.634**	

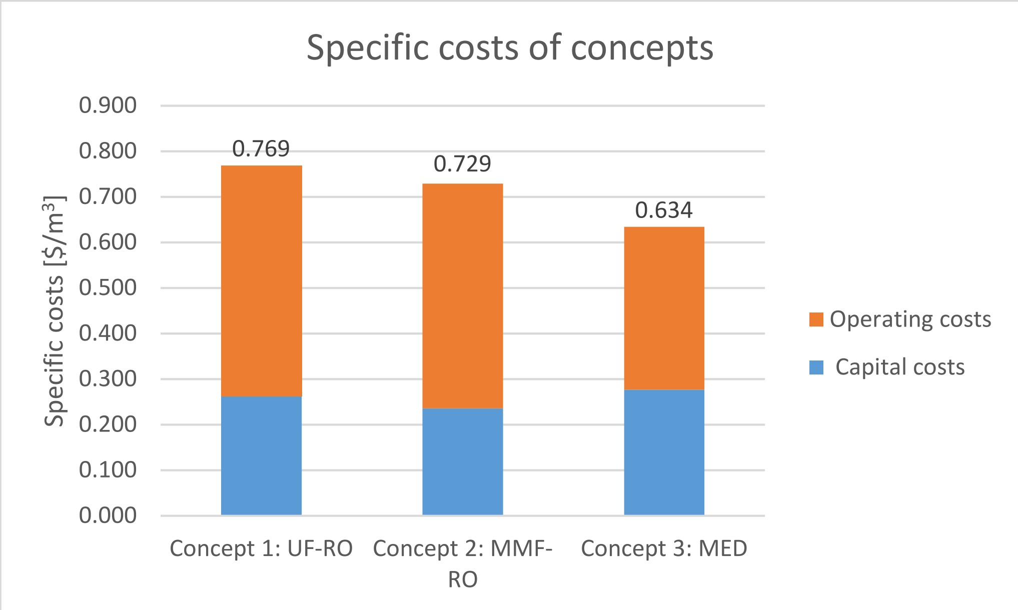


Figure 1-36: Comparison of the specific costs of the concepts

Assessment of the concepts and selection of the best-suited concept

Referring to the previous chapters, the assessment of the concepts is performed by different assessment criteria and their weightings. In Table 1-13, the weighting of the different criteria was fixed. The next step is to assess the different concepts in relation to each criterion and then enter the evaluation points into a table to obtain a general survey.

The individual points are awarded as follows:

The best concept gets 100 points for a criterion; the other concepts get their points in relation to the result of their assessment in this criterion in combination with a determined zero-level. The evaluations for the developed concepts are shown in Table 1-15 and Figure 1-37.

Table 1-15: Evaluation of the developed concepts

No.	Criteria	Weighting factor	Concept 1 Individ. points	Concept 1 Assess-ment	Concept 2 Individ. points	Concept 2 Assess-ment	Concept 3 Individ. points	Concept 3 Assess-ment
1	CAPEX	0.20	76.8	15.4	100.0	20.0	64.3	12.9
2	OPEX	0.50	76.8	38.4	78.8	39.4	100.0	50.0
3	Operating behaviour	0.06	90	5.4	100	6.0	70	4.2
4	Availability	0.05	100.0	5.0	100.0	5.0	100	5.0
5	Quality of the product	0.06	90	5.4	90.0	5.4	100.0	6.0
6	Dependance on supplier	0.03	85	2.6	90	2.7	100	3.0
7	Staff	0.05	100.0	5.0	100.0	5.0	100.0	5.0
8	Environmetal impact	0.02	100	2.0	100	2.0	100	2.0
9	References	0.03	100	3.0	100	3.0	100	3.0
	Summation	**1.00**	**-**	**82.1**	**-**	**88.5**	**-**	**91.1**
	Ranking	**-**	**3**		**2**		**1**	

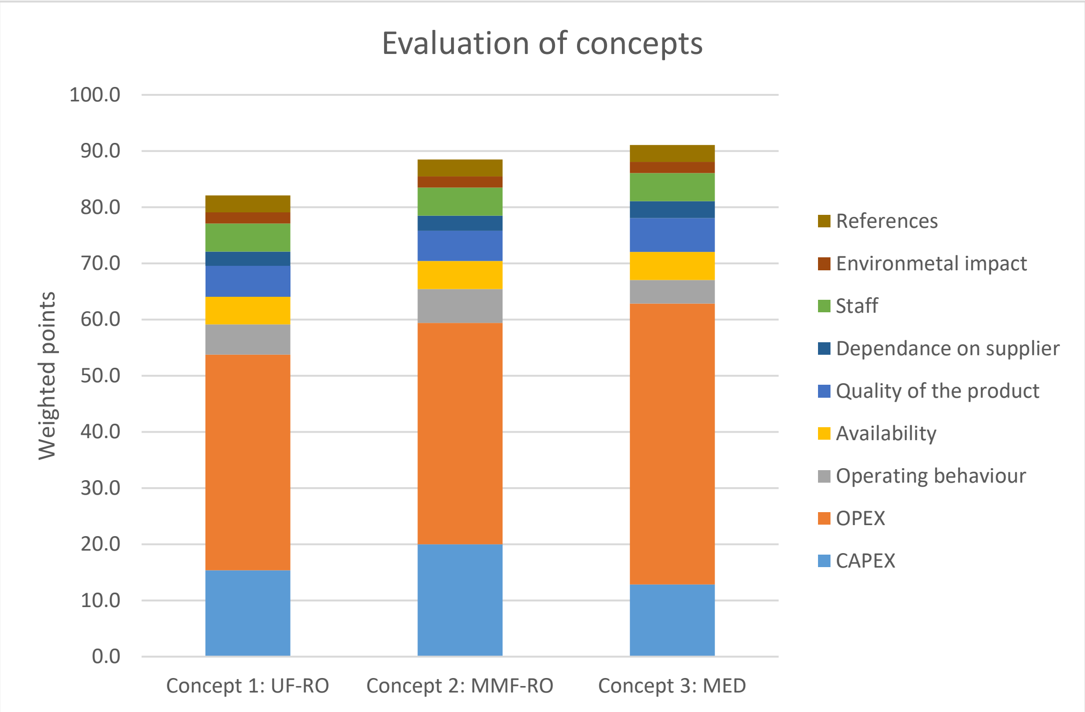


Figure 1-37: Evaluation of concepts

<u>Conclusions from the evaluation result:</u>

According to the selected and weighted criteria, the best-suited concept is concept 3. With 91.9 points concept 3 scores slightly better than concept 1 and 2. The main reason for this is the comparably low OPEX costs of the MED. However, the results of this evaluation are to be taken with caution, as Table 1-14 and all following considerations do not include the costs for thermal energy. Therefore, concept 3 can only be recommended if low-cost or cost-free thermal energy is available, for example, in the form of low-temperature solar heat, waste-heat, or geothermal heat. If this is not the case, a more thorough cost-evaluation, including the cost of thermal energy, should be done. Comparing the two RO concepts, the MMF pre-treatment is preferred to the UF pre-treatment as the capital and operating costs are lower.

1.5 Checklist for feasibility study

Table 1-16: Checklist for feasibility study

Checklist for Feasibility Study		*Drawn by:*	
		Checked by:	
NO.	DESCRIPTION	CHECKED	REMARKS
1.1	**Project targets and framework conditions**		
	a) Have you defined the desired quality and quantity of the product water?		
	b) Have you estimated the budget?		
	c) Have you set a time frame for the project?		
	d) Have you defined and clarifed approval issues?		
	e) Are all necessary permits available?		
1.2	**Identification of site**		
	a) Have you analyzed the feed water quality?		
	b) Have you investigated the connectivity of the new plant to the water demand center?		
	c) Have you determined the electrical power needed for operation of the plant and water transport?		
	d) Have you identified how the availibility of the electrical energy can be secured?		
	e) Have you solved all land ownership issues concerning the construction of the plant and pumping system?		
	f) Have you analyzed all geo-risks?		
	g) Have you analyzed all environmental risks?		
1.3	**Selection of relevant technologies**		
	a) Have you summarized the most important data in a plant design data sheet?		
	b) Have you identified the suitable pre-treatment technologies?		
	c) Have you identified the suitable desalination technology?		
	d) Have you identified the suitable post-treatment technologies?		
1.4	**Concept development and selection**		
	a) Have you developed eligible desalination concepts?		
	b) Have you evaluated the concepts and selected the best-suited concept?		

2. Basic Engineering

After finalizing the feasibility study and selecting the planning concept in chapter 1, the next planning step within the systematic approach to planning brackish water - or in general - desalination plants is Basic Engineering. Figure 2-1 shows the order of the steps.

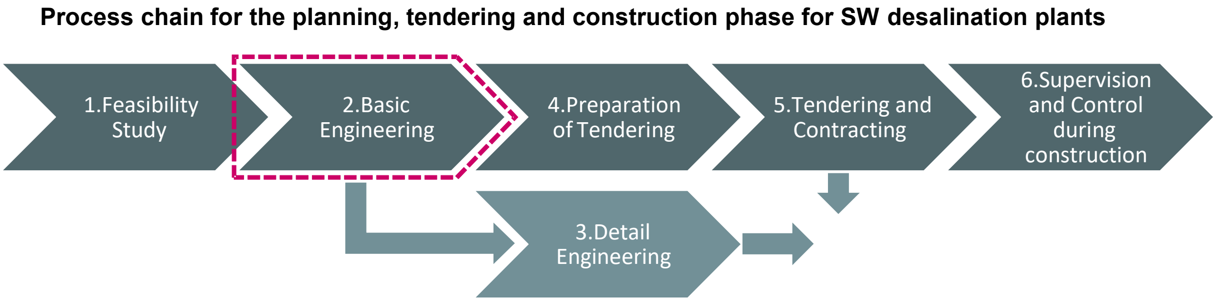


Figure 2-1: Process chain for planning, tendering and construction phase for SW desalination plant - part 2

The expected contributions by the Basic Engineering to the following planning steps, and the results from here, play a vital role in the whole SW desalination project. This is because the conceptual phase has been completed in the feasibility study, and thus, all the next planning decisions must be kept within the selected planning concept. From this planning phase onwards, there is no longer any degree of freedom to make conceptual changes.

Without a substantial reason, any conceptual changes should be avoided within the Basic Engineering. Otherwise, the feasibility of the new process considering all the chances made after the feasibility study, should be re-checked, and compared with the feasibility of the planning concept.

The aim of Chapter 2 is to provide data and documents that defines the desalination projects for the market-oriented tendering documents. The basis of Chapter 2 is the results from Chapter 1: Feasibility study.

The essential steps for a successful Basic Engineering can be summarized as follows:

- **STEP 1: Design the essential treatment steps**
  (→ see 2.1 Design of the essential treatment steps)

- **STEP 2: Create Process Flow Diagrams (PFDs)**
  (→ see 2.2 Creation of Process Flow Diagrams (PFD))

- **STEP 3: Identify and determine the battery limits and create the layout**
  (→ see 2.3 Determination of the battery limits and creation of layout)

- **STEP 4: Identify the monitoring requirements and define the degree of automation**
  (→ see 2.4 Monitoring requirements and automation)

- **STEP 5: Select suitable materials for the desalination task**

(→ see 2.5 Selection of adequate materials)

- **STEP 6: Determine the requirements for suitable chemical and spare parts storage**
  (→ see 2.6 Chemical and spare parts storage)

- **STEP 7: Determine the basic requirements for health and safety**
  (→ see 2.7 Requirements for health and safety)

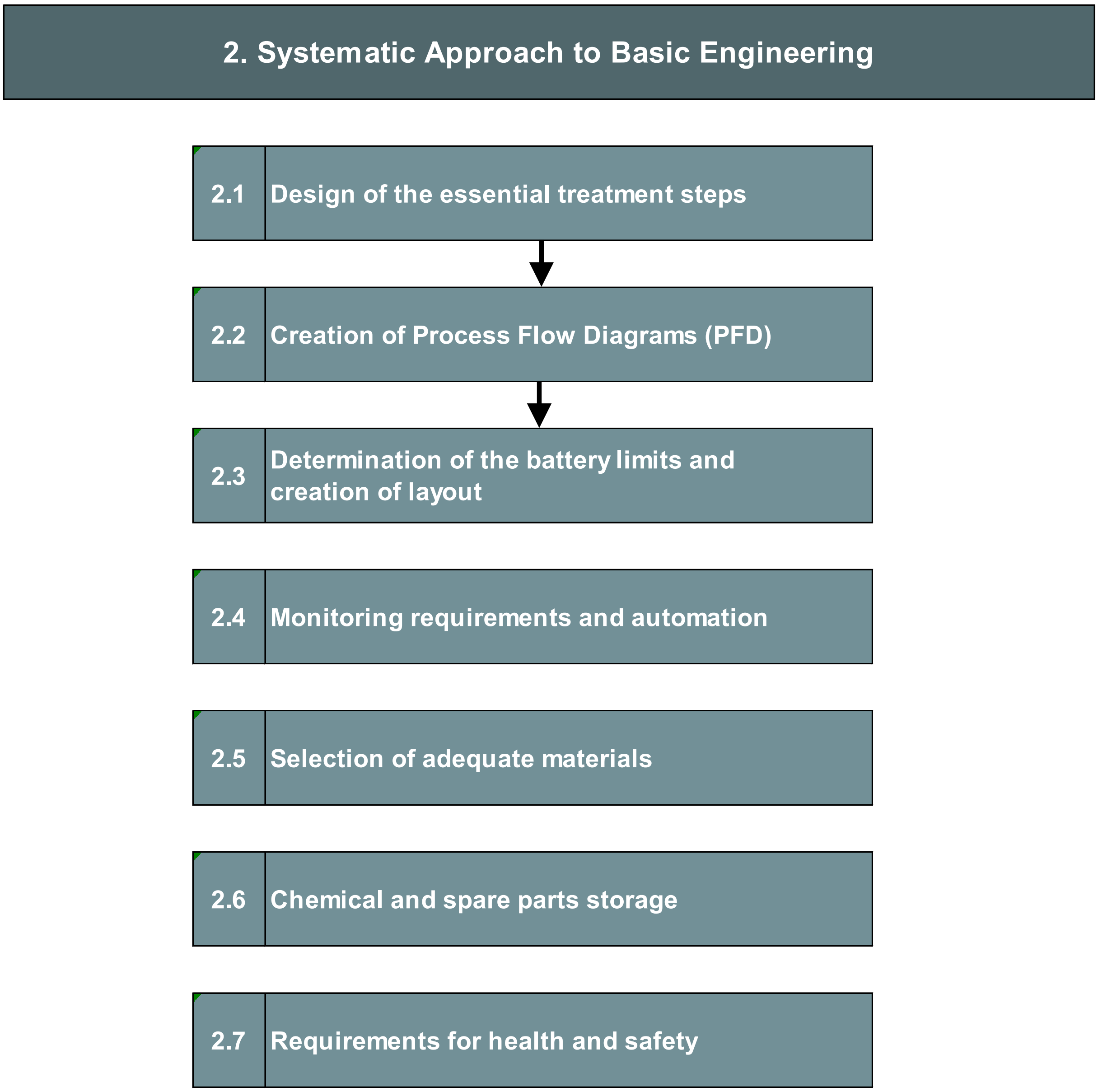


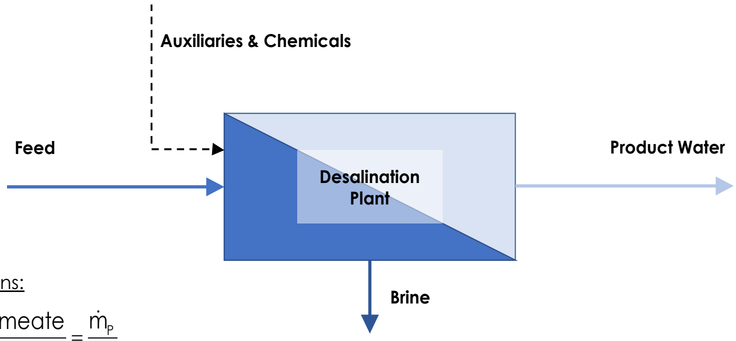
Figure 2-2: Systematic Approach to Basic Engineering

The essential results from the Feasibility Study that needs to be elaborated before the Basic Engineering are shown below in Figure 2-3. The data will be used as an example for further development within Basic Engineering.

Basic Data RO Desalination Plant

Amount of Product:	$\dot{V}_P$	=	100,00	MCM/a
Availability:	f	=	95	%
Annual operating hours:	oh	=	8322	h/a
Recovery rate RO	φ	=	45	%
Feed (TDS):	β_F	=	42000	mg/l
Permeate (TDS):	β_P	=	300	mg/l

Simplyfied Flowsheet:



Feed		
[m³/h]	[m³/d]	[MCM/a]
26.703	640.872	222,222

Product Water		
[m³/h]	[m³/d]	[MCM/a]
120	2.884	1,000

Brine		
[m³/h]	[m³/d]	[MCM/a]
26.583	637.988	221,222

Equations:

$$\varphi = \frac{\text{Permeate}}{\text{Feed}} = \frac{\dot{m}_P}{\dot{m}_F}$$

Figure 2-3: Plant design Datasheet

2.1 Design of the essential treatment steps

The design of the essential treatment steps is divided into four sections intake, pre-treatment, desalination, and post-treatment. Each is presented in the following subchapters. All four steps are interdependent within the planning phase Basic Engineering.

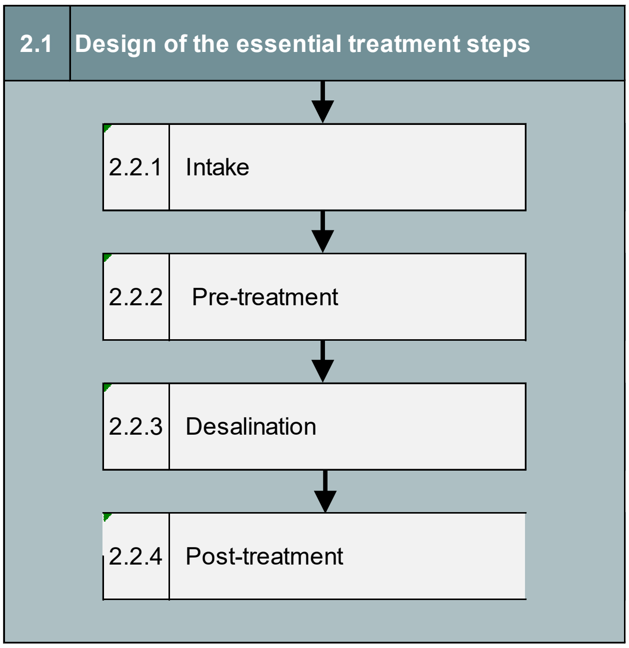


Figure 2-4: Design of the essential treatment steps

2.1.1 Intake

Seawater desalination by reverse osmosis requires feed water with low variability and relatively high quality. The intake section and the subsequent pre-treatment are responsible for reducing any critical constituents such as particulates, silt, bulk organics and microorganisms below the RO feed water target levels. The type of intake, e.g. open or sub-bottom intake, influences the treatment train of the pre-treatment stage to meet the RO feed water quality requirements. The selection of the appropriate intake system and the set of unit processes composing the pre-treatment is further influenced by several external factors, including the seawater characteristics, onshore and offshore geology, the local environment, the intended capacity of the plant and other requirements from the legal and economic perspective.

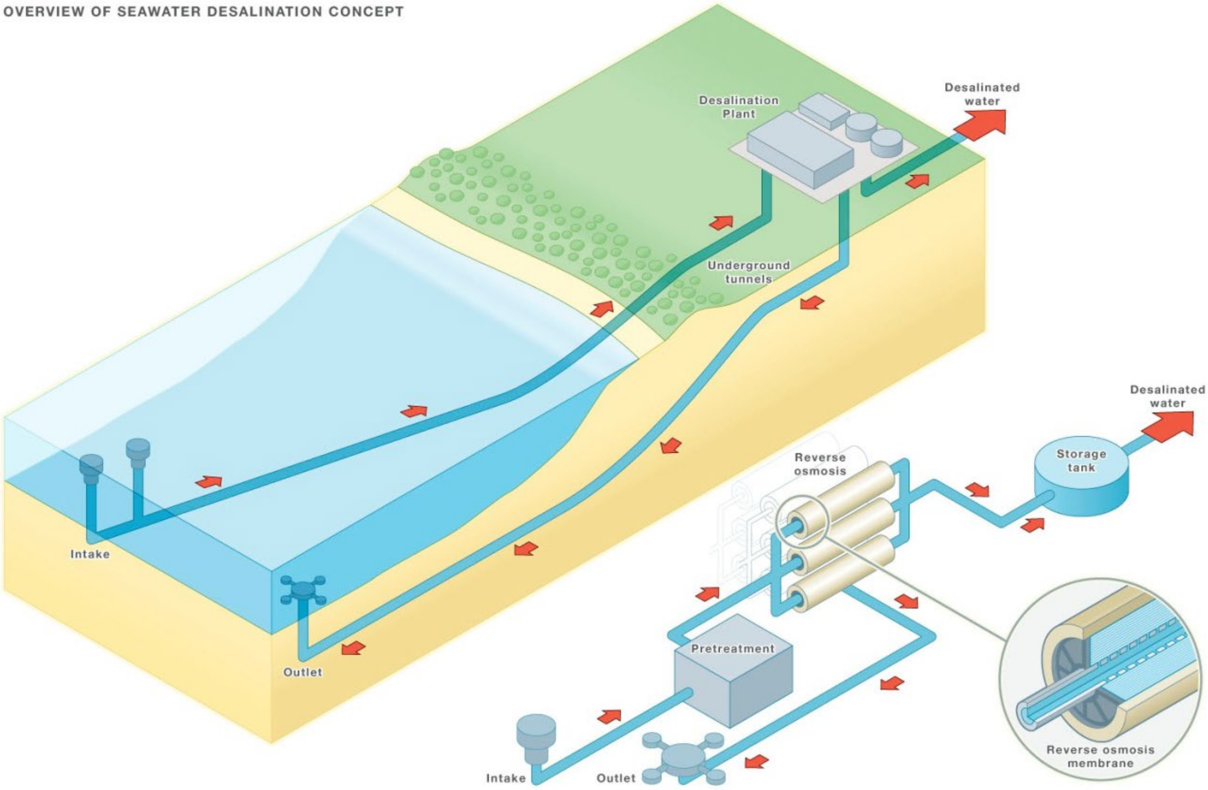


Figure 2-5: Overview of the seawater reverse osmosis concept[19]

Differences between BWRO and SWRO

When freshwater sources are scarce, alternative water sources tapping into either brackish water, treated wastewater or seawater can fill the gap. Jordan has only limited access to seawater along the coast at the Gulf of Aqaba. The Jordanian part of the Gulf of Aqaba is rather small and extends only for about 27 km in the north-eastern part of the Gulf, bordering Israel towards the West and Saudi-Arabia in the South-East. The Gulf of Aqaba is characterized by high salinities and high anthropogenic impact. Industry and other human activities pose elevated stress on the marine and coastal ecosystems. Sources of pollution include dredging and reclamation activities, coastal construction development, industrial waste, ports, oil spills, and domestic sewage. [20] Seawater is often perceived as less impaired by pollution due to larger mixing ratios compared to inland water bodies. However, a confined setting as the Gulf of Aqaba is more prone to pollution than open ocean situations.

Salinity is the main factor in SWRO governing the energy demand and thus represents the key cost factor. Table 2-1 shows the different water qualities based on salt concentration. Due to limited exchange and high evaporation, highly saline conditions characterize the seawater at the Gulf of Aqaba coastal waters. The total dissolved solids concentration (TDS) varies around 42,000 ppm making the Gulf of Aqaba one of the locations with the highest salinity in the world. In comparison, brackish groundwater available in Jordan has a moderate average salinity of 3,000 ppm with maximum concentrations between 7,000 to 8,000 ppm.

[19] Sydney Desalination Plant. (2022). https://sydneydesal.com.au/

[20] Batayneh, A.T.; Ghrefat, H.; Zumlot, T.T.; Elawadi, E.; Mogren, S.; Zaman, H.; Al-Taani, A.A.; Nazzal, Y.; Elwahaidi, M.; Elwaheidi, M. Assessing of Metals and Metalloids in Surface Sediments along the Gulf of Aqaba Coast, Northwestern Saudi Arabia. *J. Coast. Res.* 2014, 31, 163–176.

Table 2-1: Feed water quality characterization based on salt concentration

Source water	Total dissolved solids (ppm)	Classification
Drinking-Water	< 500	Fresh
Fresh water	< 1.000	Fresh
Brackish water	1.000 – 5.000	Mildly brackish
	5.000 – 15.000	Moderately brackish
	15.000 – 35.000	Heavily brackish / seawater
Seawater	35.000	Standard average seawater
	35.000 – 45.000	Seawater

Another important factor is the **seawater temperature** influencing the viscosity, RO permeability and thus, the related energy requirements in processes using porous and dense membranes. The average monthly seawater temperature at the Coast of Aqaba varies between 21.4 °C in January and 28 °C in August[21] , with an annual average of 24.3 °C. In summer, maximum temperatures may reach up to 30 °C while the minimum in winter stays slightly above 20 °C.

Besides the water temperature and salinity with its seasonal variations, placing of the intake should consider influences from industrial and domestic discharges and the flow and mixing conditions in the sea to safeguard the viability of the technical solution and minimize impacts from pollution.

State of the art intake systems

The intake system is a central part of every SWRO desalination plant to provide the intended quantity and quality reliably. Generally, two types can be differentiated: surface (or open ocean) intakes and sub-bottom intakes with a range of subcategories for both options (see Figure 2-6).

Open intakes (onshore and offshore) are particularly suitable for high intake volumes and thus applied in larger SWRO systems. They can be used for colocation (i.e. with power generation plants), are unaffected by feed water quality, but also do not improve it. The main disadvantage of open intakes is the vulnerability to main environmental concerns such as impingement and entrainment of marine fauna (jellyfish, algae blooms, etc.).

[21] Sea temperature (2022). Water temperature in Aqaba. https://seatemperature.info/aqaba-water-temperature.html

Sub-bottom intakes are mainly used for SWRO plants with smaller capacity, although seabed galleries are increasingly being considered for larger systems as well. They are unaffected by feed water quality and provide through filtration an improvement of the water quality reducing the pre-treatment requirements. Through the diffusion of seawater through the seabed,simulating a slow sand filter with low flow velocities, they eliminate impingement and entrainment. Subsurface intakes are able to remove bacteria, algae, and biopolymers, reducing both organic and biofouling of RO membranes.

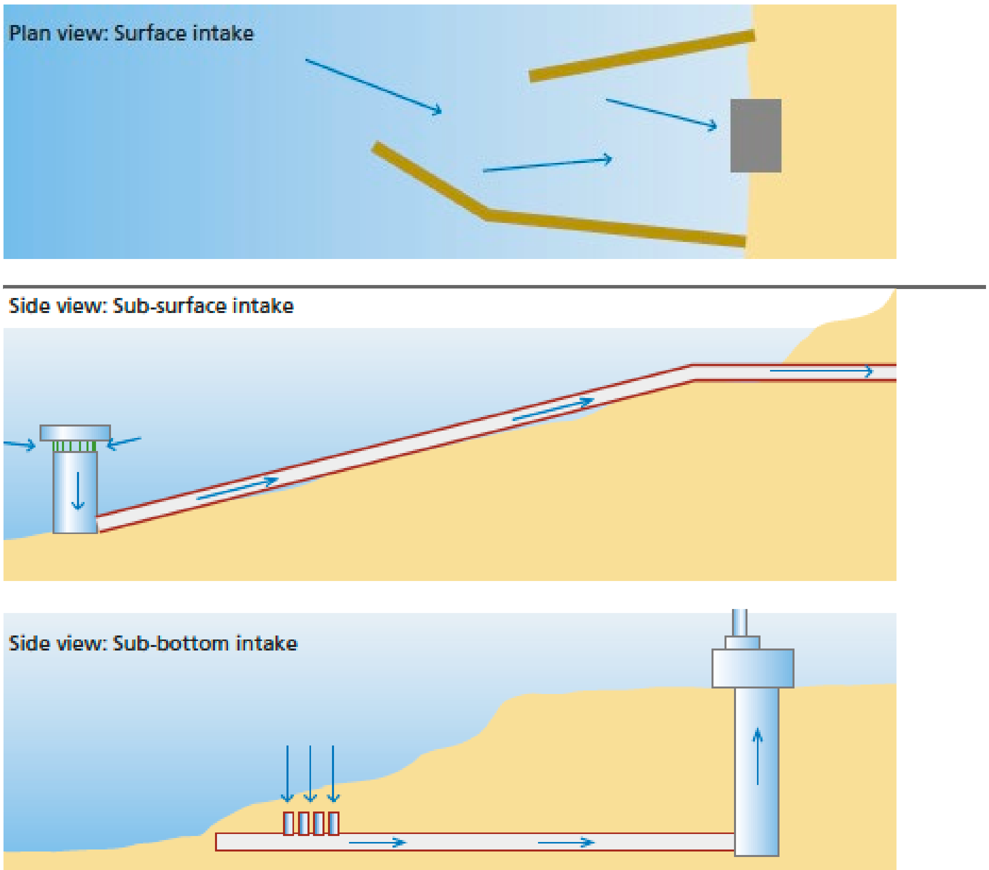


Figure 2-6: Intake modes for SWRO desalination plants: intake modes[22]

Besides the geological and hydrogeological conditions, the intake and pre-treatment system selection is based on a full assessment of the Lifecycle Costing (LCC) and the Lifecycle Assessment (LCA) of the environmental impacts. As the intake may function as a part of the SWRO pre-treatment, the proper selection of the intake system is not only defined by factors such as the plant size but also influences the downstream treatment train and thus the overall design and cost of the plant. Table 2-2 presents the main intake alternatives with their principal advantages and disadvantages. The choice of the intake system has a significant impact on the environment and the quality of the raw water to be further treated in the pre-treatment to finally meet the requirements of the RO system.

[22] Boerlage et al. (2017). Seawater intake considerations to mitigate HAB impacts.

Table 2-2: Intake options for SWRO desalination plants

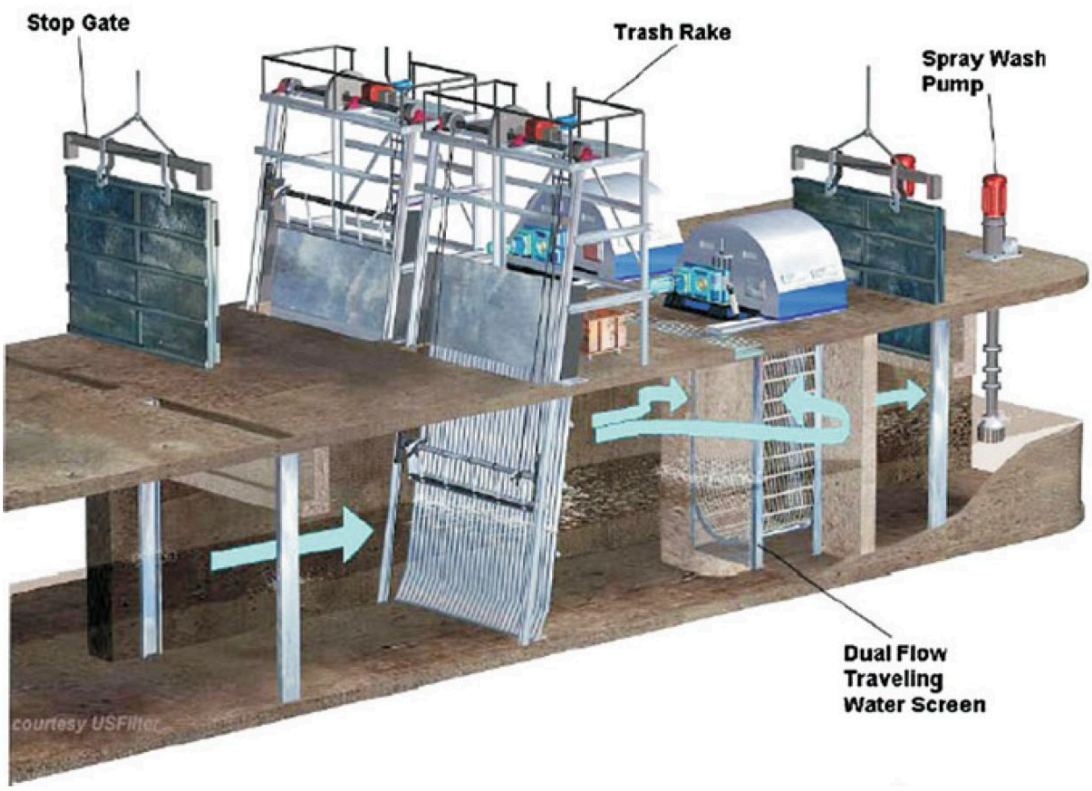
Intake alternative	Main features	Advantages	Disadvantages
Onshore open intakes	• Large deep intake canal followed by coarse and fine screening and vertical turbine pumps	• Lowest Cost • Short pipe lengths	• Highest water quality variation • High water turbidity • Impact on environment • Chemical demand • Waste generation • Complex pre-treatment
Subsurface intakes **(Offshore open intakes)**	• Submerged offshore open intake	• Cost • Independency from (hydro)geological conditions • Less impact from the surf zone	• Impact on environment • Chemical demand • Waste generation • Complex pre-treatment
Sub-bottom intake **(Beach well)**	• Collection of water from below the ocean floor or saline near-shore aquifer	• Removal of solids with resuspension into the ocean and replacing pre-treatment • Minimum environmental impact • Independency from (hydro)geological conditions	• Cost • Suitable (hydro)geological conditions required (high transmissivity of the bottom, the productivity of coastal aquifer etc.)

Surface intakes can be a single purpose or co-located with a power plant as well as offshore submerged, nearshore submerged, or nearshore surface intakes. Surface, co-located, nearshore intakes are typical for water and power cogeneration plants (e.g., many in the Gulf region), but are also used by some SWRO plants (e.g., in the USA). The use of the surface, single-purpose intakes is common for many larger SWRO systems.

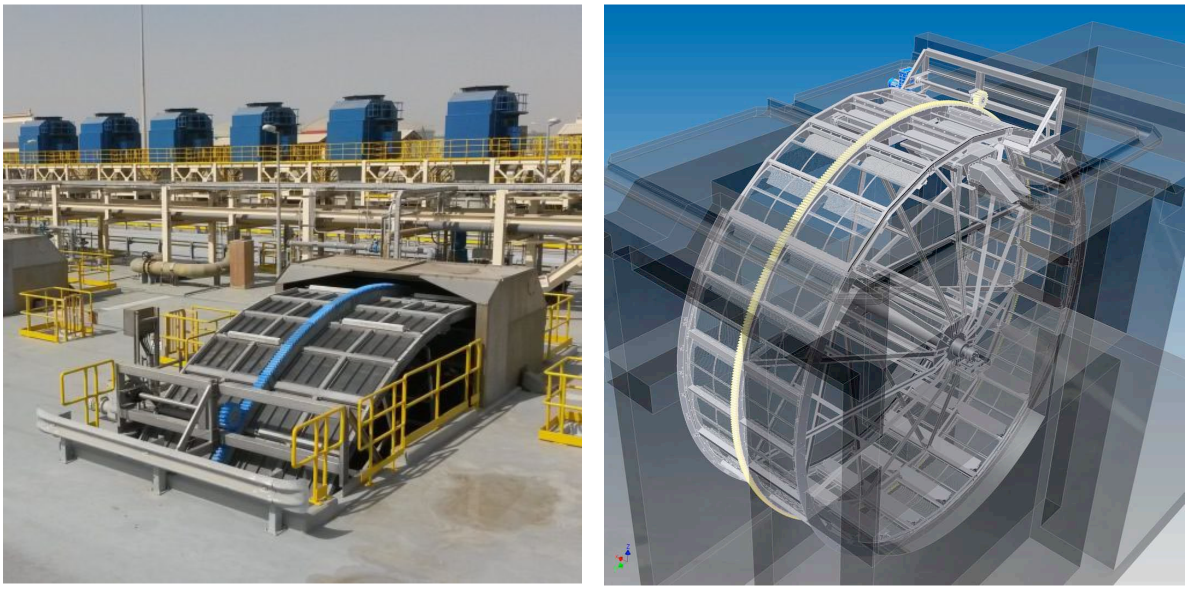
Large-scale desalination plants take the saltwater directly from the sea. Mostly this is realized by a concrete pipe. The length of this pipe can be up to several 100 meters. Accordingly, different construction methods are used for pipes of different lengths. A division is made between shoreline, channel, and offshore intakes.

Source water screening. Screening is the first treatment step of every desalination plant with an open intake. Particularly in plants with open intakes screening is quite sophisticated combining a coarse and a fine / microscreens to retain silt, plankton, sand, shell particles, and other solid debris in the saline source water. (cf. Figure 2-7 -Figure 2-8). While the coarse screen is stationary, fine screens can be either stationary or periodically moving. Intake heads used in nearshore or offshore open intakes may also be equipped with stationary screens to prevent aquatic organisms from entering the desalination plant.

The top image in Figure 2-7 displays an intake system consisting of vertical trash racks fitted with raking machines which can remove floating debris and algae. This is followed by dual flow traveling water screens. As the water flows through the screens, baskets, typically made of fiberglass with varying sizes, remove the debris. The screen is then cleaned by high pressure water sprays. Rotary drum screens, as seen in the bottom image in Figure 2-7, can also be used. Compared to the traveling screens, drum screens can rotate faster and are therefore able to handle more debris.



Traveling Water Screens

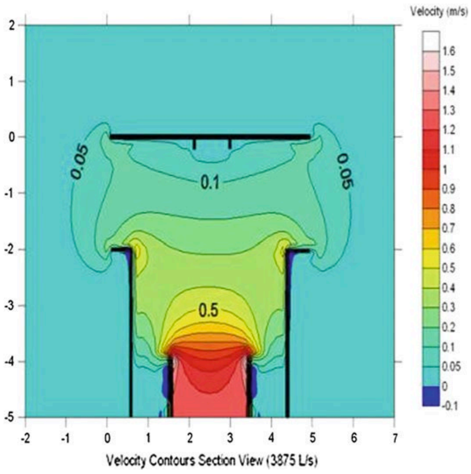


Rotating Drum Screens

Figure 2-7: Examples of surface intakes and screening

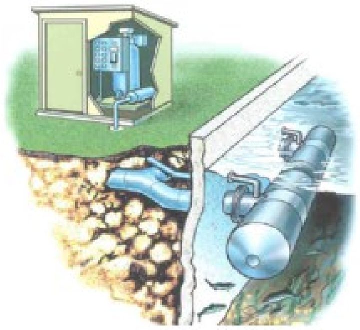
Velocity caps (cf. Figure 2-7) are a widely used feature in open intakes to avoid vertical vortices and signal the fish the danger of getting entrapped. The fish can sense the elevated horizontal flow velocity through receptors along their body that sense horizontal movement and allow them to swim away from the intake structure.

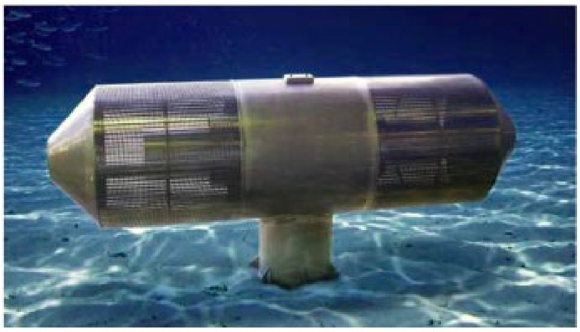
Intake Heads



Velocity Caps

Velocity cap intake during operation



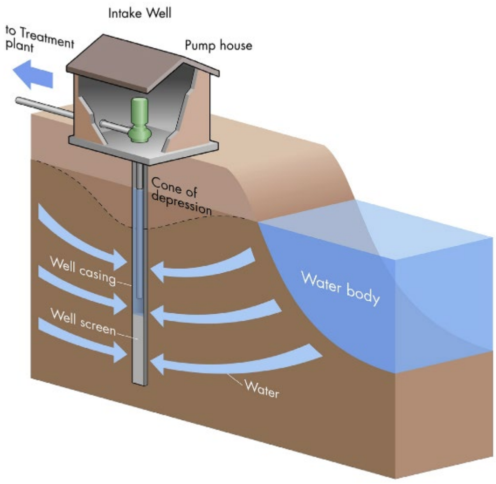


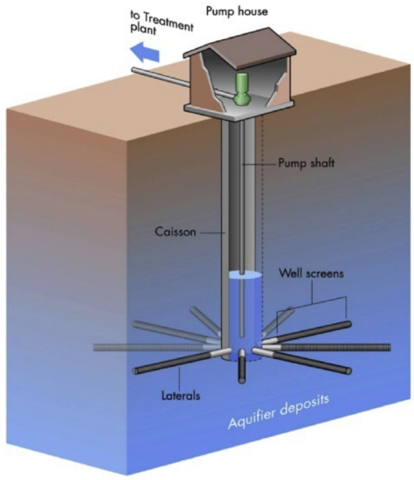
Intake Heads

Figure 2-8: Examples of surface intakes and screening II

Sub-bottom intakes can be onshore used by small to medium capacity SWRO plants or offshore wells, which are under consideration for larger SWRO systems. Sub-bottom intake options are (cf. Figure 2-9):

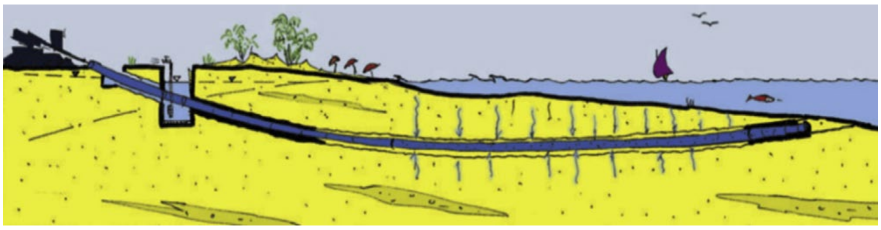
- Conventional vertical wells and Collector or Ranney Wells
- Angle wells and Horizontal wells (HDD)
- Beach gallery systems
- Offshore or seabed gallery systems



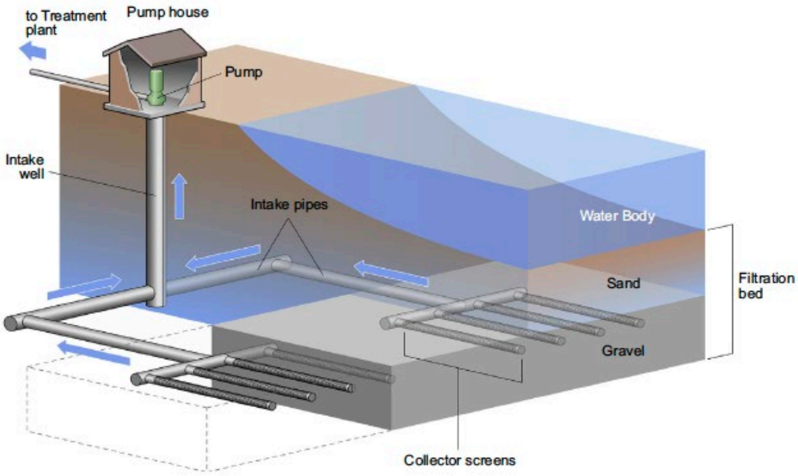


Vertical intake well

Horizontal Ranney-type intake well



Horizontal wells intake (HDD horizontal directional-drilled wells)



Infiltration gallery

Figure 2-9: Sub-bottom intake options[23]

Colocation (cf. Figure 2-10: The Carlsbad SWRO plant in California as an example of a co-located intake in SWRO Figure 2-10). Co-located intakes are an open intake method for desalination plants that are co-sited with power stations that use seawater for once-through cooling purposes. The warmer cooling water discharged by the power plant has a lower viscosity than the ambient seawater reducing the energy demand for reverse osmosis desalination. Furthermore, co-located intakes eliminate in most cases the need to construct

[23] Water Globe Consultants (2022). https://www.water-g.com/

separate intake and outfall for the desalination plant reducing the project's overall capital expenditures.

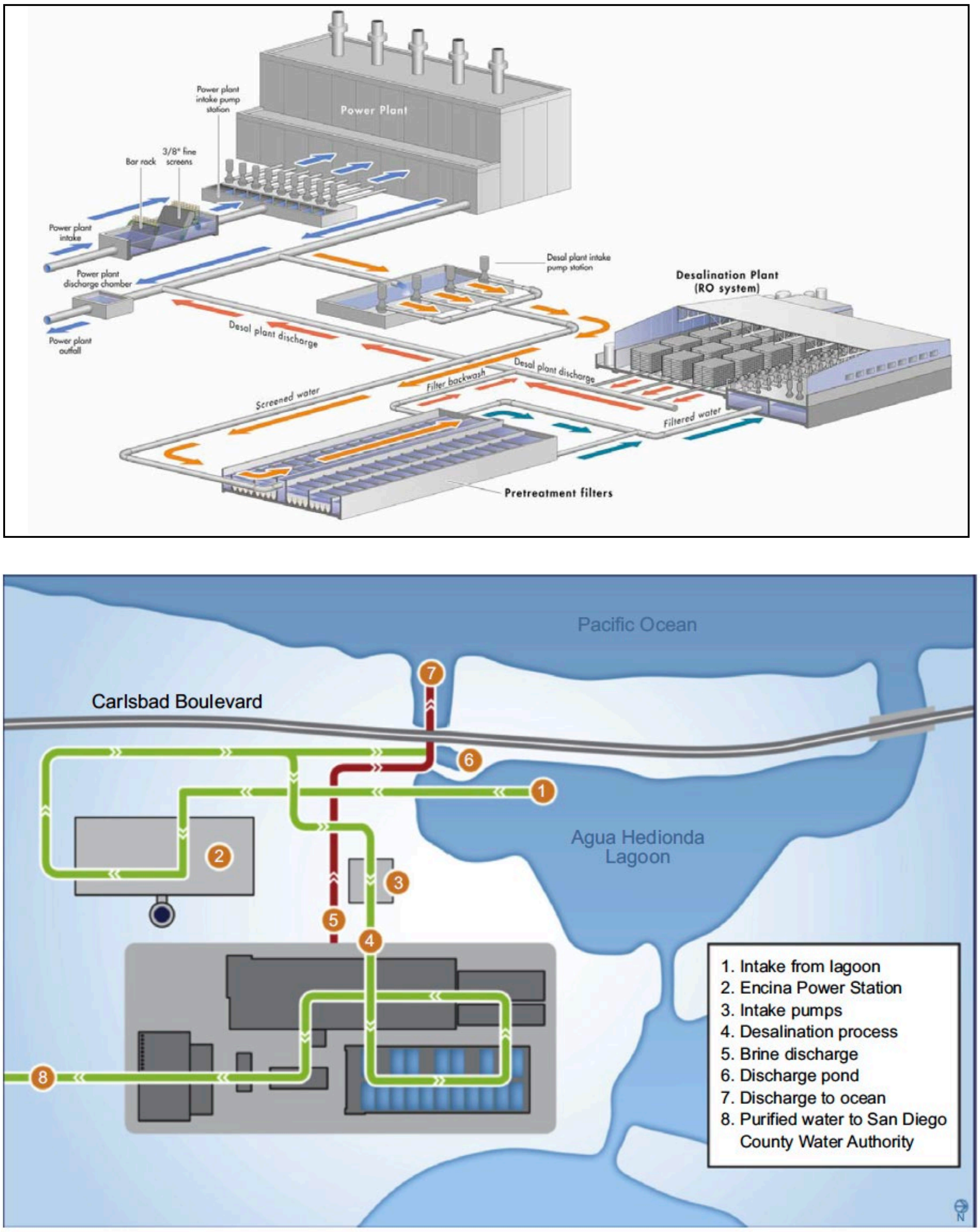
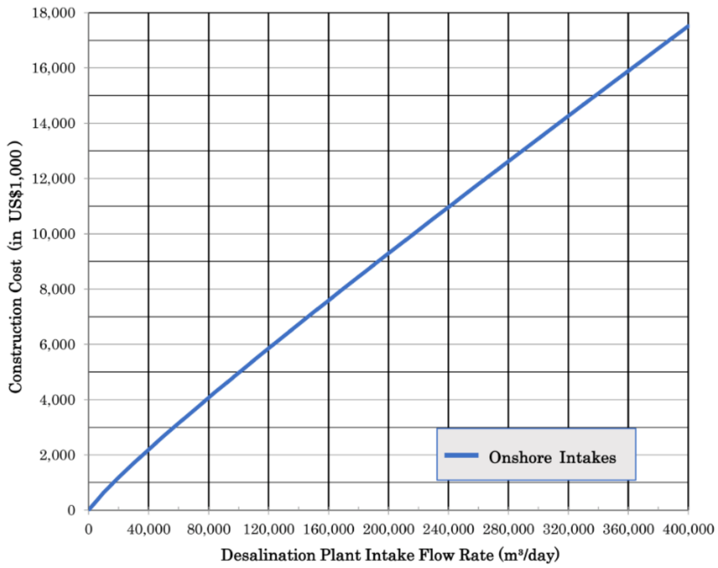


Figure 2-10: The Carlsbad SWRO plant in California as an example of a co-located intake in SWRO

Capital costs

According to Voutchkov (2019)[7], the direct capital costs for the intake system typically amount to 4.5 – 6.0% in low complexity projects and 5.0 – 6.5% in high-complexity projects.

The following figures and tables can be used for initial estimates of the construction cost for the respective intake system.



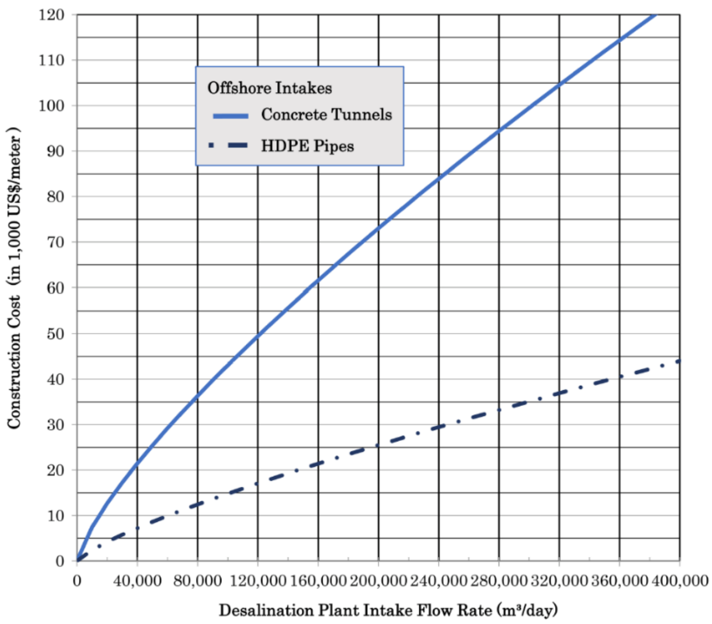


Figure 2-11: Construction cost for open onshore (top) and offshore intakes (bottom)

Table 2-3 summarizes the typical productivity and construction costs of alternative types of sub-bottom intakes implemented in desalination projects. The construction costs for HDD wells and Ranney wells are typically 20%–30% higher than the costs of vertical wells given the same capacity. Infiltration galleries are typically the costliest type of sub-bottom intakes.

The predominant type of sub-bottom intakes in SWRO desalination plants are shallow vertical wells. In seawater desalination plant with open intake, the lowest cost that collocated with the discharge of an existing coastal power plant, which uses seawater for cooling.

Table 2-3: Construction costs of sub-bottom intakes (MLD = 1000 m³/d)

Costs of Alternative Subsurface Intakes

Well Type	Typical Production Capacity (Yield) of Individual Well (MLD)	Cost of Individual Well (US$ million)
Vertical wells	0.1–3.5	0.2–1.5
Horizontal radial collector wells	0.5–20.0	1.3–6.0
Slant wells	0.5–10.0	0.8–2.8
HDD wells (e.g., neodren)	0.1–5.0	0.4–2.0
Infiltration galleries	0.1–50.0	0.5–27.0

Construction Costs of Vertical Intake Wells

Intake Well Production Capacity (m³/day)	Construction Costs as a Function of Well Intake Flow, Q (m³/day) and Well Depth, H (m)
1,000–2,000	42 Q + 730 H + 26,000
2,000–4,500	52 Q + 900 H + 52,000
4,500–6,500	68 Q + 1,150 H + 80,000
6,500–10,000	80 Q + 2,100 H + 155,000
10,000–15,000	88 Q + 2,200 H + 200,000
15,000–30,000	94 Q + 3,400 H + 270,000

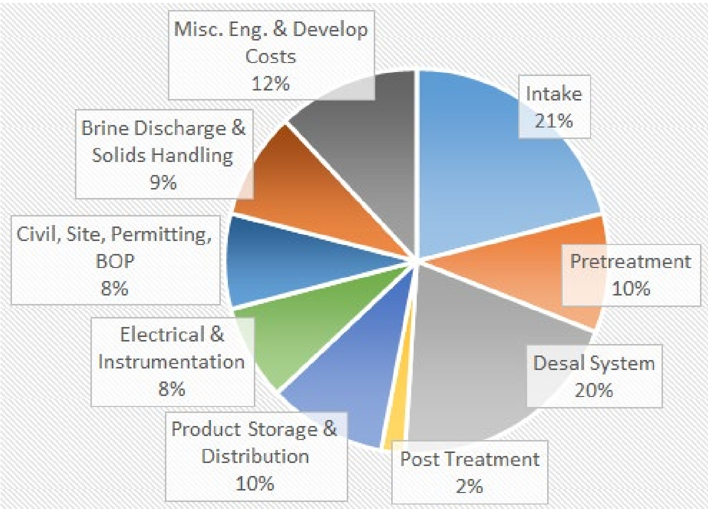


Figure 2-12: Typical SWRO capital cost breakdown [24]

[24] Advisian (2022). The Cost of Desalination. https://www.advisian.com/en/global-perspectives/the-cost-of-desalination

Operation and maintenance costs

Power is the main O&M cost factor in SWRO desalination and amounts to around 6% for the intake equivalent to 0.2 kWh/m^3.

Non-energy costs comprise chemicals, replacement, waste management, labor, maintenance, performance monitoring and other indirect O&M costs.

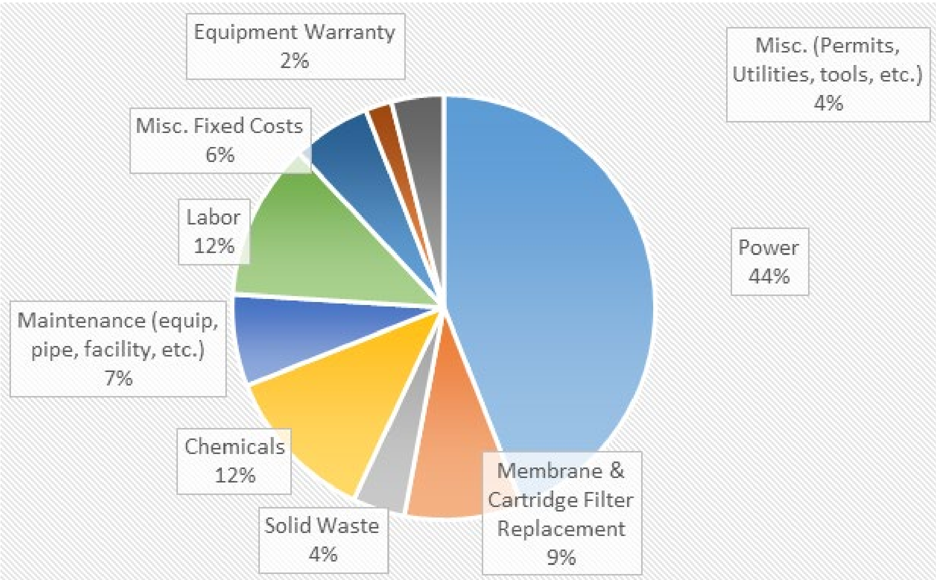
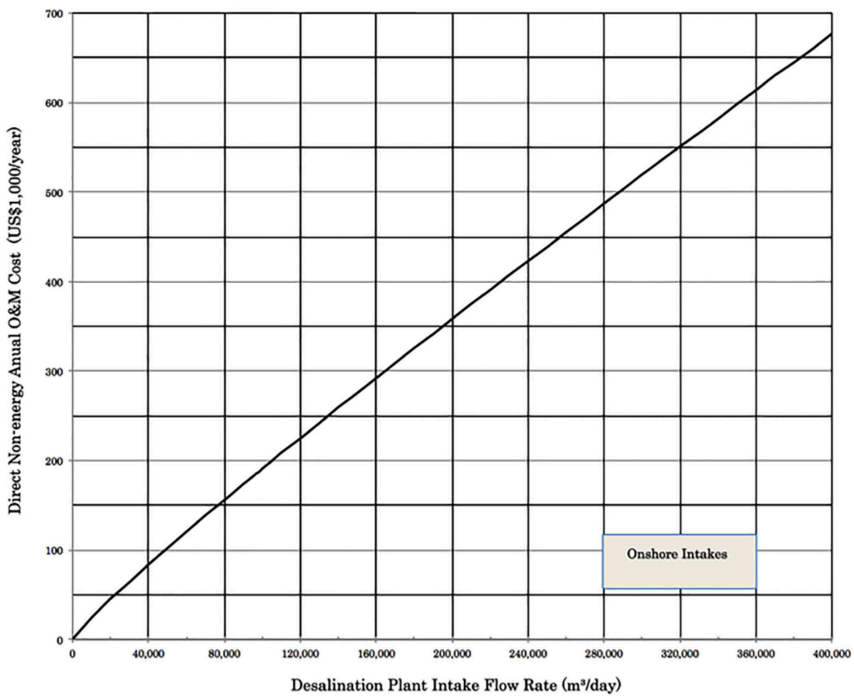


Figure 2-13: Typical SWRO operation cost breakdown[24]



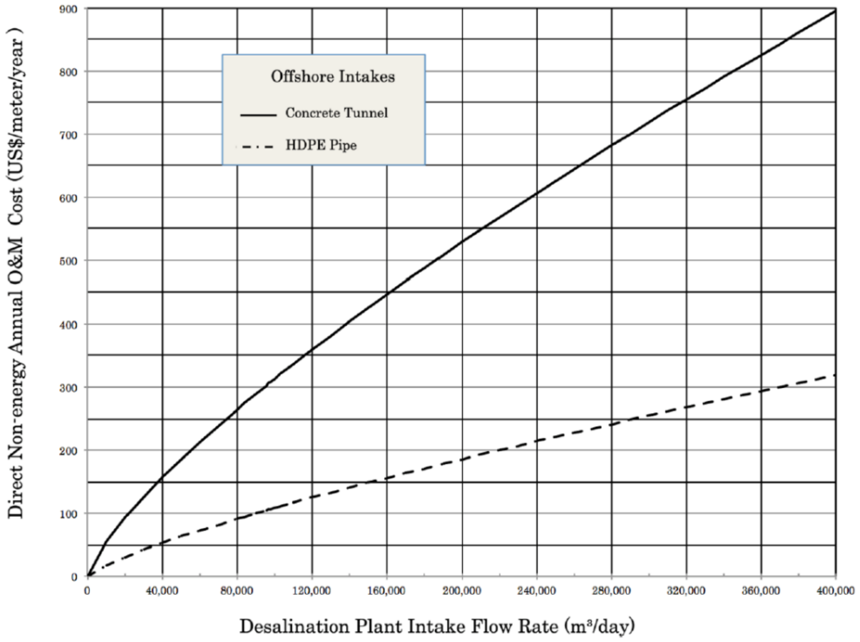


Figure 2-14: Annual O&M cost (direct non-energy) for open onshore (top) open offshore intakes (bottom)

Selection criteria

To select the optimum intake system, the site-specific situation should be analyzed along with the following criteria (besides the cost aspects discussed in the previous section):

- **Intake flowrate**

The intake selection is first determined by the required maximum flow rate of the plant (present water demand and future projections where required) and several other factors related to the treatment processes defining the overall water recovery. While smaller plants typically aim at simple to operate intakes such as beach wells, larger systems consider mostly open-intake structures either onshore or offshore. Sub-bottom intakes must take the productivity of the coastal aquifer into consideration determined by transmissivity and flow conditions at the site.

- **Location**

The optimum site selection for a desalination plant depends on many factors ranging from land availability and cost, geological conditions at land, coast and seafloor, hydrogeological situation, vicinity to densely populated areas (level of noise protection, nuisance from construction, accessibility, etc.) defining cost and feasibility. A general typology of the Red Sea coastal geomorphological conditions and the related suitability for certain intake types is given in Dehwah et al. (2014) (cf. Table 2-4 and Table 2-5).

- **Intake depth**

The water quality and temperature vary significantly with water depth. While surface water is highly impacted by turbidity, sand and other materials, deeper water levels below 10 m offer more stable and favorable conditions (better water quality, less impact from waves, less air due to breaking waves, less light reducing biofouling). Intake depth must consider naval traffic with required distances and depths.

- **Required filtration size** (protection of pumps, membranes)

Screens and micro screens – where necessary – and the related filtration size need to be selected based on the required protection of subsequent installations such as pumps, membranes, and heat exchangers.

- **Applicable regulations** (environment, construction)

The impingement and entrainment of marine organisms can be minimized by various sub-bottom and open intake technologies. Site-specific conditions and requirements from regulations must be considered in the environmental assessment of the impact of the intake system on aquatic wildlife.

- **Operational considerations**

The complexity of the intake system and the subsequent pre-treatment may pose specific operational challenges. Important factors are the reliability of the system and the required maintenance, accessibility for cleaning, rehabilitation and other servicing, demand for chemicals, waste production and management.

- **Flexibility and expandability**

In many cases, desalination projects are built with potential future capacity upgrades, which must be considered during the site selection and related selection of the intake system. In sub-bottom intakes, space limitations may limit well addition. Beach galleries are even less flexible.

Table 2-4: Geomorphological classifications of the Red Sea coastline[25]

A. Sandy Beaches
A1 - Sandy beach with corresponding nearshore sand or slightly muddy sand, coral reef complex offshore
A2 - Sandy beaches, restricted, with no reef
A3 - Offshore Island with nearshore sandy sediments and reef
B. Rocky shorelines
B1 - Limestone rocky shoreline with corresponding nearshore sand and offshore
coral reef complex
B2 - Limestone rocky shoreline with nearshore muddy sediments
B3 - Limestone rocky shoreline, nearshore deep water, no reef
B4 - Rocky headland with an offshore rocky bottom, no reef
B5 - Rocky shoreline, wadi1 sediments nearshore, offshore reef
C. Wadi intersections
C1 - Wadi sediments (boulders, pebble, and gravel) at the shoreline, variable sand, gravel and mud offshore with no reef
C2 - Wadi shoreline sediments, nearshore marine hard ground, minor nearshore sand, coral reef offshore
D. Sabkha, lagoons, and mangrove
D1 - Coastal sabkha shoreline and nearshore muddy sediments
D2 - Muddy shoreline with lagoonal muddy sediments, nearshore sand and offshore reef complex
D3 - Muddy shoreline /lagoon/ supra-tidal sabkha with no reef complex
D4 - Mangrove shoreline with nearshore muddy sediments
E. Others
E1 - Shoreline reef complex dropping to deep water in the nearshore off-reef area
E2 - Artificial channels or urban shoreline with artificially filled nearshore dropping to deep water nearshore
E3 - Natural channel

[25] Dehwah, A. H., Al-Mashharawi, S., and Missimer, T. M. 2014. Mapping to assess feasibility of using subsurface intakes for SWRO, Red Sea coast of Saudi Arabia. *Desalination and Water Treatment* 52(13-15), 2351-2361.

Table 2-5: Correlation between coastal environment and feasibility of using various subsurface intakes along the Red Sea coastline[25]

Intake Type	**Subsurface Intake System**					
Well/ Gallery	**Well System**				**Gallery System**	
Environments	**Vertical**	**Horizontal**	**Radial (collector)**	**Angle**	**Beach Gallery**	**Seabed Gallery**
A. Sandy Beaches						
A1	1(b)[2]	3	2(b)	2(b)	1(d)	1(d)
A2	1(a)	3	2(b)	2(a)	4	1(c)
A3	1(a)	3	2(b)	2(b)	1(d)	1(d)
B. Rocky shorelines						
B1	1(b)	3	1(b)	1(c)	1(c)	1(d)
B2	4	4	4	4	4	2(c)
B3	4	4	4	3	4	4
B4	4	4	4	4	4	4
B5	1(a)	3	2(b)	2(a)	2(c)	2(c)
C. Wadi intersections						
C1	4	4	4	4	4	4
C2	1(b)	3	2(c)	2(b)	2(c)	2(c)
D. Sabkha, lagoons, and mangrove						
D1	4	4	4	4	4	4
D2	4	4	4	4	4	4
D3	4	4	4	4	4	4
D4	4	4	4	4	4	4
E. Others						
E1	4	4	4	4	4	4
E2	4	4	4	4	4	4
E3	4	4	4	4	4	4

[1] Feasibility factor:

1 = Excellent	2 = Possible	3 = Questionable	4 = Not feasible

[2] Estimated Capacity (m^3/d): a. Capacity <20.000, b. 20.000-50.000, c. 50.000-100.000, d. Any Capacity

Comparison of intake options

Table 2-6 presents an overview of the main characteristics of intake options summarizing the main observations from the previous sections.

Table 2-6: Assessment of intake options for SWRO plants[26]

	Vertical wells	Infiltration gallery	Open ocean, with offshore passive screens	Open ocean with velocity cap, onshore mechanical screens	Conventional shoreline, with mechanical screens
Feasibility	Limited by local geology	Limited by local hydrogeology, offshore sea conditions	Moderate-high	High	High
Feedwater quality produced	High	High	Moderate-high	Moderate	Low
Environmental implications	No impingement, entrainment	No impingement, entrainment, but construction impacts	No impingement, low entrainment	Low impinge-ment, moderate entrainment	Impingement and entrainment
Flexibility	Low, space limitations may limit well addition	Low	Production limitations can be overcome by adding screens	Moderate	Moderate
Reliability	Wells can be rehabilitated and/or new ones added	Difficult to predict, cleaning may be marginally effective	Plugging can be monitored and cleaning is effective	Plugging can be monitored and cleaning is effective	Plugging can be monitored and cleaning is effective
Susceptibility to operational anomalies	Low	Low	Moderately vulnerable to jellyfish runs, algal blooms	Moderately vulnerable to algal blooms	Moderate to highly vulnerable to jellyfish runs, algal blooms
Maintenance	Low	When/if required, could be substantial	Pig pipeline 2X per year, clean/inspect screens quarterly	Pig pipeline 2X per year, maintain screens as required	Maintain screens as required
Construction risk	Moderate	High	Low-moderate	Low-moderate	Low
Relative capital cost, typical	Low-moderate	High	Moderate-high	Moderate-high	Moderate

[26] Pankratz, T. (2015) Overview of Intake Systems for Seawater Reverse Osmosis Facilities. Ch 1 In: Missimer T.M.et al. (eds.), *Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities*, Environmental Science and Engineering, Springer International Publishing, Switzerland: DOI 10.1007/978-3-319-13203-7_1

The table below shows a rough assessment of key criteria per intake option.

Table 2-7: Comparative water quality, cost, and reliability from various intake types

Intake Type	Relative cost (for equal capacity)	Relative intake space requirements	Relative pre-treatment space requirements	Reliability
Beach wells	Low	High	Theoretically less	Variable based on subsurface lithology
Horizontal directional-drilled wells	Medium	High	Theoretically less	Unknown
Radial wells	Medium	High	Theoretically less	Unknown
Constructed seabed / infiltration gallery	High	Medium	Theoretically less	Unknown
Submerged open intake	Medium-Low	Low	More	High
Surface – open intake	Low	Low	More	High
Co-located intake	Low	Low	More	High

Checklist

The following crucial points should be checked before the final decision technically, socio-economically, environmentally, etc.

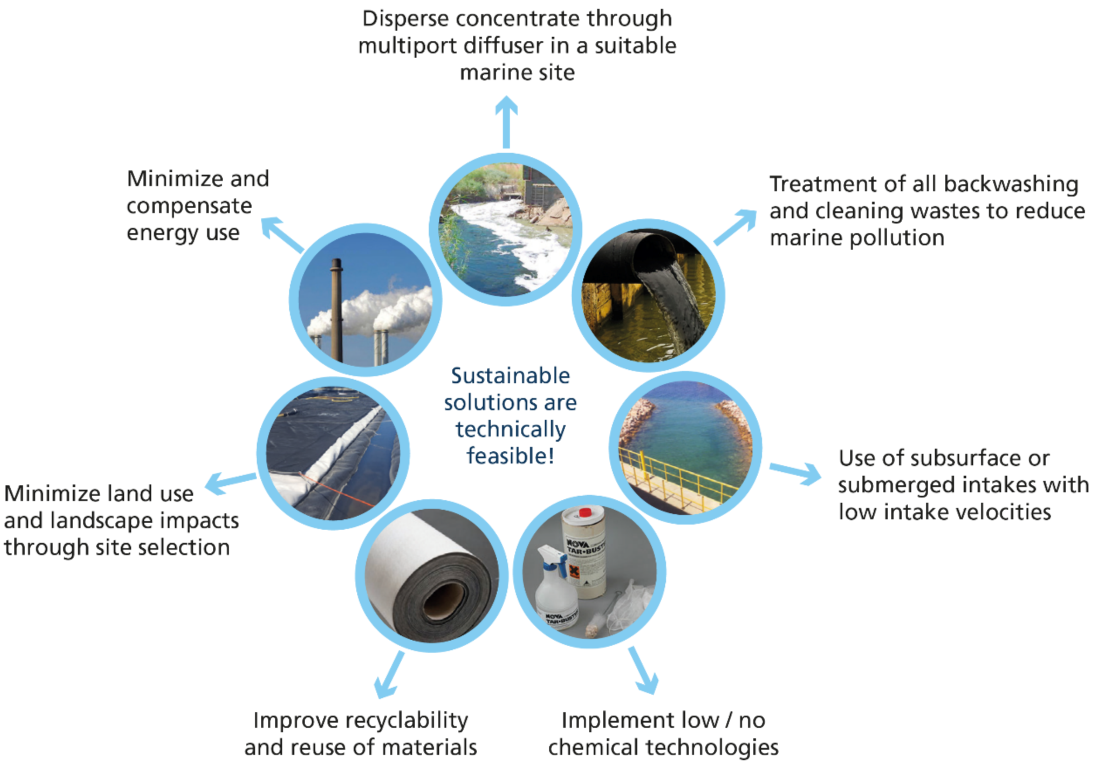


Figure 2-15: Environmental concerns (top) and sustainable and technical solutions (bottom) in RO desalination

Take away messages of Intake

- The intake system is a central part of every SWRO desalination plant to provide reliably the intended quantity and quality. The selection of the most suitable intake is part of the techno-economic optimization of the whole desalination process.
- All intake options, i.e. open intakes (onshore or offshore) and sub-bottom intakes, must be evaluated with regard to the site-specific conditions after robust assessment of the local conditions (seawater quality, bathymetry, geology, environment). A comprehensive monitoring of water quality can help in this context to avoid costly long-term problems at the desalination plant.
- Open intakes are particularly suitable for high intake volumes and thus applied in larger SWRO systems. They are vulnarable to many environmental concerns such as impingement and entrainment
- Sub-bottom intakes are mainly used for SWRO plants with smaller capacity. Through the intake via the beach / ocean floor they eliminate impingement and entrainment. are able to provide pre-treatment similar to a slow sand filter.
- The selection of the most suitable intake system is an iterative process depending on a range of local factors and case-specific requirements.
- A comprehensive monitoring of water quality in the intake site can help to avoid costly long-term problems at the desalination plant.

2.1.2 Pre-treatment

Membrane manufacturers and designers of SWRO plants rely on selected seawater quality parameters as a guide for the design of the pre-treatment system based on broad experience from operating full-scale plants (cf. Table 2-8). These guideline values must be met during all conditions and should consider the seasonal fluctuation of the concentrations, e.g., algal blooms.

Table 2-8: Guidelines for Acceptable RO Feed Water[27]

Parameter	Recommended Maximum Value	Pre-treatment Decision Issues
Silt Density Index (SDI_{15}) *	3 (never to exceed 5)	• SDI values can be influenced by the type of membrane used for the testing and feed water quality (turbidity)

[27] Jacangelo, J. G., Voutchkov, N., Badruzzaman, M., & Weinrich, L. A. (2018). Pretreatment for seawater reverse osmosis: existing plant performance and selection guidance. *The Water Research Foundation: Denver, CO, USA*

Parameter	Recommended Maximum Value	Pre-treatment Decision Issues
		• Source seawater SDI levels consistently below 2 typically indicate that no additional filtration pre-treatment is needed.
Turbidity	0.3 NTU	• Typically 0.1 NTU is preferred
Total organic carbon (TOC)	2.0 mg/L	• If below 0.5 mg/L, biofouling is unlikely and if above 2 mg/L, biofouling is expected to occur.
Iron	0.1 mg/L	• If iron is in its reduced form, SWRO membranes can tolerate up to 2 mg/L. If iron is in its oxidized form, a concentration greater than 0.05 mg/L might cause accelerated fouling.
Manganese	0.05 mg/L	• If manganese is in its reduced form, SWRO membranes can tolerate up to 0.1 mg/L. If manganese is in its oxidized form, a concentration greater than 0.02 mg/L will cause accelerated fouling.
Silica	20 mg/L	• If the concentration is higher than 20 mg/L, the colloidal silica fraction should be analyzed.
Free chlorine	0.03 mg/L	• Concentrations higher than 0.1 mg/L would cause RO membrane damage.
Oil and grease	0.1 mg/L	• Concentrations higher than 0.02 mg/L would cause accelerated organic fouling.

** One limitation of the approach is the use of a 0.45 µm filter in a dead-end filtration mode while RO processes use crossflow velocity. Hence, the nature of foulants in the SDI testing may not accurately represent the RO foulants.*

Figure 2-16 presents a decision framework for the pre-treatment selection based on the main observations from the previous section and 1.3.2: Pre-treatment technologies. Selection criteria include iron and manganese content, TOC concentration, oil and grease concentration as well as turbidity and relevance of algal blooms. The selection tool provides conventional and membrane pre-treatment options for all different cases.

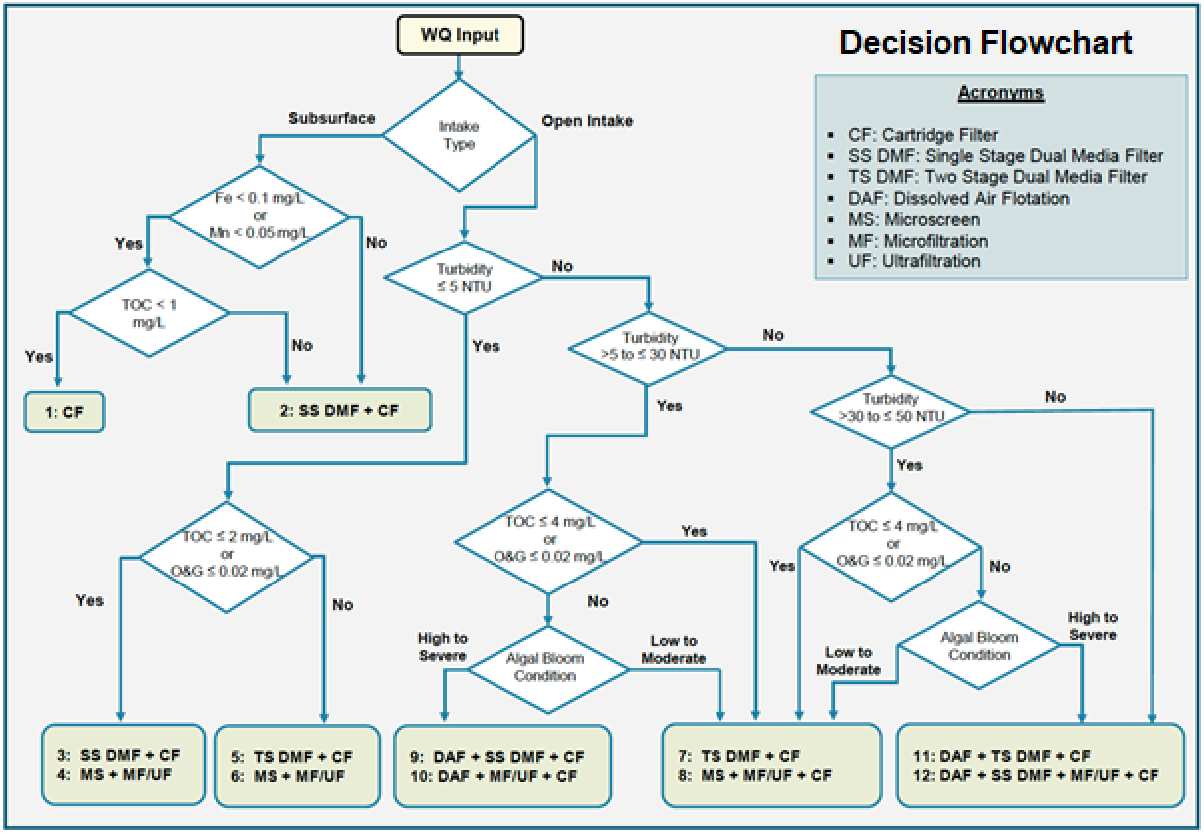


Figure 2-16: A decision framework for the selection of the pre-treatment options based on source water characteristics (NB: subsurface = sub-bottom)[28]

Pre-treatment concepts

Pre-treatment is one of the most critical key factors while designing an SWRO desalination plant. Most of the performance-limiting factors of a RO system can be positively influenced by the proper technology selection and its pre-treatment system's correct design and operation. An overview on the main pre-treatment alternatives for SWRO plants is given in the following Figure 2-17. The purpose of pre-treatment is to remove the potential foulants and scalants from the raw seawater and to prevent solved salts from precipitating, for example, on the RO membranes during the desalination process. As shown in Figure 2-18, the intake type has a distinct influence on the raw water entering the pre-treatment.

[28] Jacangelo J.G., Voutchkov N., Badruzzaman M., Weinrich L., (2018) *Pretreatment for Seawater Reverse Osmosis: Existing Plant Performance and Selection Guidance*. The Water Research Foundation, Alexandria, VA and Denver, CO: ISBN: 978-1-94124-262-9

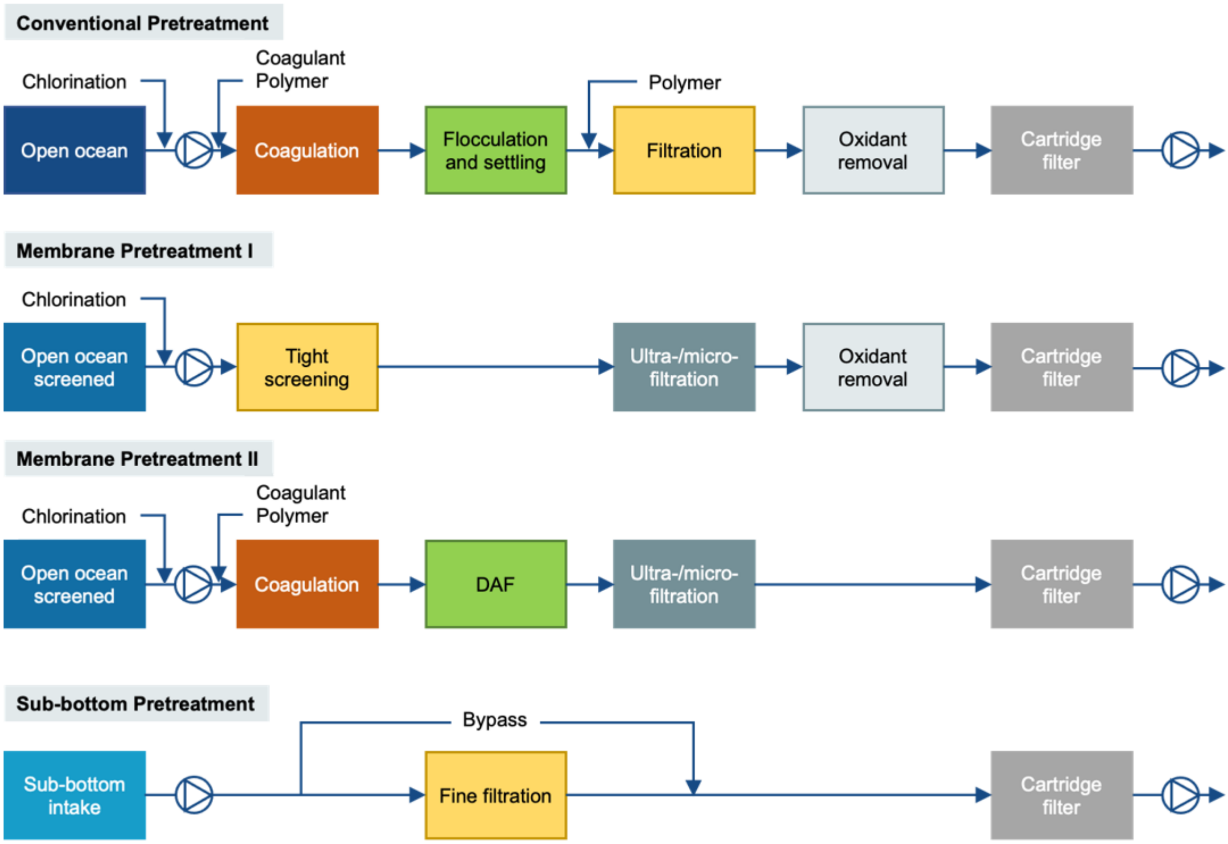


Figure 2-17: Process options for SWRO pre-treatment[29]

Conventional Pre-treatment. Most of the large SWRO plants rely on some form of open intake requiring the subsequent complex pre-treatment train (Figure 2-17). Depending on the seawater quality, loading rates of the gravity or pressure-driven granular dual media filtration stage in the range between 8-12 m/h (open intake with high-intensity algal blooms) to 14-20 m/h (open intake with good water quality) for gravity filters and 14-20 m/h (open intake with high-intensity algal blooms) for pressure-driven filters. In addition to this dosage of chemicals need to be adjusted to the specific requirements (cf. also next chapter). A detailed overview of constructive details is given in Gonzalez Olabarria (2015).[30]

Membrane Pre-treatment. As an alternative to conventional media filtration, membrane filtration, in particular ultrafiltration, may be employed as core pre-treatment technology and provides removal of suspended solids, colloids, bacteria, and viruses. As shown below, ultrafiltration has a pore size from a few nm up to 100 nm with a molecular weight cut-off from 1000 to 100,000 Da.

[29] Missimer T. M. et al. (2013) Subsurface intakes for seawater reverse osmosis facilities: Capacity limitation, water quality improvement, and economics. *Desalination* 322, 37-51. doi.org/10.1016/j.desal.2013.04.021.
[30] Gonzalez Olabarria P. M. (2015) Constructive engineering of large reverse osmosis desalination plants, Chemical Publishing Company, ISBN: 978 0820 6020 80

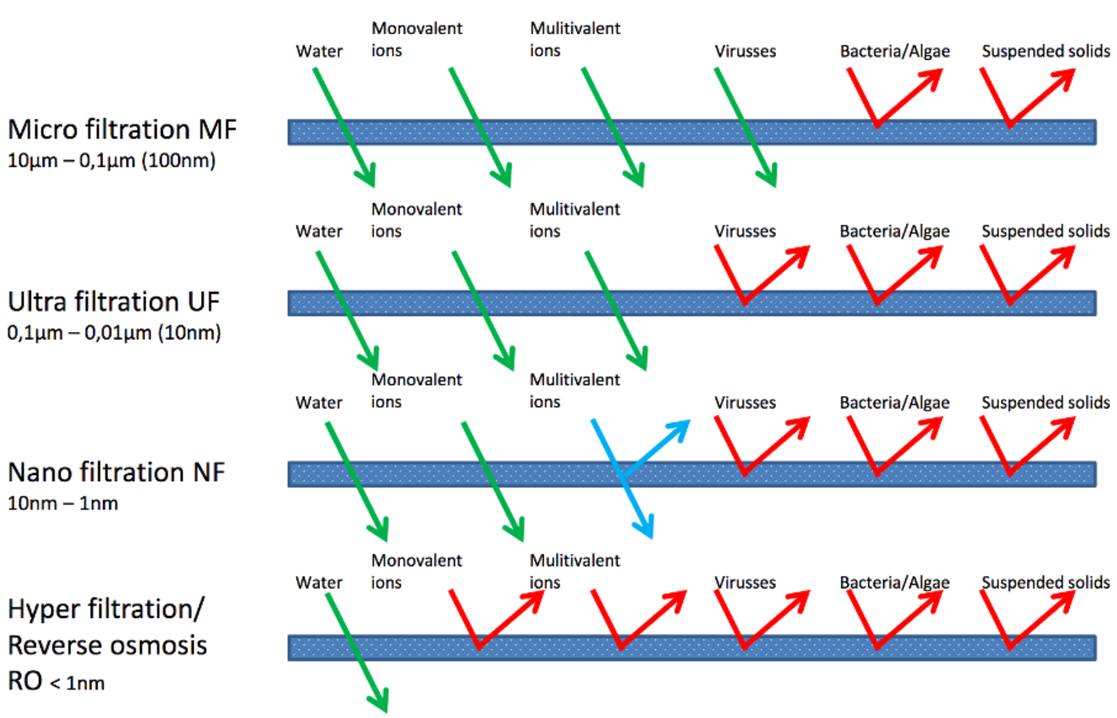


Figure 2-18: Comparison of rejection behavior in pressure driven membrane processes[29]

Ultrafiltration plants come in different designs and are mostly proprietary systems. UF membranes are available as submerged hollowfiber membrane systems that are immersed in an open tank and drawing the feed water by vacuum pumps in so-called outside-in mode in the inner lumen of the membrane. Encased membrane systems employ as well hollow fibers but the membrane fibers are packed into a cylindrical - typically 8" – casing with a length of 40" or 60". These membrane modules are operated either with inside-out flow or outside-in flow. Pressures and design fluxes are significantly higher than in submerged membrane systems.

The following figure shows the classification of membrane processes by particle size and required pressure difference.

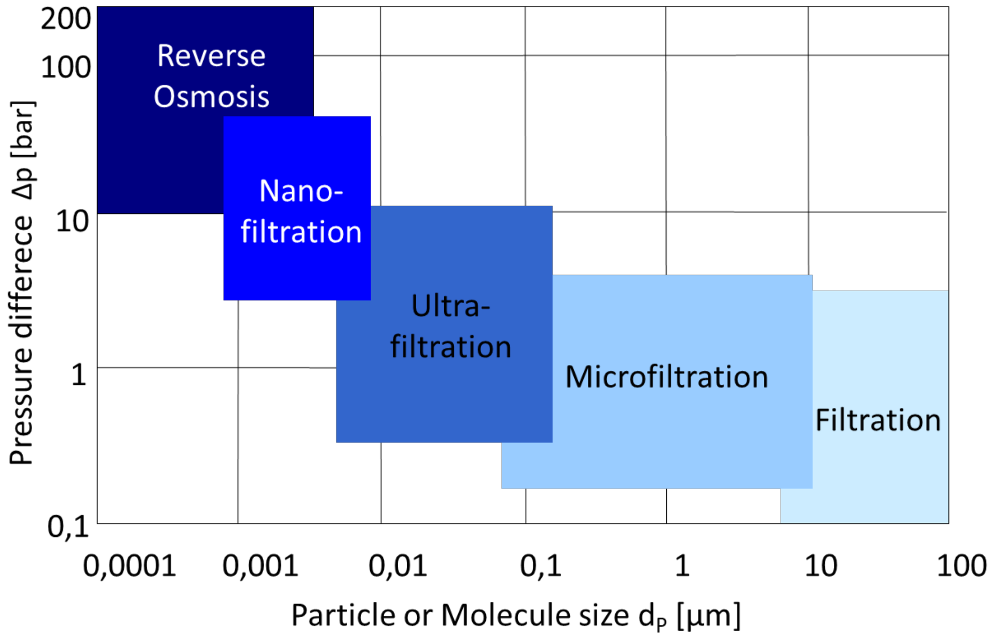


Figure 2-19: Classification of membrane processes

Sub-bottom pre-treatment. Sub-bottom intakes, such as beach wells, horizontal directionally drilled wells, and infiltration galleries, provide the highest raw water quality, meeting most of the treatment requirements already through the sub-bottom passage during intake working as a sand filtration.

The water quality already complies with the target pre-treated water quality and is directly suitable for processing through the RO system without further pre-treatment except for the addition of antiscalant to avoid precipitation of sparingly soluble salts. As explained above, this intake type is mainly applied in small SWRO plants.

Insights into the backwash of sand filters

After completion of a filter run, indicated by the increased pressure drop, the filter medium must be cleaned by backwashing. The two-rinsing media available are water and air, which flow through the filter in the opposite direction to the filtration direction. The following three washing methods exist:

- Water rinsing

Depositions on the filter media are removed by water flushing with high flow to ensure adequate bed expansion. A disadvantage is the very high flushing water consumption.

- Air-water rinsing

During air flushing, the filter cake formed at the surface of the filter bed is broken up by the large air bubbles so that removal by the subsequent water or air-water rinsing is possible. The air remaining in the filter during air flushing must also be removed from the filter material by the water. The flushing water consumption is less than a water rinse method.

- Combined air-water rinsing

This method is the most common in Europe. After the filter cake is broken up by air flushing, the following combined air-water flushing continues this process with a simultaneous discharge of the deposits. The combined air-water flushing has proven to improve material transport as opposed to only using water. At the same time, the air remaining in the filter is cleared out. The flushing water consumption is the lowest for this method.

Capital costs for pre-treatment technologies

According to Voutchkov (2019)[7], the direct capital costs for the pre-treatment system typically amount to 8.5 – 9.5% in low complexity projects and 7.0 – 10.0% in high-complexity projects.

The following figures can be used for initial estimates of the construction cost for the respective pre-treatment system. Usually, the construction costs for pre-treatment in SWRO vary in a range of 150 – 230 US$/($m^3$/d).

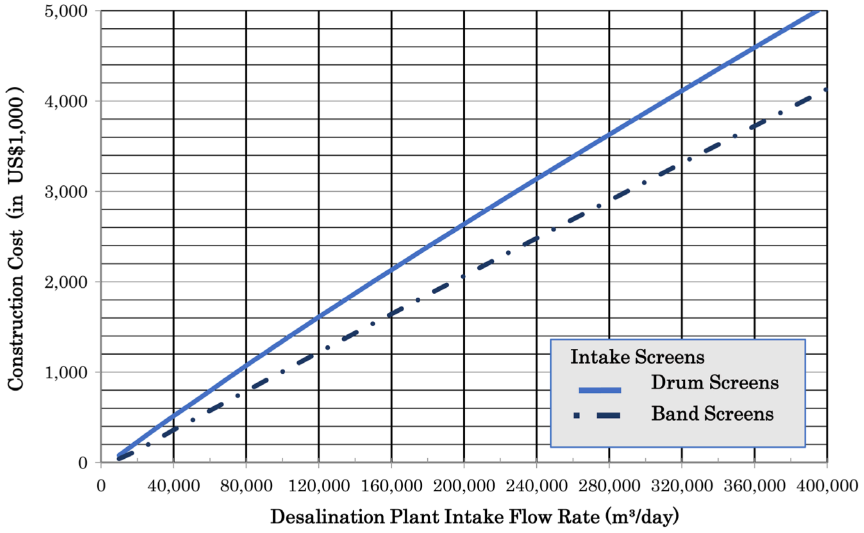


Figure 2-20: Construction cost for drum and band intake screens

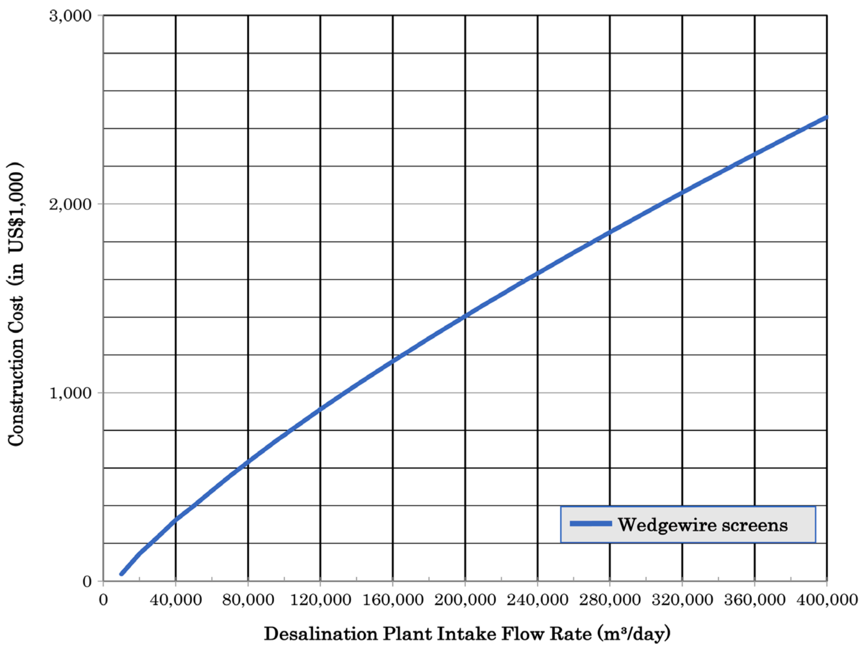


Figure 2-21: Construction cost for wedge wire intake screens

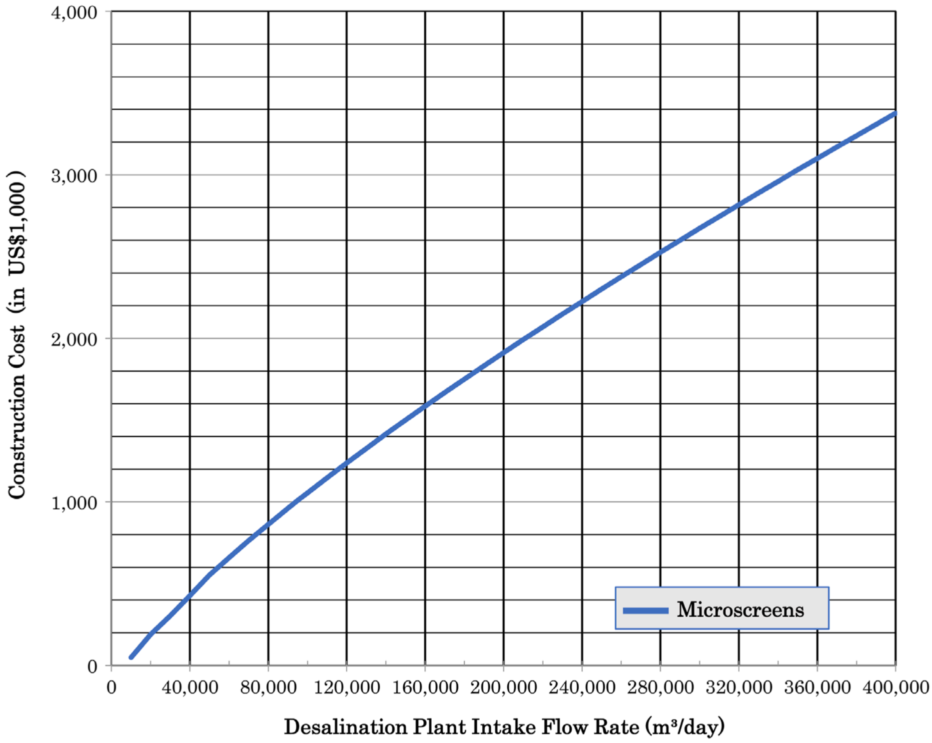


Figure 2-22: Construction cost of microscreening system

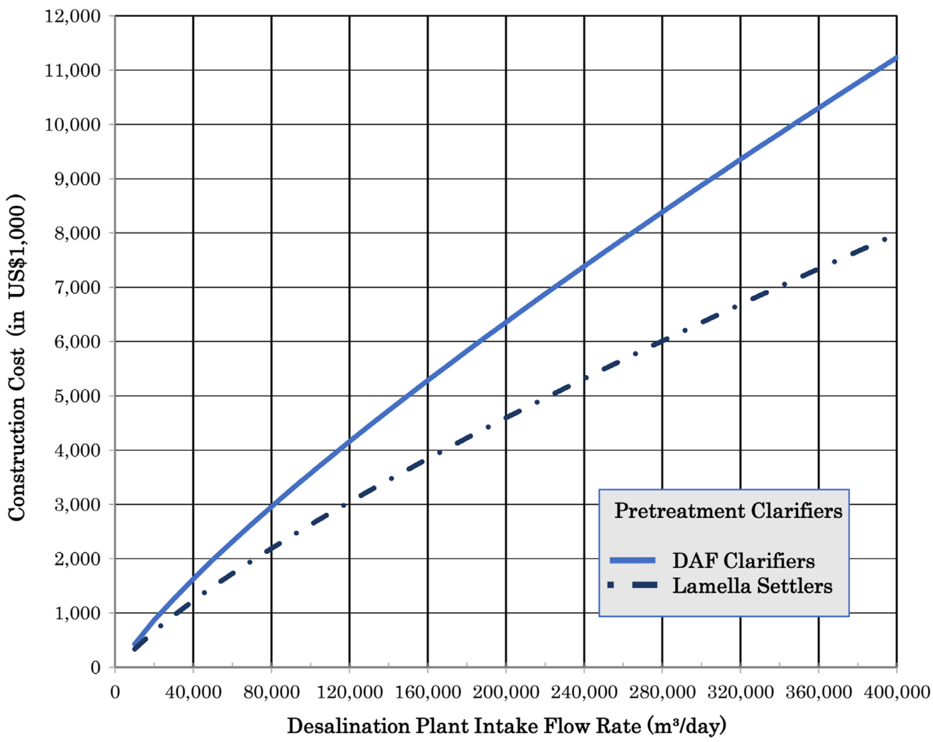


Figure 2-23: Construction cost for DAF clarifiers and lamella settlers

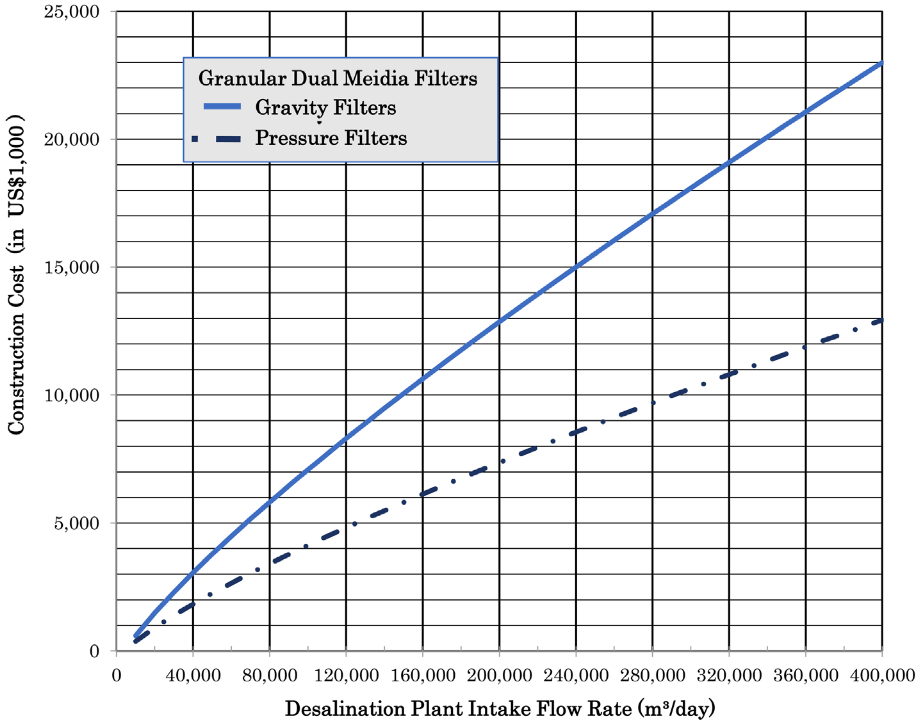


Figure 2-24: Construction cost for granular dual media filters

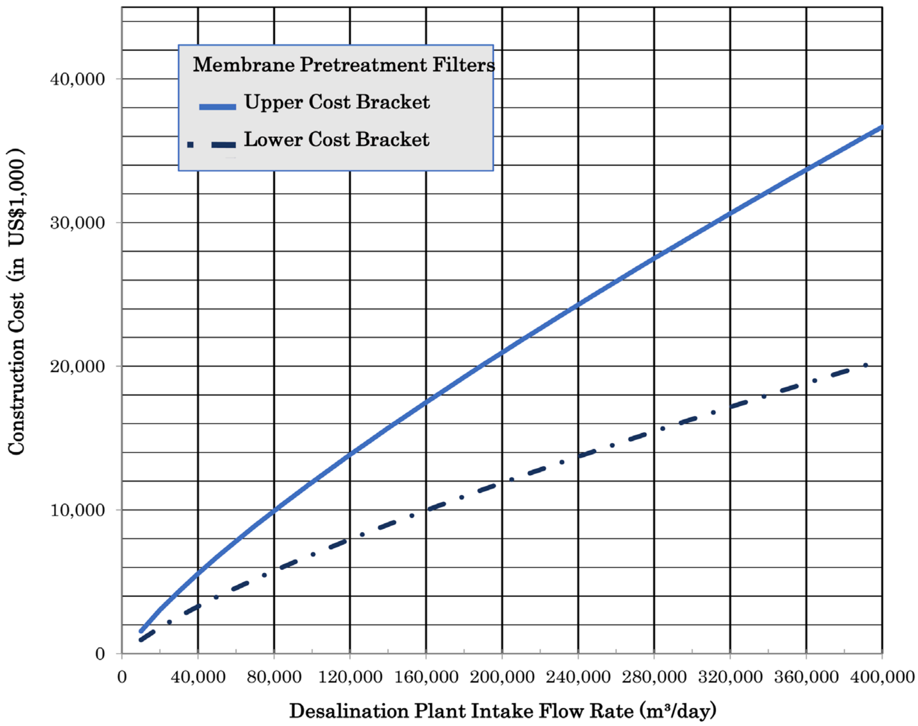


Figure 2-25: Construction cost for membrane pre-treatment filters

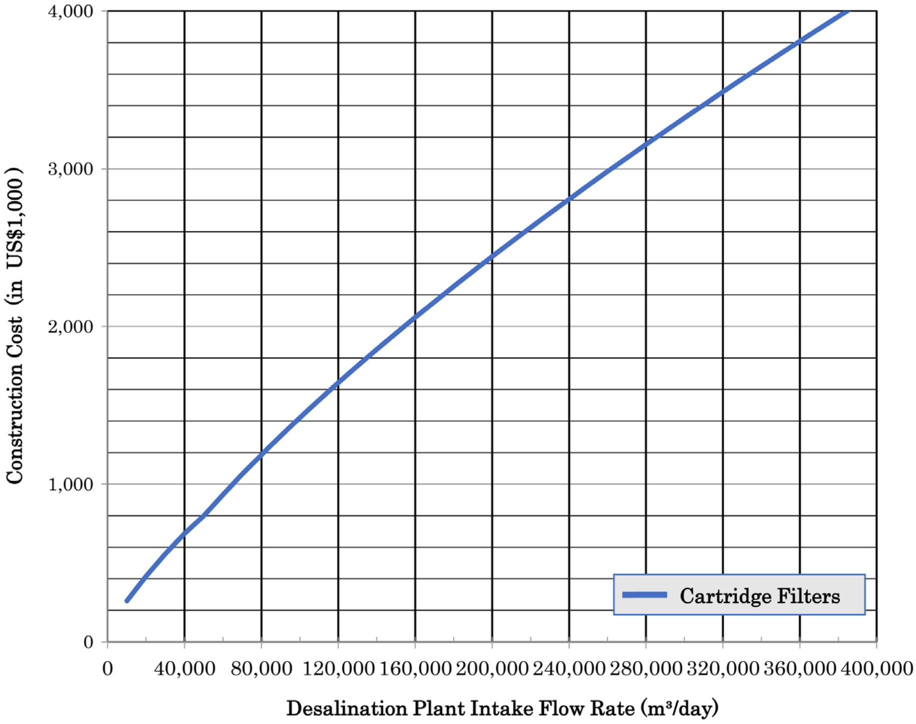


Figure 2-26: Construction cost of cartridge filtration systems

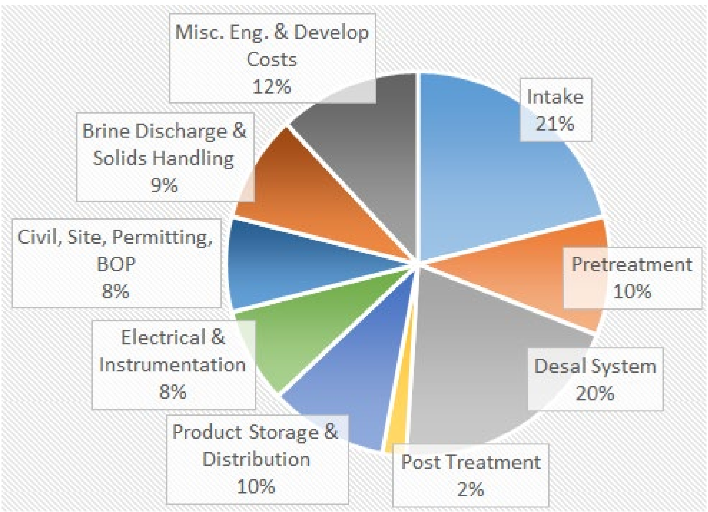


Figure 2-27: Typical SWRO capital cost breakdown[24]

Operation and maintenance costs for pre-treatment technologies

Power is the main O&M cost factor in SWRO desalination and amounts to around 15% for the pre-treatment equivalent to 0.5 kWh/m^3. Intake and pre-treatment together require about 0.7 kWh/m^3 (equivalent ¼ of the total energy demand).

Non-energy costs comprise chemicals, replacement, waste management, labor, maintenance, performance monitoring and other indirect O&M costs.

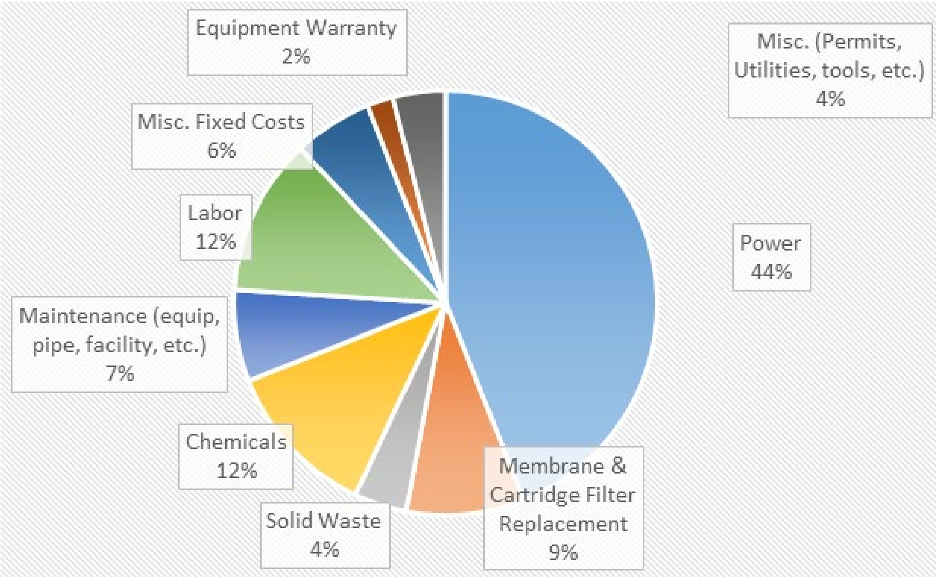


Figure 2-28: Typical SWRO operation cost breakdown[24]

The O&M costs presented in the following figures do not include expenditures for energy used for operation of the respective pre-treatment system.

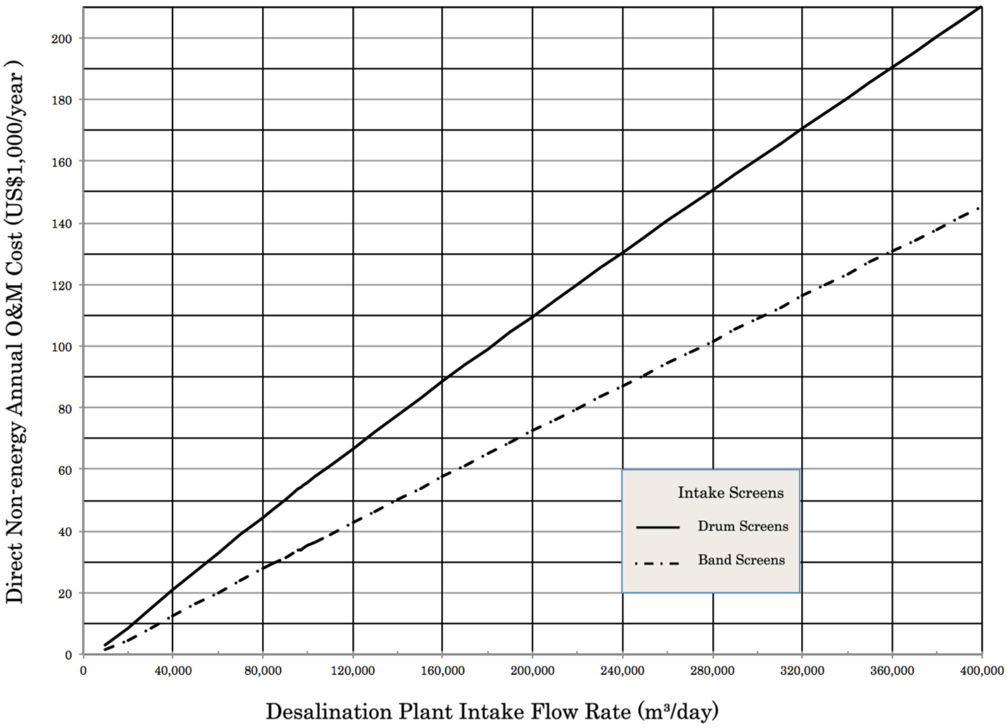


Figure 2-29: Annual O&M cost for drum and band intake screens

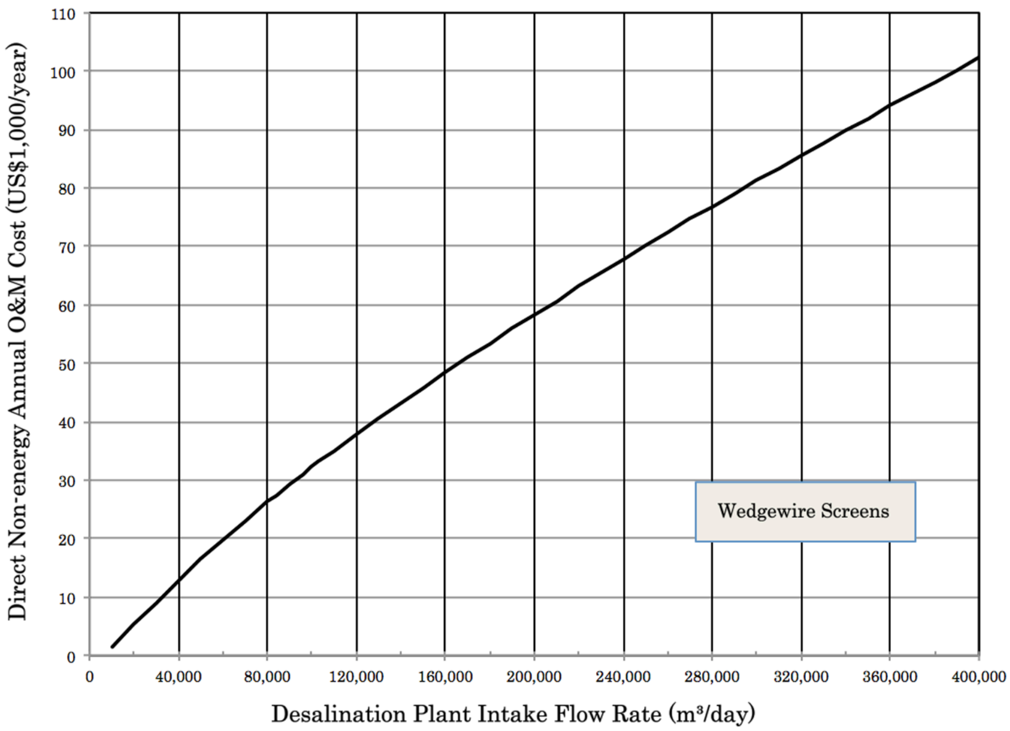


Figure 2-30: Annual O&M cost for wedge wire intake screens.

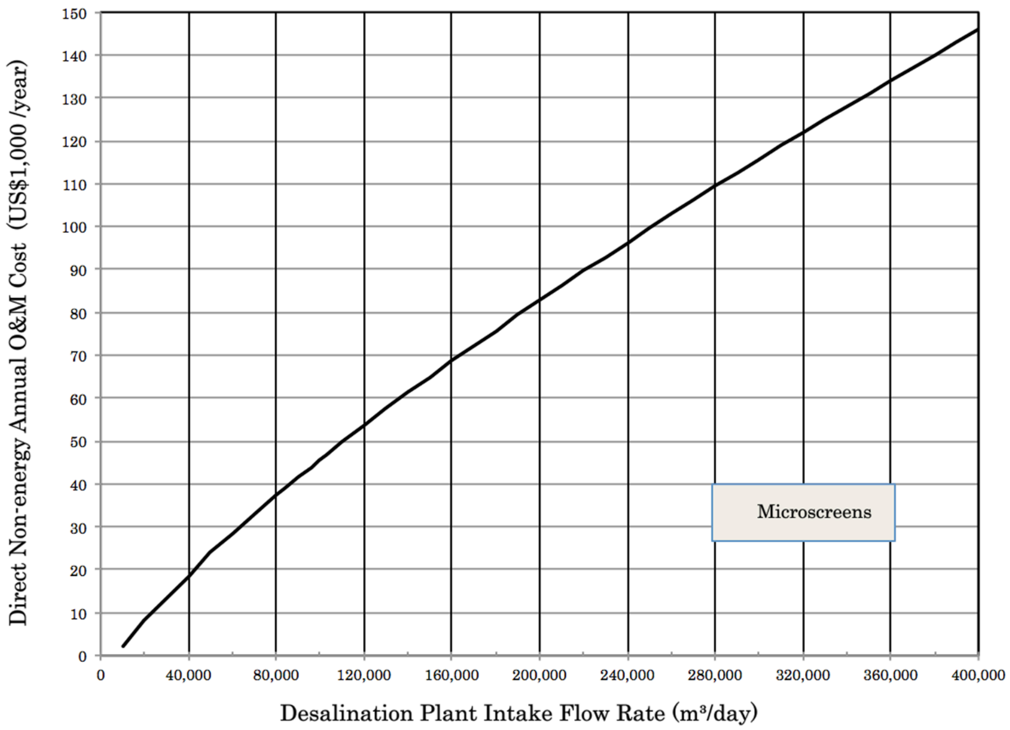


Figure 2-31: Annual O&M cost for microscreens.

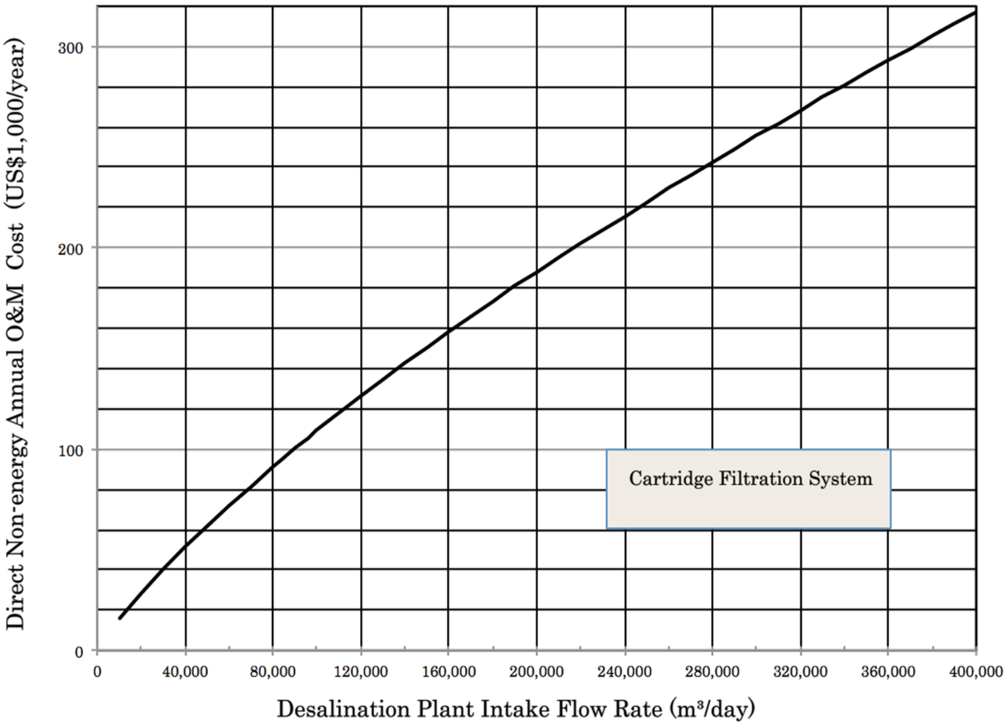


Figure 2-32: Annual O&M cost for cartridge filtration systems

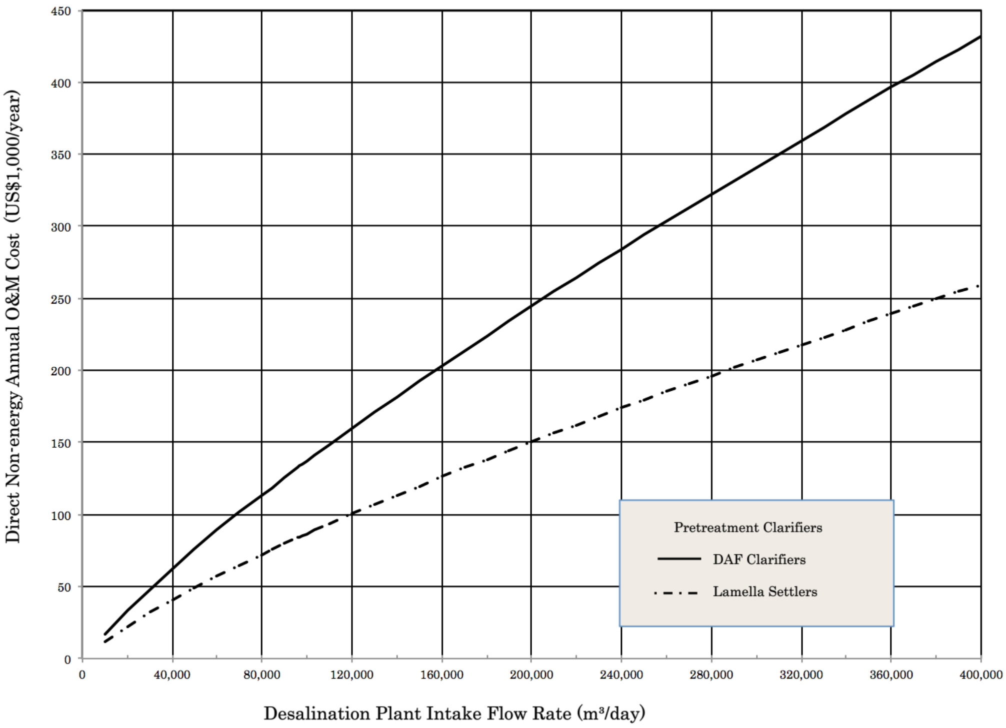


Figure 2-33: Annual O&M cost for DAF clarifiers and lamella settlers

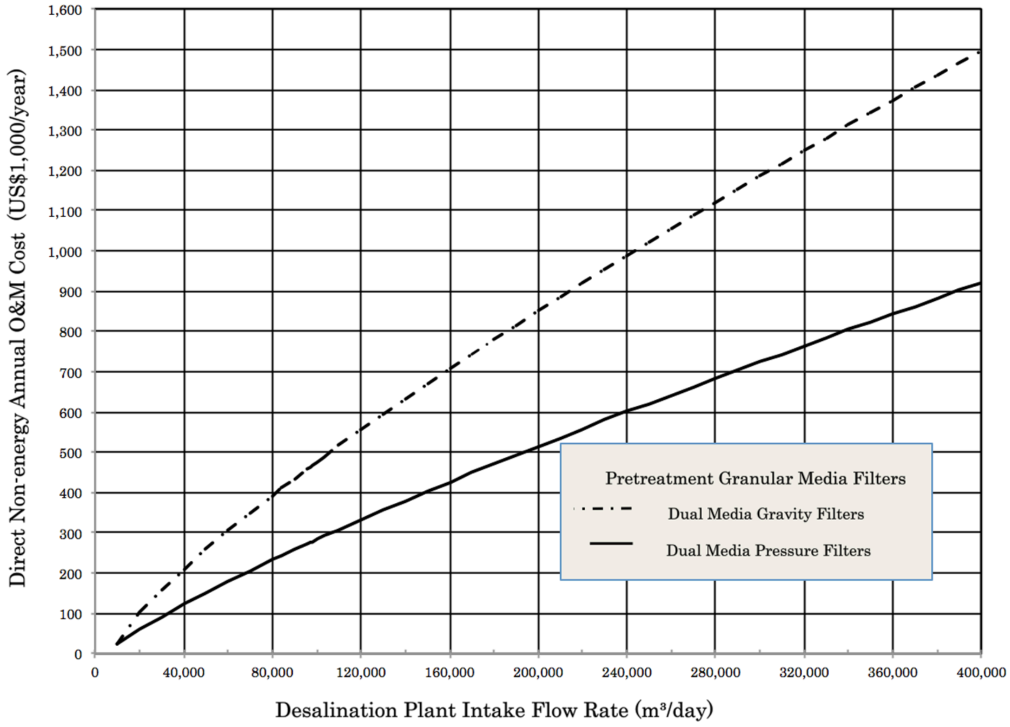


Figure 2-34: Annual O&M cost for granular dual media filters

Selection criteria for pre-treatment technologies

To select the optimum pre-treatment system, the site-specific situation should be studied using the following criteria:

- **Intake type and source water quality**
  - Seawater quality with seasonal variations and required layer(s)
  - Determination of simple physical parameters (water temperature, conductivity, etc.) and key design parameters (e.g. SDI, turbidity and TOC, cf. table below)
  - Identification of specific water quality issues (pollutants, nutrients, HAB risk, etc.)
  - Consideration of potential impact from intake type based on boundary conditions on source water quality

- **Footprint**
  - Complex pre-treatment system and required auxiliaries may require substantial space.
  - Pressure filters require less space than gravity dual media filters.
  - Membrane systems are more space-efficient than conventional systems. Space requirements vary on type of membrane system (vacuum vs. pressure driven)

- **Regulatory aspects**
  - Permitting issues regarding the discharge of pre-treatment waste streams
  - Requirements for storage and handling (OHS) of chemicals
  - Solid waste management and environmental permitting procedures

- **Costs**

- Capital costs: Impact from financing and/or procurement conditions, public entity versus private or public-private partnership
- Trade-off between capital cost and operating cost for pre-treatment systems should be considered in decision making (full life cycle cost assessment; contract duration, …)
- Operating costs: Designs with aggressive design fluxes may lead to increased operational cost from high demand of energy and chemicals and to reduced reliability.
- Reliable and robust pre-treatment systems operate more energy- and cost-efficient under all conditions

- **Operational considerations**
  - Complex pre-treatment may pose specific operational challenges.
  - Automation and monitoring systems can reduce these challenges.
  - Important factors are the reliability of the system and the required maintenance, cleaning requirements, regular replacements and other servicing, demand for chemicals, waste production and management, and ease of operation.

- **Flexibility and expandability**
  - Desalination projects are often built with potential future capacity upgrades to be considered already during the selection of the pre-treatment type and unit processes.
  - Due to their modularity, membrane systems are easily scalable.

Take away messages of Pre-treatment

- The pre-treatment is an indispensible part of the SWRO system ensuring a high-quality feed to the RO.
- The intake type and the related effects on the source water have a large impact on the complexity of the pre-treatment. Feed water from sub-bottom intakes require little to no pre-treatment
- Conventional pre-treatment involving media filtration compete with membrane filtration which is gaining interest due to higher RO feed water quality and several operational advantages including increased robustness.
- Although well designed pre-treatment may minimize fouling and scaling of the RO membranes, cleaning protocols need to be established to remove residual fouling.
- A conservative approach in the design of the SWRO system including pre-treatment is recommended. This ensures trouble-free plant operation and an increased membrane life.
- Accurate and detailed feed water analysis over a period of at least one year is required to capture seasonality effect, if any for design of the system, especially when the performance is expected to be affected by jellyfish and algal blooms.

2.1.3 Desalination

Based on the basic flow sheet of a RO module in Figure 2-35, the mass and energy balances are introduced with respect to the selected concept from the feasibility study.

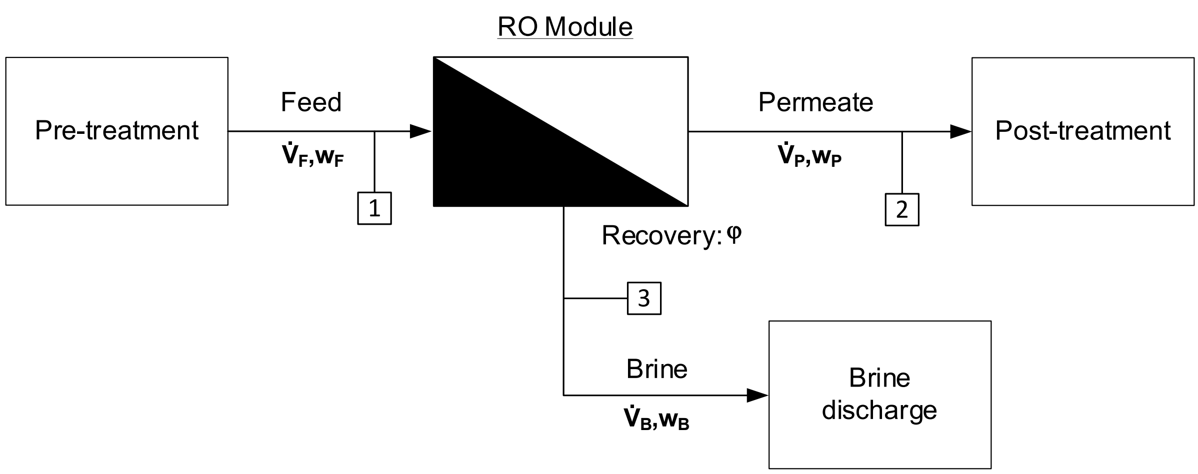


Figure 2-35: Basic flow sheet of a single element RO-module

The plant capacity (permeate max flux), water quality parameters, and the recovery rate should be given. They should be finally specified as part of the Basic Engineering.

Table 2-9: Example for a basic plant specification

ID	Description	Abbreviation	Value	Unit
1	Plant capacity	$\dot{V}_P$	100	MCM/a
2	Plant availability	f	95	%
3	TDS plant design	w_F	42.000	ppm
4	Recovery rate RO	φ	45	%

The focus on designing a membrane system (RO module) for a required permeate flow is to minimize feed pressure and membrane costs while maximizing the permeate quality and recovery. Therefore, a membrane system shall be designed so that each element of the RO unit operates within the range of recommended operating conditions.

The following gives the boundaries of these operating conditions:

- Max. recovery rate
- Max. permeate flowrate
- Min. concentration flowrate
- Max. feed flowrate

The higher the fouling tendency of feedwater, the stricter are the limits of these parameters. High-quality feedwater should lead to a high-flux design, whereas poor-quality feedwater necessitates a low-flux design. If the operational limitations are not considered, this may lead to:

- More cleanings a year
- Reduced capacity
- Increased feed pressure
- Reduced membrane life

The main limiting factors are shown in Figure 2-36 to give an overall impression of the complexity of a RO process regarding both design and operation.

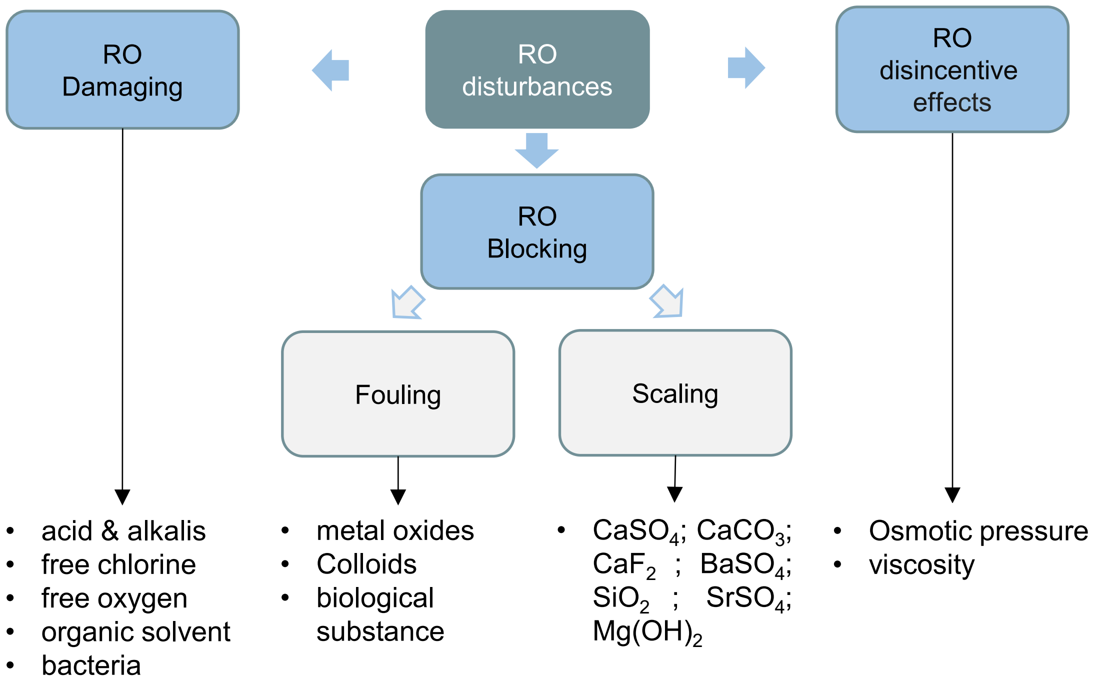


Figure 2-36: Limiting factors/ parameters for RO desalination

For the RO module pre-design following parameters of the mass- and energy balances should be specified:

- Permeate concentration $(\overline{w}_P)$
- Required feed pressure (p_a)
- Membrane area (A_M)
- specific energy consumption ($P_{t,\,HP}$)

With these given parameters a reverse osmosis calculation software can be used to calculate pressures, flow rates and TDS concentrations of the permeate and brine. The software is also used to calculate the amount of membrane modules needed for the desalination. For this reason, a specific element is considered for the calculation.

The figure below shows a spiral-wound element with polyamide thin-film composite membrane.

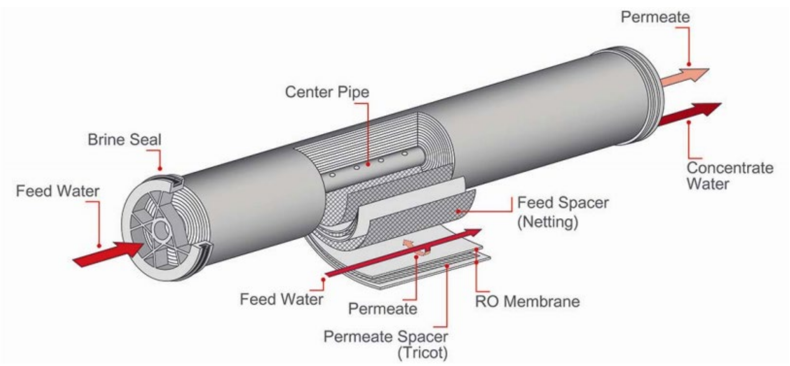


Figure 2-37: Construction of a RO spiral wound

The software of the RO membrane supplier can be used to calculate the mass- and energy balance of the RO Unit. These modules help design and calculate the performance of an SWRO plant. They also simulate the influence on performance and quality using different parameters like temperature, salinity, and salt passage. Here are some examples for such software used for the calculations and their specifications:

- LewaPlus (Lanxess)
  - Immediate calculation of system performance, including feed pressure calculations and permeate quality
  - Support for 2-pass designs
  - Automatic calculation of a recommended array for optimization of system sizing
  - Power consumption module to calculate system power costs
  - Also includes post treatment module for pH adjustment, chemical addition (re-mineralization) and degasification of the final product water
  - Adjustable capital and operating cost module using historical industry data as default values.
- WAVE (Dupont)
  - Free RO modelling software program
  - Basic but comprehensive tool with easy-to-use interface
  - Flexible design using three technologies, with multiple-unit operation combinations, plus the option to specify system-feed or net-product flow rate.
  - A powerful calculation engine with the capacity to run complex designs at high levels of accuracy.
  - Improved water-equilibrium calculations and interface.
  - True mass-balance volumes and flows that reflect changes in density due to temperature, water composition, and water compressibility
  - The capability to introduce project-specific parameters to increase the accuracy of operating-expense calculations
- IMSDesign (Nitto Group)
  - User-friendly interface with minimum learning time
  - Built-in-tools, dashboards, visualizations and reporting functionality
  - Predict performance by entering feed pressure as input
  - Include organic chemicals and BOD, COD, TOC to predict performance accurately
- PROTON (AWC)
  - Allows the user to compare the required feed pressure and permeate water quality for various membranes under identical conditions.
  - Can simulate real time impacts of changes in pH, temperature or recovery on pressure, flux and permeate quality.

- Depending on the selected membrane type, the impact on pressure, water quality and scaling potential can be seen, once the design is selected.
- The first anti-scalant software that can design reverse osmosis system, and account for membrane properties and flux rates at the various stages of a system.
- Calculates the scaling potential for over 50 different scales that can form in RO/NF membrane systems.

For a long-term trouble-free plant operation, the key design parameters should be reliable as well. For this reason, it is recommended to perform pilot tests to verify the selected design parameters for the given SWRO projects. Systematic piloting to scale-up is shown in the following flow chart.

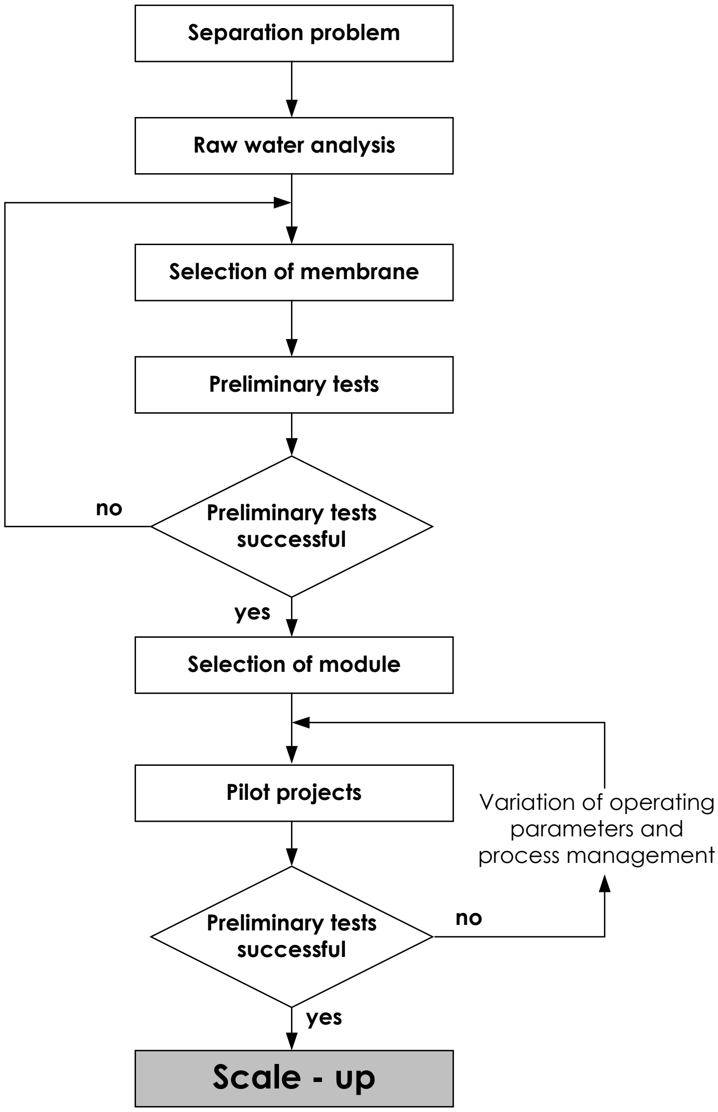


Figure 2-38: Chart for the scaling-up of a reverse osmosis plant for seawater and brackish water desalination

Particular attention should be paid to pilot tests on-site, which must take place over a sufficiently long time to make reliable statements on the continuous change in the constituents of the feed water.

Particularly, the operation conditions can cause some performance changes of the RO system, which are shown in Table 2-10.

Table 2-10: Examples of performance changes due to operating condition changes[31]

ID	changes in RO performances	Tendency*		description
		flux	rejection	
1	increase of feed pressure	+	+	The permeate flux is proportional to the net driving pressure. Therefore, the flux and rejection increase
2	increase of feed concentration	-	-	osmotic pressure decreases the net driving pressure, at lower TDS, the salt rejection decrease
3	increase of concertation flow rate	+	+	At a low flow rate, concentration polarization occurs, and osmotic pressure increases.
4	increase of temperature	+	-	permeate flux increases with temperature (3%/°C) due to viscosity of water

* increase = +; decrease = -

To optimize the energy demand, the pressure energy of the concentrate flow can be recovered by energy recovery devices (ERD), which can be installed between the feed and concentrate sides. Two main energy recovery concepts are shown below.

[31] LANXESS (2013). Principles of Reverse Osmosis Membrane Separation

ID	Description	Efficiency	Energy savings	Example
1	Energy Recovery Turbine (ERT)	max. 70 %	30% to 40%	
2	Pressure Exchanger (PX or PES)	> 95 %	50% to 60%	

Figure 2-39: Energy Recovery Devices (ERD)

Table 2-11: Comparison of ERT and PX

ID	Description	ERT	PX
1	Efficiency	Low (max. 70 %)	High (> 95 %)
2	Dynamic range Δ p, V	Wide	Narrow
3	Control behavior	Very good	Problematic
4	Mixing feed-brine	None	1-3% normal operation
5	HP pump	100 % feed	50 – 70 % feed
6	Booster pump	Not required	Required

Cleaning RO membranes

The membranes of a RO unit should regularly be cleaned by a CIP system. Figure 2-38 displays all cleaning elements of such a system in a flow diagram. The mixing tank should be built of polypropylene or fiberglass-reinforced plastic (FRP). It should also include a removable cover or manway and a temperature gauge. The membrane manufacturer recommends a heating or cooling system to optimize the solution temperature for the designated cleaning protocol. Appropriately configured valves, flow meters, and pressure gauges should be installed to adequately control the flow.

The six steps in the cleaning of elements are listed below. The required flow rates depend on the diameter of the membrane elements. It is strongly recommended to follow the manufacturer's specifications and to consult with the membrane manufacturer, if necessary.

1. Make up cleaning solutions.

2. Low-flow and low-pressure pumping. The aim is to displace the process water. The pressure should be low enough to minimize or, if possible, prevent the production of permeate and the deposition of dirt on the membrane. Discard the residual water in the concentrate to avoid any dilution of the cleaning solution.

3. Recycle. When cleaning solutions are present in the concentrate stream, recycle the concentrate and permeate to the cleaning solutions tank. The temperature should be stabilized. Adjust the pH if necessary.

4. Soak. Turn off the pump and soak the RO elements. Usually, a period of 1 hour is sufficient, but depending on the degree of fouling, soaking for multiple hours overnight is necessary.

5. High-flow pumping. The high flow rates remove the foulants from the membrane surface. At higher flow rates, the excessive pressure drop may be an issue.

6. Flush-out. RO permeate water is recommended for flushing out the cleaning solution. A minimum temperature of 20°C is recommended.

Table below lists cleaning chemicals that are used for RO membranes.

Table 2-12: Simple cleaning solutions

Foulant	Cleaner	0,1% (W) NaOH and 1,0% (W) Na_4EDTA, pH 12, 35°C max.	0,1% (W) NaOH and 0,025% (W) Na-DSS, pH 12, 35°C max.	0,2% (W) HCl, pH 1-2 and 25°C	1,0% (W) $Na_2S_2O_4$, pH 5 and 25°C	0,5% (W) H_3PO_4, pH 1-2 and 25°C	1,0% (W) NH_2SO_3H, pH 3-4 and 25°C
Inorganic salts (for example, $CaCO_3$)				Preferred	Preferred	Preferred	Preferred
Sulfate scales ($CaCO_4$, $BaSO_4$)		OK					
Metal oxides (for example iron)					Preferred	Alternative	Alternative
Inorganic colloids (slit)			Preferred		Preferred	Alternative	Alternative
Silica		Alternative	Preferred				
Biofilms		Alternative	Preferred				
Organic		Alternative	Preferred				

Notes to the table:

1. (W) denotes weight percent of active ingredient.
2. Foulant chemical symbols in order used: $CaCO_3$ is calcium carbonate; $CaSO_4$ is calcium sulfate; $BaSO_4$ is barium sulfate.
3. Cleaning chemical symbols in orders used: NaOH is sodium hydroxide; Na_4EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid; Na-DSS is sodium salt of dodecylsulfate; Sodium Laurel Sulfate; HCl is hydrochloric acid (Muratic Acid); H_3PO_4 is phosphoric acid; NH_2SO_3H is sulfamic acid, $Na_2S_2O_4$ is sodium hydrosulfite.
4. For effective sulfate scale cleaning, the condition must be caught and treated early. Adding NaCl to the cleaning solution of NaOH and Na_4EDTA may help as sulfate

solubility increases with increasing salinity. Successful cleaning of sulfate scales older than 1 week is doubtful.

5. Citric acid is another cleaning alternative for metal oxides and calcium carbonate scale. It is less effective. It may contribute to biofouling especially when it is not properly rinsed out.

2.1.4 Post-treatment

Last, but not least, the post-treatment, including remineralization of RO permeates, is the final step to adapt the product water to the specified target values for drinking purposes.

Chemical additives may be necessary for pH and mineral adjustment, corrosion control, and disinfection, depending on the product water requirements. For product water limits for Jordan, please see the feasibility study in Chapter 1.

By blending the filtered feed water with higher salinity and more bivalent ions such as calcium and magnesium into RO permeate, the quality adjustments, such as remineralization with calcite, dolomite, or carbon dioxide can be optimized. In SWRO plants, a part of the feed flow is filtered mainly by a set of cartridge filters for blending purposes.

As follows, the post-treatment technologies for the SWRO desalination plant will be introduced and specified for the selected concepts.

Requirements for post-treatment and remineralization of desalination plants

Although RO provides almost complete rejection of critical water constituents, the permeate can still potentially be contaminated with the components listed below. A brief assessment is made to decide whether further treatment is required or not.

Heavy metals in the permeate: RO membranes used for sea water desalination show a high rejection of multivalent ions. Heavy metals are mostly bivalent or trivalent, for example, iron as Fe^{2+} or chromium ions as Cr^{3+}. Because of their greater ion diameter, both are rejected up to 98-99% and represent no danger to drinking water quality.

Organics in the permeate: Like the ionogenic inorganic components, organic substances, depending on their charge and the size of the molecules, are mostly well rejected. In the case of extraordinarily high organics in the feed, each individual case must be checked in careful pilot tests as to what extent health-endangering organic substances such as organic micropollutants (pesticides, industrial chemicals, etc.) are present and how effectively selected RO membranes can reject them.

Microorganisms in the permeate: Bacteria and viruses are entirely rejected by RO membranes. However, as membranes are never totally free of defects, it is impossible to guarantee that microorganisms will not pass the membrane barrier. It is therefore strongly recommended that the permeate is continuously monitored.

Radioactive substances: Radioactive compounds are naturally present in the pedosphere and hydrosphere. Depending on the local geological conditions, groundwater, particularly “old” groundwater, can feature elevated concentrations of radionuclides such as uranium or its decay product radium, which may be present in concentrations above the Jordan guideline value of 10 µg/L. Depending on the size and charge of the target compounds, RO might reject them.

There are a number of post-treatment steps to treat permeates from reverse osmosis available for fulfilling the requirements regarding the quality of the drinking water. These are the following process steps in the order of their application:

- Alkalinisation
- Remineralization
- Adjusting the pH value
- Addition of phosphate/silicate
- Addition of fluoride
- Disinfection
- Removal of odorous gases

1. Alkalinization

In this step, the alkalinity and the calcium hardness are increased. This step is essential to produce non-corrosive water but also to dose crucial minerals into the water. The alkalinity should be targeted to be > 80 mg/l as $CaCO_3$. The listed measures are suitable for alkalization:

- Addition of calcium hydroxide (lime) and carbon dioxide
- Filtration through calcium carbonate (limestone) or dolomite ($MgO \cdot CaCO_3$) and the addition of carbon dioxide
- The addition of other substances raises the calcium, magnesium level, and alkalinity value

2. Remineralisation

Permeate with a meagre number of dissolved salts must often be remineralized. This is normally achieved by dosing one or two suitable chemical agents or using a calcite contactor system.

3. pH-Adjustment

The water from alkalization and the subsequent remineralization may have a low pH value that wouldn’t provide sufficient corrosion protection. The pH value must be adjusted between pH 7.5 and pH 8.5 by adding sodium hydroxide (caustic soda).

4. Addition of phosphate/silica

The first three post-treatment steps often do not give sufficient corrosion protection for the water distribution system after the desalination plant. The additional dosing of individual phosphates, phosphate-polyphosphate recipes, or mixtures of phosphates with silicates cultivates the building of protective films and could be necessary in the water distribution system. It can thus make a significant contribution to corrosion protection.

5. Addition of fluoride

Fluoride may be added in the form of a sodium fluoride solution or fluorosilicic acid. Concentrations of 0.5 to 1.5 mg of fluoride per litre protect teeth against tooth decay, particularly for children. As numerous studies have shown, higher concentrations have a damaging long-term effect on the bone structure.

6. Disinfection

For safety reasons, the water produced from desalination plants must be disinfected. In principle, the process itself should provide a good quality of water concerning microbiological parameters. However, contamination can occur both during the water storage and in the water distribution networks and cause serious diseases.

Typically, disinfection is made using chlorine gas or sodium hypochlorite solution. Hypochlorite solutions are safer and easier to handle than chlorine gas. Thus, it is an option to use, especially at small-scale SW desalination plants. The free chlorine concentration in the drinking water should be approximately 1-2 mg/l.

There are alternative disinfection procedures, for example, ultra-violet radiation treatment, ozonation, and the addition of monochloramine or chlorine dioxide. These processes are comparatively expensive, are not so effective, and do not have a depot effect. In case of ozonation, be aware of a high bromide content that could lead to the build of hazardous bromate.

7. Removal of odorous gases

Degasifiers are typically used as post-treatment to remove unwanted gases from the RO permeate by stripping the water with air. They reduce effluent turbidity by removing sulfide from the water stream before chlorination, removing odorous gases from the product water, and controlling corrosion by removing excess CO_2.

The following table shows the target permeate concentration recommended during each stage of post-treatment.

Table 2-13: Actual and target values for different parameters during post-treatment

	Component	Measured parameter
1	Alkalinization	Alkalinity as $CaCO_3$
2	Remineralization	TDS
3	pH-adjustment	pH
4	Addition of phosphate/silicate	PO_4^{3-}, SiO_2
5	Addition of fluoride	F^-
6	Disinfection	E. Coli, Total Coliform Residual chlorine

Options for the planning concept for post-treatment

Two different post-treatment options will be presented as examples in the following chapter. Both options can fulfil the requirements of an SWRO system comparable with our planning concept. The selected post-treatment options are mainly differing in their remineralization units in such a way that:

- Remineralization is performed by blending with the filtered feed
- Remineralization is reached with chemical agents or a calcite contactor

The monitoring requirements are presented and explained in Chapter 2.4.

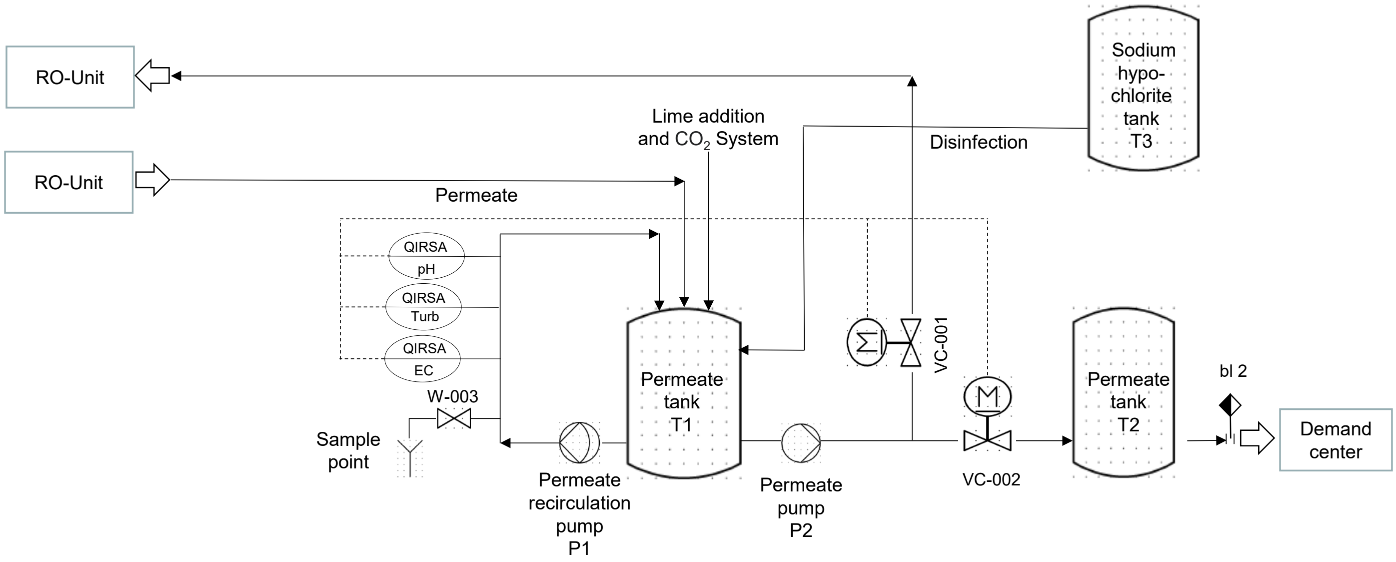


Figure 2-40: Post-treatment with blending

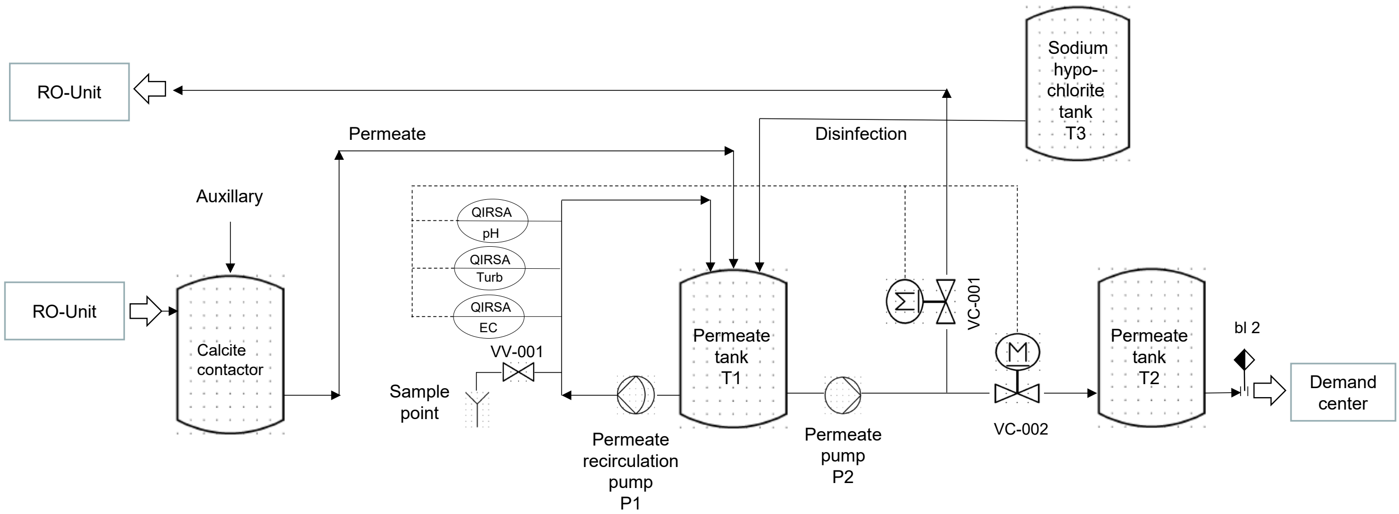


Figure 2-41: Post-treatment with chemical agents or calcite contactor

Take Away Messages for post-treatment of product water

- Plan the sequence of procedural steps in the following order:

  1. If required, chlorination and additon of acids that further reduce the pH value

  2. Addition of lime for alkalinisation. If the pH value exceeds pH 8.5 in the alkalinisation, reduce the pH to the target value by the addition of sulfuric acid

- Adequate storage and stocking of chemicals is imperative to ensure the quality of the product water

- Use high quality chemicals in the post-treatment process (e.g. lime 94% purity) to reduce waste and ensure the drinking water quality

- Regular monitoring by sampling and analysis in a high quality laboratory is necessary for continous high product water quality

- If blending the product water with other types of water, e.g. filtered feedwater, for the remineralization, the post-treatment and the monitoring needs to be conducted after the blending. RO-permeate monitoring is not enough for the final quality safeguarding.

2.2 Creation of Process Flow Diagrams (PFDs)

Process engineering flow diagrams (PFDs) are used for the development, definition, and clarification of technical processes in the form of a technical drawing. They significantly enhance the discussion with potential bidders during the tendering and contracting phase. This greatly reduces the risk of misunderstandings.

2.2.1 Definition of utilities

Before the preparation of PFDs, the utilities of the desalination plant must be defined in a proper way. The utilities must include the essential plant parts of the desalination project. It is recommended to define the utilities according to the plant functions and select suitable abbreviations as shown in Table 2-14.

Table 2-14: Utilities and their abbreviations

ID	Utilities	Abbreviation
1	**Utility Pre-treatment**	**PR**
2	**Utility Desalination**	**DE**
3	**Utility Post-treatment**	**PO**
4	**Utility Discharge**	**DI**
5	**Utility Compressed air high**	**CH**
6	**Utility Service water**	**SE**
7	**Utility Energy recovery**	**ER**

2.2.2 Development of PFDs

There are several types of flow diagrams available that differ by the degree of detail and information. The EN ISO 10628 norm defines the level of detail and defines the different types of flow diagrams. The different types of flow diagrams and their classification in the planning phases is shown below:

- Basic flow diagram (BFD) → Basic Engineering
- Process flow diagram (PFD) → Basic Engineering
- Piping & instrument diagram (P&ID) → Detail Engineering

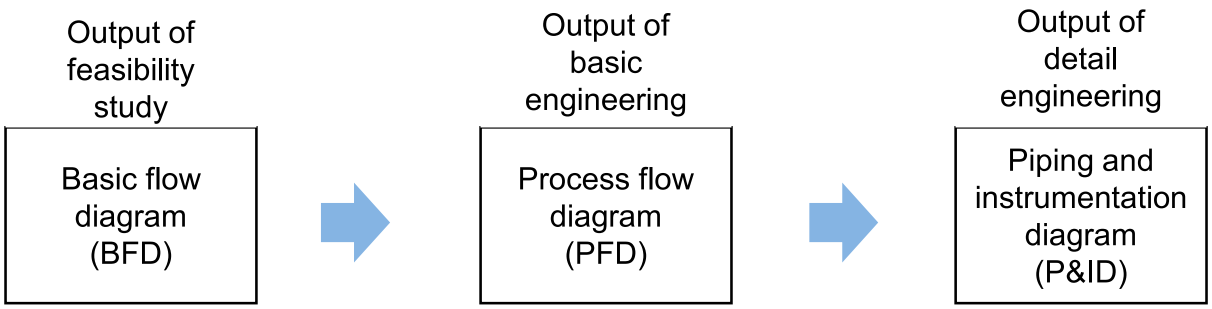


Figure 2-42: Hierarchy of flow diagrams

Basic flow diagram (BFD):

- The basic flow diagram or block diagram is typically used for a less detailed description of a process with the intention to clarify overall concepts without concern for the details of implementation. Therefore, it shows in a simple schematic form the essential process steps as well as the main material flows of a technical process or desalination plant.
- The principal parts of this process are represented by blocks or frames, which are connected by lines that show the relationship of the blocks.
- The blocks are named with a keyword for definition and clarification of the process step.
- Mass or energy flows are shown as flow lines, with thicker lines symbolizing the main material flows and arrows indicating the direction of the flows.
- Special arrows mark the entrances and exits of the main flows into or out of the process.
- The basic flow diagram is structured in such a way that the material flow runs from left to right.
- It should contain at least the following basic information:

a. Denomination of blocks;
b. Denomination of ingoing and outgoing material flows;
c. The direction of main flows between blocks.

The block diagram may also contain additional information:

a. Denomination of the main flows between the blocks;
b. Flow rates of ingoing and outgoing materials;
c. Flow rates of the main flows between the frames;
d. Characteristic operating conditions such as conductivity, pH, and recovery rates.

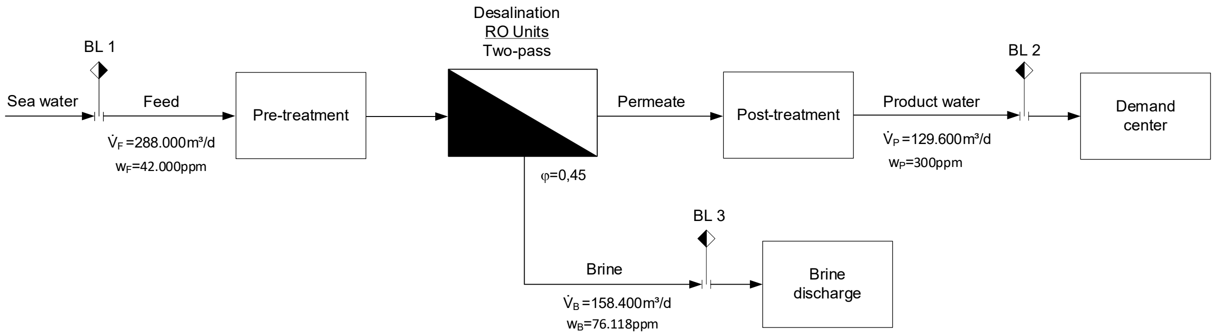


Figure 2-43 shows the basic flow diagram for an SWRO desalination plant with a product water output of ~12.000 m³/h (~288.000 m³/d).

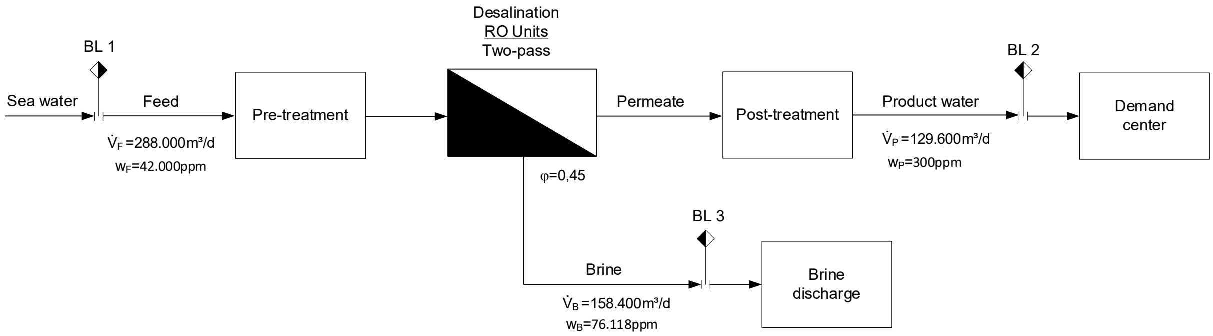


Figure 2-43: Basic flow diagram SWRO (BL = Battery Limit)

Process flow diagram (PFD):

The process flow diagram is an extension of the basic flow diagram. It includes information about the process itself, providing more details. The PFD depicts a process or a process plant by means of graphical symbols which are interconnected by flow lines. The graphical symbols represent equipment; the flow lines flow of mass or energy.

The process flow diagram should at least contain the following basic information:

a. Kind of equipment necessary for the process, except drives;
b. Reference designations for equipment, except drives;
c. Route and direction of ingoing and outgoing material flows;
d. Denomination and flow rates of ingoing and outgoing materials;
e. Denomination of energy flows or flows of energy carriers;
f. Characteristic operating conditions.

It may also contain the following additional information:

a. Denomination of flows and flow rates of process fluids between the process steps;
b. Essential valves in the logical process position with respect to their function;
c. Functional demands for process measurement and control at essential points;
d. Supplementary operating conditions;
e. Denomination of equipment and characteristic data of equipment indicated on the drawing or in separate lists;
f. Elevation of platforms and approximate relative vertical position of equipment.

For the planning concept that was developed in the Feasibility study, exemplary PFDs were developed. Due to the complexity of the details of the utilities, for each utility, a separate PFD was created, as shown below.

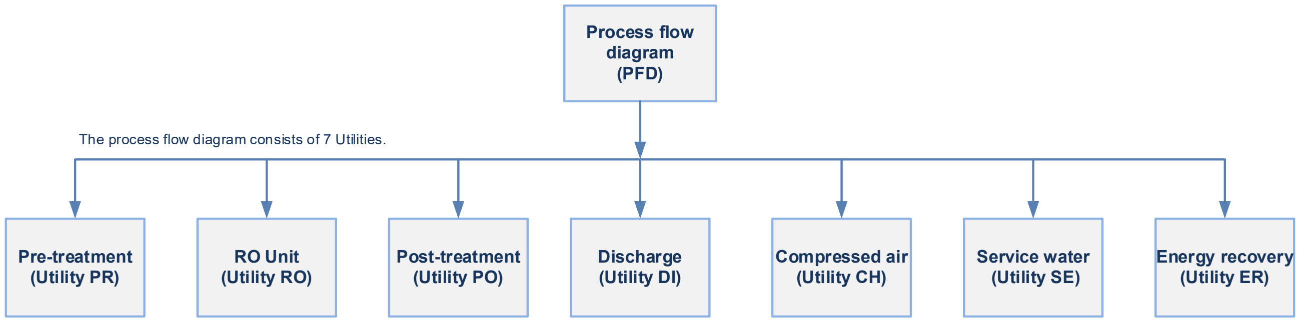


Figure 2-44: Process flow diagram (PFD) for the planning concept

Please find below selected PFDs that were created for the planning concept.

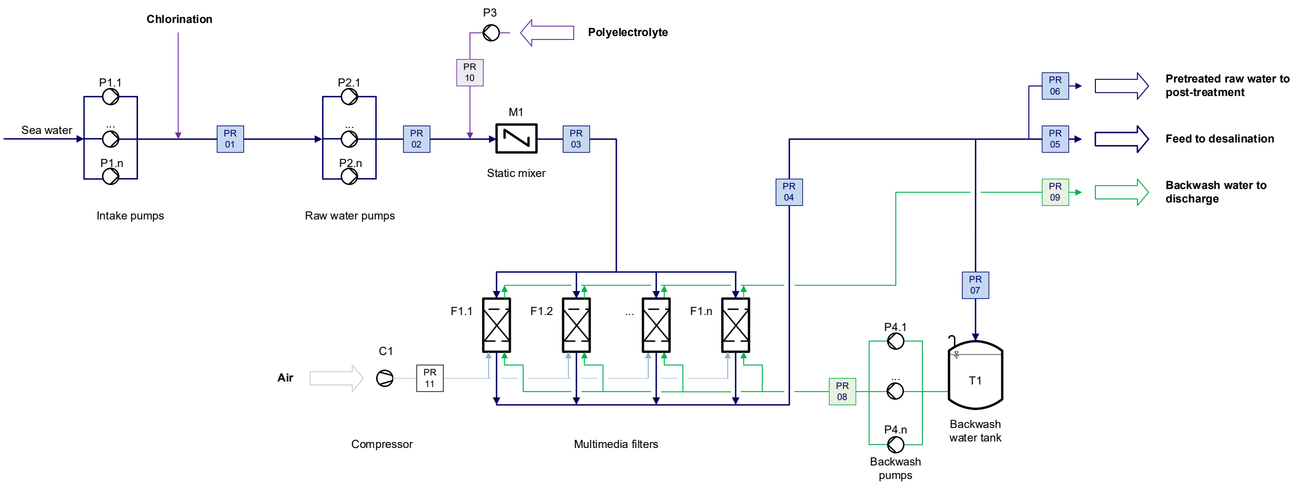


Figure 2-45: Process flow diagram for utility pre-treatment

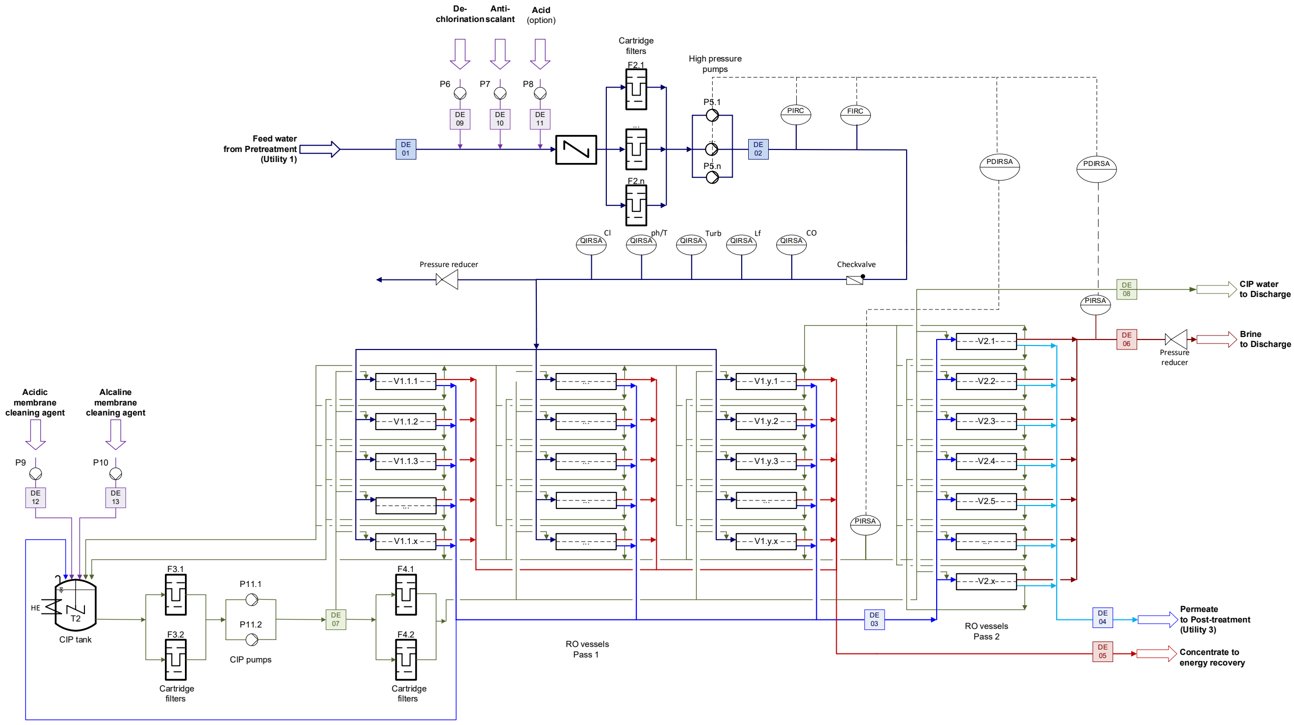


Figure 2-46: Process flow diagram for utility desalination

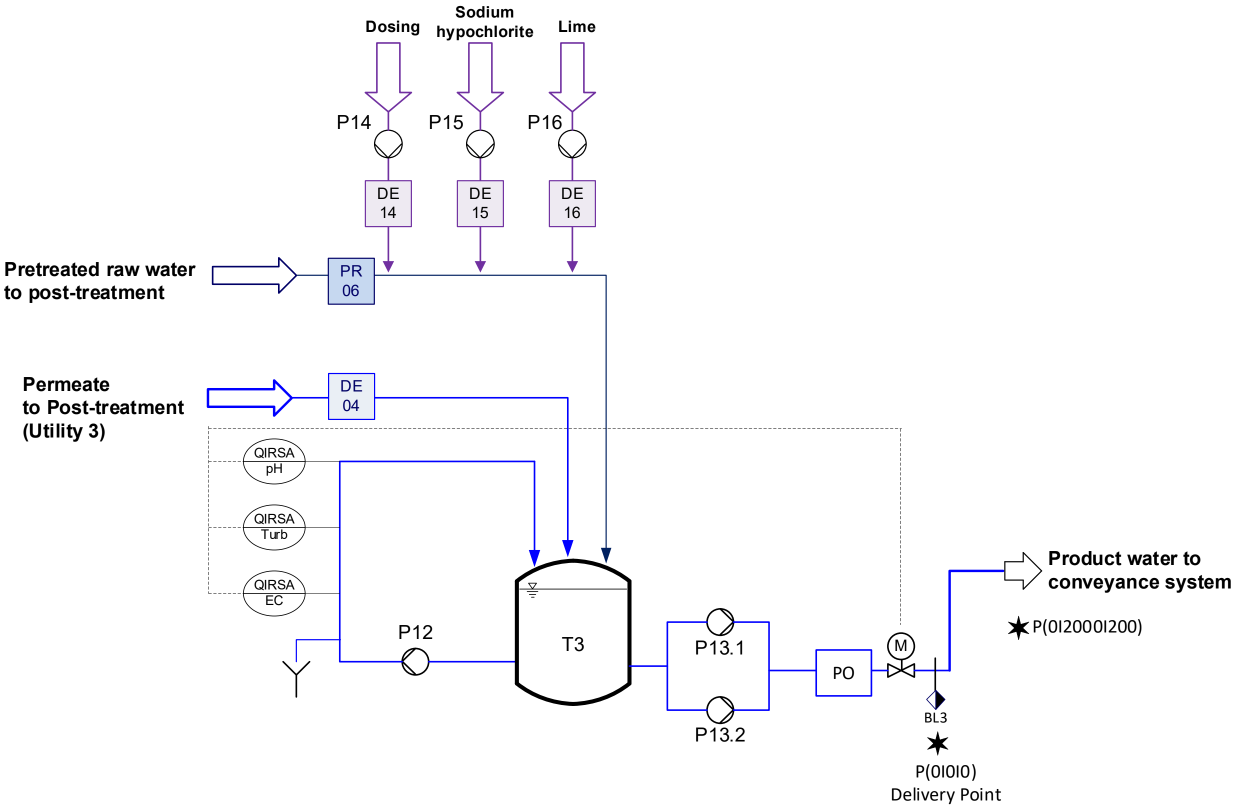


Figure 2-47: Process flow diagram for utility post-treatment

2.3 Determination of battery limits and creation of the layout

Battery limits are defined boundaries between the employer and contractor, which may be physical (e.g., a flange on a pipe) or some other means for example, represented by a map coordinate. Battery limits should be described in a very appropriate way (for example, a drawing or map including a verbal description). By definition, battery limit comprises one or more geographic boundaries, imaginary or real, enclosing a plant or unit being engineered and/or erected, established for the purpose of providing a means of specifically identifying certain portions of the plant, related groups of equipment, or associated facilities. Battery limits in general, simply outline the limit of the work to be done by particular engineering contractors.

In order for the contractor and their subcontractors to carry out the work asked by the employer on the desalination plant, battery limits need to be defined so that the contractor is informed on the scope of their responsibilities. All lines and equipment inside battery limit **(ISBL)** defines the contractor's scope of work, whereas outside battery limit **(OSBL)** shall either be implemented by the client, the corresponding departments of the government or any other engineering contractor.

To avoid unnecessary costs, confusion and misunderstandings regarding responsibilities between the parties for the plant planning and construction, it is therefore crucial to set the boundaries of duties clearly. This is done by drawing a sharp line between above mentioned inside and outside battery limits.

The driving factors to consider for a clear and distinct division of ISBL and OSBL are the following:

- Geographical size
- Location within the plant
- Project execution philosophy
- Costs and other control requirements
- Financial arrangements
- Management objectives and directives

<u>Inside battery limit (ISBL):</u> Refers to the area where the plant or the process plant and equipment are located. All equipment, instruments and associated components (piping, etc.) that are used for the desalination process elements of this area, therefore responsibilities of the contractor. ISBL is functional-based and refers to equipment and other components that are solely dedicated to a single process whether or not the equipment is physically located within the geographical boundaries of the unit.

- **Consists of:**
    - Process pipe and valves
    - Instrumentation and controls
    - Towers, pumps, reactors, tanks, filtration systems etc.
    - Footings and access/support structures or skids
    - In-site storage facilities

- **Cost: ISBL** plant costs are the cost of procuring and installing all process equipment. ISBL costs include purchasing and shipping costs of equipment, land costs, infrastructure, piping, catalysts, and any other material needed for final plant operation or construction of the plant.

<u>Outside battery limit (OSBL):</u> Refers to the area which is outside the plant boundary limit. OSBL is away from the equipment and the process plant. The facilities and pieces of equipment which are not directly affiliated with the process of desalination but are critical in order to run the plant are filed under OSBL**.**

- **Consists of:**
  - Out-of-site storage, utilities, energy systems
  - Feed and product storage
  - Distribution facilities
  - Interconnecting pipe (between the plant and other facilities)
  - Environmental facilities
  - Cable, power supply, instrumentation (non-process)
  - Safety and fire protection
  - Roads and connections for the plant
  - Fencing and security

- **Cost: OSBL** costs are initially estimated as a percentage of the **ISBL** costs. If not a lot of information is available, a rule of thumb is to use **40%** of the **ISBL** costs as an estimate for **OSBL**.

Usually, all process lines and offsets/ utility lines from OSBL entering ISBL are separated by flange connections at the battery limit. Normally these battery limits will be clearly defined inside the piping and instrumentation diagrams and shall be submitted for the client´s review to rule out clashes during later stages of the project.

In addition, the SWRO desalination plant consists of different kinds of elements that various subcontractors need to provide. These elements are each given tag numbers and listed, which makes the delegation of duties to the subcontractors well defined and simple.

The battery limits for planning a desalination plant should be defined in detail in the Basic Engineering. In addition, all battery limits should be illustrated and described with a schematic view, as shown below:

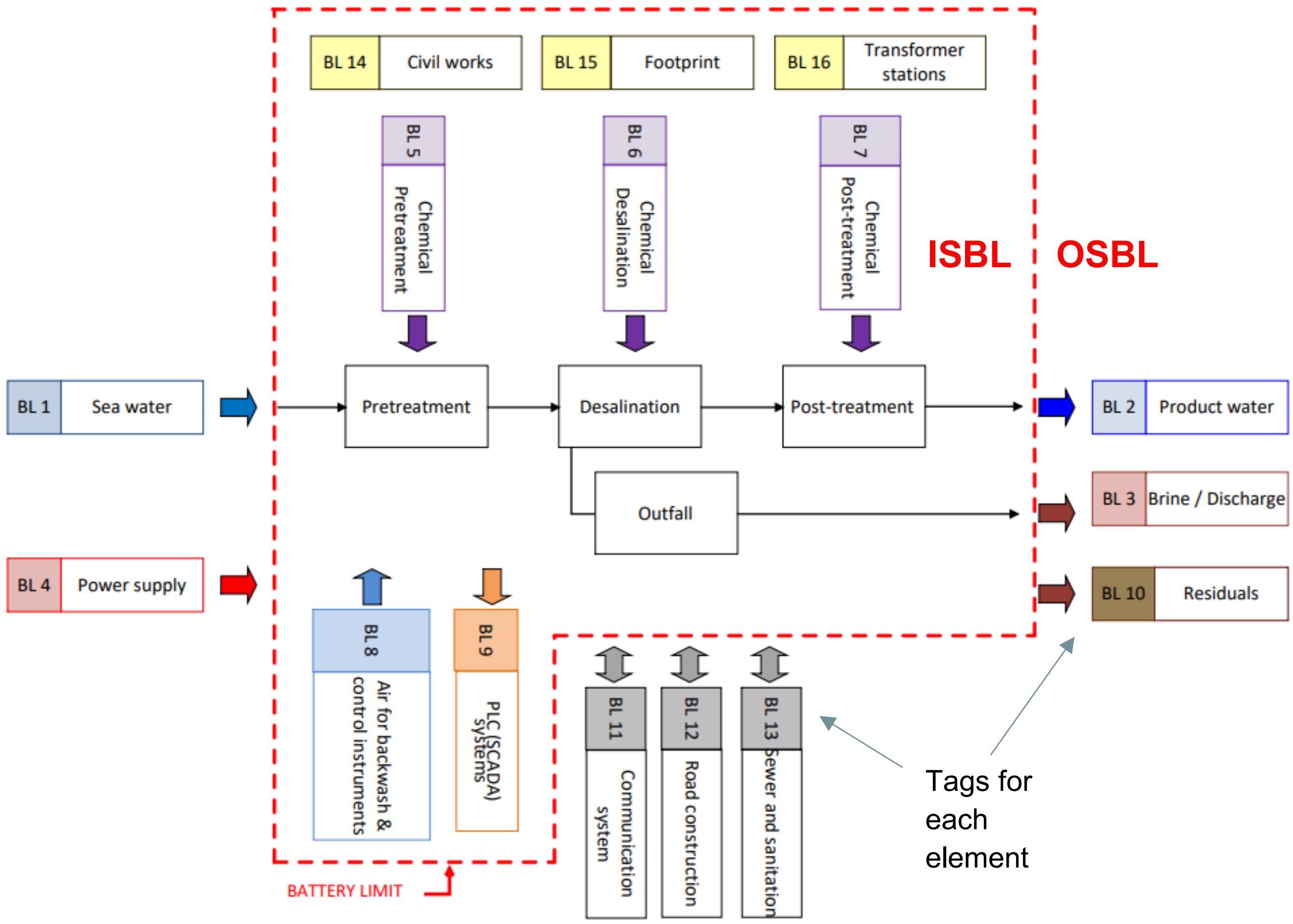


Figure 2-48: Example for battery limits

It is recommended to create a detailed list of the battery limits as well, besides their graphical representation. The detailed list should include at least the data indicated in the table below.

ID	Battery limits	Description	Specification	Note
BL1	Sea water inlet	Connection point (flange) / pipe from abstraction facility		
BL2	Product water outlet	Connection point (flange) / pipe to demand center		
BL3	Brine / discharge outlet	Connection point (flange) / pipe to surface discharge		
BL4	Power supply	Connection to public grid		
BL5	Chemicals Pretreatment	Storage & supply in/with IBC containers		
BL5.1	Polyelectrolyte	Flocculation		
BL6	Chemicals Desalination	Storage & supply in/with IBC containers		
BL6.1	SMBS Dechlorination	Dechlorination		
BL6.2	Antiscalant	Antiscaling		
BL6.3	Acid	Antiscaling (optional)		
BL6.4	NaOH (for CIP)	Alkaline cleaner		
BL6.5	HCl (for CIP)	Acid cleaner		
BL6.6	Na-DDS (for CIP)	Surfactant		
BL7	Chemicals Post-treatment	Storage & supply in/with IBC containers		
BL7.1	NaOH	pH adjustment		
BL7.2	$Ca(OCl)_2$	Remineralization & disinfection		
BL8	Air	Air inlet into building		
BL9	PLC signals	From control room to remote control		
BL10	Residuals	Waste disposed from the plant		
BL11	Communication system	Telephone lines		
BL12	Road construction	Asphalt roadworks		
BL13	Sewer and sanitation	Sewer system connections		
BL14	Civil works	-		
BL15	Footprint	-		
BL16	Transformer stations	-		

Figure 2-49: Detailed list of battery limits

Creation of a layout

The layout (installation plan) provides each component's positioning, dimensions, and identification regarding the defined connection points specified in the battery limits. For the pre-design of the site plant, the components parts can be shown in simplified form (dummy, blank box) in the layout, which should contain the following basic information:

- Main components of the desalination plant
- Tag number of each component
- Indication of potential zones of danger
- Reserving space for future expansions

- The reference point of GPS coordinates (with angle specification)
- Orientation an arrow showing the north direction
- If necessary, main wind direction
- Buildings and storages
- Footpath, roads, loading stations, etc.
- Pipe and cable tray (below & ground)

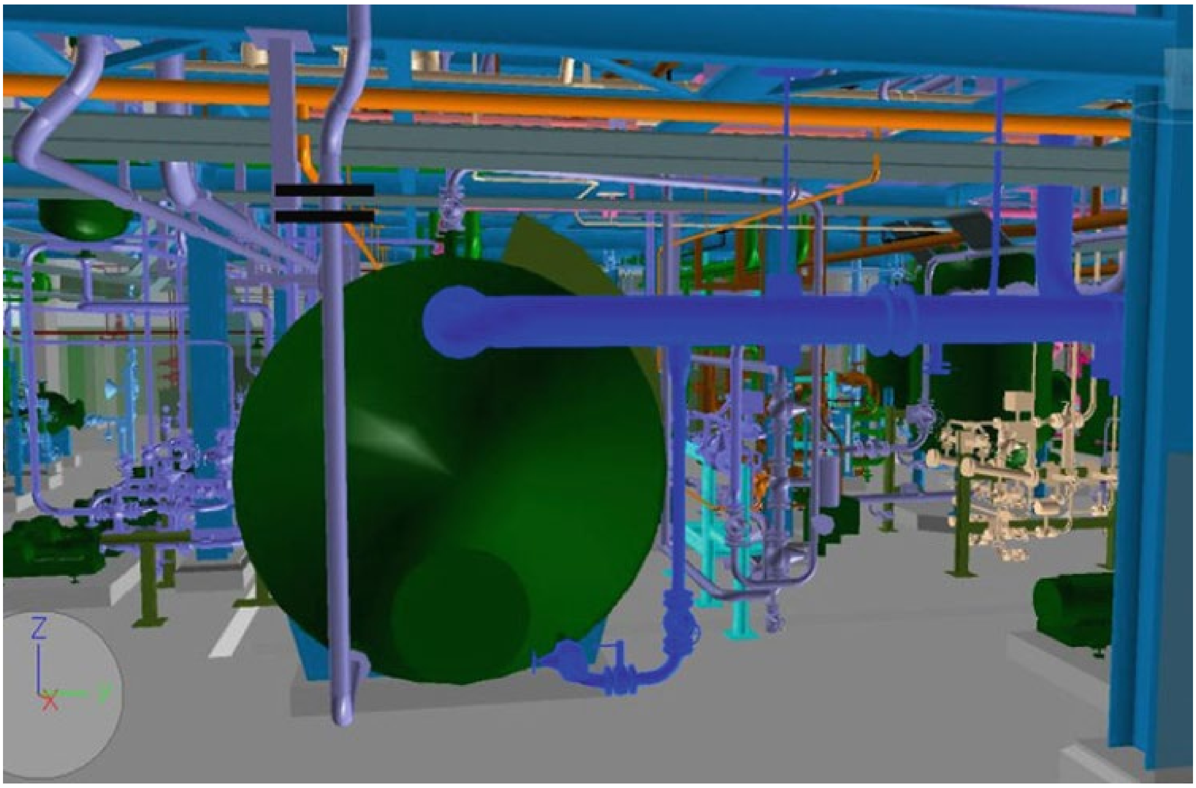


Figure 2-50: Example of a 3D piping system

2.4 Monitoring requirements and automation

SCADA-Automation (Supervisory Control and Data Acquisition)

The SCADA process control technology is used to control and monitor the entire plant process. The system is to be designed as an automation system for interactive process information, operation, and optimization. Supplementary requirements serve the purpose of increased safety for operation as well as operational data archiving, evaluation, and documentation. For large scale seawater desalination plants, SCADA automation is essential. For smaller-scale plants, data collection from the sensors and actuators is sufficient. A certain degree of automation, e.g. automated flushing, is also useful for small scale seawater plants to optimize the use of skilled personnel.

The process control system can be divided into four levels, illustrated in Figure 2-51.

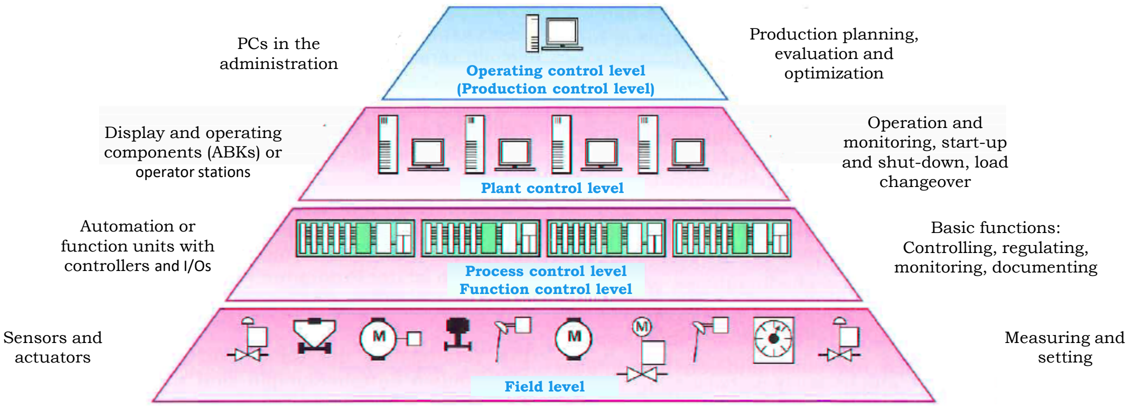


Figure 2-51: Overview of the process control system

<u>Level 1: Field level (near-process level)</u>

The Field level is the lowest level of the automation hierarchy and consists of field devices such as sensors and actuators. These sensors and instruments transfer local indication and information on processes and machines for monitoring and analysis.

<u>Level 2: Process control level (Aggregate or component level)</u>

This level consists of automation and function units with controllers and I/O's. Its basic functions include controlling, regulating, monitoring and documentation.

<u>Level 3: System control level (Operating and coordination level)</u>

This level contains display and control components and also operator stations (OS). The main tasks are to operate, observe, start-up, shut down, and make changes to the workload.

<u>Level 4: Operation control level (Observation and documentation level)</u>

This level is made up of PCs with the responsibility and capability of administration of the whole operation. Planning, evaluation, and optimization of the production are some of the tasks resolved from the operation control level.

Monitoring Requirements

Besides the permits and regulatory monitoring requirements, it is recommended to define additional tasks to evaluate the efficiency of the desalination plant. These monitoring actions must be considered in the plant configuration and are listed and defined as follows:

- Permits and regulatory
- Sample points (quality)
- Operating costs
- Operational or process
- Electrotechnical, building, equipment, and machinery
- Environmental and safety
- Auxiliaries & spare and wearing parts

Permits and regulatory monitoring requirements

According to the license application, there are defined monitoring points in the plant process which should be recorded continuously or in specified intervals (laboratory test, for example, COD). In Figure *2-52* the most essential sample points are indicated.

It is highly recommended to record the measurement points online and record them into an operating log, automatically set in the PCS. An operating log only in paper form can lead to a lack of information.

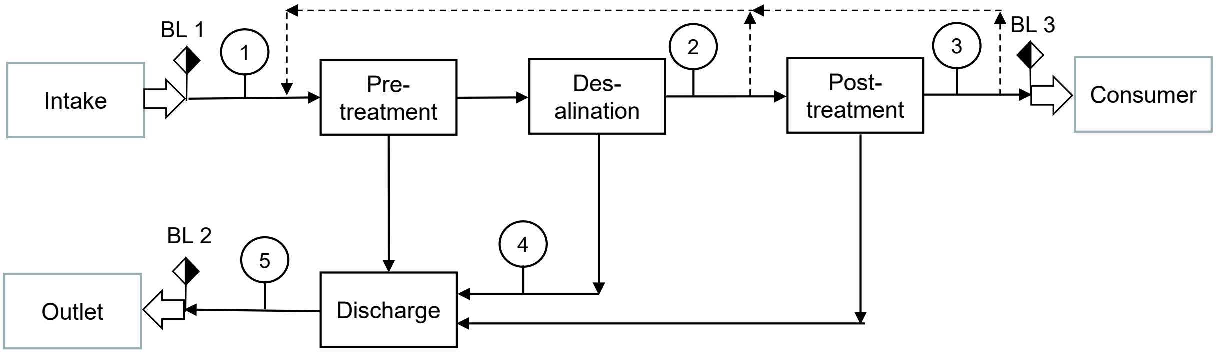


*Figure 2-52: Monitoring points**

*1= Intake monitoring requirements; 2&3= permeate and product water quality monitoring requirements; 4&5= brine monitoring requirements

Additionally, a measuring point and sampling plan should be defined, where also the required values for the water quality should be given.

If, for example, the required water quality isn't achieved, automatic control devices should stop the system automatically or cause an automatic return; an example is shown in the following basic flow diagram.

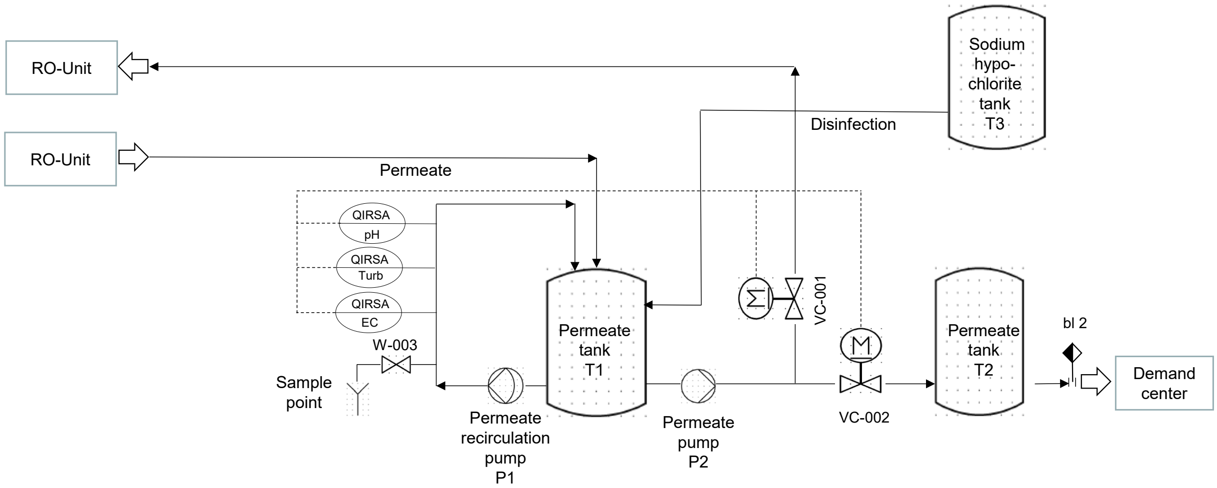


Figure 2-53: Self-monitoring permeate measuring points

The water monitoring sensors are represented by the three oval shapes in the flow diagram. They can be used for various process control engineering tasks. In Figure 2-53 they represent sensors measuring the permeate quality. In this case, the measured parameters are the pH-value, the turbidity and the electrical conductivity. The letters QIRSA stand for **Q**uality **I**ndicating **R**ecording **S**witching **A**larm according to ISO 3511. This acronym specifies that the sensor measures a value, which is recorded and displayed in the process control system (PCS). Depending on the measured values, the valves VC-001/VC-002 controlling the permeate recirculation is switched between the states open and closed. If a set value range is exceeded or undershot, the valve opens, and an alarm is triggered in the system. The different designation systems like ISO 3511 are explained in more detail in chapter 3.1.2.

<u>Sample points monitoring requirements</u>

Besides the defined parameters referring to approval, it is necessary to define further sample points, which should be monitored in the inlet or outlet area. It is essential to take countermeasures concerning future trends.

<u>Operating costs</u>

It is highly recommended to calculate the annual cost for energy and materials required by the desalination plant. For this purpose, suitable instruments for energy measurements and chemical consumption should be installed.

<u>Operational or process monitoring requirements</u>

To ensure a safe and continuous operation and to prevent malfunctions, the process/ the efficiency of the desalination should be checked referring to the mass-and energy balance at specified intervals; in addition, the efficiency check can be automatized within the PCS.

(1) Operational monitoring abstraction

(2) Operational monitoring pre-treatment

(3) Operational monitoring desalination (membrane fouling)

(4) Operational monitoring post-treatment

The measuring equipment should deliver enough data to evaluate each of the above-mentioned monitoring units separately.

Electrotechnical, building, equipment, and machinery monitoring requirements

A careful maintenance plan for each component should be defined to extend the desalination plan's service life. For this reason, it is essential to take records of long-term operational performance data and evaluate them regularly.

Additionally, in specific intervals, the main components should be inspected by an expert. It’s common to arrange a maintenance contract, including remote maintenance.

Environmental and safety monitoring requirements

To avoid accidents or take measures in case of an accident, fire, or other calamities, it’s crucial to define operating instructions and a safety and rescue concept, in which the security devices (firefighting, safety shower) and escape rescue plan are defined. This should also include standard operation procedures and environmental management plans to deal with fluid and solid wastes.

Auxiliaries & spare and wearing parts

The concept of the auxiliaries & spare and wearing parts should be defined per year to avoid bottlenecks regarding logistics planning,

2.5 Selection of adequate materials

The selection of suitable materials is of crucial importance for the cost-efficient operation of seawater desalination plants. These findings derive essentially from the fact that both the capital costs and the operating costs for desalination plants are highly dependent on questions regarding the materials used.

Insights into the fundamentals of corrosion

Before the standard materials for modern desalination plants are investigated, it is crucial to discuss the corrosion problem first. As the working fluid may be highly aggressive to many metallic materials, which are of engineering relevance, the knowledge about the physical and chemical background of the corrosion mechanisms is of fundamental importance.

Corrosion is described as the destruction of metals by chemical or electrochemical reactions with their surrounding medium, such as, for example, seawater. In the general sense, in addition to chemical and electrochemical reactions, physical processes such as the erosion of metallic material by abrasive ingredients in flowing media (metal erosion by grains of sand) may also be regarded as a different form of corrosion.

Although the dissolution of metals in an aqueous environment, in other words, corrosion, generally occurs according to the basic principles described above, corrosion may also appear in different forms. To better understand this, it makes sense to analyze the various forms of corrosion individually.

We can differentiate between the following forms of corrosion, together with the mechanisms which cause them, are listed in Table 2-15.

Table 2-15 Forms of corrosion and their causal mechanisms

Corrosion mechanism	Corrosion form
General attack	▪ Uniform corrosion / General corrosion
Local attack	▪ Crevice corrosion ▪ Under deposit corrosion ▪ Tuberculation ▪ Filiform corrosion ▪ Pitting corrosion ▪ Microbiologically influenced corrosion
Environmental attack	▪ Stress corrosion (SSC) ▪ Hydrogen influenced cracking (HIC) ▪ Corrosion fatigue cracking (CFC)
Velocity influence	▪ Erosion corrosion ▪ Cavitation ▪ Fretting corrosion
Galvanic attack	▪ Galvanic corrosion

Corrosion mechanism	Corrosion form
Intergranular attack	▪ Intergranular corrosion
Dealloying or selective attack	▪ Dealloying or selective corrosion

A detailed explanation of all forms of corrosion would go far beyond the scope of this guideline. Therefore, only the forms of corrosion that are the most important for seawater desalination will be examined in the following text.

<u>General corrosion (uniform corrosion)</u>

General corrosion or uniform corrosion is the electro-chemically generated removal of metal in corrosive media, which is distributed more or less evenly over the whole metal surface. This form of corrosion is one of the most widespread forms of corrosion, which can be observed particularly in low alloyed steels or cast iron.

If the passive layer is chemically or mechanically destroyed over the whole metal surface, then the bare surface of the metal is completely exposed to the corrosion process. The metal is then corroded at a relatively constant velocity until it is fully dissolved.

Uniform corrosion may be one of the most common types of corrosion, but it is predictable and can be counteracted in the design phase using suitable material thicknesses.

<u>Crevice corrosion</u>

Crevice corrosion represents a local form of corrosion. The cause of this form of corrosion is a crevice between two metallic materials, or a metal and a non-metal. Such a crevice with a risk of corrosion may often appear under the seals, under organic or inorganic deposits, at connecting joints, for example, between two tubes which are placed within each other or between two overlapping plates or even at welded joints. Critical for the corrosion mechanism is that no matter how the crevice is constructed, it is in contact with a corrosive medium or is filled with this medium and that what is more or less a stagnant water area develops in the crevice.

From the facts given above, countermeasures can now be derived for the slowing down or the reduction of crevice corrosion. The possible causes of the formation of crevices, for example, at welded connections or under the seals, can be avoided through actions at the design phase. Non-homogeneity in the corrosive medium, brought about by very slow velocities or through the geometry of the flow channel, for example, through sharp bends, may be counteracted by changes in design. The forming of possible caking, crusts, and adhesions, organic or inorganic, where there is contact to corrosive media must be avoided.

<u>Under-deposit corrosion</u>

Under-deposit corrosion is, in its mechanism, a form of crevice corrosion that takes place in the crevice between the metal surface and the deposits which form on it. It is of no significance whether these deposits originate from scaling or biological fouling or even comprise suspended solids present in the water.

To avoid under-deposit corrosion, consistent measures must be undertaken which prevent such deposits, in other words fouling and scaling.

Tuberculation

Tuberculation is also a form of crevice corrosion which occurs in water cooling systems. Carbon steel and cast iron corrode very quickly if the cooled water has high concentrations of bicarbonates, sulfates, or chlorides. During this, corrosion products cause “tuberculation” in the form of isolated caking on the metal surface. This will yield, in turn, crevice corrosion, particularly at the points of tuberculation. Inhibitors are placed in the cooling water system to avoid this corrosion. Flow velocity and temperature are monitored, or the metal surfaces are protectively coated.

Filiform corrosion

Filiform Corrosion is a further form of localized corrosion based on the crevice effect. If a coating is scratched in places or is locally damaged in any other way, then corrosion can develop at the damaged points between the coating and the metal. Coated steel, aluminum, or magnesium suffer particularly under this form of corrosion if, at the same time, relative humidity of over 65 % is present. Filiform Corrosion can therefore be reduced by avoiding high humidity. In addition, galvanizing or a zinc-based primer under the coating can provide help against filiform corrosion.

Pitting corrosion

Pitting corrosion is when the metal surface is attacked by a large number of relatively small, localized corrosion areas. In pitting corrosion, the destruction of the passivation layer does not occur everywhere but only locally on the surface of the metal. Thus, small pits form on the metal surface.

A characteristic of this form of corrosion is that no significant corrosion is too visible on the rest of the surface besides hollowed-out holes on the metal surface caused by the corrosion. The formation of pitting corrosion is based on the electrochemical dissolution of the metal, which occurs in a similar manner as crevice corrosion. A difference to crevice corrosion is that the locally corroded areas are not determined by crevice which is already present or by caking on the metal surface. Rather, the localized points of corrosion occur due to an electrochemical attack on the passivation layer by aggressive chemicals, such as chloride. The presence of a passive layer on the metal surface provides certain protection and, therefore, is one of the pre-conditions to avoid pitting corrosion as well.

If the passivation layer is destroyed at various localized points and if at the same time sufficient oxidation potential is also present, then an electro-chemical dissolving of the metal begins at these bare points (pitting). As soon as such a corrosion process is underway, a large undisturbed metal surface reacts cathodically against the relatively small, pitted areas. In other words, the metal surface, which is well protected by the passivation layer, is also protected cathodically. In contrast, the corrosion process in the pits, which then behave in an anodic manner, is further accelerated.

In contrast to general corrosion pitting corrosion poses a great danger for stainless steels.

In addition to the chloride concentration and the pH value, the temperature is an important factor in the potential for pitting. Higher temperatures increase the danger of pitting. Higher proportions of Cr, Mo, and in particular N increase the resistance of stainless steel against pitting corrosion. It is common in practice to describe pitting resistance by using the so-called PREN (pitting resistance number), which is defined as follows:

PREN = % Cr + 3.3 * % Mo + 16 * % N

The higher the PREN, the greater the resistance of the material against pitting corrosion. In other words: The material can be used at higher temperatures.

Environmental attack

Some metals show a variety of forms of corrosion behavior under different environmental conditions, such as under mechanical stress. Among the influences relevant to corrosion are:

- mechanical stress
- presence of hydrogen
- fatigue

Galvanic corrosion (bimetallic)

Galvanic Corrosion is referred to if two metals with different potentials EH° are in contact with each other in a corrosive medium and thus cause a corrosive process.

Cavitation

Erosion may be accompanied by cavitation at places with high flow velocities. Cavitation is referred to as very fine vapor bubbles formed in the flow as a result of condensation suddenly, then disappearing (collapse) and causing very strong localized variations in velocity in their immediate environment of up to 500 m/s. Such vapor bubbles are created if the flow is speeded up locally in such a way that the predominant hydrostatic pressure at that point is below the vapor pressure of the water. Such flow conditions may occur on the impellers of pumps with fatal consequences.

Plant components in the low-pressure region with high velocities are particularly in danger of cavitation, as there the probability of bubble formation above is higher.

Although cavitation and erosion are both mechanically effective mechanisms of corrosion, they leave different forms of damage. While erosion results in a bright metal surface, the surface and the material which is damaged by cavitation are sponge-like in extreme cases:

Hydrogen Induced Cracking (HIC)

Hydrogen can significantly influence the properties of a metal. In the presence of hydrogen (in atomic or molecular form), the ductility of metals generally decreases. At the same time, they become brittle. HIC can occur as a consequence of or at the same time as electrochemical forms of corrosion, as hydrogen is produced as part of these.

Hydrogen is also produced in the molecular or atomic form in thermal processes, such as welding or melting, or in chemical processes, such as pickling. This can then form metal hydrates with the metal. High carbon steel with a tensile stress value of over 1,241 MPa can become brittle. Low C concentrations in the steel reduce the danger of HIC if, at the same time, H_2S is not present.

Stress Corrosion Cracking (SCC)

Stress corrosion cracking describes the forming of cracks in a metal under tensile stress and in a corrosive environment. The interaction of various effects can, if at the same time the metal is susceptible to the build-up of cracks, lead to SCC, whereby a permissible tensile strength limit must be exceeded. Particularly prone to this form of corrosion are stainless steels under tensile strength and in chlorinated water or copper alloys in an ammoniac atmosphere. SCC is usually accompanied by HIC.

Velocity influenced corrosion / erosion corrosion

The flow velocity plays an important role with regards to the corrosion rate. Through an increased velocity over metal surfaces, in danger of corrosion can, on the one hand, both localized non-homogeneities and biological or inorganic caking be avoided, through which possible rates of corrosion can be significantly reduced. On the other hand, too high a flow velocity can be the reason for the destruction of the passivation layer on metal surfaces which protects against corrosion. High flows can even suppress the passivation layer's formation on metals that are bare at the beginning.

On the contrary, flow velocities mainly increase the danger of pitting corrosion and biologically determined corrosion. Velocities under 1 m/s should be critically regarded in this context. In practice, empirical values, obtained from the experience of characteristic cases, are taken as the upper limit for the maximum permissible velocities.

Insights into the material selection for desalination plants

The availability of a desalination plant is also reduced due to poor material selection, which is reflected in shortages in water production and increased water production costs. This task must be solved entirely at the very beginning, in other words, in the planning phase, but at the very latest in the procurement phase of the construction of a desalination plant. The results of the material selection must be specified in the tendering documents.

The selection of adequate and corrosion-resistant materials is highly dependent on high pressure and low-pressure applications. All plant components and piping from the inlet structures up to the permeate piping must be specified. A special focus should be placed on the difference between feed and brine in seawater systems. Salts are concentrated to such an extent that materials used in the feed area may not be resistant to brine.

Metal materials

Different alloys of stainless steels are used for high-pressure piping applications.

Stainless steels are the most cost-effective metal material for desalination plants due to current materials technology and market prices for certain metals. Stainless steel 316L is the most commonly used grade in RO desalination plants. However, in the feed and brine piping, 254SMO, AL6XN and 317LNMO are used for enhanced corrosion resistance which is a key factor when choosing metal materials in a seawater desalination plant.

- **Stainless Steel 316L / UNS: S31603**

316L is the most common stainless steel used in desalination applications. It is an austenitic stainless steel with a moderate resistance against pitting and crevice corrosion (moderate PREN=25) and is subject to stress corrosion cracking (SCC) at a temperature higher than 60 °C in the presence of oxygen. A good deaeration is necessary. Additionally, 316L is subject to SCC from the outside in a saline atmosphere. The risk of pitting and crevice corrosion during shut-downs is very high. Therefore, all surfaces must be cleaned by flushing. The use of this stainless steel in high saline environments of the plant should be avoided.

<u>Areas of application:</u> permeate (piping), second-pass RO.
Not suitable for source seawater and seawater concentrate.

- **Stainless Steel 1.4462 / UNS: S31803 (DUPLEX)**

1.4462 is a duplex stainless steel (austenitic/ferritic) with a similar (compared to 316L) resistance against pitting and crevice corrosion but is not subject to SCC. It has a higher strength than 316L but its capability to be welded is more complex (subject to the proper training). 1.4462 costs are some 20 % higher than the costs of 316L.

<u>Areas of application:</u> permeate (piping), second-pass RO.

- **Stainless Steel 1.441 / UNS: S32750 (SUPER DUPLEX)**

Super Duplex 1.441 is the most common super duplex grade in the market. It was particularly designed for service in aggressive chloride-containing environments (PREN ≥ 40). It has very good resistance to localized corrosion and stress corrosion cracking in combination with high mechanical strength. It is widely used in oil & gas, hydropower, pressure vessels, pulp & paper, structural components and chemical tankers.

<u>Areas of application:</u> intake pump parts in direct contact with the saline water (i.e., pump casting, bell mouth, shaft, and impeller), feedwater piping, concentrate piping, energy recovery devices and fine screening panels are made of super duplex stainless steel for seawater installations. When it comes to wetted pump materials in high-pressure feed pumps, super-duplex stainless steel is recommended for SWRO applications.

- **Stainless Steel 254SMO (6Mo) / UNS: S31254**

This steel grade is a super austenitic stainless steel developed for use in halide containing environments such as seawater, hydrochloric acid and sulfuric acid. It has a high molybdenum content (approximately 6%) and a high PREN around 43, providing excellent resistance to pitting and crevice corrosion and high strength compared with conventional austenitic stainless steels such as 316L.

These types of stainless steel are costly materials (254SMO is 2.5 times costlier than 316L), so they are best used for particular parts only.
<u>Areas of application:</u> All applications.

- **Stainless Steel 317LMN (317LNMO) / UNS: S31726**

According to a study by Al-Odwani, Al-Tabtabaei, and Abdel-Nabi, titanium performed best when exposed to the corrosive effects of Arabian Gulf seawater. However, the analysis found that the highly alloyed stainless steel 317LNMO was the most cost-effective material.

Alloy 317LMN (UNS S31726) is an austenitic chromium-nickel-molybdenum stainless steel that outperforms 316L and 317L in terms of corrosion resistance. The alloy's resistance to pitting and crevice corrosion is also improved by the addition of molybdenum and nitrogen (PREN = 38). Alloy 317LMN can also be easily welded and processed. The overall cost of a desalination plant will still increase if stainless steel 254SMO and 317LNMO are used instead of 316L. However, over the course of a desalination plant's life, the use of 317LNMO will prove more cost-effective because of lower maintenance costs and improved products. So, this alloy could be considered as an alternative for some of the above mentioned costly high-alloy steels instead.

Plastic materials

In general, plastic materials are used for low-pressure, low-temperature applications. The main advantages of plastic materials are, for example, higher corrosion resistance, lower costs, and lighter weight compared to concrete or steel piping.

- **PVC (polyvinyl chloride)**

Permeate piping
Intake piping
RO distribution piping for flow rates from 1 to 2 m/s
Low-pressure concentrate piping
Wastewater discharge piping to a sanitary sewer
Disinfection system piping
Well casing for vertical wells as subsurface intake

- **FRP (Fiberglass-reinforced plastic)**

Pressure vessels of RO membranes
Energy recovery system, low pressure side only
RO system low pressure piping
Well casing

- **HDPE (high-density polyethylene max. diameter: 2m)**

Intake piping (more expensive, flexible but available for fewer different diameters and also costlier)
Horizontal directionally drilled wells
Wastewater discharge piping to a sanitary sewer
Outfall piping

- **PP (polypropylene max. diameter: 0.6m)**

Disk filter material (micro screen)

Filter cartridges

Outfall piping

- **GRP (glass reinforced plastic, max. diameter: 4m)**

Intake piping

Wastewater discharge piping to a sanitary sewer

Outfall piping

Table 2-16: Recommended velocities for the piping materials[32]

Piping material	Recommended velocity
Steel tubes (galvan	▪ < 2 m/s (seawater and concentrate piping) ▪ 1.5 - 3 m/s (permeate piping)
PVC	▪ 1 - 2 m/s
FRP	▪ < 3.7 m/s
HDPE	▪ < 7.6 m/s
PP	▪ < 3 m/s
GRP	▪ <5 – 6 m/s

Take Away Messages for material selection

- The selection of suitable and corrosion-resistant materials depending on the components is mandatory
- The selection of more expensive but corrosion-resistant materials reduces the risk of downtime and costs in maintenance
- If plastic materials are suitable, especially in low pressure applications, they are preferable to metallic materials

[32] https://rules.dnv.com/docs/pdf/dnvpm/cn/2004-08/GL_15.pdf
https://www.engineeringtoolbox.com/flow-velocity-water-pipes-d_385.html
https://www.engineeringtoolbox.com/pvc-schedule-40-pipe-friction-loss-diagram-d_1147.html
https://www.tsmfiberglass.com/files/ENG1000%20Engineering%20Piping%20Design.pdf
https://www.kebechem.com/images/pdf/PP_2.pdf
https://www.flowtite.com/wp-content/uploads/1901_Flowtite_TechCharacteristics_EN.pdf

2.6 Chemical and spare parts storage

When dealing with chemicals, hazardous materials or dangerous equipment, the safety instructions according to the safety data sheets of each material should be followed; therefore, the safety instruction for each chemical and operating instructions must be available to the operating personnel. These instructions are essential to prevent injuries caused by lacking or improper use of protective gear, tools or equipment. Additionally, some of these signs are very crucial during emergency situations. Internationally valid pictograms must be placed around the plant where workers handle or work with dangerous equipment or substances. An excerpt of the essential pictograms is shown in the figure below.

Figure 2-54: Examples for hazard and safety signs according to ISO 7010[33]

[33] https://en.wikipedia.org/wiki/ISO_7010

Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is an internationally agreed-upon standard managed by the United Nations that was set up for the assortment and labelling of hazardous materials.

Core elements of the GHS include standardized hazard testing criteria, universal warning pictograms, and harmonized safety data sheets that provide users of dangerous goods with a host of information. The main GHS hazard pictograms are shown in the following figure.

Pictogram	GHS	Chemicals	Description - Handling
 Flammable	GHS02	Na-DDS	Flammable; substances produce explosive mixtures when in contact with air or water or are self-inflammatory. Keep away from open fire or heat; seal containers tightly; store fireproof
 Oxidizing	GHS03	$Ca(OCl)_2$	Has an oxidizing effect and fuels fire. Mixing with flammable substances produces explosive mixtures. Keep away from flammables and do not mix with them; keep stored clean.
 Compressed gas	GHS04	N_2	Gas cylinders under pressure can explode when heated; cryogenic gases produce cold burns. Do not heat; wear protective gloves and goggles for cryogenic gases.
 Corrosive	GHS05	HCl, $Ca(OCl)_2$, $Ca(OH)_2$, H_2SO_4, $NaOH$, $NaClO$, $Na_2S_2O_5$, Na-DDS	Destroys metals and corrode body tissue; heavy eye damage possible. Avoid contact; wear protective googles and gloves; in case of contact rinse eyes or skin with water.
 Toxic	GHS06	Na-DDS	In small quantities causes immediate serious damage to health or death. Do not inhale, touch or swallow. Wear personal protective equipment. Contact immediatly poison control center or doctor.
 Harmful	GHS07	HCl, $Ca(OCl)_2$, $CaCl_2$, $Ca(OH)_2$, $Na_2S_2O_5$, $C_3H_3NaO_2$	Causes damage to health, irritates eyes, skin or airways. In larger quantities leads to death. Do not inhale, touch or swallow. Wear personal protective equipment. In case of skin irritation or eye contact, rinse with water or suitable agent.
 Health hazard	GHS08	$(C_2H_2O_4)$	Has an allergenic effect, causes cancer, mutagenic, toxic for reproduction and fertility damaging or organ-damaging Before working with such substaces, you must be well informed; wear protective clothes, gloves, eye and mouth protection or breathing protection
 Environmental hazard	GHS09	$Ca(OCl)_2$, $NaClO$	Harmful to aquatic organisms, toxic or very toxic, acute or with long-term effects. Only dispose of in hazardous waste, never allow to enter the environment.

Figure 2-55: GHS pictograms of frequently used chemicals. Chemical symbols in order used: Na-DDS is sodium salt of dodecyl sulfate; $Ca(OCl)_2$ is calcium hypochlorite; N_2 is nitrogen; HCl is hydrochloric acid; $Ca(OH)_2$ is calcium hydroxide; H_2SO_4 is sulphuric acid; NaOH is sodium hydroxide or lime; NaClO is sodium hypochlorite or bleach; $Na_2S_2O_5$ is sodium metabisulfite; $CaCl_2$ is calcium chloride; $C_3H_3NaO_2$ is sodium acrylate; $C_2H_2O_4$ is oxalic acid.

Ensure that all containers of hazardous chemicals in the SWRO desalination plant are properly labelled in accordance with the GHS and can be easily distinguished by operating personnel. It should also be mentioned that labels must be resistant to water and other possible damages. If any label is missing or illegible after the arrival from the suppliers or during operation, they must be reattached or replaced. For this reason, it might be useful to have spare labels at hand.

Containers, leakages and collection trays

The seawater desalination plant must have a storage facility to house various chemical substances needed for the operation of the plant. **Outdoor storage of chemicals is not an option for obvious reasons.** The chemicals must be isolated from the environment and solar radiation to such an extent that the manufacturer's storage instructions are followed, and the safety standards are kept. When planning the storage space for the containers, these regulations and standards must therefore always be taken into account. These could be the humidity, temperature, lighting conditions etc. The protection of the containers against rain and other external factors must also be ensured when constructing proper storage.

Accidental or intentional mixing of chemicals in containers with other substances or water must be prevented to avoid dangerous reactions. For this reason, every chemical should have its own collection tray and must be appropriately labelled.

When it comes to containing any liquid substance in the plant, leakages must be avoided at all costs for environmental and safety reasons. To prevent leakage, ensure that the liquid contained does not react corrosively with the container material. To ensure resistant containers and labels, store the chemicals in the supplier's original containers. The containers should also be tightly sealed and away from any objects that can cause punctures by accident during storage. **In conclusion, containers and packaging for chemicals must be sufficiently resistant against mechanical, thermal, and chemical impacts.**

Depending on the container (IBC, barrel), all the water-hazardous substances should be placed on the collection tray (see Figure 2-56) to be able to collect the entire amount of fluid in the event of leaks. Further security measures must be taken into account so that chemicals don't seep away into the underground.

Figure 2-56: Collection tray chemicals[34]

In case of high consumption of hazardous substances, large containers from up to 20 m³ can be considered. The storage containers should be placed over a collection tray (see Figure

[34] Denios (2021). https://www.denios.de/shop/gefahrstofflagerung/auffangwannen/

2-57) or designed with a double wall with leakage monitoring (see Figure 2-58). In both cases, a tanking area should be constructed.

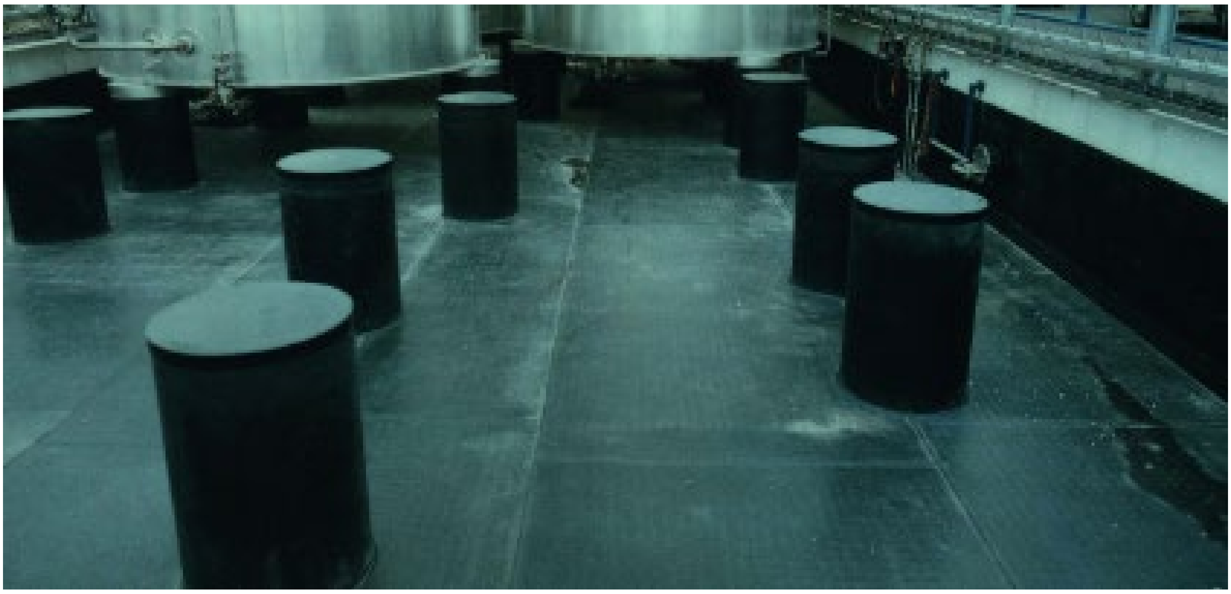


Figure 2-57:Collection tray coated with HDPE[35]

Figure 2-58:Double-walled HDPE tanks[36]

Plastic containers (IBC, barrel) shouldn't be stored outside, especially not under solar radiation due to the UV light. It is recommended to store chemicals in specific chemical storage containers (see Figure 2-59) or in dedicated buildings.

[35] STEULER-KCH (2021) URL: https://linings.steuler.de/de/produkte-leistungen/mechanisch-verankerte-auskleidungen
[36] Formoplast (2021) URL: https://formoplast.com/de/home.html#slide-3

Additionally, a reasonable air exchange rate must be considered in chemical warehouses.

Figure 2-59: Chemical storage container[34]

Explosion and flame hazard

In case of an explosion hazard, there must be certain explosive zones defined (see Figure 2-60).

Zone 0 is an area where an explosive atmosphere is present continuously for long periods or will frequently occur.

Zone 1 is an area in which an explosive atmosphere is likely to occur occasionally in regular operation. It may exist because of repair, maintenance operations, or leakage.

Zone 2 is a place in which an explosive atmosphere is not likely to occur in regular operation but, if it does occur, will persist for a short period only. These areas only become hazardous in case of an accident or some unusual operating condition.

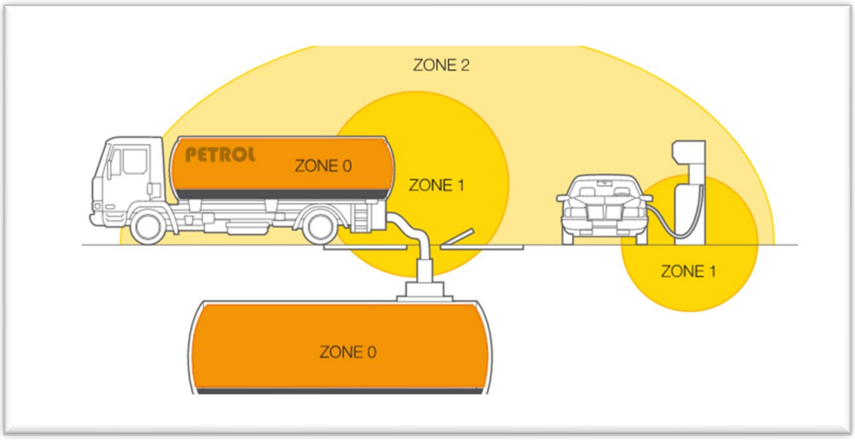


Figure 2-60: Explosive zones[37]

In the case of flammable liquids in significant quantities, there should be an extinguishing water retention system planned. There are various extinguishing water retention systems; two of them will be presented as follows.

[37] Petzl (2021). https://www.petzl.com/INT/en/Professional/Classification-of-ATEX-zones?ActivityName=Explosive-atmosphere

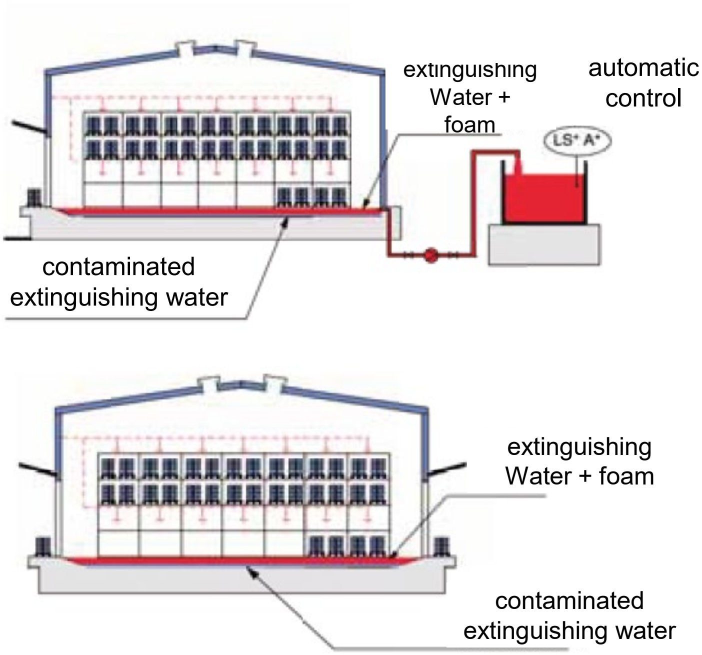


Figure 2-61: Examples for extinguishing water retention system[38]

In existing or new chemical storage facilities where an extinguishing water retention system must be considered, extinguishing water retention barriers must be installed (see Figure 2-62).

Figure 2-62: Extinguishing water retention barriers[39]

A sprinkler system that is connected to a fire alarm system for hazardous substances has to be foreseen.

[38] VdS 2557 (2013-03). Planung und Einbau von Löschwasser-Rückhalteeinrichtung
[39] Thomas (2021). https://www.thomas.biz/

There should be a compact filling station for refilling considered, for example, from an IBC to a barrel for chemical storage. Furthermore, it is also necessary to define a reloading point for the supplier to unload the chemicals on a specific area.

Inventory and storage size

Inventory management is an essential systematic approach to sourcing, storing, and keeping track of components and materials in a plant and benefits operational efficiency and longevity. It is crucial to have spare parts, tools, chemicals and consumables stored beforehand in the storage facilities of the plant. This is important to avoid placing unnecessary orders and having operational difficulties because of lacking goods and spare parts. Therefore, a systematic approach for ordering and storing these goods is considered during the plant design, which can only be ensured with a proper storage size, layout and inventory management/tracking infrastructure (automated systems and software).

Spare parts and chemicals shouldn't be stored in the same container or warehouse due to safety reasons and corrosion!

Operations always require an ample supply of MRO (maintenance, repair, operations) spare parts on hand to make sure that the production runs uninterrupted. If the needed part is not readily accessible, it may cause additional downtime and high expenses tied to expedited shipping. Having too much MRO stored leads to higher purchase and carrying costs.

With the consumption data per year, it is possible to calculate the economic order quantity to dimension the storage area's size.

Economic order quantity (EOQ) can be calculated as such:

$$Q = \sqrt{\frac{2DS}{H}}$$

where:

$Q = \text{EOQ units}$

$D = \text{Demand in units (typically on an annual basis)}$

$S = \text{Order cost (per purchase order)}$

$H = \text{Holding costs (per unit, per year)}$

Regarding the condition of Jordan, the availability of the chemicals should also be considered in the calculations so that the economic order quantity may be around 3 to 5. Furthermore, it is recommended to consume the chemicals within one year after their delivery.
Additionally, it is recommended to consider a storage area for empty containers and a 10 to 15% safety factor.

In the following figure, economic order quantity is calculated as an example for phosphoric acid. In this case, the annual consumption of phosphoric is around 48 t/a, so that with the economic order quantity of 6, the storage capacity for phosphoric is (=48/6) 8t per order considered; these are around five m³ or 5 IBC (density of phosphoric acid is 1,57 g/cm³).

Considering the safety factor and area for empty containers for phosphoric acid in total 10 m³ (10 IBC) were taken into account.

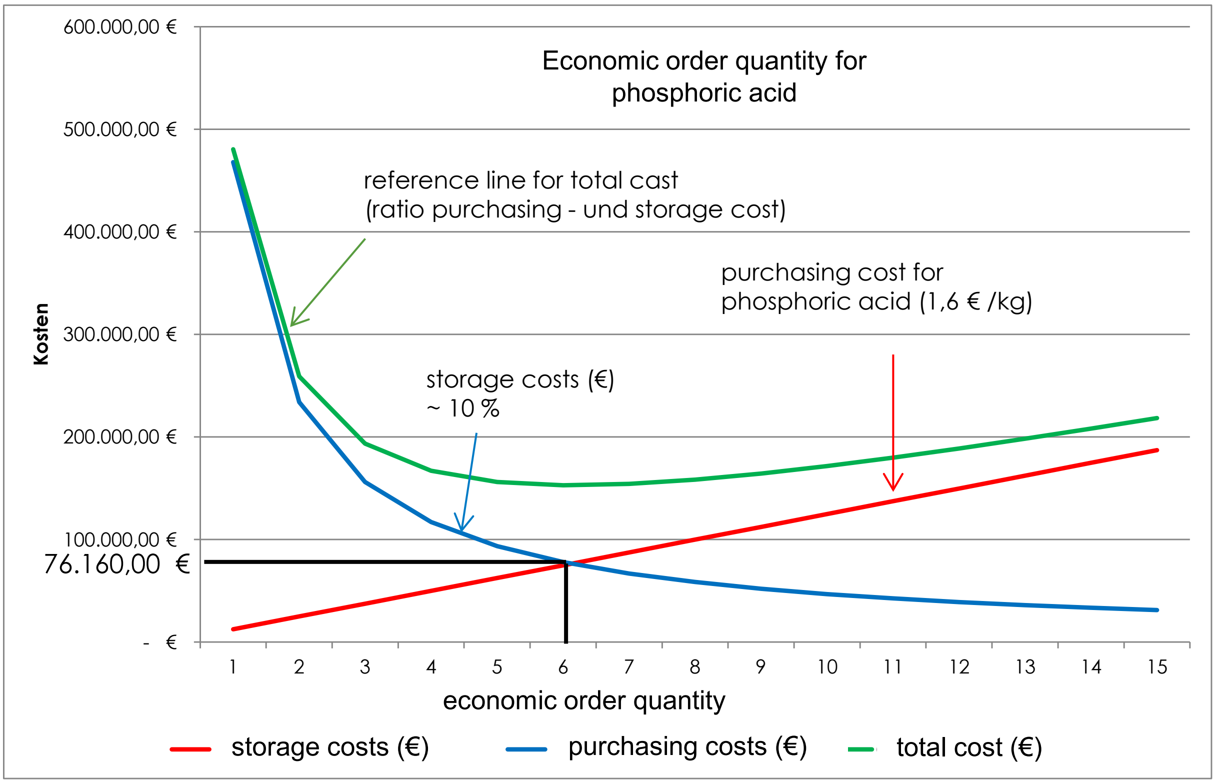


Figure 2-63: Optimum economic order quantity

This calculation is done for all chemicals and materials. The sum is then used to determine the total storage volume needed which will be used for the planning and construction of the storage facility.

2.7 Requirements for health and safety

Plant and operational safety measures are essential cornerstones of responsible plant design. These safety measures are generally based on the following risks and hazards:

- Dangers to human health, e.g., operating personnel and residents
- Hazards to the environment, e.g., emissions of environmentally harmful substances
- Endangering of economic assets, i.e., ultimately dangers for the plant itself or safeguarding of production and thus profitability

One of the ways to ensure the above-mentioned safety measures in a seawater desalination plant is to implement various safety systems and devices in the vicinity of hazardous substances and dangerous machinery during the planning phase. These are explained below:

Chemical emergency systems

In case of accidents with chemicals, all body parts which have been in contact with chemicals must be rinsed thoroughly with clean drinking water. This is done most effectively by using an emergency shower. These can provide around 30L of water per minute and often include a separate emergency eye shower. In the event of contact with chemicals on the eye, an eye-wash must be administered using the eye shower apparat or an eye-wash bottle. Emergency showers should be placed near places where chemicals are stored, handled or transported by operators in large seawater desalination plants. The showers must always be operational and easily accessible in case of an emergency. For this reason, an independent fresh drinking water piping must be connected to the showers. This will ensure that even if the plant's freshwater production is halted, the showers will still be operational for use. The location of the shower and eye-wash should be marked, and the bottles should never be removed.

Figure 2-64: Emergency shower including eye-shower; Right: Emergency eye-wash bottle

Fire-fighting measures

According to national standards and the scale of the building, some elements of fire prevention and fighting systems that should be considered during the planning process include **sprinkler systems**, **fire protection doors**, and **fire alarm systems**.

There should be firefighting equipment available to extinguish minor fires at the plant. Because not all fire extinguishers may be used on every fire, they must be chosen according to their category (A, B, C, or D). Extinguishers must be kept in their designated locations at all times. The use of black and yellow striped tape on the floor to denote the location of extinguishers and other equipment has shown to be effective.

The installation of fire and rescue plans is very crucial in large seawater desalination plants. The fire and rescue plan serves three main purposes:

First: It shows the location of fire-fighting equipment.

Second: It shows the emergency exits and the best way to get there from its location.

Third: It gives the fire-fighters a layout of the facility, when the fire and rescue plan is handed over to them in an event of emergency.

An exemplary fire escape plan is depicted in the figure below.

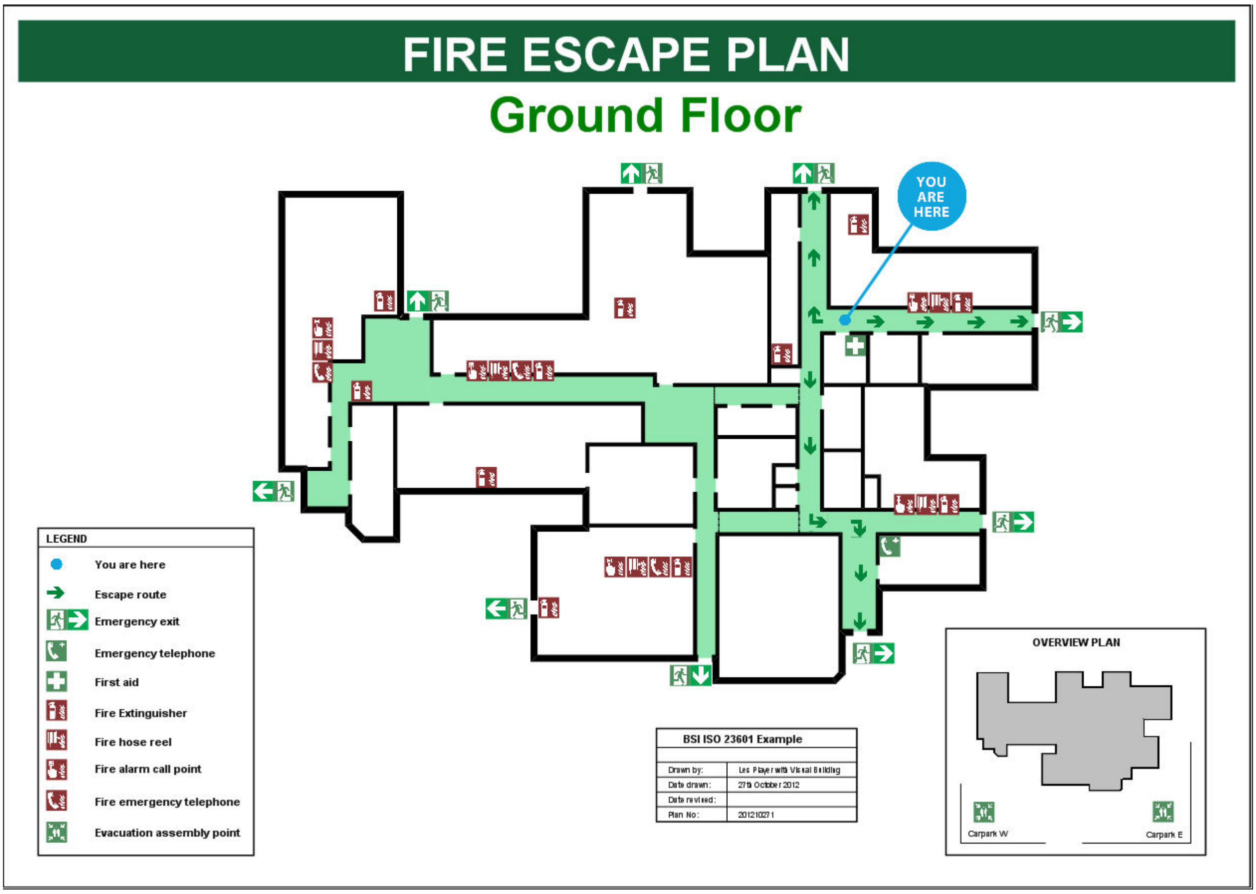


Figure 2-65: Exemplary escape and rescue plan[40]

Electrical emergency systems

[40] https://www.visualbuilding.co.uk/guides/specials/fire-escape-plans

Kill switches, or emergency stops, are a common safety mechanism to shut off machinery in an emergency. Unlike a normal shut-down switch or shut-down procedure, which shuts down all systems in order and turns off the machine without damage, a kill switch is designed and configured to abort the operation as quickly as possible (even if it damages the equipment) and to be operated simply and quickly. Kill switches are usually designed to be noticeable so that every operator or even a bystander can find and operate them. It should be an important criterion during the planning phase for all large machinery which could pose a safety threat to include a kill switch. These emergency stops should never be removed or covered and always be easily distinguishable.

Figure 2-66: Emergency kill switch[41]

Protective covers, or safeguards, block rotating or workers from reaching into otherwise dangerous machinery parts. Often the machinery cannot be started without the protective cover in place. Like kill switches, those safety installations should never be manipulated or removed for easier handling or other reasons.

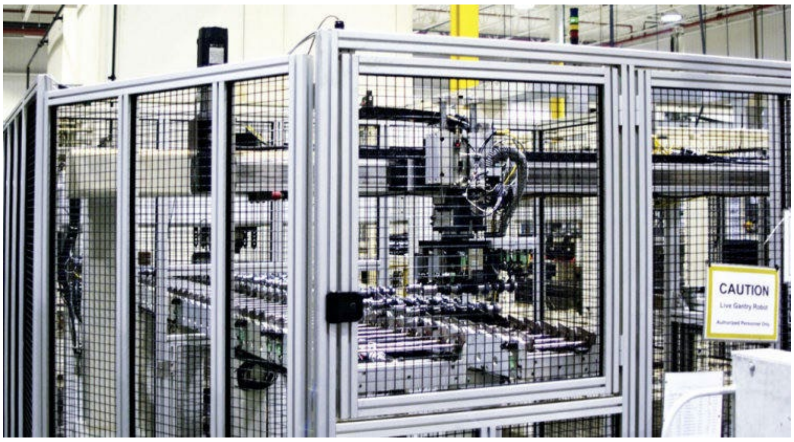


Figure 2-67: Fixed guards make it difficult to access dangerous parts of machinery[42]

There are various other measures that must be taken into account, in particular during the planning phase. These measures are the **Plant Safety Concept** and the **HAZOP-Study**.

[41]https://en.wikipedia.org/wiki/Kill_switch#/media/File:Not-Aus_Bet%C3%A4tiger.jpg
[42]https://www.pilz.com/en-INT/support/knowhow/law-standards-norms/iso-standards/choosing-guards/fixed

Plant Safety Concept

The process engineering department draws up the plant safety concept at most internationally active plant designers in close cooperation with all engineering disciplines and with a dedicated safety department. This also shows that plant safety is of crucial importance and scope for every plant engineer. The final definition of the safety concept is carried out in close coordination with the customer and, if necessary, with the authorities involved in granting the operating license.

Factors influencing the creation of the safety concept include:

- Legal and other local requirements in the place where the plant is built such as noise limits, occupational health and safety requirements
- Requirements arising from the type of the plant or from the raw materials or chemicals processed or produced in the plant
- Contractual requirements for safety, such as guarantees on the availability of the plant

Various measures are available for meeting the required safety criteria:

- Inherently safe process control
- Self-monitored regulation and control of the process within defined and monitored limit values
- Separate safety-related system for plant shutdown via interlocking logics (ESD)
- Separate mechanical safety systems (e.g., safety valves, bursting discs), which lead to safe disposal
- Redundancy of critical systems and voting structure
- Diversity of systems such as stand-by systems or drives with different power supplies
- Fail-safe principle in case of loss of drives or power supplies
- Structural measures such as explosion protection walls, acoustic hoods, enclosures, etc.

Plant safety is ensured by several such nested protection layers, as shown in the figure below. The aim is for the plant to always bring itself back into a safe operating state by self-regulation. The subsequent protection layers take effect only when this is no longer sufficient.

In addition to the dedicated safety department, the safety concept must also be coordinated with the engineering disciplines involved, such as equipment, machinery, instrumentation, electrical engineering, installation planning, piping planning and construction.

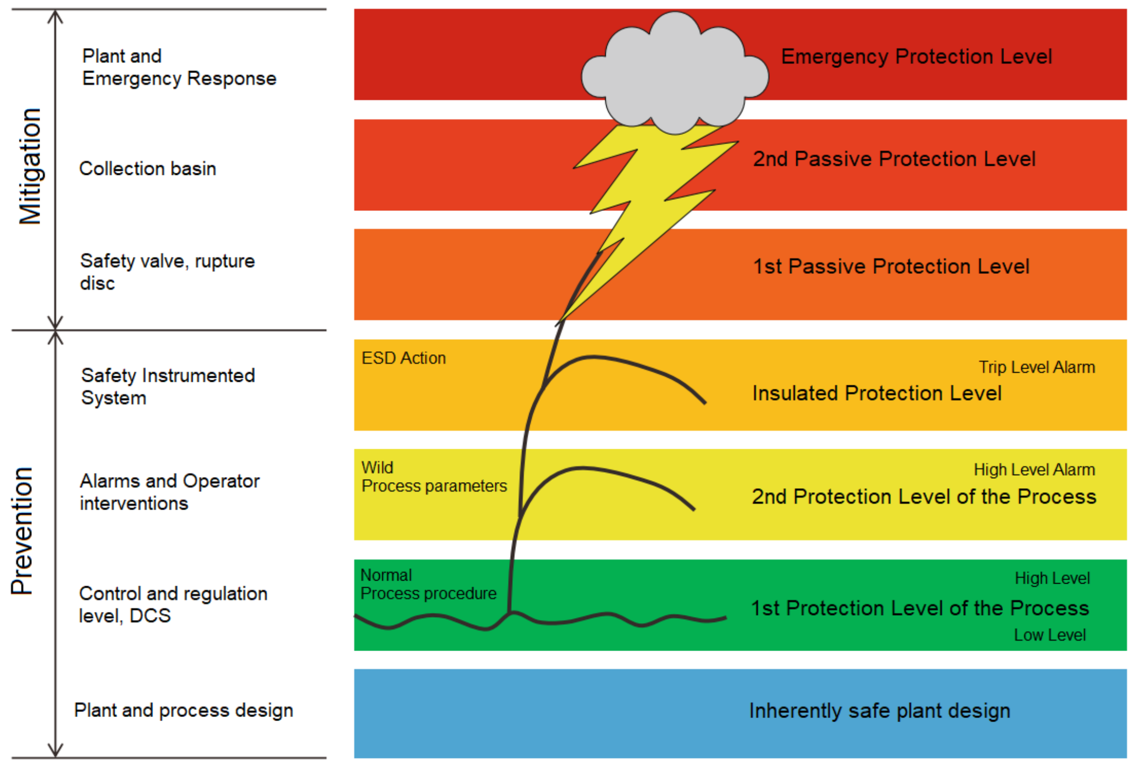


Figure 2-68: Protection layers of a plant[43]

In addition to concept development, the following information is developed here:

- Information about critical components or critical operating states for components
- Information on measures to control the risks and hazards
- Information on safety conditions and effects on further plant planning

The safety concept is developed and pre-agreed in the early phase of the project. It is continuously developed during further project development, and all changes must be documented.

Ideally, a chemical process with the lowest possible hazard potential should be selected from the outset. The primary aim is, therefore, to prevent hazards from arising in the first place. **Inherently safe process control** can be achieved, for example, by chemical processes that run at lower pressure or temperature or by processes whose stable and safe operating point is kept within broader limits and is thus easier and more stable to control.

Hazard and Operability Study (HAZOP)

The Hazard-and-Operability (HAZOP) study is an analytical method to demonstrate the operational safety and operational capability of a plant. The HAZOP study is considered to be Standard procedure for the review of plant design. Based on the plant safety concept developed, it is investigated what happens and how the plant reacts when its operation

[43] Springer Grundlagen der Anlagenplanung Tople 2018

deviates from its target behavior. The following documents are usually required to carry out a HAZOP study:

- Process Flow Diagram (PFD), if available Piping and Instrumentation Diagram (P&ID)
- Description of operation modes

During the HAZOP study, the entire process is systematically evaluated in its sequence against each PDF or P&ID under the guidance of a HAZOP expert (independent consultant or specialist from the plant designer) based on a defined procedure in terms of operability (safety and availability). Results and measures of a HAZOP study are:

- Identification of weaknesses
- Creation of proposals for the elimination of identified vulnerabilities
- Definition of the activity list for completion
- Checking the completion of the activity list
- Discussion of additions and changes compared to the HAZOP study based on manufacturer information
- Making proposals for the elimination of identified vulnerabilities
- Definition of the activity list for completion
- Checking the completion of the list of measures
- Documentation of questions and answers in the HAZOP log as well as red entries in project documents
- Necessary measures

The HAZOP study is usually performed at the end of the Basic Engineering. The results are then incorporated into the documents (e.g., the PFD and P&ID) before processing the Detail Engineering. However, various supplier information and P&ID of suppliers or package unit suppliers are not yet available. Such P&ID will be subject to a separate HAZOP study later when they become available. Changes to P&ID that are HAZOP relevant must be "postHAZOPed", as well as changes to shutdown points on-site or in operation.

The HAZOP study is based on a systematic approach to finding non-obvious causes of disturbances of intended operation. In the HAZOP procedure, four stages are passed through for the analysis, which is defined as follows.

HAZOP study step 1: Prognosis of disturbances

The planned target functions of a system are assumed to deviate from the intended operation. A system or a subsystem of a plant is examined, and a checklist with concrete parameters and keywords is run, and all disturbances or deviations which are conceivable for this system are taken into consideration. Examples of such concrete parameters and keywords are listed in the table below.

HAZOP study step 2: Determination of the causes

From the set of hypothetical disturbances from step 1, the realistic disturbances are determined by asking questions about the causes. Faults for which no possible cause can be found or is conceivable are discarded as unrealistic. What remains are the so-called relevant disturbances. The disturbances identified as relevant are described and documented with their causes. In Table 2-17 some HAZOP-Parameters are presented as an example.

Table 2-17: Example of HAZOP-Parameters and their keywords

Parameter	Key Words
Flow rate	None, too high, too low, strongly fluctuating
Pressure	Too high, too low, vacuum, strongly fluctuating
Temperature	Too high, too low, expansion, strongly fluctuating
Filling Level	Too high (to overfill), too low (to no level)
Other compositions of the Input materials	Aggregate state, impurities, wrong usage of chemicals
Power and auxiliary failure	power failure, electrical energy, cooling water, control air
Machinery failure	Leakage, material selection, dry running of pumps
Incorrect operation	Non-opening or non-closing of fittings

HAZOP study Step 3: Classification of the effects

The effects of the disturbances identified as relevant are assessed and described. In the process, possible countermeasures are initially assumed to be available. The classification of the impacts is done in two categories:

1. Classification as operational disturbance. These only influence the plant condition, the production process, or the product quality

2. Classification as an accident. If the effects pose hazards to people and/or the environment, e.g., because of a release of a hazardous substance, they are considered a serious hazard. An accident can result from an operational disturbance. If the impacts cannot be estimated

and assessed to a sufficient extent, appropriate questions should be formulated and referred to responsible professional engineers or external experts.

HAZOP study Step 4: Identification of countermeasures

Based on the causes found in step 2 and the impacts found in step 3, countermeasures that prevent the operational disturbance and/or its effects are identified and described. Usually, the countermeasures (for example, safety valves, mechanical/automatic interlock, safe plant shutdown) are already in place, and the HAZOP item is thus checked off. However, additional countermeasures are often identified or decided in the HAZOP study, then incorporated into engineering. All countermeasures to prevent incidents must comply with state of the art in safety engineering. As a result of the HAZOP analysis, the results will be specified in the control & interlock description of the plant. Additionally, it should be discussed if an emergency generator is required for the safe shut down of the plant.

2.8 Checklist for Basic Engineering

Table 2-18: Checklist for Basic Engineering

Checklist for Basic Engineering		*Drawn by:* *Checked by:*	
NO.	DESCRIPTION	CHECKED	REMARKS
2.1	**Design of essential treatment steps**		
	a) Have you applied a conservative approach in the design of the pre-treatment?		
	b) Have you designed the desalination to be reliable?		
	c) Is the post-treatment designed to ensure high product water quality?		
2.2	**Creation of Process Flow Diagrams**		
	a) Have you defined the utilities of the desalination plant?		
	b) Have you created PFDs for all utilities?		
2.3	**Determination of battery limits and creation of the layout**		
	a) Have you defined the battery limits in detail?		
	b) Have you created a detailed list and illustrated the battery limits in a schematic view?		
	c) Have you created a rough layout of the plant?		
2.4	**Monitoring requirements and automation**		
	a) Have you defined tasks to evaluate the efficiency of the desalination plant?		
	b) Have you defined the measuring points?		
	c) Have you defined the essetial level of automation?		
2.5	**Selection of adequate materials**		
	a) Have you selected suitable and corrosion-resistant materials depending on the components?		
2.6	**Chemical and spare parts storage**		
	a) Have you considered safety measures for chemical storage?		
	b) Did you consider an extinguishing water retention system and a sprinkler system?		
2.7	**Requirements for health and safety**		
	a) Have you conducted a rough hazard analysis?		

3. Detail Engineering

As shown in Figure 3-1, Detail Engineering is an additional step in planning a SW desalination plant that can be taken after Basic Engineering. The Detail Engineering documents can then be used in the Tendering and Contracting process to compare the bids. The following chapter describes the specifics of Detail Engineering.

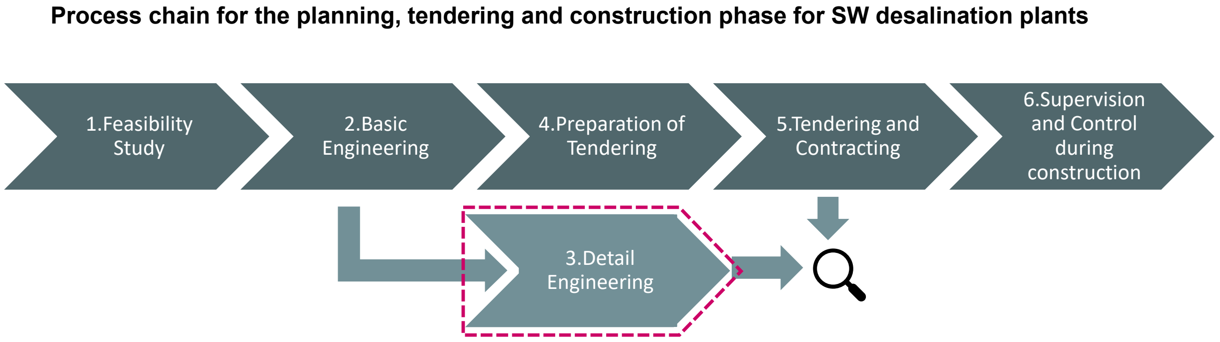


Figure 3-1: Process chain for planning, tendering and construction phase for SW desalination plant - part 3

The degree and the scope of detailed information to be defined within the Detail Engineering can differ in each individual project. Considering the seawater project, there is no need to develop and provide Detail Engineering at the manufacturing level of detail. A manufacturing level would require an unnecessarily high effort and would not be useful for purchasing and contracting purposes. The Detail Engineering provides the necessary information to be used in the evaluation of the submitted bids.

The aim of Chapter 3 is to give an overview of the most important documents that should be provided by the manufacturer. In addition to that, this chapter focuses on the understanding and handling of piping and instrumentation diagrams as well as the revision of the time schedule and the financial model. The basis of Chapter 3 are the results from Chapter 1: Feasibility study and Chapter 2: Basic Engineering.

Detail Engineering for an SWRO plant can be described as follows:

- SWRO Detail Engineering is a set of documents, tables, and drawings that define only necessary detail aspects of an SWRO project development.
- Detail Engineering is a key component for every project development as well as SWRO desalination projects. Detail Engineering is used for the different stages of a SWRO project.
- Detail Engineering for SWRO is one of the typical engineering services which is delivered by international desalination engineering companies.
- Detail Engineering follows the previous step of Basic Engineering.
- It contains, in detail, diagrams and drawings, civil works, instrumentation, control system, schedule of activities, costs, economic evaluation that are developed by the contractor/plant manufacturers.
- The SWRO Detail Engineering is very time consuming and, thus, very costly. Therefore, it shall be carefully tailored for the given SWRO project.

The essential steps for a suitable Detail Engineering can be summarized as follows:

- **STEP 1: Evaluation of the P&ID**
  (→ see 3.1 Development of the P&ID)

- **STEP 2: Define and create the detailed time schedule**
  (→ see 3.2 Detailed time schedule)

- **STEP 3: Calculate the CAPEX and OPEX in detail**
  (→ see 3.3 Detailed financial model)

- **STEP 4: Key documents**
  (→ see 3.4 Key documents)

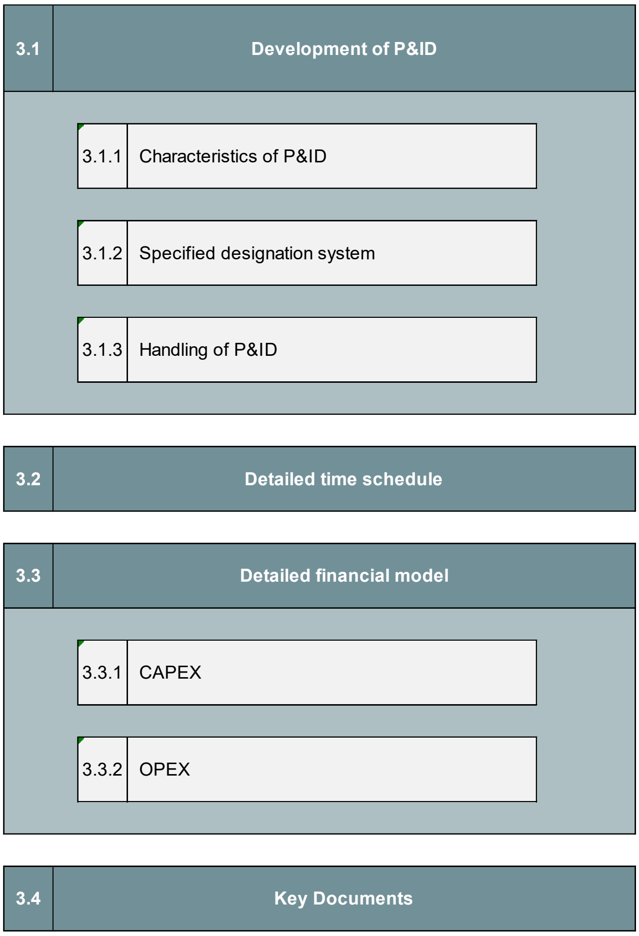


Figure 3-2: Systematic approach to Detail Engineering

3.1 Evaluation of P&ID

Detail Engineering is developed by the determination of detailed characteristic data of the SWRO plant in several steps. Every calculation, determination, and decision within these individual steps influence the next step, but it can also have retroactive effects on previous determinations. An important aspect of the Detail engineering is piping & instrumentation diagrams. They are a key element of communication between all involved parties.

3.1.1 Characteristics of P&I diagram

Piping & Instrumentation diagram (P&ID):

The piping and instrumentation diagram (P&ID) is based on the process flow diagram (PFD). It represents the technical realization of a process by means of graphical symbols for equipment and piping together with graphical symbols for process measurement and control functions.

Compared with the PFD the level of detail has increased further. The P&ID shows the connection of the flow lines, the flow directions, and all the fittings in a pipeline. In addition, connection types such as flange or welded connections can be shown. All pipelines are labelled. The designation of the pipes shows the nominal size (e.g., diameter), the medium, the pipe class, and the insulation (if needed). The P&ID should contain all measuring points of the process, including labelling and all lines of action of control and regulation devices.

The piping and instrument flow diagram is the relevant basic document for pipeline and instrument planning.

The P&ID should contain at least the following basic information:

a. Function or type of equipment, including conveyors and installed spares,
b. Identification number of equipment,
c. Characteristic data of equipment indicated on the drawing or in separate lists,
d. Indication of nominal diameter; pressure rating; material and type of piping,
e. Details of equipment, piping, valves, fittings, and thermal insulation,
f. Process measurement and control functions with an identification number,

The P&ID may also contain the following additional information:

a. Denomination of flow rates or amounts of energy or energy carriers,
b. Route and direction of flow of energy or energy carriers,
c. Type of essential primary elements and sensors,
d. Essential construction materials for equipment,
e. Elevation of platforms and approximate relative vertical position of equipment,
f. Reference designation for valves and fittings,
g. Denomination of equipment,

Due to its complexity, the P&IDs of the different utilities (as defined in chapter 2.2.1) had to be divided into several sub-utilities. As mentioned before, Detail Engineering does not have to be performed at a manufacturing level, this also applies to the creation of P&ID. However, the understanding and handling of such a diagram should be ensured. For this case, the handling of P&IDs will be described in the following chapter along with some examples.

3.1.2 Specified designation system

Norms for graphic representation:

To develop the above-mentioned diagrams and the resulting data sheets, various graphic standards should be observed. In this case, the following norms are essential:

- EN ISO 10628 Diagrams for the chemical and petrochemical industry
  Part 1: Specification of diagrams
  Part 2: Graphical Symbols
- ISO 15519 Specification for diagrams for the process industry
  Part 1: General rules
  Part 2: Measurement and control
- ISO 7268 Pipe components – Definition of nominal pressure
- DIN EN 62424 Diagrams for process measurement control functions

Designation system:

There are different types of designation systems that can be used in Detail Engineering for desalination plants. We present the designation systems according to KKS and to ISO.

KKS:

The power plant identification system (KKS) is a system for the uniform and systematic identification of systems, facilities, and equipment in the electricity and heat supply. The KKS is also used for the designation of processes in process and chemical engineering.

Figure 3-3 shows the principal concept of designation according to KKS.

Serial number of breakdown level	0	1			2			3	
Process designation	Total plant	System designation			Equipment unit			Component code	
Designation of data character	G	F_0	$F_1F_2F_3$	F_N	A_1A_2	A_N	A_G	B_1B_2	B_N
Type of data character	(A) or (N)	(N)	AAA	NN	AA	$N_1N_2N_3$	(A)	AA	NN

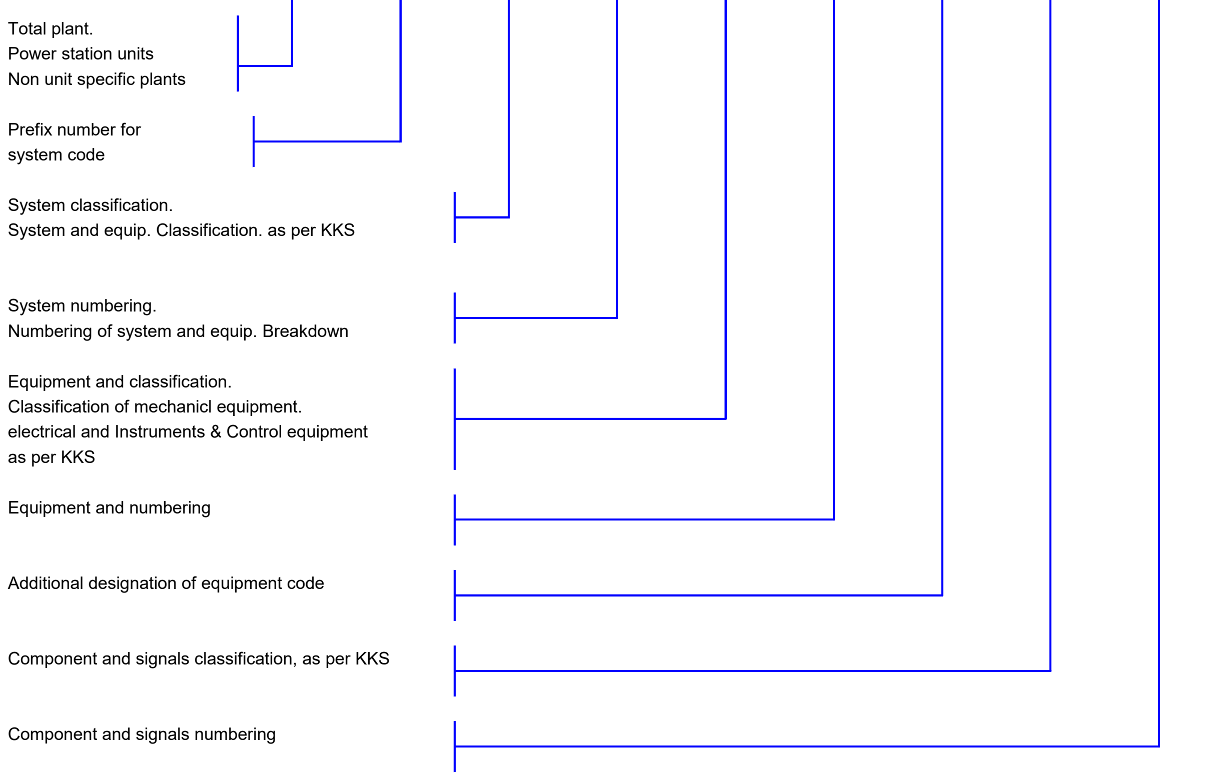


Figure 3-3: Concept of designation according to KKS

The KKS code consists of alpha letters (A) and numbers (N).

With the KKS it is possible to designate

- process-related systems and items of equipment according to their functions in mechanical, civil, electrical, and control as well as instrumentation engineering
- points of installation of electrical and control as well as instrumentation devices in installation units (e.g., cabinets, panels, consoles)
- locations in structures, on floors and in rooms, and of fire areas and topographical determinations (surface area grid)

The code is divided into 4 (0-3) breakdown levels in the process-related code and in 3 (0-2) breakdown levels in the point of installation code and the location code (see Table 3-1).

Table 3-1: Breakdown levels in KKS

ID	Breakdown level (BDL)		0	1	2	3
1	Process-related designation	=	Part of a plant	System code	Equipment unit code	Component code
2	Point of installation code	+	Part of a plant	Installation unit code	Installation space code	
3	Location designation	+	Part of a plant	Structure code	Room code	

In Detail Engineering of desalination processes, it is common to use the process-related designation according to KKS (see Table 3-2).

Table 3-2: Details of process-related designation according to KKS

ID	Breakdown level (BDL)		0	1		2	3
1.1	Process-related designation	=	Part of a plant	System code		Equipment unit code	Component code
1.2	Designation		G	F_0 F_1 F_2 F_3 F_N F_N		A_1 A_2 A_N A_N A_N A_3	B_1 B_2 B_N B_N
1.3	Data character		A or N	(N) A A A N N		A A N N N (A)	A A N N
1.4	Example	:	RO	GDK 01	.	AA 010	GA
1.5	Description	:	Reverse osmosis	G=Water supply D=Treamtent system K=Piping system 01= Number		Valve No.	Gate valve

A = alpha letters
N = numbers

EN ISO 10628:

EN ISO 10628 (Diagrams for the chemical and petrochemical industry - Part 1: Specification of diagrams / Part 2: Graphical Symbols) defines the rules for reference designation systems.

Table 3-3: Hierarchic levels and structure indicators of a designation system according to ISO 10628

Level	Structural element / description	Remark	Structure indicator
1	Site	location-related, unambiguous worldwide	AAA
2	Industrial complex	location-related, unique at one site	XXXX
3	Process plant / Plant unit	object-related	AXNN
4	Subprocess / Plant component / Utility	object-related	AXXN
5	Technical item (technical category of apparatus or process control system item)	object-related	AXNNN
6	Equipment	object-related	XNNNN

The designation system according to IEC/ISO 81346 consists of maximum 6 breakdown levels (see Table 3-4).

Table 3-4: Breakdown levels (ISO designation system)

ID	Breakdown level (BDL)		1	2	3	4	5	6
1	Process-related designation	=	Site	Industrial complex	Process plant / Plant unit	Subprocess/ Plant component / Utility	Technical Item	Equiment
2	Data character		AAA	XXXX	AXNN	AXXN	AXNNN	XNNNN
3	Example	:	AK	SWRO	V1	TRO1	VV 010	SM
4	Description	:	Aqaba	Seawater desalination Plant	Process plant 1	Subystem RO Unit 1	Valve No.	Knife gate valve

A = alpha letters
N = numbers
X = alphanumeric

A system identification structure from 5 or 6 levels can be selected.

Example 1: System identification structure from 5 levels

AAAXXXX_AXNNAXXN_AXNNN

Example 2: System identification structure from 6 levels

AAAXXXX_AXNNAXXN_AXNNN_XNNNN

DIN EN 62424:

DIN EN 62424 establishes a symbol as well as a letter system for depicting basic functions of measurement and control equipment in relation to the plant with which it is associated. The letter code for identification of instrument function and examples is presented in the following table:

Table 3-5: Letter code for identification of instrument functions according to ISO 3511

	First Letter	Succeding letter	
		Inside the oval	Outside the oval
A	Analysis		Alarm
B	Optical measurement	Restriction, limitation	
C	Conductivity	Controlling	
D	Density	Difference	
E	Electrical tension		
F	Flow rate	Fraction	
G	Gauging, position or length		
H	Hand operated		Upper limit value
I		Indicating	
J	Electrical power		
K			
L	Level		Lower limit value
M	Moisture or humidity		
O		Optical display	
P	Pressure of vacuum		
Q	Quantity	Integrating or summating	
R	Nuclear radiation	Recording	
S	Speed or frequency		Switching
T	Temperature	Transmitting	
U	Multivariable		
V	Oscillation/Vibration		
W	Weight or force		
X	freely available variable	freely available variable	
Y	Position specification	Calculation function	
Z			Emergency or safety acting

Examples	
PR 001 AH	Pressure recorder with alarm function in case of too high pressure
LIC 001 AH	Level controller with display and alarm function in case of too high level
PDI 001	Differential pressure indicator
TIC 001 AL	Temperature controller with display and alarm function in case of too low temperature
AI 001 pH	Analytical value indicator (pH)
FC 001	Flow controller

Comparison between KKS and ISO:

Figure 3-4 and Figure 3-5 show examples for a designation of a valve in a technical plant according to KKS and to ISO.

Breakdown level (BDL)	0	1	2	3
Process-related designation	Total plant/ Part of a plant	System code (simplified)	Equipment unit code	Component code
Example	Reverse osmosis	Water supply treatment system	Valve No. 010	Gate valve No.01
KKS	RO	GDK 01	AA 010	KA01

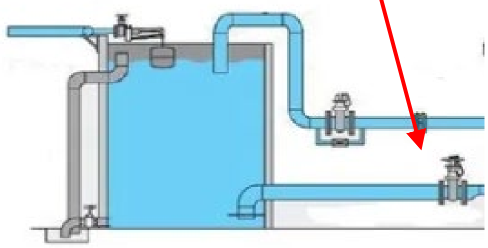
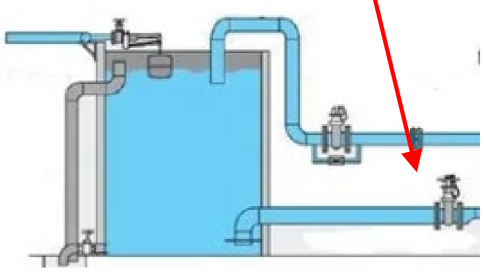


Figure 3-4: Designation of a valve according to KKS

Breakdown level (BDL)	1	2	3	4	5	6
Process-related designation	Site **(can be ignored)**	Industrial complex **(can be ignored)**	Process plant/ Plant unit **(can be ignored)**	Subprocess/ Plant component **(can be ignored)**	Technical Item	Equiment **(can be ignored)**
Example	Aqaba	Seawater desalination Plant	Process plant No.01	Subsystem RO Unit	Valve No. 010	Knife gate valve
ISO	AK	SWRO	V01	TRO1	VV 010	SM



The recommended minimum designation is VV 010

Figure 3-5: Designation of a valve according to ISO

Table 3-6 compares the details and differences between the two designation systems.

Table 3-6: Details and differences of the designation systems

Designation systems according to KKS

ID	Breakdown level (BDL)	-	-	0	1	2	3
2,1	Process-related designation	-	-	Total plant/ Part of a plant	System code	Equipment unit code	Component code
2,2	Data character	-	-	A or N	(N)AAANN	AANNN(A)	AANN
2,3	Example	-	-	RO	GDK 01	AA 010	KA01
2,4	Description	-	-	Reverse osmosis	KKS code G=Water supply D=Treatment system K=Piping system 01= Number	KKS code Valve number AA= valve 010=number	KKS code KA=Gate valve 01= Type 1

A=alpha letters N=numbers X=alphanumeric

Designation systems according to ISO 10628-1

ID	Breakdown level (BDL)	1	2	3	4	5	6
1,1	Process-related designation	Site	Industrial complex	Process plant/ Plant unit	Subprocess/ Plant component	Technical Item	Equiment
1,2	Data character	AAA	XXXX	AXNN	AXXN	AXNNN	XNNNN
1,3	Example	AK	SWRO	V01	TRO1	VV 010	SM
1,4	Description	Aqaba	Seawater desalination Plant	ISO code V= Process plant 01= Number	ISO code T=Subystem RO=RO Unit 1=Number	ISO code Valve number VV=Valve 010=number	ISO code SM=Knife gate valve

A=alpha letters N=numbers X=alphanumeric

The following comparison depicts the advantages and disadvantages of the two designation systems.

Advantages KKS:

- Defined designation systematic from small to complex process plants
- Common designation system for mid-size to big power plant / desalination plant mainly in MENA countries
- Based on the KKS designation system the KKS codes can be exchanged with a defined standard

Disadvantage KKS:

- Specific (and complex) KKS codes

Advantage ISO:

- Breakdown levels can be reduced (only not for level 5: technical item) & codes can be specified according to a defined standard

Disadvantage ISO:

- A defined designation systematic is not given and that may be a problem in case of mid-size to big process plants

After consultation and coordination with GIZ and WAJ, it was decided to use the ISO designation system in the further course of the project. For this example, we only considered the breakdown levels 4 and 5 according to ISO. The following Table 3-7 shows the breakdown of level 4 (utilities) and level 5 (technical item).

Table 3-7: Breakdown levels 4 and 5 according to ISO

ID	Breakdown level (BDL)	4	5
1.1	Process-related designation	Utilities	Technical Item
1.2	Data character	AXXN	AXNNN
1.3	Example	PR01	VV001
1.4	Description	ISO code see utility	ISO code See technical Item

A=alpha letters *N=numbers* *X=alphanumeric*

Table 3-8 and Table 3-9 show the abbreviation lists for the defined utilities and the specified technical items for the example SWRO plant.

Table 3-8: Utilities and their abbreviations

ID	Utilities	Abbreviation
1	Utility pre-treatment	PR
2	Utility desalination	DE
3	Utility post-treatment	PO
4	Utility discharge	DI
5	Utility compressed air high pressure	CH
6	Utility service water	SE

Table 3-9: Abbreviations of technical items

ID	Technical Item according to ISO	Abbreviation
1	Valve	VV
2	Check valve	VH
3	Control valve	VC
4	Tank	VE
5	Pump	P
6	Measuring device Quality	MQ
7	Measuring device pressure	MP
8	Measuring device flow rate	MF
9	Measuring device level	ML
10	Measuring device temperature	MT

The designation of the piping system is presented in Table 3-10.

Table 3-10: Designation system for piping

Piping system overview

ID	Piping Tag no. 1	Description Tag no. 1	Piping Tag no. 2	Piping Tag no. 3	Piping Tag no. 4	Piping Tag no. 5	Description Tag no. 5	Description Tag no. 6	Description Tag no. 7
1	PR	Utility pre-treatment				PE	Welded plastic pipe HDPE 100		
2	DE	Utility desalination				SS	Welded stainless steel pipe		
3	PO	Utility post-treatment				-	-		
4	BD	Utility brine discharge				-	-		
5	TE	Utility technical building equipment	Flowrate m³/h	pressure m³/h	temperature max. °C	-	-	Pipe diameter	Pressure class according to ISO
6	CH	Utility compressed air high pressure				-	-		
7	CL	Utility compressed air low pressure				-	-		
8	DI	Discharge				-	-		
9	BS	Buildung service water				-	-		

After defining the designation system for piping, the data can be transferred into data boxes that can be included in the P&IDs.

Template

Tag no.1	F [m³/h]	Tag no.2
	p [bar]	Tag no.3
	T [°C]	Tag no.4
Tag no.5	Tag no.6	Tag no.7

Example

PR01	F [m³/h]	160
	p [bar]	4
	T [°C]	max. 30
PE	DN200	PN16

3.1.3 Handling of P&I diagram

Basic flow diagrams, process flow diagrams and piping and instrumentation diagrams are generally used for communication between the different parties which are involved in the development planning, installation, and operation of a plant. The P&IDs have the highest degree of detail compared to other diagrams. For this reason, it is important that all parties use the same nomenclature to ensure proper communication.

For this purpose, it is recommended to use ISO 10628 for the designation of apparatus, material flows, instruments, and pipelines. This standard also contains the graphic symbols used in P&IDs and their description. For the measuring and control position, the DIN EN 62424 is used.

The figures below provide a list of symbols that are often used in process engineering, according to ISO 10628. They are divided into different subject groups.

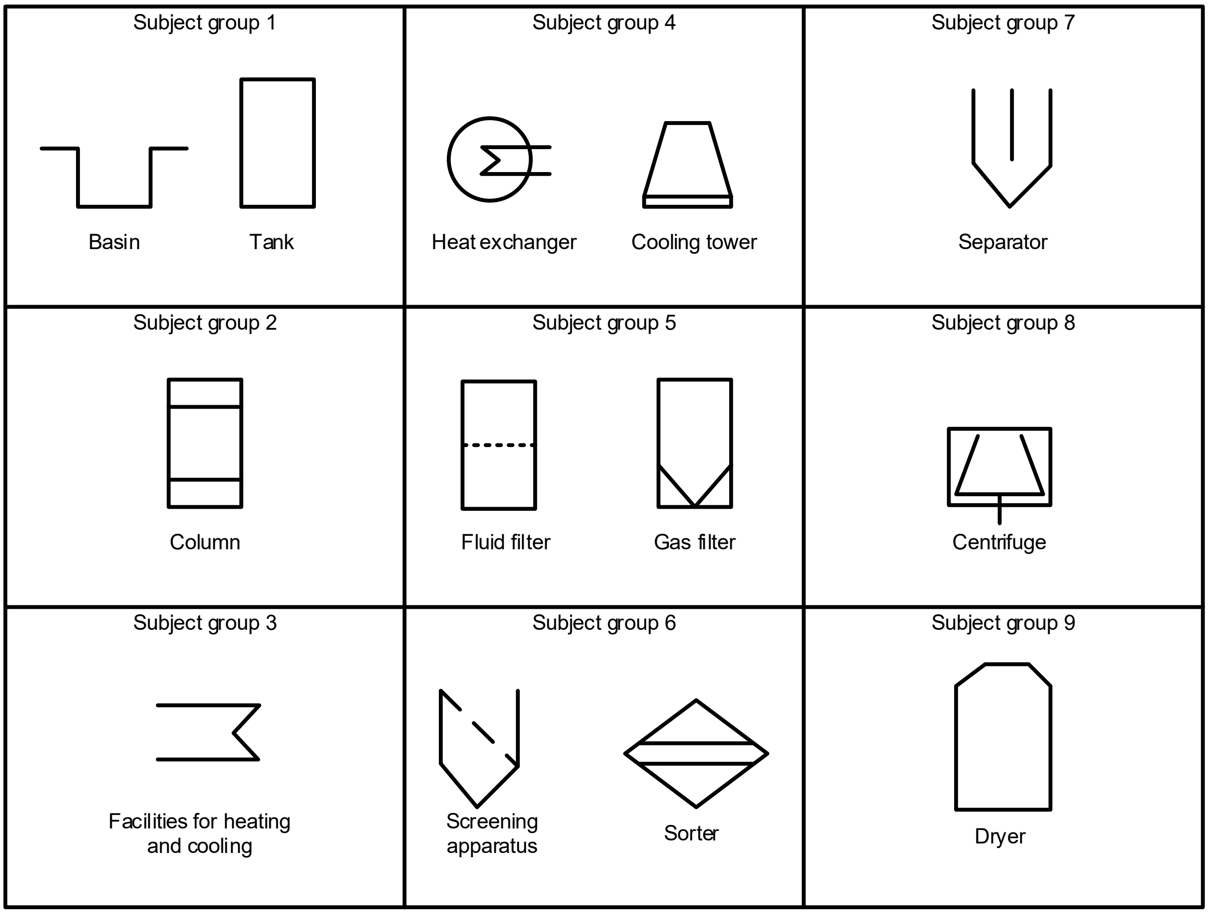


Figure 3-6: Symbols in process engineering according to ISO 10628 (Group 1-9)

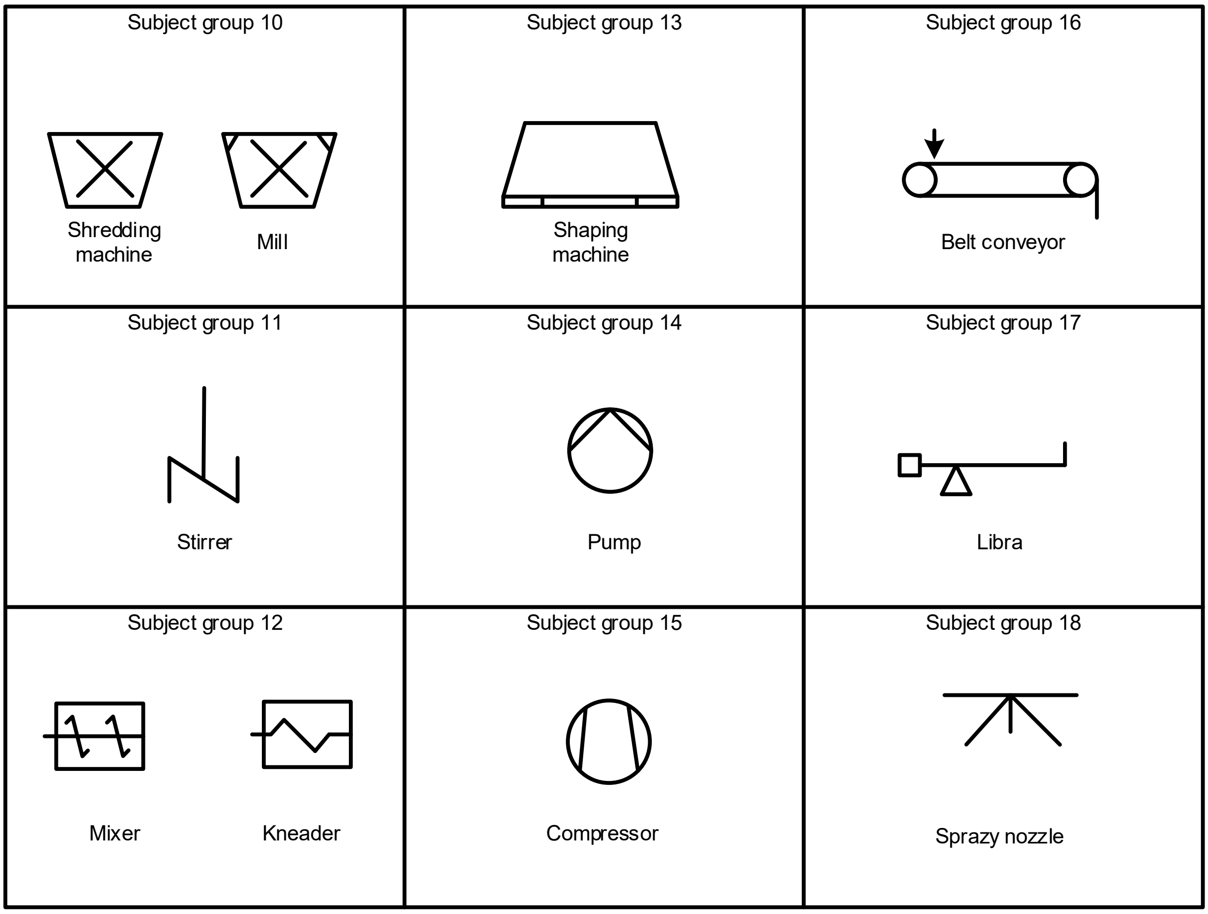


Figure 3-7: Symbols in process engineering according to ISO 10628 (Group 10-18)

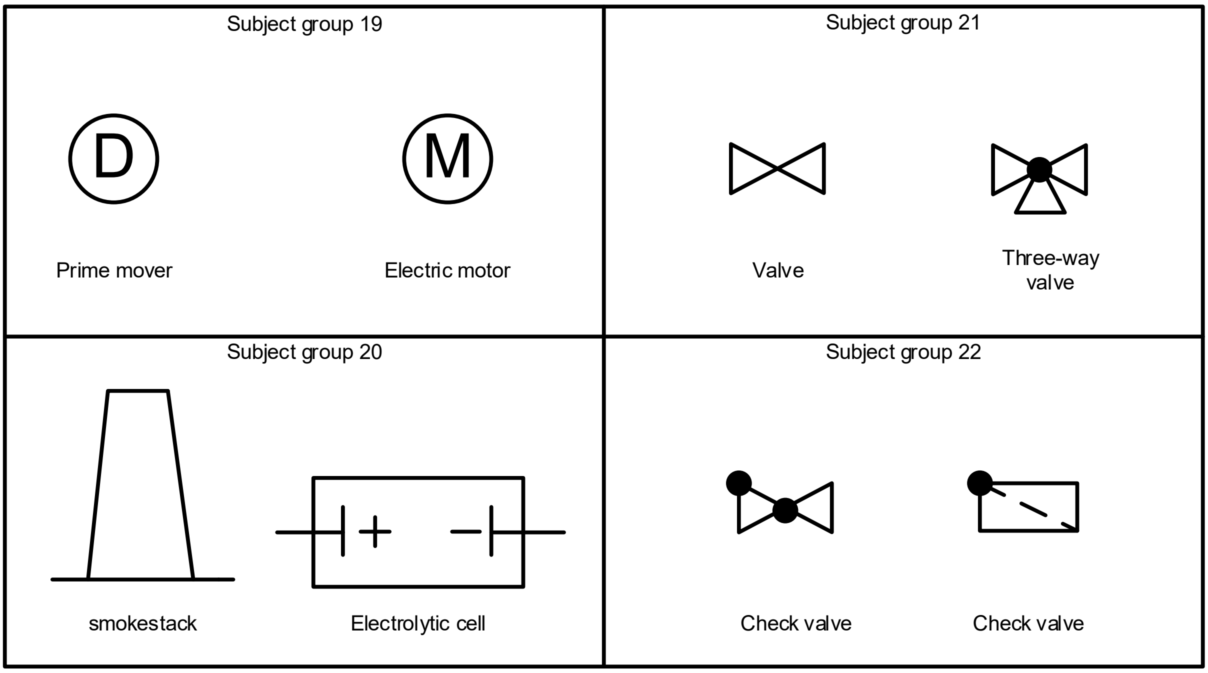


Figure 3-8: Symbols in process engineering according to ISO 10628 (Group 19-22)

As the previously mentioned characteristics of P&IDs show, the diagrams provide plenty of information about the process operation. Basic knowledge of engineering and the depicted processes is required to properly understand and evaluate P&IDs.

The first step in analyzing a P&ID is to become familiar with the input and output flows. This gives an overview of the different material flows and signal lines involved in the process or sub-process. In addition, this provides information on whether the material flow is located within the overall process system or has been supplied from outside. This is especially helpful if material flows are already used in different P&ID sheets from other utilities, so you can understand how the material flow is composed and what its initial properties were. This is shown in Figure 3-9.

Figure 3-9: Example 1 – Input and output flows

At this point, the detailed process design is secondary in order to get an overview of the P&ID. Therefore; Example 1 merely shows the input and output flows. At this point, it must be emphasized that the clear identification of the flows is important. For this purpose, it is helpful to assign unique identifying terms to the flows such as IF01, IF02 etc. Also, a description that identifies the place of origin for incoming flows and the destination for outcoming flows should be included. After gaining a precise overview of the different flows, the detailed process design can be thoroughly analysed. Therefore, two examples and the according to descriptions are provided below.

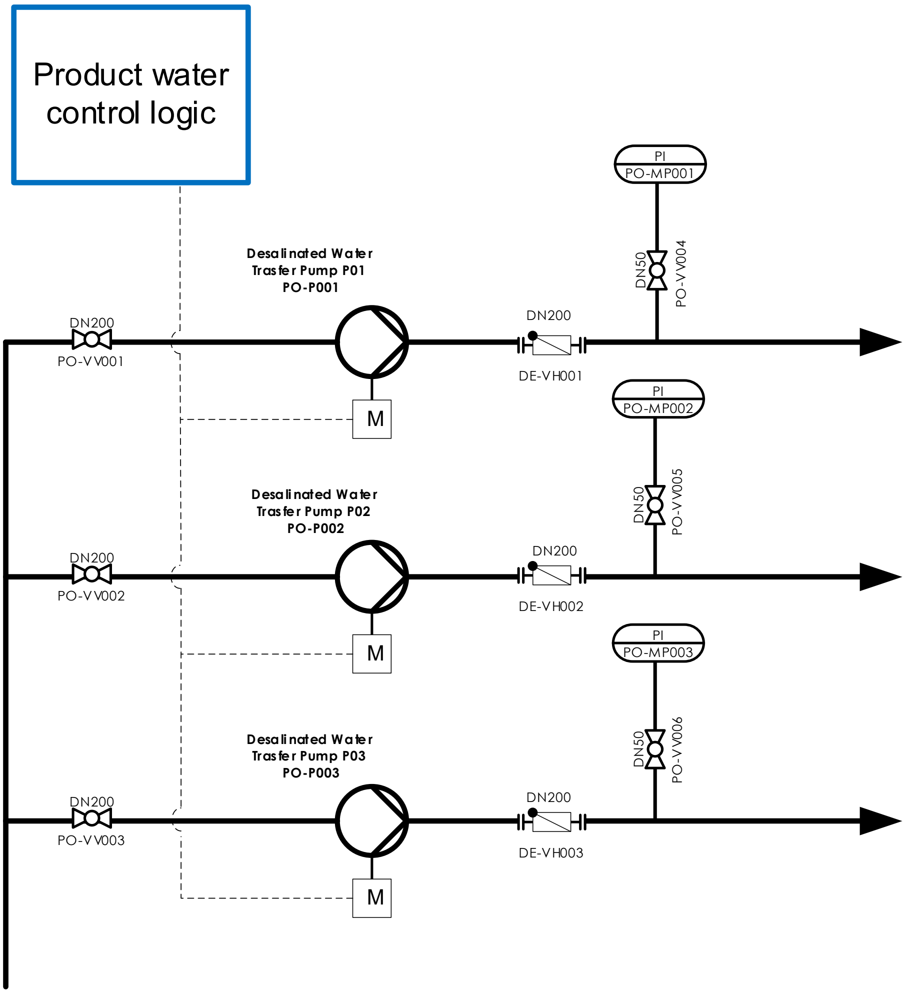


Figure 3-10: Example 2 – Redundantly connected pumps

- **Description Example 2:**

  In the section shown here, three redundantly connected pumps are shown which transport the desalinated water further. Of these three pumps, only two will be in operation while the other one will be used as a reserve for maintenance or repair, thus ensuring continuous operation. Furthermore, a check valve with flanged connections is located behind the pump. This check valve prevents the medium from flowing back. Behind it there is a pressure gauge with an upstream valve. This valve serves the purpose of replacing the gauge in the continuous process. The pumps are controlled by the control unit (here: Product water control logic), which is indicated by the dashed lines. Additional data on the pumps can be found in their technical datasheets, but it is still important to clearly identify the instruments as it is done in the example so that they can be clearly assigned. Also, the valves are labelled and numbered according to ISO 10628, and the nominal diameter is provided as well.

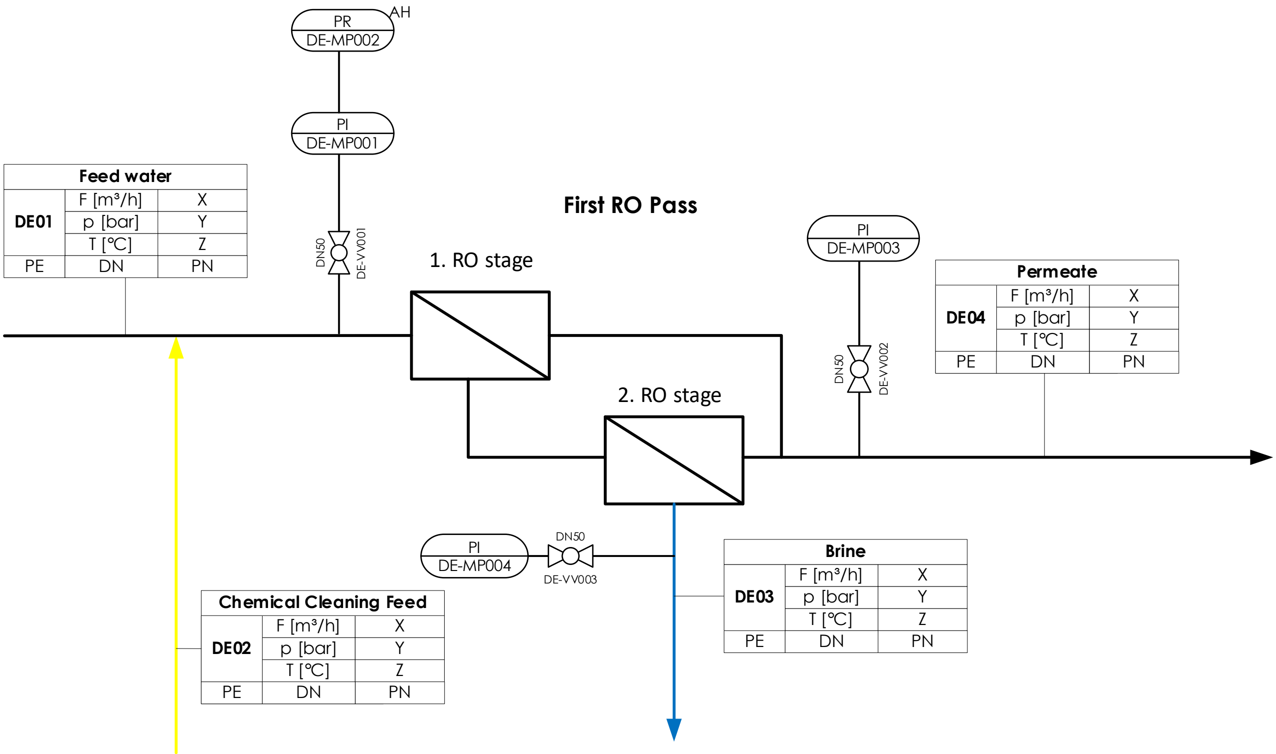


Figure 3-11: Example 3 - RO Pass

- **Description Example 3:**

  In the section of a desalination plant shown here, one can see a two-stage RO Pass in which the feed water stream is separated into two streams, the brine and the permeate. In addition, one can see a stream for a Chemical Cleaning Feed, which is necessary if the RO pass is cleaned. In addition, various pressure measuring points are shown, which are equipped with upstream valves. The shut-off valve connected upstream of the pressure gauges serves the purpose of replacing the gauge during continuous operation. Furthermore, an exact description of the mass flows can be seen as well as information about the pipe diameters. In addition, the various valves and flows are numbered so that they can be clearly assigned and identified in material and component lists.

The examples shown here only show sections of P&IDs of the different utilities. They exemplify the application of the previously described standards and characteristics of P&IDs. The complete scope of P&IDs for all utilities and possible sub-utilities requires more effort to be able to evaluate them. It is even more important that all parties involved use the same labelling, preferably the standards described here. When analyzing P&IDs, one should also use the supplied process description as support as well as other specifications of the individual devices and instruments, which are described separately or are noted on the individual P&IDs.

For the assessment of a P&ID, whether the mapped process can be improved or realized at all, a certain knowledge regarding mass and energy balances as well as safety-relevant aspects is required. Moreover, the state of art should be considered to select the best possible technology. The basic prerequisite is the clear understanding of the P&ID.

3.2 Time schedule

The considered time schedule, which was developed in the feasibility study, must be adjusted, and updated during and after the Detail Engineering and according to the project progress.

The time-influencing factors are highly dependent on the complexity and the scale of the planned desalination project.

Figure 3-12 shows an example of a project time schedule for an SWRO desalination plant according to Detail Engineering.

The timeframe of this project will be approx. three years and three months. Depending on local conditions, the project duration can be shortened or prolonged.

- Pos. 1 / Feasibility study (SW treatment without SW abstraction) (3 months)
  At this point of the planning, the feasibility study is already completed.
- Pos. 2 / Basic engineering (2 months)
  At this point of the planning, the Basic Engineering is already completed.
- Pos. 3 / Approval time (Approval authority) (6 months)
  At this point of the project, the approval time is still ongoing. The timeframe of this position is strongly dependent on the processing time of the approval authority and can vary. The approval process should be started during basic engineering. The following positions in the time schedule do not depend on the approval, but the approval shall be present before submission and awarding.
- Pos. 4 / Preparation of tendering (3 months)
  The preparation of tendering is described in chapter 4.
- Pos. 5 / Preparing tendering documents (Bidders) (3 months)
  The potential bidders get 3 months to prepare and finish their tendering documents if the desired overall project timeframe allows and/or according to special challenges in the project, the given timeframe can be prolonged.
- Pos. 6 / Tendering and contracting (3 months)
  Tendering and contracting are described in chapter 5.
- Pos.7 / Manufacturer design phase
  The manufacturer starts his detailed engineering (3 months)

The position 8 and 9 are discussed in chapter 6.

- Pos. 8 / Construction phase (20 months)
- Pos. 9 / Test runs and training for operators (Plant manufacturer) (3 months)

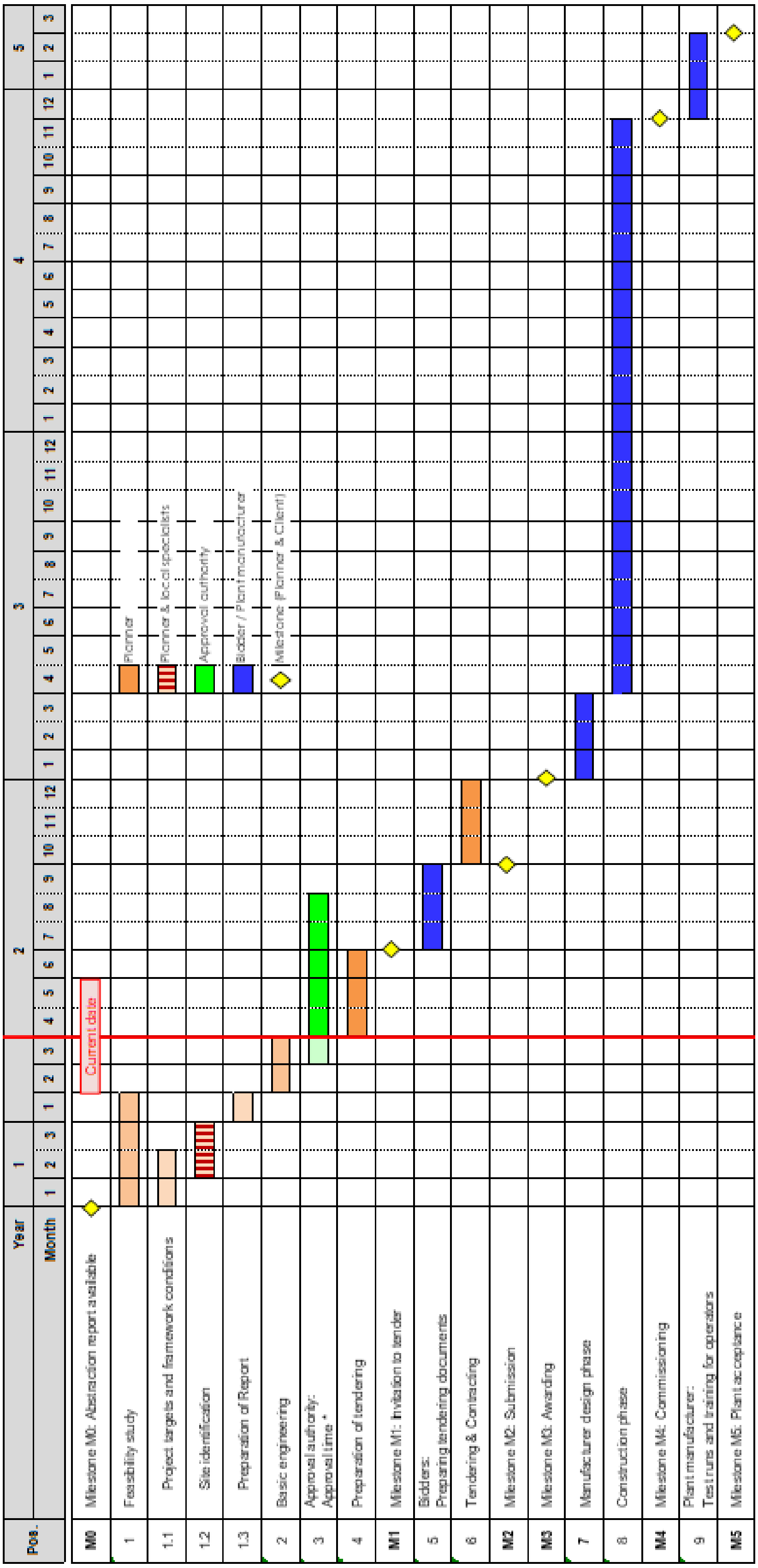


Figure 3-12: Exemplary project time schedule (Each position is to be checked and adapted to the real project)

3.3 Detailed financial modelling

3.3.1 CAPEX

After Detail Engineering, the roughly calculated CAPEX cost from the feasibility study can be adjusted and calculated more precisely. Information from detailed data sheets is used to determine the market prices of the considered components.

Table 3-11 shows an example for the determination of prices. It is recommended to split the CAPEX list into two sections, the direct capital costs and the indirect capital costs. These two sections are subdivided into more specific groups. The estimated costs are calculated for a desalination plant with a two-pass RO system. The plant's capacity was determined at 100 MCM with a yield of 45%, salt content feed 42.000 ppm and an availability of 95%.

Table 3-11: CAPEX calculation

Pos.	Cost-Items	% of Total Capital Cost	Costs ($)
	Direct Capital Costs		
1	Plant Site-Related Construction (Excluding Land Aquestion)	1.5	5,717,825
2	Intake Construction costs	5.5	20,965,359
3	Pretreatement	8.5	32,401,010
4	RO System Equipment	33	125,792,157
5	Post-treatement Costs	2	7,623,767
6	Plant Discharge Costs	2	7,623,767
7	Waste and Solids Management	2	7,623,767
8	Costs of Electrical and Instrumentation System	4.5	17,153,476
9	Costs of Auxilary and Service Equiment and Utilities	1.5	5,717,825
10	Building Costs	3	11,435,651
11	Startup, commissioning, and Acceptance testing	1.5	5,717,825
	Total Direct Capital Costs	65	247,772,430
	Indirect Capital Costs		
12	Preliminary engineering	1	3,811,884
13	Pilot Testing	1	3,811,884
14	Detailed Design	3	11,435,651
15	Construction Management and oversight	4	15,247,534
16	Administration, Contracting	2.5	9,529,709
17	Environmental permitting	1	3,811,884
18	Legal Services	1	3,811,884
19	Interest during construction	3.5	13,341,592
20	Debt services reserve	5.5	20,965,359
21	Other financial costs	2.5	9,529,709
22	Contingency	10	38,118,835
	Total Indirect Capital Costs	35	133,415,924
	Total Capital Costs	100	381,188,355

The CAPEX is generated based on Voutchkov (2019)[7] and on previously gathered experience. This calculation provides an efficient overview of the different cost points and their percentage on the total capital costs. The calculation based on this cost model can vary from 15% up to 50% from the actual cost; after the specification of the required equipment (exact cost and quantification), the accuracy of the calculation increases. However, the calculated price should be compared with the incoming offers during the tendering and award phase. Negotiations with potential suppliers can be very efficient to achieve better prices.

3.3.2 OPEX

After Detail Engineering, the OPEX list from the feasibility study must also be updated. The Operation and Maintenance Costs are divided into two sections, the Variable O&M costs and O&M costs. Each section is divided into more specific groups. In Table 3-12 different cost factors and the assumptions are portrayed.

Table 3-12: Cost factors for OPEX calculation for Detail Engineering

Parameter	Unit	Process data
Plant availability	%	95
Salt content feed	ppm	44,000
Max. salt content permeate	ppm	300
Product water (Permeate)	m³/h	12,016
	m³/d	288,392
	m³/a	100,000,000
Yield	-	0.45
Feed	m³/h	26,703
Brine	m³/h	14,687
Annual operating hours	h/a	8,322
Funding period	a	25
Total interest rate and repayment rate	%	5
Maintenance & repair	-	3% of investment
Insurance	-	0,5% of investment
Cost of personnel	$/person/a	20,000
Staff	person	75
Chemicals and additives	$/m³	0.03
Replacement of membrances and cartigde filters	$/m³	0.02
Electrical energy	kWh/m³	3
Energy Mix Renewable	%	25
Energy Mix Grid	%	75
Total electrical consumption	kW	36,049
Electrical energy consumption Renewable	kW	9,313
Electrical energy consumption Grid	kW	27,938
Electrical energy costs Grid	$/kWh	0.12
Electrical energy costs Renewable	$/kWh	0.03
Waste disposal	$/m³	0.017

The estimated costs are calculated for a desalination plant with a two pass RO system. According to the given information, the OPEX was calculated and is represented in Table 3-13.

Table 3-13: OPEX calculation

Pos.	Cost-Items	% of Total O&M Costs	Costs per year ($)
	Variable O&M Costs		
1	Total Electrical energy	58.4	30,225,000
1.1	Electrical energy Renewable	4.5	2,325,000
1.2	Electrical energy Grid	53.9	27,900,000
2	Chemicals	5.8	3,000,000
3	Replacement of membranes and cartridge filters	3.8	2,000,000
4	Waste stream disposal	3.3	1,700,000
	Total Variable O&M Costs	71.3	36,925,000
	Fixed O&M Costs		
5	Personnel costs	2.9	1,500,000
6	Insurance	3.7	1,905,942
7	Maintenance & Repair	22.1	11,435,651
	Total Fixed O&M Costs	28.7	14,841,592
	Total O&M costs	100.0	51,766,592

Table 3-14: Total costs of a SWRO plant

Total cost calculation				
Plant capacity:	**12,016 m³/h**	**Operating time:**	**8,322 h/a**	
Daily production:	**288,392 t/d**	**Dist. production:**	**100.00 MCM/a**	
Funding period	**25 a**			
1.	**Investment costs**	**I**	**381,188,355**	**$**
1.1	Direct Capital Costs	I_m	247,772,430	$
1.2	Indirect Capital Costs	I_r	133,415,924	$
2.	**Total annual capital costs**	C_{totl}	**27,046,250**	**$/a**
3.	**Fixed O&M costs**	C_{fix}	**14,841,592**	**$/a**
4.	**Variable O&M costs**	C_{var}	**36,925,000**	**$/a**
5.	**Total annual O&M Costs**	$c_{fix+var}$	**51,766,592**	**$/a**
6.	**Total annual costs**	C_{total}	**78,812,842**	**$/a**
7.	**specific product water costs**	C_p	**0.788**	**$/m³**

According to Table 3-13, the main source of costs is the required energy. It is useful to take this into account at the beginning to negotiate efficient deals with energy suppliers. In addition to that, decisions concerning energy provision should be made early in the process, so that potential sources of renewable energy cam be taken into account. Even though this might increase the investment costs, it should be a cost-effective solution in the long term.

In Table 3-14 the total calculation according to the OPEX and CAPEX calculation is given. The annual costs summarize to $78,812,842. This leads to water production costs of 0.788 $/m³ for product water. In the tendering process, the calculated OPEX can be compared with the data of the incoming offers.

In this case, the calculated water price is a good reference value for comparing different offers during the negotiations.

3.4 Key documents

The following list provides important documents which ought to be delivered by the manufacturer.

- The detailed process, civil, mechanical, electrical environmental, control and instrumentation design of the desalination plant, including heat and mass balance and P&IDs and electrical one-line diagrams
- The process description
- The drawings, documents, calculations, etc., required for the Construction of the desalination plant
- The detailed layout and site plan
- Detailed plant design datasheet
- List of auxiliaries and spare parts
- Detailed technical specifications
- A detailed time schedule

4. Preparation of tendering

As shown in Figure 4-1, preparation of tendering can begin after the basic engineering has been completed. The following chapter describes the step of preparation of tendering in detail.

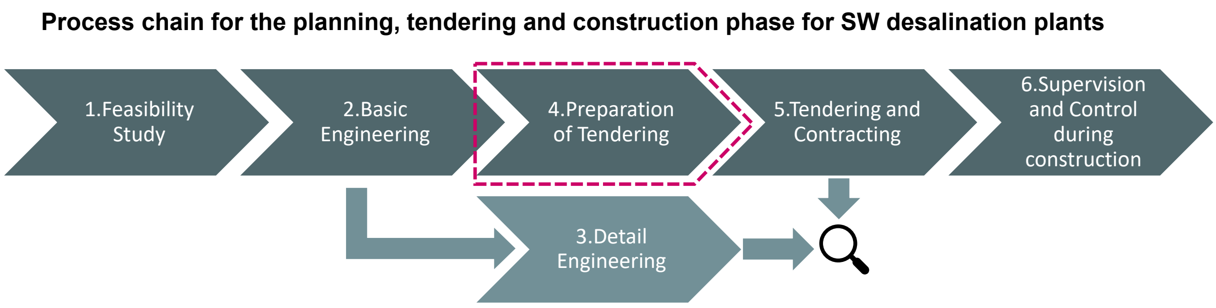


Figure 4-1: Process chain for planning, tendering and construction phase for SW desalination plant - part 4

Before starting the tendering process, the whole project must be defined as described in the previous chapters. The tendering process must be prepared carefully to be able to approach national and international bidder companies, depending on the project's specific needs for contracting.

The aim of Chapter 4 is to provide information that leads to market-oriented tendering documents to obtain offers for reasonably priced desalination plants. The basis of Chapter 4 is the results from Chapter 1: Feasibility study and Chapter 2: Basic Engineering.

The essential steps for successful preparation of the tendering process can be summarized as follows:

- **STEP 1: Understand and define the objectives of market-oriented tendering**
  (→ see 4.1 Objectives of market-oriented tendering)

- **STEP 2: Clarify the involvement of the private sector in the desalination project**
  (→ see 4.2 Involvement of the private sector in desalination projects)

- **STEP 3: Define warranty criteria and specific penalties for the project**
  (→ see 4.3 Definition of warranty criteria)

- **STEP 4: Compile the basic essential documents from the previous planning stages such as the feasibility study and basic engineering**
  (→ see 4.4 Compilation of basic documents from previous planning stages)

- **STEP 5: Prepare the market-oriented tendering documents using the documents that were developed from the feasibility study and the basic engineering**
  (→ see 4.5 Preparation of market-oriented tender documents)

Figure 4-2 shows the approach for the systematic preparation of the tendering process.

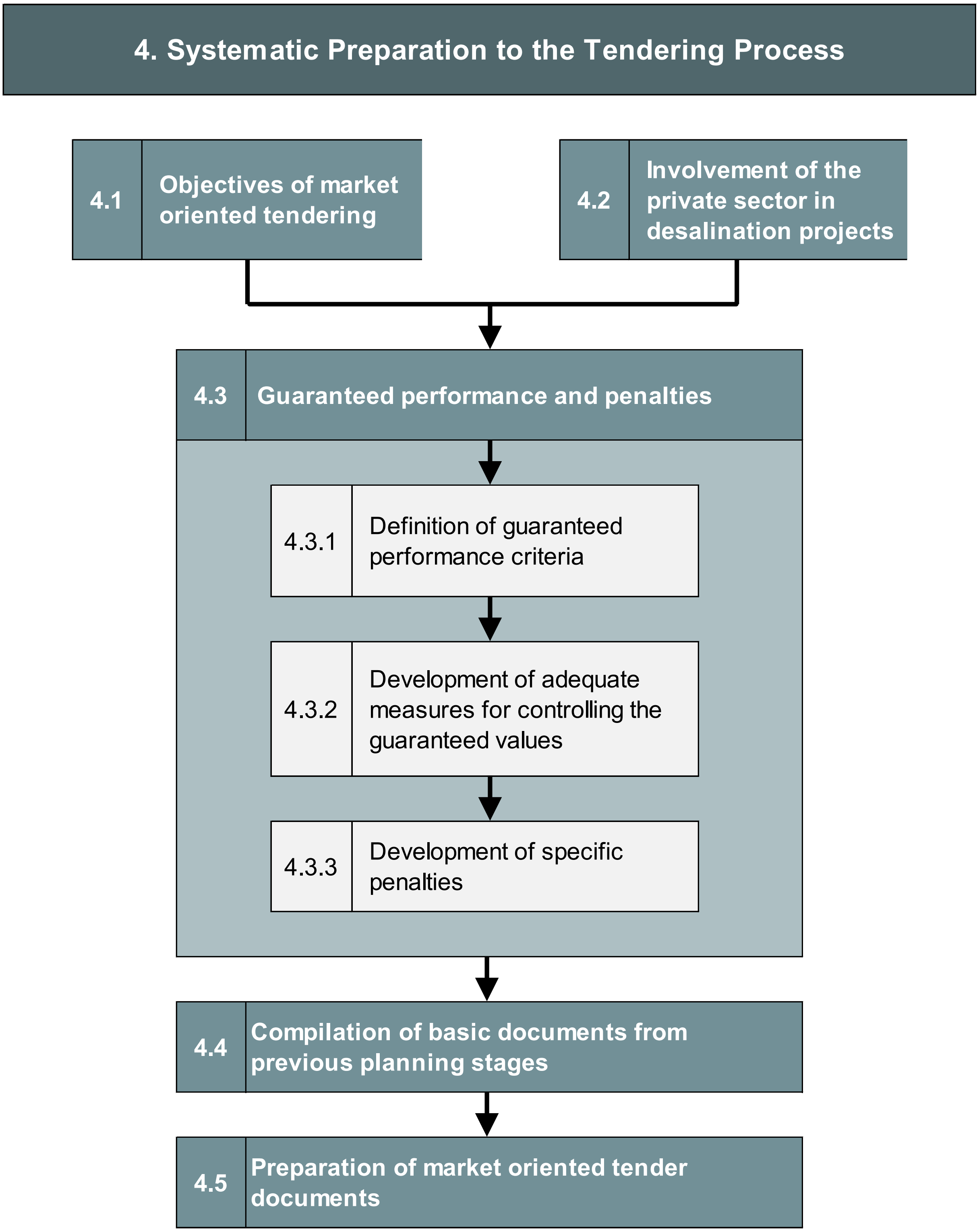


Figure 4-2: Systematic Preparation of the Tendering Process

4.1 Objectives of market-oriented tendering

First, the following objectives are part of the tendering philosophy and must be defined in writing. To achieve a market-oriented tender, the up-to date technology and prices as well as their availability on the local market must be applied to all required equipment, materials, and services in all project planning phases, from the feasibility study through basic and detail engineering to the tendering process itself.

The market orientation will help to increase the acquisition capability of the required plant, equipment, materials, and services and reduce the risks of off market prices and possible unavailability.

- **Objective of the tender:**
  Based on the results of dedicated planning – as a minimum the completed feasibility study and the basic engineering - the potential bidders are requested to propose their most reasonable and competitive bids for the desalination project.

  Assessment of the success:
  A high number of tender-based bids are placed by the eligible bidders in the relevant market with their best prices and reasonable conditions.

- **Objective of the contracting:**
  Based on the evaluation results of the tendering and the negotiations with the bidders, the legal responsibilities, and rights of both contact parties must be fixed to ensure the project objectives by the valid and applicable procurement laws.

  Contract conclusion:
  A successful tendering process results in the conclusion of the procurement contract that can legally secure the project objectives and covers any possible deviation from the initial agreement.

- **Way to success:**
  Apply the "market orientation" to all required equipment, materials, and services through all project planning phases, from pre-feasibility study to basic and detailed engineering, including the tendering. Market orientation will help to diminish a deviation from the realistically planned purchases of equipment, materials, and services and reduce the risk of their non-availability and unnecessary high prices.

The common law of business usually expressed as **"you get what you pay for"** is the principle that one cannot pay a little and get a lot. Paying a low price will not guarantee that the buyer will receive a product of high-quality value. In other words, a low price of goods or services may indicate that the producer compromised quality.

This quote is often attributed to the British artist and poet John Ruskin. It is stated here as written by Ruskin. Or simply, **"you get what you pay for."**

The common law of business balance can be easily understood by the dependence from CAPEX & OPEX of a desalination plant over the years of operation shown in Figure 4-3.

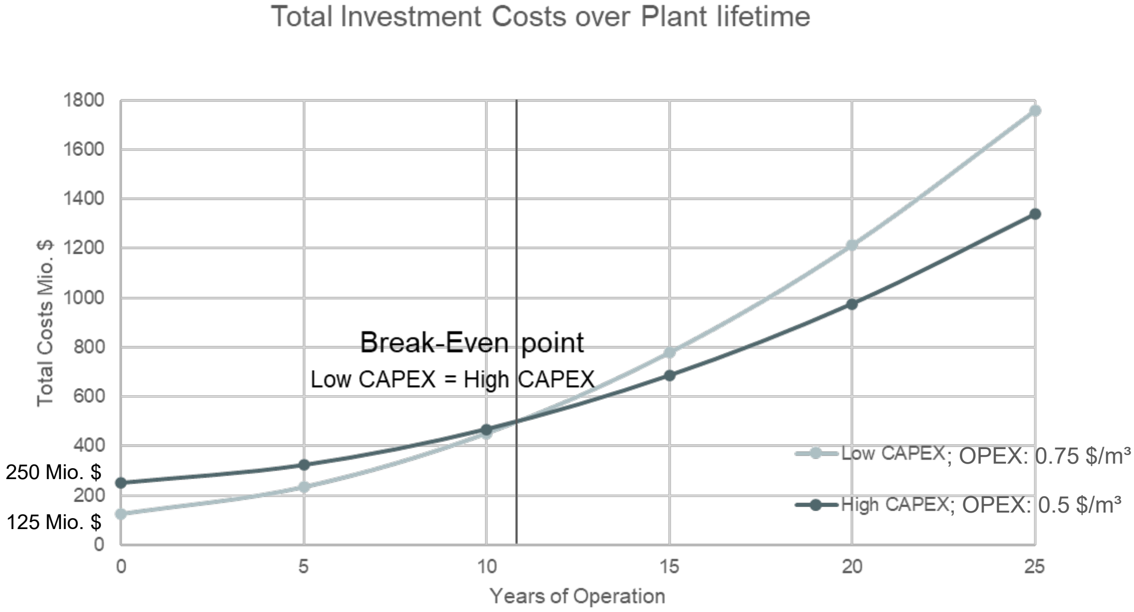


Figure 4-3: Total Cost over Plant Lifetime - Dependence from CAPEX & OPEX - example

An example calculation of two cases is compared in Figure 4-3. The low CAPEX curve is an example of a cheap desalination plant that starts with an investment of 125 Mio. $ and causes costs of 0.75 $/m³ in water production due to higher operation and maintenance costs. As an example, for an expensive desalination plant, the high CAPEX curve starts with an initial investment of 250 Mio $, doubling the investment costs of the low CAPEX curve. Due to the higher investment costs, materials and components with high quality and a higher degree of automation are implemented. The OPEX is lower than the cheap desalination plant with 0.5 $/m³.

According to the common law of business, the cheap desalination plant has a higher total lifetime cost than the desalination plant with a higher initial investment. This should always be considered in the tendering and contracting process, even when a donor organization is supporting the CAPEX investment.

Take Away Messages – Objectives of market-oriented tendering:

- “Market orientation" must be applied to all required equipment, materials and services in all project planning phases from the feasibility study to the tendering process
- Apply the common “law of business” to the tendering and contracting processes, be aware of the fact that a low price of a good may indicate that the producer compromised quality and that in the long run low prices may be more expensive..

4.2 Involvement of the private sector in desalination projects

Integrating private companies in infrastructural desalination projects has vast advantages for increasing operational efficiency and reducing supply risks. In addition, outsourcing the engineering and management services can pave the way to bring new international experience and technologies to the country. Before preparing the tender documents, the type of involvement of the private sector must be clarified. This involvement also influences the framework of the overall strategy for the operation and the management of desalination plants.

In general, it is a good approach to identify synergies between the private and public sectors. A cooperation between private and public sector parties can be very fruitful in the development of the water sector and, specifically, the sector of desalination. The involvement of stakeholders from different branches, such as the contractor's union, engineering union, private sector companies, consulting firms, academia (research institutions) and public sector entities in discussions and consultations strengthens learnings through the exchange of knowhow in a sustainable way. It is advisable to establish a joint committee as shown in Figure 4-4.

Figure 4-4: Joint Committee for the enhancement of the Jordan water sector

Joint extensive consultation sessions, workshops, and discussions should be held to identify and find means to mitigate the risks and challenges faced by both the private sector and WAJ. Such risks include access to secured finance, contractual concerns, acceptable and bankable contracts, qualifications of contractors, investment incentives, and capacity building needs.

A joint committee could organize such meetings, draw conclusions, and decide on the roadmap for the Jordanian desalination sector.

4.2.1 Insight into contractual choices when dealing with private sector companies

There are many ways to involve private companies within the lifetime of a seawater desalination project. In the following, the terms "employer" and "contractor" will be used to distinguish between the contractual parties taking responsibility for the realization of desalination projects, according to the definition by the International Federation of Consulting Engineers (FIDIC).

Employer according to FIDIC:

Employer means the person named as "employer" in the contract data and the legal successors in title to this person.

Contractor according to FIDIC:

Contractor means the person named as "contractor" in the letter of tender accepted by the employer and the legal successors in title to this person.

The most relevant contract types that are internationally used are listed in Table 4-1 below. The contract types clearly define the roles and responsibilities of the employer and the contractor. These contract types cover the responsibility fields of the constructors from the employer's perspective, such as providing engineering services, the construction, the operation, and the ownership of the desalination plants.

Table 4-1: Responsibilities of the contractor with regards to the contract types

Contract Type	Engineering services	Construction	Commissioning	Operation	Financial risk for investment	Owner during the term of the contract	Owner after the term of the contract
D&B	X	X					
TC	X	X	X				
EPC	X	X	X				
DBO	X	X	X	X			
B(O)OT	X	X	X	X	X	X	
BOO	X	X	X	X	X	X	X

Decision tree for the selection of a suitable contract type

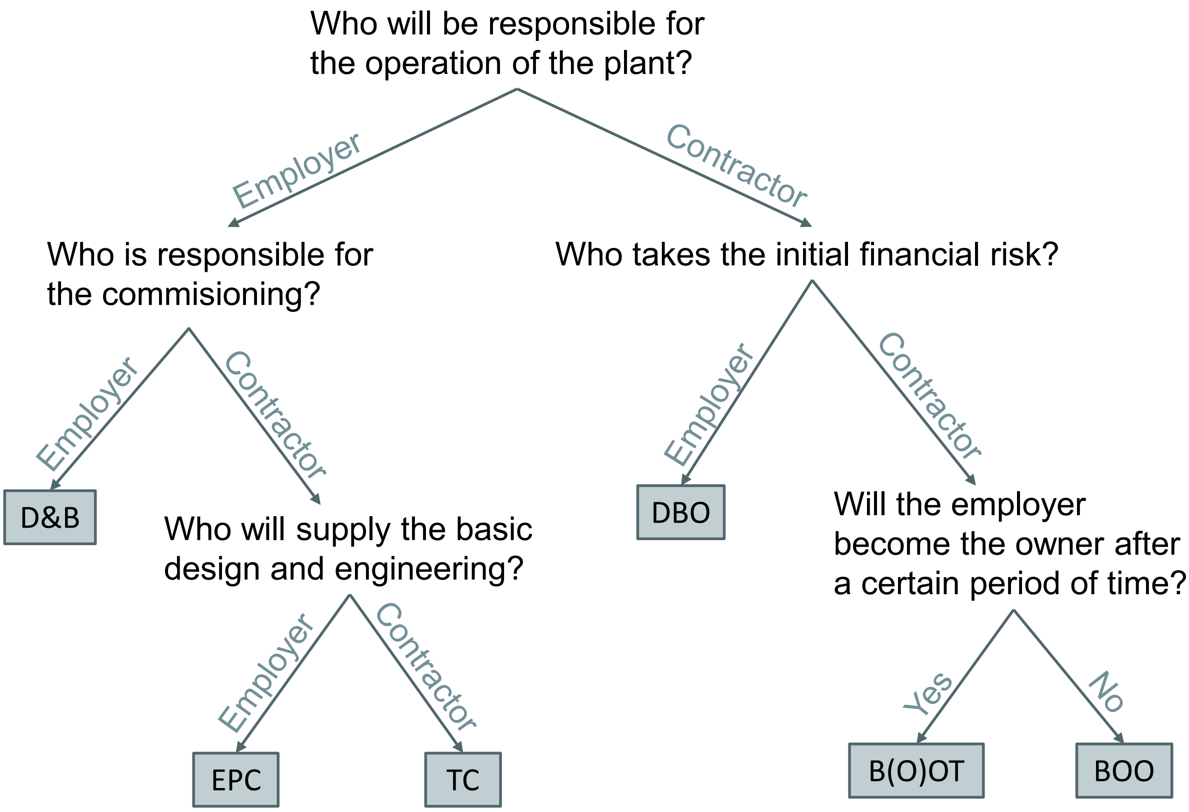


Figure 4-5: Decision tree for the selection of a suitable contract type

All contract types shown in Table 4-1 and Figure 4-5 can be distinguished into contract types that exclude the operation by the contactor and contract types that include the contractors' operation (Management Contracts).

Turnkey Contracts (TC) are contract types that exclude the operation of the desalination plants by the contractor. They can be described as follows:

- Design & Build (D&B) contracts have internationally served as the basis for the configuration of international TC contracts. In D&B contracts, the customer has to approve the design before the construction starts. The major drawback of D&B contracts is that the commissioning of the installation is not included. Therefore, the employer must ensure smooth commissioning and stable trial operation. The contractor must not cover this risk. Hence, D&B contracts do not cover requirements for a desalination plant entirely, so contract types such as TC, EPC, and BOT were developed.

- In Turnkey Contracts (TC), the development and construction of the design are carried out parallelly. The contractor is responsible for designing, building, and commissioning the desalination plant based on the technical specifications provided by the customer. The increased responsibility of the contractor in TC offers some advantages like faster development by parallel engineering and construction and the reduction of communication needs between the employer and the contractor.

- Engineering Procurement and Contracting contracts (EPC) are very similar to turnkey contracts (TC), and often there is no distinction made between them like in the "Silver Book" (contracting conditions for EPC/TC) by the International Federation of Consulting Engineers (FIDIC), published in 2017. The actual difference between the two contract types is that, in the EPC, the customer (employer) provides basic engineering to the supplier (contractor). The supplier develops a detailed design based on the provided basic engineering. In contrast, in the TC, the supplier (contractor) accomplishes both basic and detailed engineering.

Within EPC and TC, there is the possibility to regulate the payments via Open Book Estimation (OBE), which is helpful to ensure that a competitive price is obtained especially when tendering is not possible. In OBE, the contractor expenses are covered by the employer. An agreed additional margin is paid that serves as profit margin for the contractor. In this approach, a high-cost control is ensured to avoid paying a potentially too high lump-sum price. In case a percentage calculation for the profit margin is applied, the motivation for cost saving measures is reduced as in this case the profit margin would also be reduced. Therefore, the profit margin should be fixed.

Description of contract types that include the operation of the desalination plants (Management contracts) by the contractor:

- In the water sector, the Design-Build-Operate (DBO) contract is a widely used contract type. The development and construction and the operation of the desalination plant lie in the contractor's responsibility. The capital investment responsibility lies with the employer.

- The Build-Operate-Transfer (BOT) contract is also a well-known contract type that has been used mainly in large-scale desalination plants. In contrast to the DBO, the employer agrees to pay the contractor for a previously agreed water capacity instead of providing the major part of the total investment after the commissioning of the plant. This has the disadvantage that the employer, unlike in DBO contracts, has to pay a commercial water rate for possible overcapacity and is possibly sensitive to exchange risks if the currency is not a world currency. In a BOT, the facility is handed over to the customer after a pre-determined period of operation (usually between 10-20 years).

- A Build-Operate-Own (BOO) contract is similar to the BOT contract with one difference that the customer (employer) will not become the owner of the plant after a defined time.

An offtake agreement for the product water is a key element during the execution of a project with a BOT or BOO contract. It is recommended that such an agreement incorporates a clear and bankable risk allocation mechanism.

The main elements of the offtake agreement to be considered are[44]:

- take or pay mechanism
- non-insurable events, or events beyond the control of the developer, should be covered by the off-taker
- transparency regarding macro-economic risks (exchange rates, inflation, electricity price, and fluctuation in base interest rates)
- dispute resolution, compensation, termination, and step-in rights.

The large-scale desalination projects in Israel are successful examples for Build-Operate-Transfer (BOT) contracts. This contract type ensures that the employer purchases all water produced by the plant for a fixed price. The overproduced water quantities are used for groundwater recharge (MAR, Managed Aquifer Recharge). The income is invested in the operation and maintenance of the plant, paying the lender, the energy costs and the operator's income [45].

Checklist for the selection of the most suitable contract type:

- Determine the overall strategy whether the operation of the desalination plant shall be in the responsibility of the employer or the contractor.

  Operation in the employers responsibility → EPC/TC contracts

  Operation in the contractors responsibility → DBO/BOT/BOO contracts

- Determine the financing structure and where the risk of the investment whether the employer or the contractor shall take the risk for the initial capital investment

  Employer takes the initial financial risk → EPC/TC/DBO contracts

  Contractor takes the initial financial risk → BOT/BOO contracts

4.2.2 Suitable contract types for seawater desalination projects

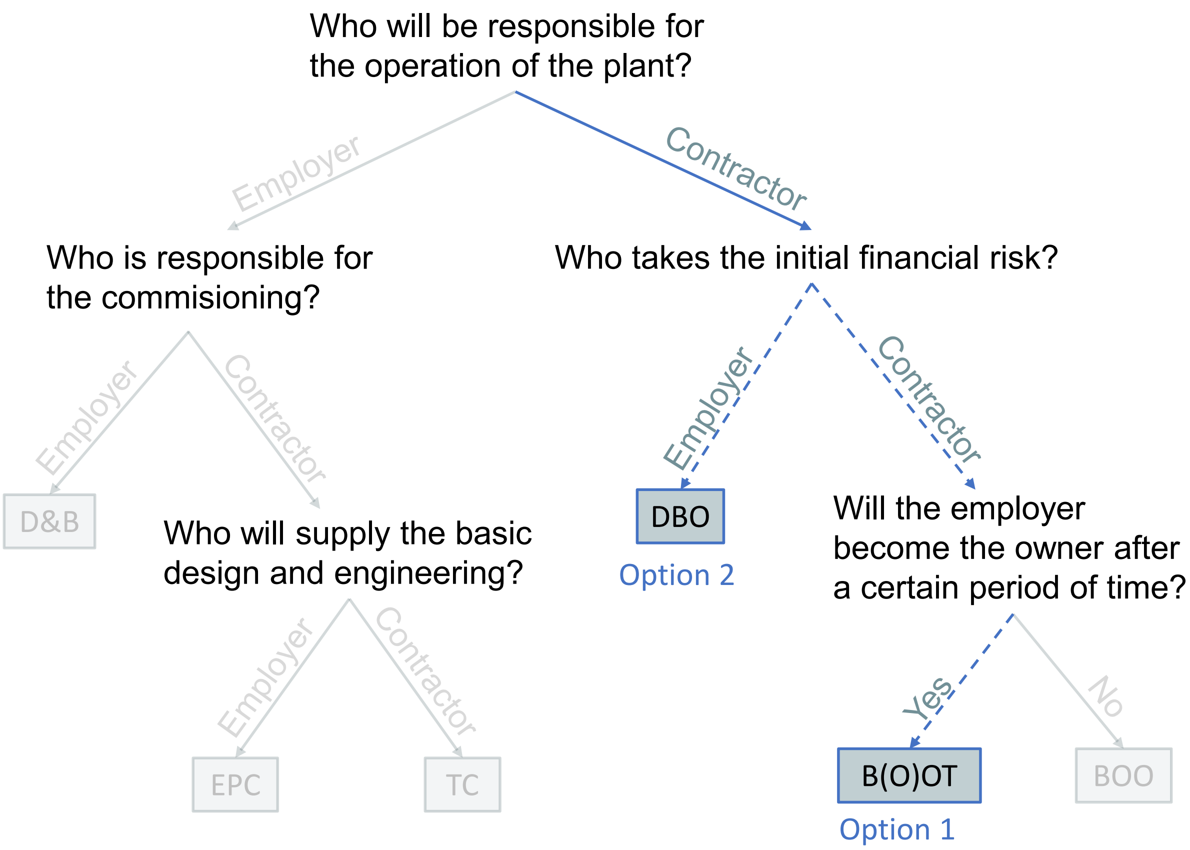
For large-scale seawater desalination projects (SWRO), the involvement of national and international private companies in the projects has the advantage, for Jordan, that international know-how and technology trends are brought into the country. Thus, MWI, WAJ, and the universities can expand and consolidate existing and new knowledge to take a leading expert position in desalination. Management contracts such as BOT can be a practical approach to ensure a proper plant operation and knowledge transfer. Large-scale desalination systems are

[44] Implementation of built-operate -transfer schemes: obstacles & solutions, Authors: F. Lokiec, R. Meerovitch

[45] Public–Private Partnerships in the Water Sector: The Case of Desalination, Authors: Robert A. Greer , Kyungsun Lee, Amanda Fencl , Gretchen Sneegas

highly interesting to international companies as they can receive BOT contracts facilitating a constant cash flow over around 25 years.

Two possibilities could be advantageous to contract large-scale desalination plants in Jordan.



- **Option 1 – B(O)OT contract:**
  In this case, the initial financial risk lies with the contractor, who is also responsible for the operation of the plant. The employer agrees to purchase the desalinated water for a previously agreed-upon water rate. After about 25 years, the ownership of the plant is transferred to the employer.
- **Option 2 – DBO contract:**
  In the case of DBO, the contractor is also responsible for operation, but the employer takes the financial risk. Therefore, the employer does not have to pay the guaranteed water rate for potential overproductions, and the exchanges risks are reduced.

Take Away Messages – Contractual choices when dealing with private sector companies

- The integration of private companies within infrastructural desalination projects has vast advantages regarding higher operational efficiency and reduction in supply risks.
- Contract types clearly define the roles and responsibilities of the employer and the contractor.
  - Determine the financing structure and the risk of the investment: is the employer or the contractor responsible for the risk of the initial capital investment

4.3 Guaranteed performance and penalties

The supplier (contractor) must ensure during the construction phase that the desalination plant is complete and ready for operation. Additionally, the desalination plant must be:

- operationally capable and
- safe within the delivery limits, which meets:
- all start-up and shutdown,
- operating and standstill requirements and
- all hazards arising from the operation of the plants.

The technologies must correspond to state of the art at the time the delivery contract comes into force, whereby all details must be optimally coordinated with each other in terms of function and economy and together represent a uniform whole. In addition, the supplier must comply with and fulfill all regulations and requirements to be observed. Finally, the supplier must ensure the quality and suitability of the delivery with regard to material, construction, machining, production and execution of the assembly.

Within the operation phase of the desalination plant the supplier must ensure to reliably deliver the agreed water quantities with the assured quality to the point of delivery.

What is the employer's task at this point?

Before preparing the tendering documents, it is essential to

- define the guaranteed performance indicators, and
- develop measures to ensure that the supplier complies with the specified criteria

But how to ensure and verify that the supplier provides the guaranteed services?

- **STEP 1: Define the guaranteed performance criteria**
  (→ see 4.3.1. Definition of guaranteed performance criteria)

- **STEP 2: Develop adequate measures and tools to control the supplier**
  (→ see 4.3.2. Development of adequate measures for controlling the guaranteed values)

- **STEP 3: Develop specific penalties**
  (→ see 4.3.3. Development of specific penalties)

The definition of these criteria is, of course, not sufficient. They must also be clearly and comprehensibly incorporated into the tender documents and the contractual work scope.

4.3.1 Definition of guaranteed performance criteria

Guaranteed performance of the plant

The **quality and quantity of product water** are the essential indicators of the performance of the seawater desalination plant. The contractor must guarantee that daily as well as monthly and annual water quantities are delivered. Therefore, it is essential to define a designated delivery point, where the water quality and quantities are measured. That designated delivery point shall also be decisive for possible claims in legal proceedings. The contractor shall be entitled to increase daily quantities in case that there was a shortfall so that he is able to meet the monthly and annual total quantities. These temporary increases should not be significant, as these are unplanned increases that can put a strain on the water supply system.

However, they are not the only essential values that should be guaranteed to ensure the plant's lifetime. The most critical indicators for warranty obligations in addition to the ones stated above are shown in Figure 4-6.

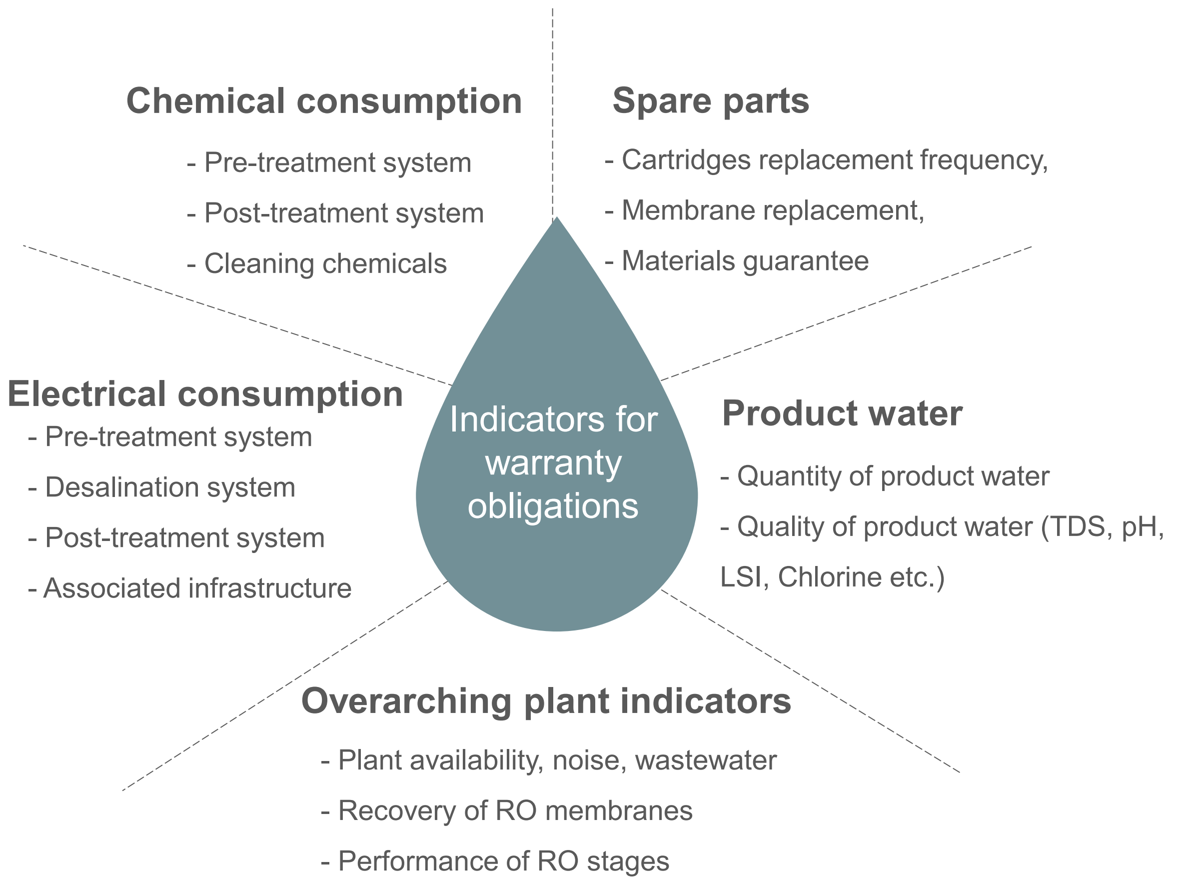


Figure 4-6: Most important indicators for warranty obligations

The description of the leading SWRO plant performance indicators is below.

- **Electrical consumption:**

As energy (electricity) takes a large portion of the operation cost of any desalination plant, guaranteeing electricity consumption is very important. Otherwise, the actual specific water production cost of the plant cannot be controlled.

The power consumption guarantee can often be stated as a "Specific Energy Consumption", defined as kWh/m3, which includes all power consumed from the raw water pumps through to the final water storage tank.

- **Membrane replacement:**

  RO membrane elements are expensive and are one of the most significant cost factors in the RO plant consumables. Therefore, guaranteeing the membrane replacement percentage or yearly replaced membranes is crucial. This ensures the proper selection of the membrane type and quality and is an indicator of the soundness and efficiency of the pre-treatment units. Furthermore, the contractor shall guarantee that all the reverse osmosis membranes give the proper flow and quality for five years from the start-up.

  A standard manufacturer's membrane performance guarantee will include 100% replacement in the first 12 months and thereafter a pro-rated amount till the end of 3 years. The specified annual replacement rate should not exceed 15%.

  On large projects, manufacturers will entertain extension of the warranty period to 5 years under specific operating conditions.

- **Micron cartridges replacement frequency:**

  Although the cartridges themselves are usually not expensive, replacing them frequently will be a significant cost factor in the desalination plant consumables. Furthermore, the frequent exchange of cartridge filters leads to higher effort in storing and managing the effort of the plant personnel. Therefore, guaranteeing the cartridge replacement frequency is very important. This ensures the proper selection of the micron filter and cartridge quality and is an indicator of the soundness and efficiency of the pre-treatment units.

  The contractor may include a relatively safe replacement rate. such as no more than once every two months, if required to do so.

- **Pre-treatment chemical consumption:**

  The types and dosing rates (quantity) of pre-treatment chemicals should be guaranteed as well. These chemicals are crucial for the proper operation of the desalination plant. Therefore, their selection and consumption play a significant role in the integrity of the plant's performance. Poorly selected chemicals – quality and quantity - will have devastating effects on the RO plant membranes and performance and their significant share in the operation costs. These chemicals are:

  - the antiscalant,
  - anti-oxidant,
  - disinfectants such as chlorine (either liquid or gas),
  - acid,
  - caustic,

- coagulants and
- flocculants.

- **Cleaning chemicals:**
  The frequency and quantity of the cleaning chemicals used in the cleaning of the RO plant should be guaranteed as well.

- **Post-treatment chemical consumption:**
  Post-treatment chemicals quantity and types should also be guaranteed as they play a significant role in the final quality of the treated water. Any mistakes will affect the water quality, the upstream structures such as pipes, pumps, and tanks, and the impact on the cost. Such chemicals are used for disinfection of water, correcting pH, ensuring the stability of the product water, and sometimes demineralization is needed.

- **Spare parts list:**
  The recommended spare parts for the plant operation and their quantities should also be guaranteed to enable proper spare parts management. The scope of the spare parts should be capable of guaranteed plant availability over the year.

- **Water quality after pre-treatment before the RO desalination unit:**
  The water quality after the pre-treatment and before the RO-system should be guaranteed and monitored (pH, SDI, Iron, Turbidity and free Chlorine)

- **Recovery of RO membranes:**
  The water recovery of RO membrane elements also needs to be guaranteed to estimate and evaluate the plant's overall performance.

- **Performance of RO stages:**
  On large desalination plants, the employer may request that the performance of each stage of RO be guaranteed separately.

- **Materials guarantee:**
  The contractor must guarantee the material durability of the main components according to the terms stated.

Guarantees (indicators for warranty obligations)			
No	Description	Unit	Value
1	**Electricity Consumption**	kWh kWh/m^3	
2	**Membrane element replacement**	Pc /year % of total	
3	**Cartridge replacement**	Qty frequency	

Guarantees (indicators for warranty obligations)			
4	**Chemicals**		
	Anti-scalant / type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Anti-oxidant / type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Pre-treatment Chlorine / type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Pre-treatment Acid /type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Pre-treatment Caustic / type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Coagulant	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Flocculant	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Post treatment acid - type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Post-treatment Caustic / type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	Re-mineralization - type	Dosing rate in ppm kg/m³ or l/m³ kg/year or l/year	
	CIP chemicals	kg/m³ or l/m³	

Guarantees (indicators for warranty obligations)			
		kg/year or l/year	
5	**RO Recovery – overall**	%	
	First Pass RO Recovery	%	
	Second pass RO recovery	%	
6	**Pre-treatment water Quality** Turbidity SDI Fe pH Chlorine	 NTU mg/l mg/l	
7	**Effluent water quantity**	m^3/h	
8	**Overall Effluent water quality** TDS pH LSI Chlorine Turbidity …etc	mg/l mg/l NTU	
9	**Noise level**	dB	
10	**Overall wastewater**	% and m3/h (where backwash waste volume cannot be discharged at an uncontrolled rate)	

Take Away Messages – Definition of warranty obligations and the guaranteed performance:

- Set guaranteed performance indicators for plant operation
- Define a designated delivery point that is decisive for possible claims in legal proceedings
- Define indicators for warranty obligations that will be combined with specific penalties in the tendering documents

4.3.2 Development of adequate measures for controlling the guaranteed values

In the tendering documents, sufficient measures for controlling the guaranteed values must be defined. The essential steps and milestones are shown in Figure 4-7. Such a graph should be created and incorporated into the tender documents.

In a BOT contract, the initial financing risk lies with the contractor. Therefore, the contractor risks financial consequences if the guaranteed values are not met. However, the employer can still apply measures to have control over the commissioning process.

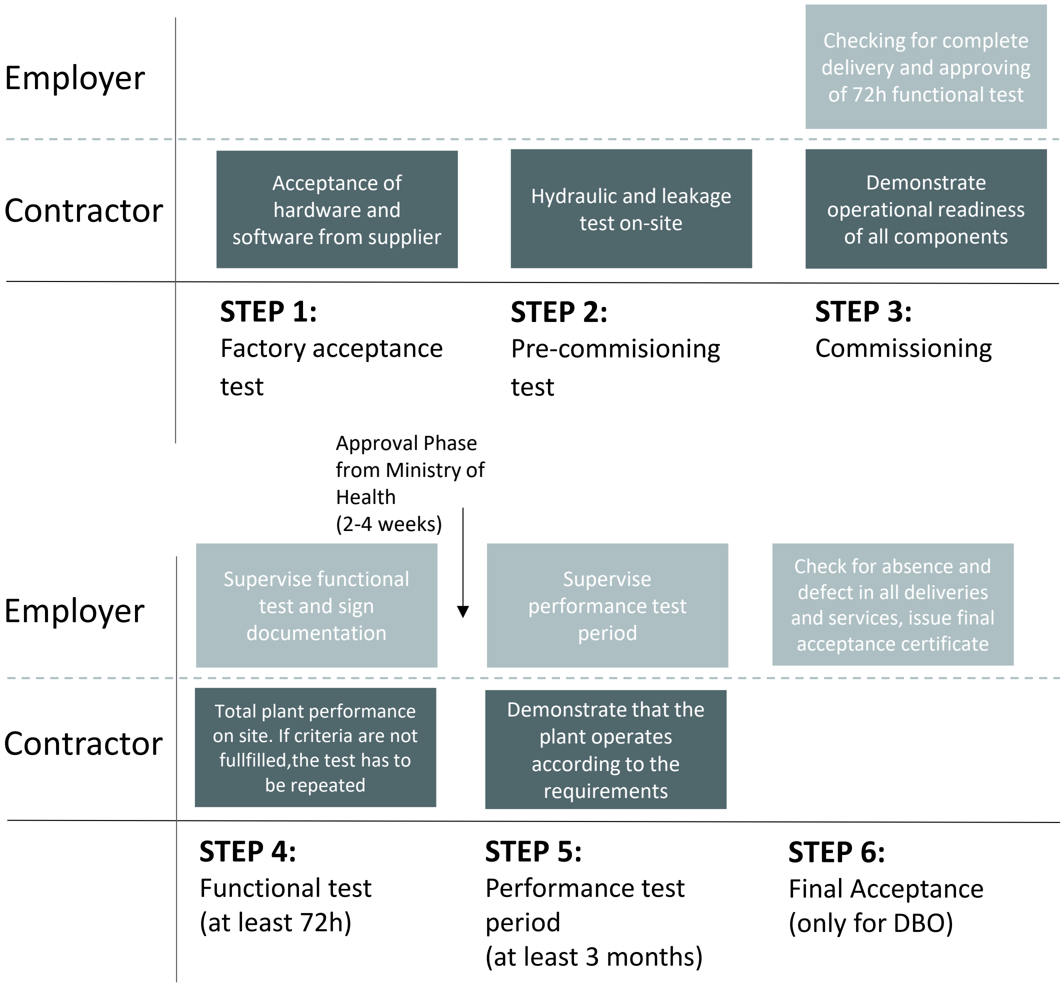


Figure 4-7: Essential steps until the final acceptance of the desalination plant

- **STEP 1: Factory acceptance test (FAT, at the supplier's workspace)**
  The contractor's supplier needs to test and demonstrate the functional integrity of their hardware and software prior to shipping the components. The required tests must be completed successfully and certified with a "Ready for Shipment" certificate. Due to the high cost/benefit ratio, the FAT can be skipped for large-scale SWRO plants.

- **STEP 2: Pre-commissioning test (hydraulic and leakage test on-site)**
  The pre-commissioning test can include parts or the entire plant system for pre-testing the hydraulic and identifying potential leakages before the commissioning.

- **STEP 3: Commissioning, including checking the completeness of the delivery**
  The contractor needs to inform the employer at least three weeks before the start of the commissioning. The commissioning lies in the responsibility of the contractor. The completeness of the delivery is the basis for the employer's approval for the commissioning and the functional test. Within the scope of the completeness check, the contractor must demonstrate the operational readiness of all components, including the process control system.

- **STEP 4: Functional test – (at least 72 h) (total plant performance on site)**
  The contractor must undertake a functional test run in the presence of the owner's representative and/or engineer/consultant on behalf of the owner. The performance and the procedure shall be fully documented and duly signed by all representatives participating. In case that the specified criteria are not fulfilled during the period, the functional test must be repeated. It is highly recommend to conduct the functional test for at least 24 h. If any failure or unscheduled shutdown occurs during the test, the entire test must be repeated.

- **STEP 5: Performance test period – (at least 3 Months) (total plant performance on site)**
  The contractor must undertake performance testing over a representative period. The performance test period should be at least three months for large-scale SWRO plants. During this time, the contractor must demonstrate that the desalination plant operates according to the specified performance and environmental requirements. The required measurements must be carried out by and under the contractor's supervision and the employer's supervision. The proper operation and installation of the measuring devices and provision of the operating personnel are the contractor's responsibility. The employer is authorized to demand the termination of the performance test period if the safe operation in compliance with the warranty criteria cannot be ensured. After completing the rectification work by the contractor, the performance test period will be restarted after the employer's approval. The contractor must prepare a detailed report on the tests and measurements carried out. A +/- 5% measurement tolerance is permissible for all contractually agreed performance values determined by measurement. Within this tolerance, the applicable performance warranty is considered fulfilled. Exceeding the tolerance in the sense of deterioration shall be deemed a breach of warranty. If the tolerance is exceeded in the sense of improvement, no crediting shall be considered. The tolerance is not permissible for legal limit values.

- **STEP 6: Final acceptance including technical approval**
  The final acceptance should only be issued after satisfactory completion of the tests mentioned above. In addition, the as-built drawings, the design manual, and the maintenance manual must be provided by the contractor in good quality in paper and electronic versions. The manuals must also include a list of the suppliers and their correspondence addresses. As part of the technical acceptance, the absence of defects in all deliveries and services must be checked by the employer or the engineer on behalf of the employer. The final payment is usually linked to the issue of the final acceptance certificate. The employer will take over the desalination plant after the final acceptance. In the case of BOT contracts, the ownership remains with the contractor.

Take Away Messages – Development of adequate measures for controlling the guaranteed values:

- Define checkpoints at which the contractor is controlled. The contractor has to prove that the delivery is complete, the installed plant works within the target values.
- A function test (at least 72h) significantly reduces the risk for critical problems during the performance test period (at least 3 months).
- The final acceptance should only be issued after the satisfactory completing of the performance test period. In addition, the as-built drawings, the design manual and maintenance manual must be prior provided by the contractor in good quality.

4.3.3 Development of specific penalties

If the contractor does not meet the specified warranty values, the employer should claim contractual penalties. The contractual penalties must be already defined in the tendering documents.

The amount of the reduction shall be based on the economic disadvantage suffered by the employer over the expected service life of the plant as a result of the non-achievement of the performance guarantee.

Suppose the guaranteed availability of the plant or the guaranteed throughput is not achieved. In that case, the employer reserves the right to demand compensation for the costs of any additional measures that may be necessary as a result, whereby the agreed reduction amounts are to be offset against this claim.

A reduction shall not be considered for the conditions from the permit and other statutory requirements. Figure 4-8 shows possible reasons for contractual penalties.

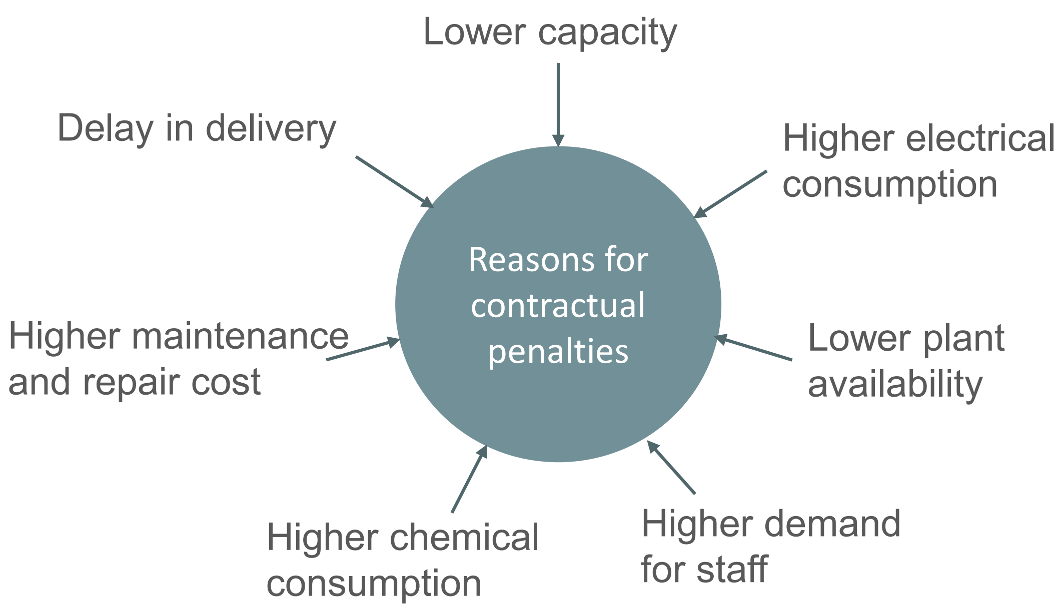


Figure 4-8: Reasons for contractual penalties

The specific contractual penalties can only be enforced depending on the financial involvement of the employer in the desalination project. The following list shows as an example some options for enforcing contractual penalties that may vary for specific project conditions. The requested contractual penalties must be realistic and balanced.

1: DBO - The initial investment is the responsibility of the employer

The sum of all types of penalties below shall be limited to a total of 20 % of the contract sum.

Type of Penalty:

- **Delay in Delivery:**

For each workday that the plant is not in operation, the employer shall charge a penalty of 0.5 % of the contract sum. The total liability is limited to 5% of the contract sum.

- **Availability (related to 8500 h/a, 100 %, of operation):**

Availability	Penalty
90 to < 95%	0.25% of the contract sum
85 to < 90%	1% of the contract sum
80 to < 85%	2% of the contract sum
75 to < 80%	3% of the contract sum

- **Capacity:**

If the plant's capacity is 0.5% less than the value of the guaranteed capacity, for each 0.5% step, a penalty of 1% of the contract sum shall be applied, up to a maximum of 5%. However, instead of paying the penalty, the contractor may upgrade the plant, within a reasonable time, at its cost, to achieve the guaranteed capacity.

- **Electrical consumption:**

If the electrical consumption exceeds the guaranteed consumption, the employer shall charge a penalty depending on the percentage of the increased electricity demand

Increase in electrical consumption	Penalty
x to < 2.5%	1.25% of the contract sum
2.5 to < 5%	2.5% of the contract sum
5 to < 7.5%	3.75% of the contract sum
7.5 to < 10%	5% of the contract sum
> 10%	Employer has the right to demand rectification/rejection of the plant

The total penalty is limited to 5 % of the contract sum.

- **Chemical consumption:**

If the chemical consumption exceeds the guaranteed consumption, the employer shall charge a penalty depending on the specific costs for the chemical consumption of the plant.

The total penalty is limited to 2.5 % of the contract sum.

- **Waste stream:**

If the amount of waste stream exceeds the guaranteed amount, the employer shall charge a penalty depending on the specific disposal costs.

The total penalty is limited to 2.5 % of the contract sum.

2: B(O)OT - The initial investment is the responsibility of the contractor

In the case of BOT tenders, there must be a different approach for penalties compared to the DBO contracts. The penalties must be set to reduce the water price that will be paid to the employer. Most of the reasons mentioned above for contractual penalties are, in this case, within the responsibility of the contractor.

Nevertheless, also for BOT, contractual penalties need to be defined and could be based on the following indicators:

- **Delay in delivery:**

For each workday that the plant is not in operation, the employer shall charge a penalty that reflects the value the employer would pay to purchase water from an alternate source, including administrative fees.

- **Availability (related to 8500 h/a of operation):**

The specific penalty for the plant availability could be calculated in the same way as the plant's delivery delay.

- **Capacity:**

The specific penalty for the plant's capacity could be calculated in the same way as the delay in delivery of the plant.

- **Waste stream:**

If the amount of waste stream exceeds the guaranteed amount, the contractor shall pay the additional costs depending on the specific disposal costs.

Take Away Messages – Development of specific penalties:

- Contractual penalties are essential in case that the contractor does not meet the specified warranty values. The contractual penalties must be already defined in the tendering documents.
- The specific contractual penalties can only be enforced depending on the financial involvement of the employer in the desalination project. Different specific penalties must be applied in case of an DBO or BOT project.

4.4 Compilation of basic documents from previous planning stages and creation of bidder forms

The basic documents from previous planning steps are essential to be included in the tender documents for desalination projects. The most important documents to be included are shown in Figure 4-9.

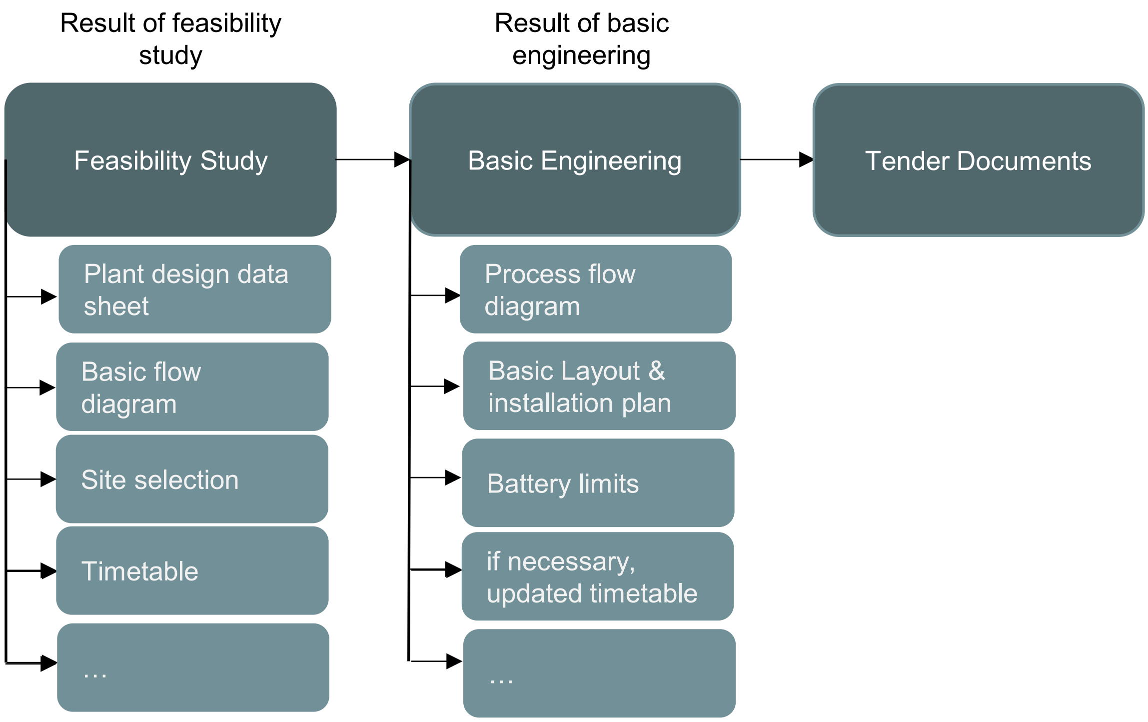


Figure 4-9: Essential documents and data from previous planning stages

In addition to the documents of the previous planning stages, bidder forms to be filled by the bidding contractor must be created. Within the basic engineering, utilities for the example seawater desalination plant are defined as shown in Table 4-2.

Table 4-2: Defined Utilities for the example saltwater desalination plant

ID	Utilities	Abbreviation
1	Utility Pre-treatment	PR
2	Utility Desalination	DE
3	Utility Post-treatment	PO
4	Utility Discharge	DI
5	Utility Compressed air high	CH
6	Utility Service water	SE
7	Civil works	CW

For all the defined utilities, different bidding forms must be created as listed below:

- Proof of Design - Utility Intake
  Proof of Design - Utility Pre-treatment
  Proof of Design - Utility Desalination
  Proof of Design - Utility Post-treatment
  Proof of Design - Utility Discharge
- Power consumption – All Utilities
- Chemical consumption – All Utilities
- Spare & wearing parts, consumables
- Additional offer
- Execution dates of the services

4.5 Preparation of market-oriented tender documents

In this chapter, we consider the tendering procedure from the point of view of an engineer working for the public authorities and responsible for the procurement of the SWRO plant. At this stage, we assume that the essential results from the previous planning stages are completed, and the vital documents for tendering are already compiled.

When drawing up the tender documents, care should be taken to ensure that the service packages are not put out to tender as a "black box". In the case of such a complex system as a desalination plant, this could lead to non-comparable and unsuitable offers from bidders. Likewise, a detailed invitation to tender with an unreasonably high grade of detail, in which "every screw" is defined, is not very effective. In this case, the desired cost reduction benefits through market-oriented tendering would be realized as only a reduced number of bidders would feel motivated to enable the necessary competition. For comparability, it is however very crucial to include the minimum functional specifications that define the quality and standards the goods and services need to meet. This ensures that the lowest-priced bid still meets the necessary properties.

Detailed design based on defined service packages can bridge market-driven functional tendering to generate genuine interest in the project from potential suitable bidders.

Additionally, the tender documents should also include terms discussing:

<u>Leasing of site:</u> The bidder must also be granted access to the site during the tendering phase. After award, the contractor must be given the right to use and lease the land.

<u>Insurance:</u> The contractor is to provide all the insurances required by the employer. At his own cost, the contractor can add other insurances that he finds necessary.

<u>Bonds:</u> For large-scale SWRO desalination projects, the bidder should submit a bid bond with his bid. The purpose of the bid bond is to provide an assurance to the Employer that the winning bidder will undertake the contract under the terms at which it bids. Additionally, a performance, payment and warranty bond should be included in the contract.

<u>Disputes and Arbitration:</u> For the resolution of any disputes arising during the Design-Build Period, a Dispute Adjudication Board will be jointly appointed by the parties. The Board should consist of either one or three members. If the dispute cannot be settled amicably, the contract should include provisions for the resolution by international arbitration. For any disputes arising during the operation period, a one-person “Operation service DAB” should be appointed by both parties.

The tender documents need to have a good structure as a basis for clear communication with the bidders. A structure that includes the most important criteria is shown below.

LETTER OF INVITATION

PART I TENDERING PROCEDURES

Section 1 - Instructions to Bidders

This section should contain:

- General
- Contents of Tendering Documents
- Specifications for the preparation of bids
- Submission and opening of bids
- Process of evaluation and comparison of bids
- Award of contract
- Eligible countries

Section 2 – Bid Data Sheet

This section consists of provisions that are specific to each procurement and supplement the information or requirements included in Section 1 - Instructions to Bidders.

Section 3 - Evaluation and Qualification Criteria

This section should contain:

- Requirements for Pre-Qualification
- Bid evaluation criteria
- Necessary qualifications of Bidders

Section 4 - Bidding Forms

This section contains the forms which are to be completed by the Bidder and submitted as part of its bid.

PART II REQUIREMENTS

Section 5 - Employer's Requirements

This section should contain:

- General requirements
- General material requirements
- General constructional requirements
- General functional services
- General technical safety requirements
- Process control system requirements
- Specification of the scope of supply and services
- Technical performance of the desalination plant
- Operation modes
- Degree of automation
- Safety system and monitoring
- Constructional demands
- Drawings

PART III CONDITIONS OF CONTRACT AND CONTRACT FORMS

Section 6 - General Conditions of Contract (GCC)

This section contains the general clauses to be applied in all contracts. These Conditions are subject to the variations and additions set out in Section 7 (Particular Conditions of Contract).

Section 7 - Particular Conditions of Contract (PCC)

This section contains provisions that are specific to each contract and that modify or supplement the GCC. Whenever there is a conflict, the provisions herein shall prevail over those in the GCC. The clause number of the PCC is the corresponding clause number of the GCC.

Section 8 - Contract Forms

This section contains forms, which, once completed, will form part of the contract. The forms for Performance Security and Advance Payment Security, when required, shall only be completed by the successful Bidder after contract award.

4.6 Checklist for the preparation of tender documents

Table 4-3: Checklist for preparation of tendering

Preparation of tender documents		*Drawn by:*	
		Checked by:	
ITEM No.	DESCRIPTION OF ITEMS THAT NEED TO BE INCLUDED IN THE TENDER DOCUMENTS	CHECKED	REMARKS
4.1	**Market-oriented tender**		
	a) Did you apply market-orientation to create a broad competition?		
	b) Did you apply the law of business to ensure that you get adequate quality?		
4.2	**Involvement of private sector**		
	a) Is the right contract type selected? (Who takes the financial risk?)		
	b) In case of B(O)OT: Is the water tariff structure defined?		
4.3	**Warranty obligations**		
	a) Are the warranty obligations defined?		
	b) Is the warranty period of specific components realistic and on a fair level?		
	c) Did you include the essential steps until the final acceptance of the desalination plant?		
	d) Have specific penalties been developed? (Indicator, Value)		
4.4	**Compilation of basic documents, did you include:**		
	a) Plant design data sheet		
	b) Complete and clear raw water analysis		
	c) Basic flow diagram		
	d) Selected site including land topography and coordinates		
	e) Time schedule		
	f) Process flow diagram		
	g) Basic Layout & installation plan		
	h) Battery limits including existing infrastructure		
	i) Bidder forms		
4.5	**Tender documents**		
	a) Are all items from 4.1 - 4.4 checked and included?		
	b) Have you specified the general information of the tender process?		
	1. Submission deadline		
	2. Submission procedure - electronical or paper		
	3. Late bids		
	4. Confidentiality		
	5. Award of contract		
	6. Eligible countries		
	c) Did you compile all basic instructions to the bidders within one bid data sheet?		
	d) Did you define the necessary qualification criteria for bidders?		
	1. Bidder's references (size, type of project)		
	2. Financial requirements (annual turnover, credit score)		
	3. Subcontractors		
	4. Pending Litigation and Arbitration		
	e) Did you define the bid evaluation criteria and their weighting?		
	f) Did you include all important bidding forms?		
	g) Did you specify the Employer's requirements?		
	1. Did you include, that all system components need to be resistant to brackish water?		
	2. Did you specify all essential plant functions as normal operation, shutdown, cleaning?		
	3. Did you define the requirements for the plant documentation?		
	h) Did you include international standardized FIDIC contracts or equal?		
	i) Have you clearly included the prioritisation of the contractual work?		

5. Tendering & Contracting

As shown in Figure 5-1, the tendering process can be started after the creation of the market-oriented tendering documents have been prepared. The tendering and contracting process is described in the following chapter.

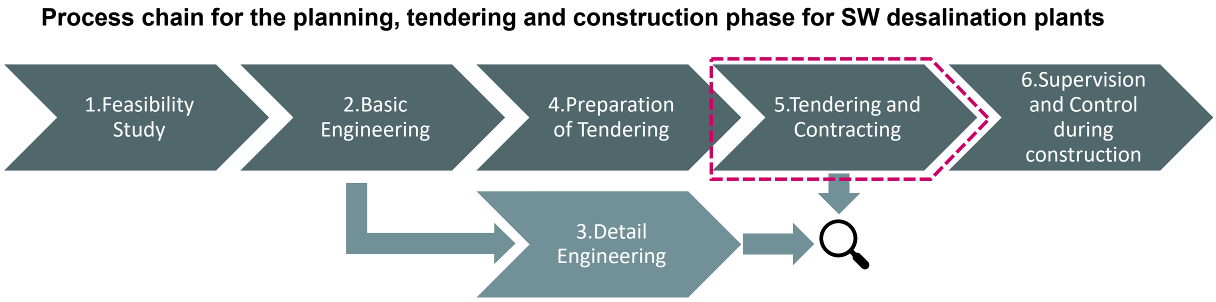


Figure 5-1: Process chain for planning, tendering and construction phase for SW desalination plant - part 5

The tendering process for the SWRO project should address national and international bidders.

The aim of Chapter 5 is to support the entire tendering process from the start to the selection of a final bid, including the signature of the contract. Chapter 5 is based on the tendering documents created in Chapter 4: Preparation of tendering.

The essential steps for the successful conduction of the tendering process are:

- **STEP 1: Understand and lead through the process of tendering**
  (→see 5.1 Essentials for the tendering process)

- **STEP 2: Select and compile suitable contract documents**
  (→see 5.2 Compilation of the contract documents)

- **STEP 3: Clarify the roles and responsibilities of the parties involved in the project**
  (→see 5.3 Roles and responsibilities of employer and contractor)

Figure 5-2 shows the systematic approach to the preparation of tendering and contracting.

5. Systematic Approach to Tendering and Contracting

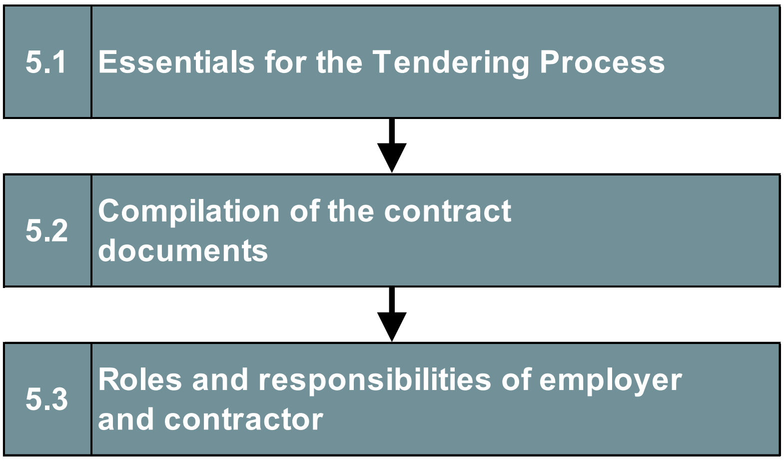


Figure 5-2: Systematic approach for tendering and contracting

In the following, the term "bidder" describes the contractor's role within the tendering process.

5.1 Essentials for the tendering process

The tendering process should be structured to reduce failure risk and perform a fair competition between the bidders. Figure 5-3 shows the essential steps within the tendering process.

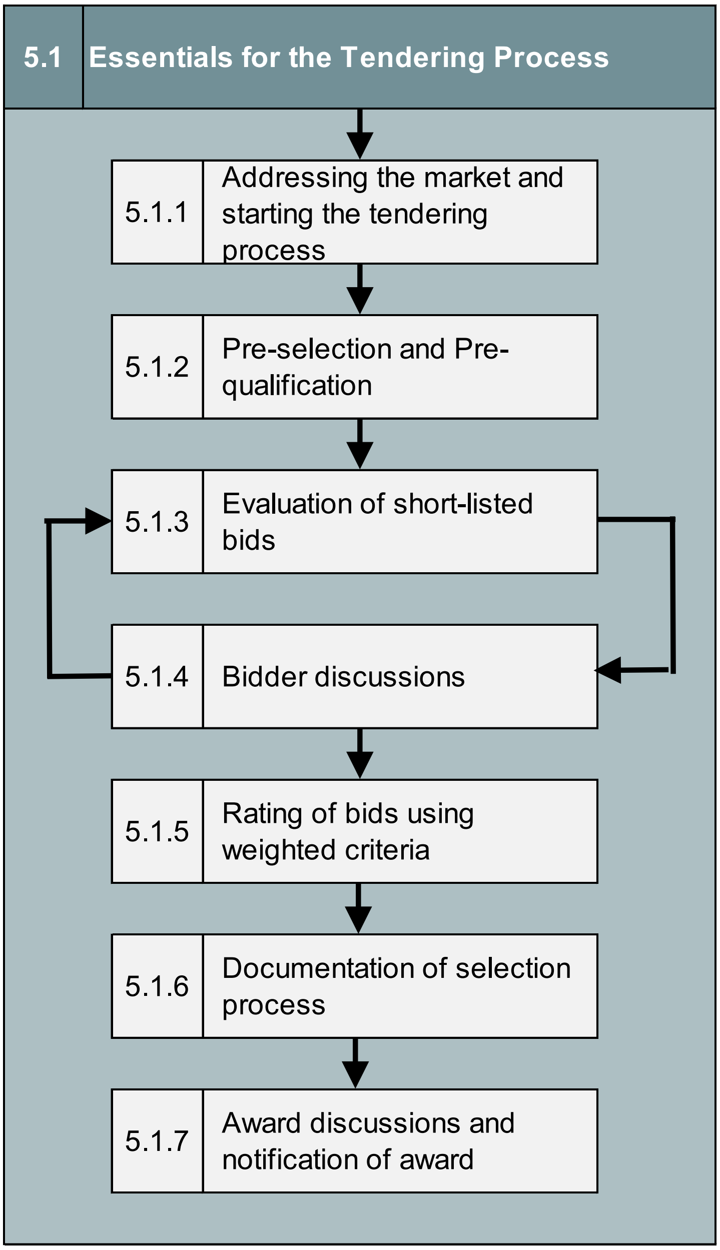


Figure 5-3: Steps for a successful tendering process

Contractual models are tools that should be used after considering the characteristics of the project, the parties involved, and the responsibilities assumed by each of them regarding project risks. The contract model chosen is a key factor in the successful achievement of the objectives of the project.

Within the most widely used contractual modalities in the international infrastructure market, the TC (turnkey contract) is the one that offers the best response for the development of large and complex projects, where the weight of technological developments is important when choosing a successful bidder.

The proper development of a desalination plant by means of a turnkey contract requires consideration of the following aspects:

- **Risks:** Determination of the risks of the project and assignment in the contract of the responsibility of these risks to the parties.
- **Negotiations:** The type of contract should not be imposed but negotiated between the two parties and decided by the common agreement.
- **Client Requirements:** The turnkey contract requires the customer to have an adequate and experienced technical structure to define their parameters, monitor their development, approve and receive the works. If the client does not have their own technical and experienced staff, they should hire companies to provide such expertise.
- **Contractor Requirements:** The turnkey contract requires the successful bidder to have sufficient technical expertise and economic solvency in line with the size of the project. Companies should demonstrate that they have the personnel, materials and procedures with experience in similar contracts. It is common practice to train consortia between companies that are complementary in the distribution of jobs and the assumption of risks and responsibilities.
- **OBE Phase:** Introduce into the procurement process and estimation open book phase that allows for adjustments and agreed designs and prices, which will reduce the risk of the project, contingencies and construction phase deviations that result in costs and claims; this practice will have a better end result with a more transparent and fair treatment pf the actual costs of the project.

After the appropriate contractual model is chosen, the market needs to be addressed via appropriate channels to start the tendering process. The tendering documents can be published on the employer's website and dedicated websites and marketplaces for desalination projects. Next, the obtained bids must be pre-selected and checked according to the requirements of the pre-qualification. Only the shortlisted bids should be evaluated in more detail after excluding those that do not meet the criteria. The evaluation of the shortlisted bids also includes discussions with the bidders. As a next step, the bids need to be rated according to weighted criteria defined in the tender documents. This will lead to the selection of the winning bid for the desalination project.

Finally, the selection process of the winning bid should be documented for future desalination projects. The winning bidder receives the award notification, and award discussions will be held for discount and contractual negotiations.

Figure 5-4 shows the necessary discussions and meetings with the bidders required for a successful tender.

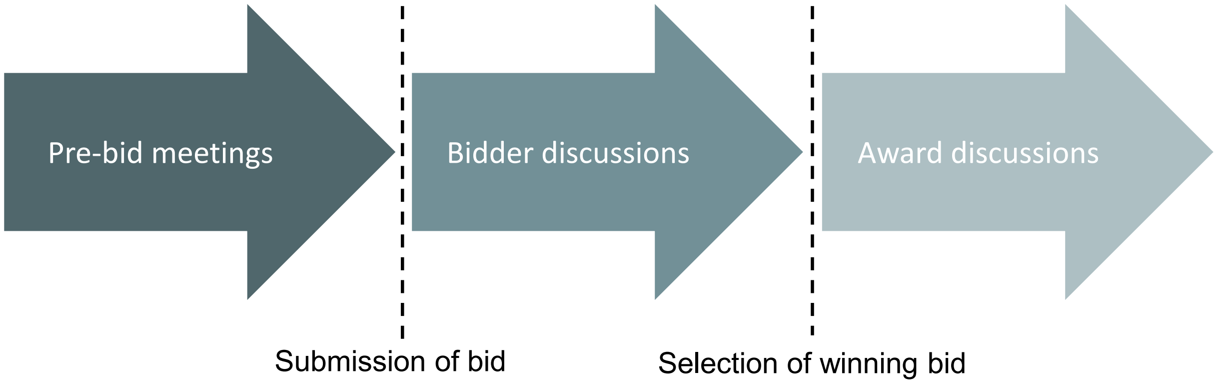


Figure 5-4: Necessary discussions with the bidders

5.1.1 Addressing the market and starting the tendering process

Whether the national or international market shall be addressed within the tendering process, some key points need to be considered.

- An on-site appointment, including an introduction of the bidder, should take place before the bid is submitted. Such a "Pre-bid meeting" is crucial in understanding MWI/WAJ needs and contractors' concerns. The "Pre-bid meeting" is an excellent platform for direct interaction between both contract parties. MWI/WAJ can brief about the project, explain the needs and vision, the contractors can share their views, ask questions, and discuss various topics that can be essential for reasonable pricing. All matters discussed during the pre-bid meetings shall be documented and shared with all bidders to comply with fair competition. Innovations and ideas from a bidder that are confidential are excluded.

- Bidders shall be given sufficient time to submit a bid at least 3 months according to the capacity of the SWRO desalination plant and the complexity of the overall projects)

- The scope of supply must be defined in a clear way for seawater desalination projects. The battery limits as the electrical energy supply and the point of water delivery must be specified.

- All formal framework conditions for implementing the tendering process must be clearly defined in the tendering documents. The bidders must know:

    - Who is responsible for the desalination project at the employer site?
    - Where and in what format must the bids be submitted?
    - When is the submission deadline?
    - When should the project be launched?
    - What are the evaluation criteria for the submitted bids?

After addressing all the points mentioned above, the tendering process can be started. The tendering documents can be published on the employer's website and dedicated websites and marketplaces for desalination projects. In addition, it is helpful that the employer directly contacts potential bidders by sending them the tendering documents or inviting potential bidders to participate in the bids. This approach is highly recommended for tenders that shall address the international market.

Details about the contents and ideas developed in submitted bids or discussions remain confidential and shall not be communicated to competitors to ensure fair competition.

Take Away Messages – Addressing the market and starting the tendering process:

- Demand and conduct "Pre-bid meetings" with the bidders before the submission deadline of the tender
- Set the submission deadline in a way that the bidders have sufficient time for the “Pre-bid meetings” and to prepare good bids
- Last Check: All formal framework conditions for the implementation of the tendering process must be clearly defined in the tendering documents

5.1.2 Pre-selection and Pre-qualification

Fairness and trust between the employer and the bidders can only be built if all parties adhere to the rules and deadlines specified within the tendering documents. First, the employer needs to exclude all bids that do not meet the formal criteria and are invalid. The employer is obliged to give the bidder the chance to submit clarifications. Depending on this point, Figure 5-5 shows the necessary exclusion conditions.

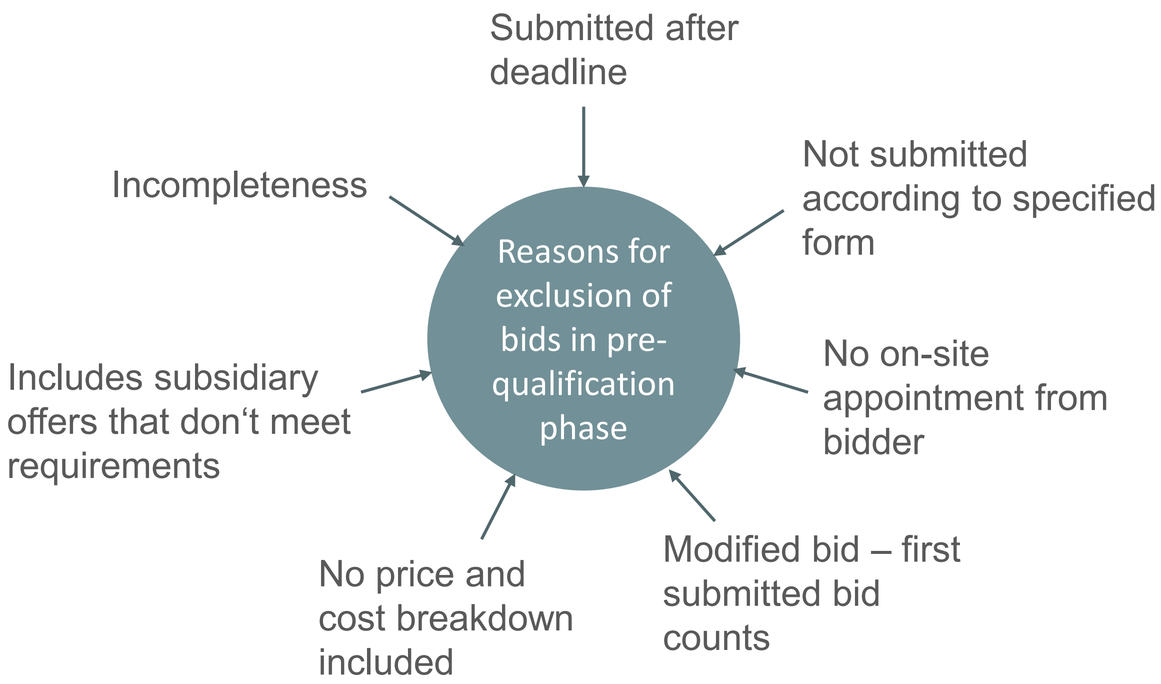


Figure 5-5: Reasons for exclusion of bids in the pre-qualification phase

The list of reasons for the exclusion are described below:

- Bids that did not meet the submission deadline
- Bids that were not submitted according to the specified form (hard copy and digital)
- No on-site appointment has taken place (if it was mandated)
- The modification of bids is not allowed – The first submitted bid counts
- Incomplete bids and bids where additionally requested documents and forms have not been provided within the set deadline
- Bids that include subsidiary offers that do not meet the minimum requirements
- Bids that do not include the requested price and cost breakdown

After checking the formal criteria, a shortlist of bids is created. It is recommended that the shortlist of bids has at least three qualified bids to be evaluated in the next step.

There is the possibility to cancel the tendering process in case no qualified bids were submitted. In addition, the tendering process can also be canceled in case there are crucial changes in the tendering documents necessary and due to other serious reasons, such as no feasible bid has been submitted. All clarifications should be shared with all bidders to comply with fair competition.

Take Away Messages – Pre-selection and Pre-qualification:

- If requested by the emplyer, the bidder can submit clarifications
- Exclude all bids that do not meet the requirements that were specified in the tender documents
- Create a short-list of bids for detailed evaluation

5.1.3 Evaluation of shortlisted bids

The shortlisted bids must be evaluated according to specific and predetermined criteria. A selection of essential criteria for the evaluation of desalination plants is shown in Figure 5-6.

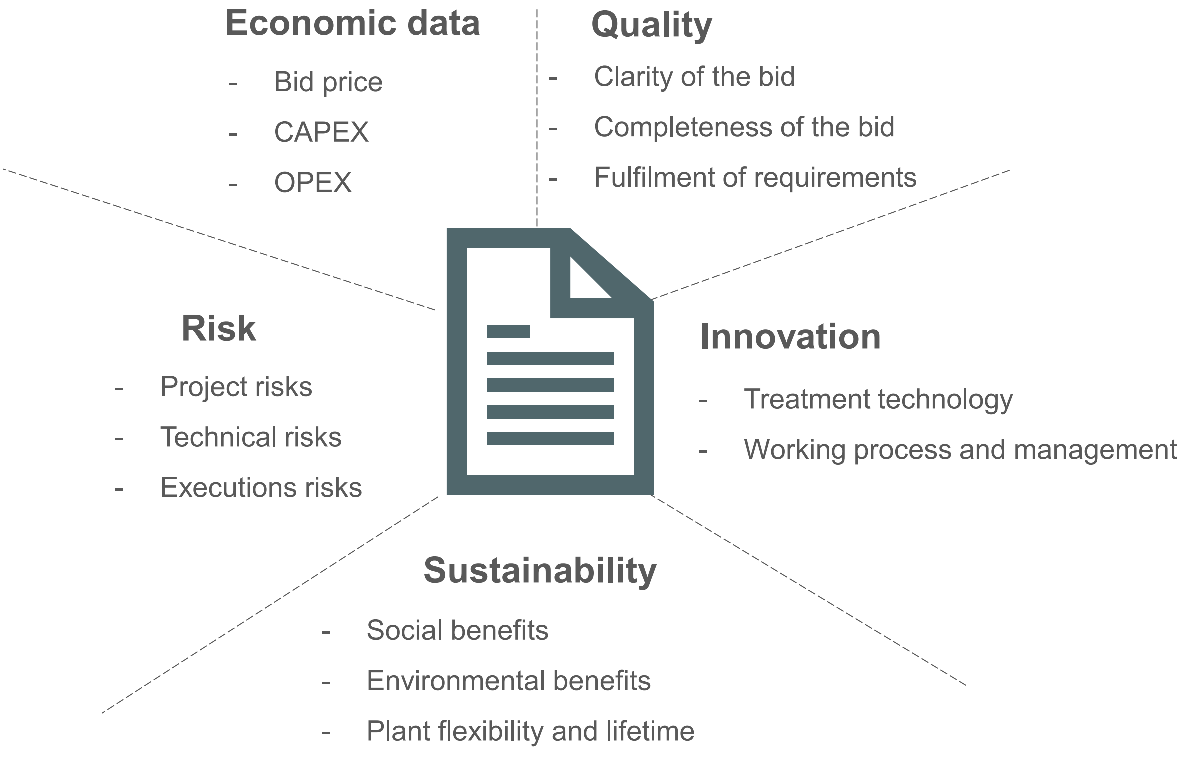


Figure 5-6: Selection of criteria for evaluation

Economic data, including the total bid price and the CAPEX/OPEX, are essential criteria for the bid selection. Nevertheless, other non-technical criteria should also be included in the evaluation procedure. This approach can reduce the risk and problems that could occur during the erection and operation phase of the desalination plant.

The evaluation of the bids according to the shown criteria can be carried out in three evaluation steps. The bids need to be evaluated from a computational, technical, and economic point of view shown in Figure 5-7.

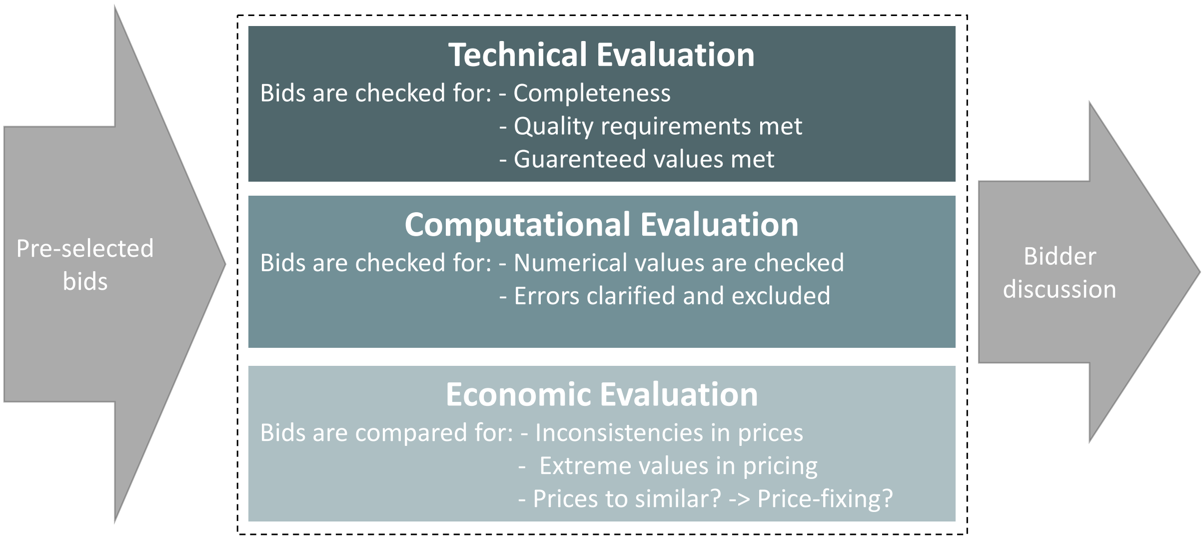


Figure 5-7: Evaluation of pre-selected bids

- Technical Evaluation:
  Checking whether the technical requirements are met according to the specified design in the tendering documents. For example, in case that the employer has conducted his detailed engineering, the P&Is and detailed drawings need to be checked by the employer to evaluate whether the bidder has considered all essential technical components. Likewise, subsidiary offers also need to be checked and assessed whether these are permissible.

Is the bid complete? Are all components and services in the bid included?

Do the suggested components in the bid satisfy the quality requirements?

Can the proposed technical solution meet the guaranteed values?

- Computational Evaluation:
  The specified numerical values must be checked to ensure that they are added up correctly to exclude errors in the calculation. Errors must be clarified with the bidders. It is recommended to include an excel sheet of the scope of supply in the tendering documents that the bidder must submit in addition to his bid. It is important that the bidder also prints the excel sheet and signs it, so no misunderstanding and the legal basis is created.

- Economic Evaluation:
  Identify inconsistencies and prove the appropriateness of the pricing within the scope of supplies.

Are there inconsistencies in pricing?

Are specific components offered too cheaply or too expensively?

Are the prices of the bids too similar, so that price-fixing must be assumed, which makes fair competition impossible?

Take Away Messages – Evaluation of shortlisted bids:

- Evaluate the bids according to economic and quality criteria
- Achieve comparability of the short-listed bids
- Find and eliminate price inconsistencies

5.1.4 Bidder discussions

Bidder discussions on-site or in an online meeting are essential for the employer to clarify questions that arise during the inspection and evaluation of the bids. The results of the bidder discussions need to be recorded in the minutes of the meeting and need to be accepted by both potential contact parties. The minutes of the meeting will then be part of the contractual documents if it comes to the conclusion of the contract.

Bidder discussions are done after the pre-qualification of bidders.

5.1.5 Rating of bids using weighted criteria

The contractor is obliged to select the bidder according to award criteria and their weighting specified in the tendering documents. The lowest price is always an important indicator but not sufficient to choose the bidder. Potential award criteria and their prioritization are shown in Figure 5-8.

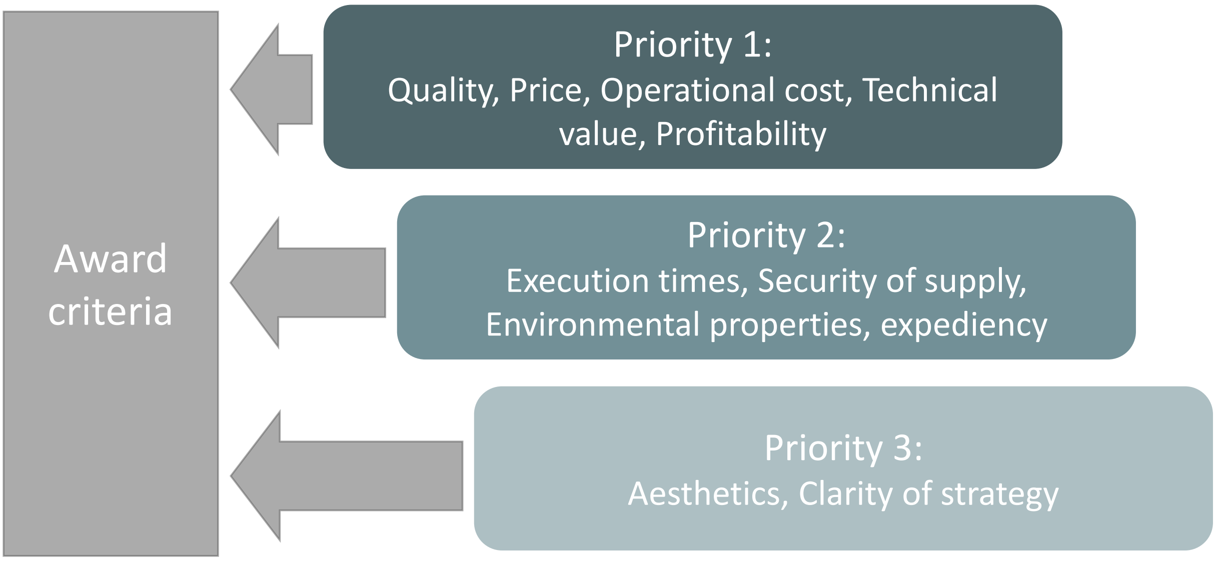


Figure 5-8: Award criteria

Many criteria should be taken into account in the process of choosing a bidder. It is helpful to divide the criteria into priorities and use them to weight the criteria. When selecting a bidder, factors such as price, operational cost, and quality are essential indicators and should be assigned to priority one. Nevertheless, criteria such as execution times, security of supply and environmental properties should also be considered when choosing a bidder. These could be assigned to priority two and therefore given a lower weighting. Priority three can be used for criteria like aesthetics, which aren't as crucial for the selection process but should still play a factor.

Figure 5-9 shows an example for selecting a bidder. Imagine the steps described in chapter 5.1.1 to chapter 5.1.4 have been completed so that next, the bids must be rated using weighted criteria.

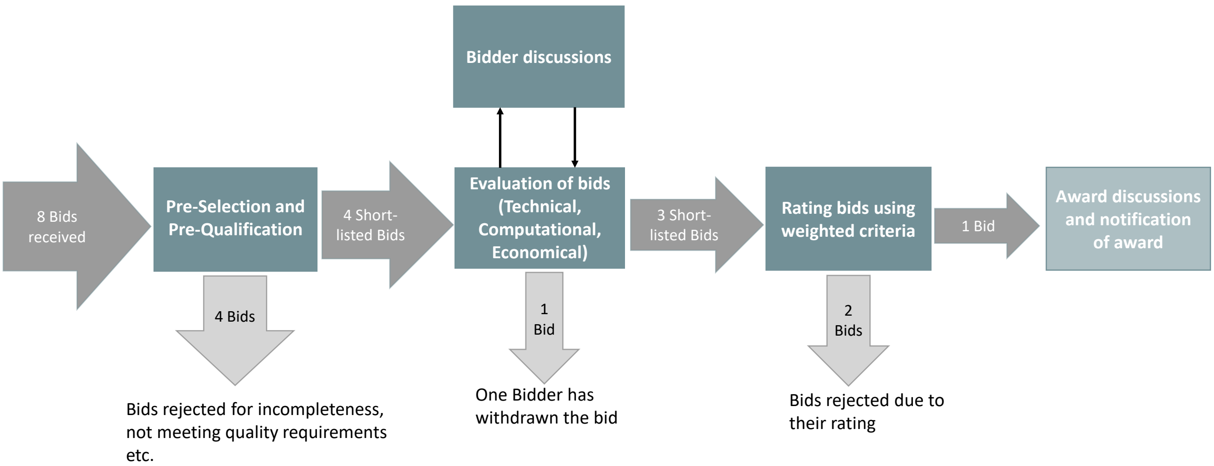


Figure 5-9: Example process of bidder selection

In this tendering example, eight bidders have submitted a bid. The employer must exclude four bids within the pre-selection and pre-qualification due to reasons mentioned in Figure 5-5 (Chapter 5.1.2). The reason for this may be such factors as incompleteness or late submissions. After checking the bids for formal criteria, a shortlist consisting of the four remaining bids is created. Next, the shortlisted bids will be evaluated, and bidder discussions will be held with the remaining bidders.

In this example, one bidder withdraws his bid during this process. After the evaluation and the bidder discussions, the employer creates a rating of the remaining three bids using the weighted criteria specified in the tendering documents.

Table 5-1 shows an example of the results of the assessment according to the award criteria.

Table 5-1: Results of assessment according to the award criteria – Example values for understanding the process

	Bid A	Bid B	Bid C
Total CAPEX	3.4 Mio. €	3.8 Mio. €	4.1 Mio. €
Total OPEX	0.45 €/m³	0.36 €/m³	0.31 €/m³
Methodology and Workplan	Sloppy work plan, time schedule ok, good methodology	Excellent work plan, good time schedule, detailed and professional methodology	Good work plan, good time schedule
Relevant Experience	3 x Valid References	3 x Valid References	2 x Valid References
Professional appearance	Sloppy documents and bad communication	Excellent and detailed bid, good communictaion	Excellent and detailed bid, good communictaion

For each of the criteria, the bids must be evaluated by a scoring system. The employer must have a strategy for giving points for each criterion. Table 5-2 shows an example of how the points could be assigned.

Table 5-2: Scoring system – Example project

	Type of Criteria	1 Point	2 Points	3 Points	4 Points	5 Points
Total CAPEX	quantitative	Lowest CAPEX + 30-40%	Lowest CAPEX +20-30%	Lowest CAPEX + 10-20%	Lowest CAPEX + 5-10%	Lowest CAPEX
Total OPEX	quantitative	Lowest OPEX +30-40%	Lowest OPEX +20-30%	Lowest OPEX + 10-20%	Lowest OPEX + 5-10%	Lowest OPEX
Methodology and Workplan	qualitative	Simplified plan	←	←	←	Comprehensible and targeted plan
Relevant Experience	qualitative	1 reference project	2 reference projects	3 reference projects	4 reference projects	5+ reference projects
Professional appearance	qualitative	Insufficient cooperation and sloppy documents	←	←	←	Professional appearance and good cooperation

The bid with the lowest CAPEX gets the maximum number of points. The other bids are compared to the bid with the lowest CAPEX: for each 5-10% increase in total CAPEX cost, one point from the maximum points is deducted. The same scoring system is applied to the criteria OPEX.

To be able to assess the relevant professional experience, the bidders need to describe their relevant project experience in the field of desalination projects. The size and capacity of the plants in relation to the product water provide information about the relevance of the experience. Bidders with no relevant reference projects are excluded in the beginning of the procurement process. Each reference project receives one point. The evaluation of the criteria professional appearance and methodology and workplan must be assessed as objectively and fairly as possible. The bid shall be evaluated with five points for a coherent, detailed, and targeted execution plan. If the plan is simplified and sloppy, the bid only receives one point. If the quality of the methodology and workplan range somewhere between, the points must be assigned accordingly.

Similarly, a professional appearance and good cooperation shall be rewarded with five points, while insufficient cooperation and sloppy documents only get one point.

Next, the total scores can be calculated according to the weighting of the criteria. Table 5-3 shows how the points would be assigned to the three bids in our example project.

Table 5-3: Assignment of points to bids – Example project

	Type of Criteria	Weighting	Min. Points	Max. Points	Bid A	Bid B	Bid C
Total CAPEX	quantitative	30 %	1	5	5	4	3
Total OPEX	quantitative	30 %	1	5	1	4	5
Methodology and Workplan	qualitative	20 %	1	5	2	5	4
Relevant Experience	qualitative	10 %	1	5	3	3	2
Professional appearance	qualitative	10%	1	5	2	5	5

Table 5-4 shows an example of how the total score can be calculated.

Table 5-4: Calculation of total scores – Example project

	Weighting	Score - Bid A	Score - Bid B	Score - Bid C
Total CAPEX	30 %	5/5 *30 = 30	4/5*30 = 24	3/5*30 = 18
Total OPEX	30 %	1/5*30 = 6	24	30
Methodology and Workplan	20 %	8	20	16
Relevant Experience	10 %	6	6	4
Professional appearance	10%	4	10	10
TOTAL Points	100%	54	84	78

In this example, bid B has the highest total score and is the favored bid (84 Points). Therefore, award discussions are being held with bidder B. If these are successful, the contractor is notified of the award.

Take Away Messages – Rating of bids using weighted criteria:

- Not only economic critera should be taken into account in the process of choosing a bidder. It is helpful to divide the criteria into priorities and use them to weight the criteria. The award criteria and their weighting have to be specified in the tender documents.
- After evaluation of the shortlisted bids and bidder discussions, a rating has to be created by assigning points for each criteria. With these, the total score of each bid is calculated according to the weighting to ensure a fair evaluation process.
- The employer will start award negotiations with the bidder having received the highest score followed by a notification of the award

5.1.6 Documentation of selection process

It is essential to produce good documentation of the tendering process, particularly the underlying reasons for the bid selection and the decision-making process itself, as a basis for future desalination projects. For this purpose, it is recommended to work out documentation according to the topics listed below:

1 Objectives of the tender

2 Summary of the submission process

3 Evaluation of offers

3.1 Statements in cover letter

3.2 Modifications to the scope of services

3.3 Completeness of the documents

3.4 Completeness of the prices

3.5 Validity of the offers

3.6 Technical check

3.6.1 Main offer

3.6.2 Secondary offer

3.7 Economic check

3.7.1 Restrictions to the contract conditions

3.7.2 Check of values and calculations

3.7.3 Check of secondary offers and options

3.7.4 Check on possible price-rigging

3.7.5 Price adjustment

3.7.6 Price comparison and cost-benefit analysis

3.8 Making a shortlist of bidders

3.9 Price negotiations

4 Summary and recommendation

5.1.7 Award discussions and notification of award

The contractual details like payment schedule, bonds, and a potential discount must be clarified with the favorite bidders in award negotiations before the official bid acceptance notice. If the award discussions are not successful, award discussions with the second rated bidder will be started. As a final step of the tendering process, the winning bidder must receive the notification of award. At this point, it is fair to also thank the remaining bidders for their participation and submission about good future cooperation. The entire process ends with signing the contract, which is dealt with in the following chapter.

5.2 Compilation of the contract documents

Internationally standardized and proven contract models provide a uniform and more straightforward contract process in desalination projects. Using internationally proven contracts avoids problems and uncertainties in the contract's execution, which otherwise increases the costs and project execution time. In addition, it could be a practical approach to use the same methodology that the General Tenders Department (GTD) / Ministry of Public Works and Housing is using in Jordan for issuing tenders. WAJ has already collaborated with GTD in issuing the Wastewater Treatment plants tenders. The tenders issued by GTD are transparent, with general conditions, special conditions, drawings, bill of quantities, and governing contract specified.

The International Federation of Consulting Engineers (FIDIC) is an essential international governing body of national associations of consulting engineers in the construction industry. Standardized contract models for different application areas have been developed by FIDIC and can be used for the development of contract documents.

However, as FIDIC documents are rarely used for direct use in large desalination projects, they can be used as a basic framework and serve as a reference. The most suitable FIDIC contracts for construction projects with a public party as the employer and a private party as the contractor are the following:

- Conditions of Contract for Plant and Design-Build for Electrical and Mechanical Plant, and Building and Engineering Works, Designed by the Contractor (Yellow Book)
- Conditions of Contract for EPC/Turnkey Projects (Silver Book)
- Conditions of Contract for Design, Build and Operate Projects (Gold Book)

The regulations of the **Yellow Book** state that the contractor designs and constructs the plant by a functional service description provided by the employer.
The **Silver Book** contains a contract for turnkey construction (EPC/TC). It assigns full responsibility for the project's planning, procurement, and construction to the contractor based on a lump-sum agreement.

According to FIDIC, the silver book is not suitable for the listed circumstances below:

If there is insufficient time or information for bidders to scrutinize and check the employer's requirements or for them to carry out their designs, risk assessment studies, and estimation

If construction will involve substantial work underground or work in other areas which tenderers cannot inspect unless special provisions are provided to account for unforeseen conditions or contract

If the employer intends to supervise closely or control the contractor's work or to review most of the construction drawings

The **Gold Book** is the only contract in which the contractor is responsible for operation service. However, he is not involved in financing the project, nor does he have the benefit of the operation output. Figure 5-10 shows the selection tree for FIDIC contracts.

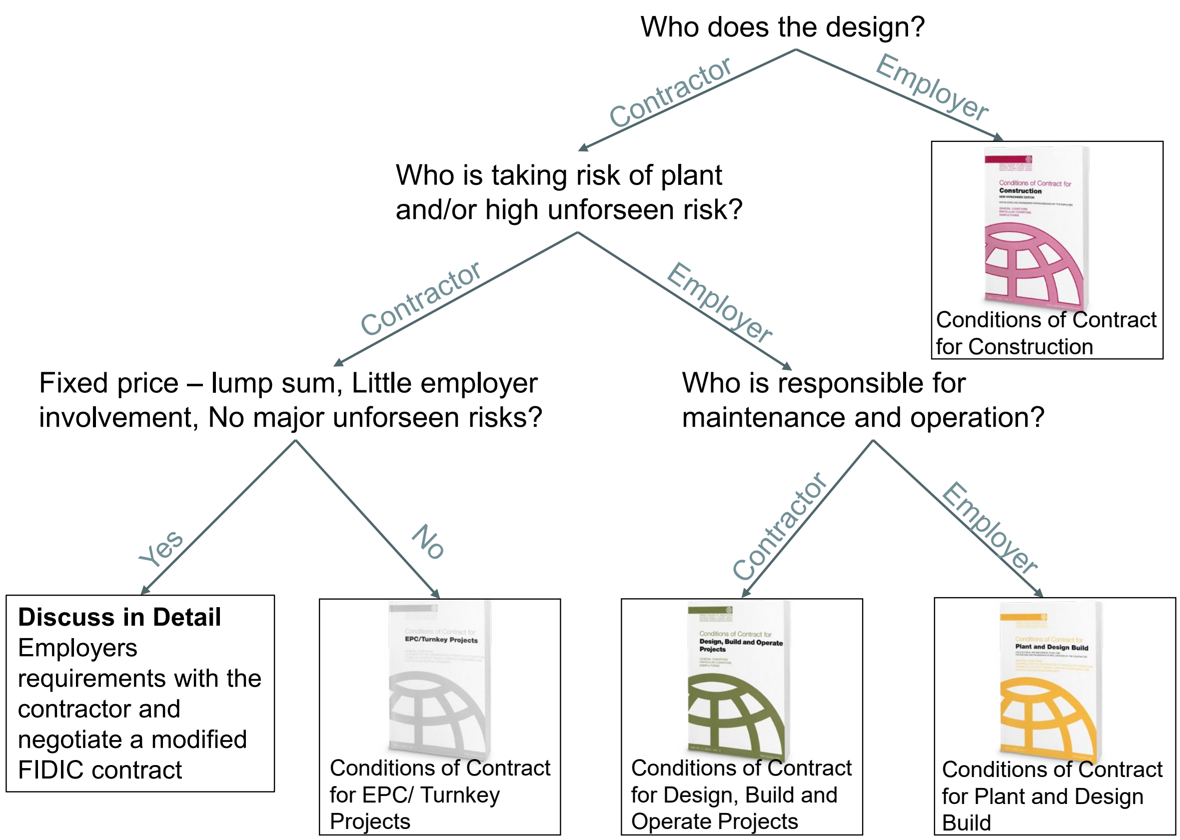


Figure 5-10: Selection of FIDIC contract

The contract is only one part of the total contract work in desalination projects. The prioritization of the validity of the various components of the agreement according to FIDIC is listed below.

Priority according to FIDIC:

1. The Contract Agreement
2. The Letter of Acceptance
3. The Letter of Tender
4. The Particular Conditions Part A – Contract Data
5. The Particular Conditions Part B – Special Provisions
6. The General Conditions
7. The Employer's Requirements
8. The Schedules
9. The Contractor's Proposal and any other documents forming part of the contract

Within the contractual work, it is essential to include the warranty values and the penalties that were developed for the specific desalination project in chapter 4. Consideration of these values provides a legal basis for contractual disputes.

Take Away Messages – Compilation of the contract documents:

- Chose the right contract according to the future tasks and services of the contractor
- Use international standardized contracts and forms, FIDIC contracts can be a good reference in this respect
- Adhere to the prioritisation of the contract work
- Include the warranty values and the penalties that were developed for the specific SWRO desalination project

5.3 Roles and responsibilities of the employer and the contractor

Trustful and professional cooperation between the employer and the contractor can only exist if the roles and responsibilities of both parties are clearly defined and documented in writing. Figure 5-11 shows the bases for trust-building between the employer and the contractor.

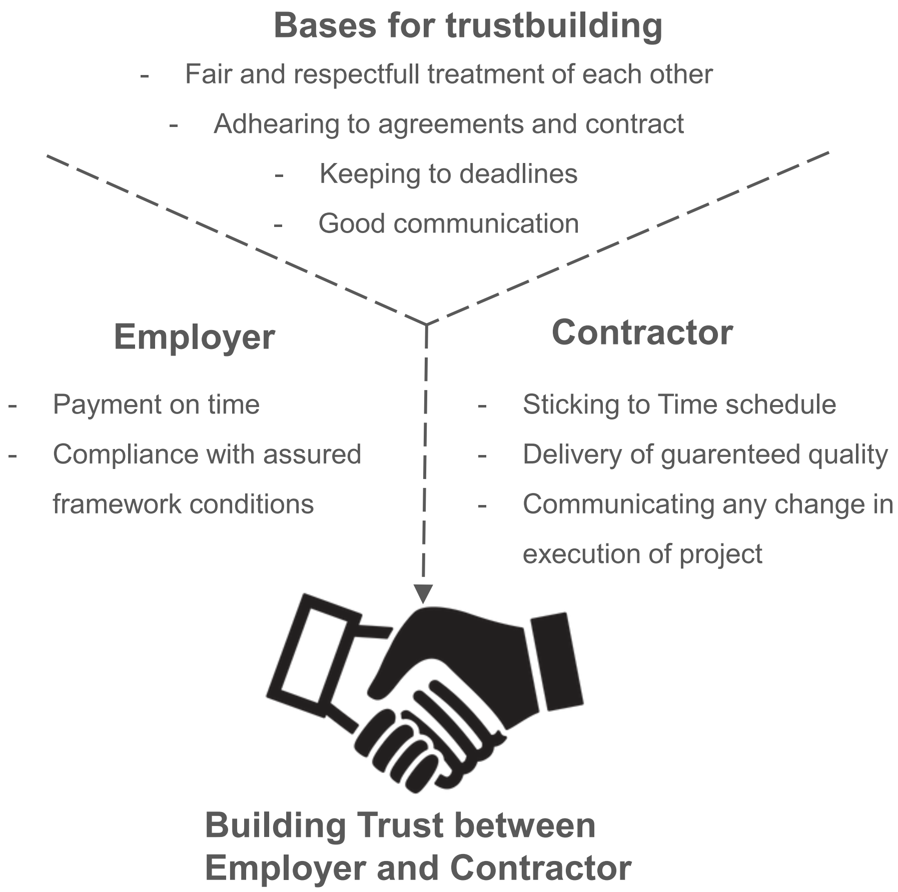


Figure 5-11: Building Trust between Employer and Contractor

The payments must be made at the agreed times and in the agreed amount on the employer's part. The contractor must not be hindered in the performance of his activities. All points that can lead to a delay in project execution must be clarified in advance by the employer, such as land procurement, where the desalination plant will be erected.

On the other hand, the contractor is responsible for ensuring that the desalination plant will be built on time according to the contract work, including his bid. In addition, the contractor has to ensure that the desalination plant operates according to the guarantee values specified in the tender documents by the employer. Therefore, a designated delivery point must be defined against which the product water capacity is measured.

The responsibly matrix below shows the responsibility of the employer (WAJ/MWI) and the desalination contractor. This principle can be adapted to all types of desalination projects in Jordan.

Table 5-5: Responsibility Matrix

Responsibility Matrix		
Description of responsibility	**Desalination Employer (WAJ/MWI)**	**Desalination Contractor**
Location		
Land allocation and land ownership	X	
Provide permanent electric power to the site	X	
Electricity connection with existing supply at the site		X
Water Source	X	
Raw Water Analysis	X	
Topography	X	
Soil Analysis	X	
EIA	X	
Up Stream of Desalination Plant		
Intake or beach wells		X

Responsibility Matrix

Description of responsibility	Desalination Employer (WAJ/MWI)	Desalination Contractor
Desalination Plant		
Process Design		X
Detailed Engineering		X
Raw water Storage tank		X
Pre-treatment units		X
Desalination plant		X
Product Water storage tank		X
Pumping of water to the grid	X	
Distribution pipes	X	
Buildings (Storage, control room, office,..etc)		X
Functional Test, Performance Period, Final Acceptance Test		X
Down Stream of Desalination Plant - Brine Disposal		
Outfall to sea		X
Performance		
Raw Water Quality		X
Raw Water Quantity		X
Product water Quality		X
Product water Quantity		X

Responsibility Matrix

Description of responsibility	Desalination Employer (WAJ/MWI)	Desalination Contractor
Operation and Maintenance - depending on the type of contract (DBO, B(O)OT)		
Operation staff		X
Operation chemicals		X
Operation consumables		X
Operation electricity costs		X
Any increase in electricity tariffs	X	
Spare Parts		X
Membranes		X
Product water analysis and testing		X
Monitoring		X
Financing		
Financing of the construction – depending on the type of contract (DBO, B(O)OT)	X	X
Financing of the operation – depending on the type of contract (DBO, B(O)OT)	X	X
Ownership		
Ownership of desalination plant – depending on the type of contract (DBO, B(O)OT)	X	X
Handover of the plant		
Operation Manual		X
Training		X
Plant in good operating condition		X
Release of performance bond	X	
Operation Manual		X

Description of responsibility	Desalination Employer (WAJ/MWI)	Desalination Contractor
Bonds and other cost		
Sales tax (if applicable)		X
Bid bond		X
Performance bond		X
Maintenance bond		X
Insurance		X
Payment and penalties		
Payment of contractor's invoices	X	
Failure of MWI/WAJ to take the produced water - Take or Pay	X	
Failure of MWI/WAJ to provide the contractual raw water quality	X	
Failure of MWI/WAJ to provide the contractual raw water quantity	X	
Penalties – product water quality deviation		X
Penalties – product water quantity deviation		X
Penalties – according to the tender documents		X

Take Away Messages – Roles and responsibilities of the employer and the contractor:

- Adhere to the roles and responsibilites for a fair and smooth cooperation
- Make sure that the roles and responsibilites are clearly defined, communicated and fixed in writing as a binding part of the cotract documents
- Stick to the defined roles and responsibilites, even when conflicts arise
- Never make conceptual changes in the SWRO project at the stage of tendering and contracting precedure

5.4 Checklist for the selection of bid and tendering

Table 5-6: Checklist for selection of bid and tendering

Selection of bid and contracting			*Drawn by:*	
			Checked by:	
ITEM No.	DESCRIPTION OF ITEMS THAT NEED TO BE INCLUDED IN THE TENDERING AND CONTRACTING	NEC CODE	CHECKED	REMARKS
5.1.1.	**Adressing the market**			
	a) Did you demand and conduct "Pre-bid meetings" before the submission deadline?			
	b) Did you set the subission deadline so the bidders have sufficient time for the "Pre-bid meetings and preparing good bids?			
	c) Have you done a final check of the tendering documents before starting the tender process			
	1. Who is responsible for the desalination project at the employer site?			
	2. Where and in what format must the bids be submitted?			
	3. When is the submission deadline?			
	4. When should the project be launched?			
	5. What are the evaluation criteria for the submitted bids?			
5.1.2.	**Pre-selection and Pre-qualification**			
	a) Have you excluded all bids that do not meet the requirements that were specified?			
	b) Have you created a short-list of bids?			
	c) Did at least one bid meet the requirements? If not the tendering process must be cancelled or repeated			
5.1.3.	**Evaluation of shortlisted bids**			
	a) Have you evaluated all shortlisted bids by mathematical evaluation?			
	b) Have you evaluated all shortlisted bids by technical evaluation?			
	1. Is the bid complete? Are all components and services in the bid included?			
	2. Do the suggested components in the bid satisfy the quality requirements?			
	3. Can the proposed technical solution meet the guaranteed values?			
	c) Have you evaluated all shortlisted bids by economic evaluation?			
	1. Are there inconsistencies in pricing?			
	2. Are certain components offered too cheaply or too expensively?			
	3. Are the prices of the bids too similar, so that price-fixing must be assumed that make a fair competition impossible?			
	d) Are the shortlisted bids compareable?			
	e) Have you identified and eliminated all price inconsistencies?			
5.1.4.	**Bidder discussions**			
	a) Have you clarified all questions concerning the bid?			
	b) Have you documented the bidder discussions?			
5.1.5.	**Rating of bids using weighted criteria**			
	a) Have you compiled all criteria information from the shortlisted bids?			
	b) Have you assigned points to the bids for each criteria?			
	c) Have you calculated the total scores according to the weighting?			
5.1.6.	**Documentation of selection process**			
	a) Have you documented the selection process?			
5.1.7.	**Award discussions and notification of award**			
	a) Have you discussed contractual details with the favoured bidders according to the selection process?			
	b) Have you selected the winning bid and notified him of the award?			
	c) Have you thanked the remaining bidders for their submission?			
5.2.	**Compilation of the contract documents**			
	a) Did you choose the right contract type according to the future tasks of the contractor?			
	b) Did you use FIDIC contracts or similar contracts?			
	c) Did you include the warranty values and penaltiess in the contractual work?			
	d) Did you clearly communicate the prioritization of the contractual work?			
5.3.	**Roles and responsibilities of the employer and the contractor**			
	a) Have you clearly define and defined the roles and responsibilities?			

6. Control and supervision until final acceptance

As shown in Figure 6-1, after tendering and contracting, the construction can start which has to be supervised and controlled. The following chapter describes the measures for control and supervision during the construction phase.

Process chain for the planning, tendering and construction phase for SW desalination plants

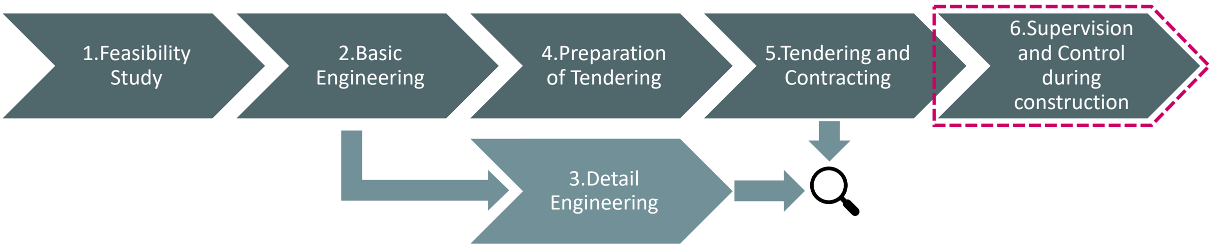


Figure 6-1: Process chain for planning, tendering and construction phase for SW desalination plant - part 6

Control and supervision during erection, commissioning and test runs until final acceptance (also referred to as project controlling) aims to ensure that the erection of the SWRO desalination plant is carried out on time and in accordance with costs and quality. This aim is reached by monitoring the execution of the project for compliance with the permits, the execution plans, and the tender documents, as well as the generally recognized rules of technology and the relevant regulations. Due to its complexity, it represents a very demanding task in construction projects.

The aim of Chapter 6 is to support the process of control and supervision from the start of the construction phase to the final acceptance of the plant.

The essential steps for successful control and supervision until final acceptance can be summarized as follows:

- **STEP 1: Understand the essential tasks for control and supervision**
  (→see 6.1 Essentials for control and supervision)

- **STEP 2: Understand the Tools for project controlling**
  (→see 6.2 Tools for project controlling)

- **STEP 3: Define the essential steps in the construction phase**
  (→see 6.3 Essential steps in the construction phase)

- **STEP 4: Prepare the final acceptance certificate**
  (→see 6.4 Final acceptance)

Figure 6-2 shows the different steps for the systematic approach to project controlling. In the following sub-chapters, the steps will be explained in detail.

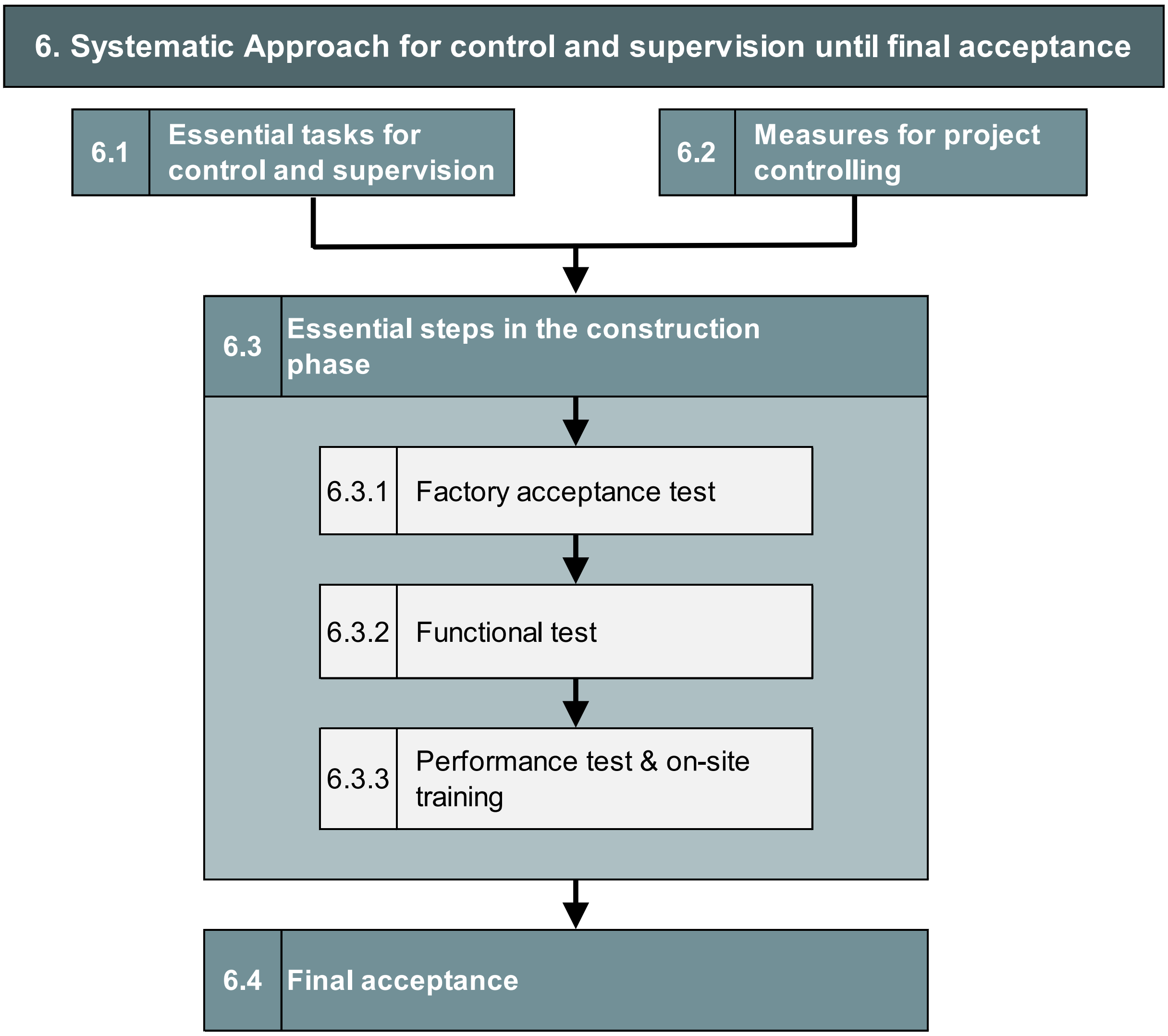


Figure 6-2: Systematic approach for control and supervision until final acceptance

6.1 Essential tasks for control and supervision

There are some general rules which have to be applied in the construction phase. These rules must be fixed in a protocol at the beginning of the project, including the agreement of all project participants.

These rules are:

1. Changes in the scope of supply cannot be made without the employer's consent and/or his authorized representative in coordination with other project participants.

2. If there is a change of a technical nature between two project participants, the result must be recorded in writing; the employer, as well as his authorized representative, must be informed of the outcome in written form without delay

3. When the coordination between two project partners is relevant to deadlines and costs, realizing these points always depends on the employer's consent and/or his authorized representative.

4. Intermediary deadlines are to be taken as seriously by all project participants as penalized final deadlines. Failures to meet the agreed coordinated internal deadlines are documented in written form from the beginning of the project. In this regard, schedule delays due to force majeure, e.g., inclement weather, shall be listed separately.

5. There must be notices to proceed within the construction phase – starting from the approval of the detailed design towards starting the functional tests, the performance test period, and the final acceptance. After the final acceptance, the contractor can request the permit to operate the desalination plant. Therefore, the documents such as O&M manuals, the maintenance schedule and water production plans must be approved by the employer.

To have reasonable control of all process steps during the construction phase, different essential tasks need to be performed by the employer or his authorized representative. These tasks include project management, project controlling, the inspection of equipment and the preparation and implementation of the final acceptance. The following Table 6-1 shows the essential tasks which must be executed by the employer or authorized representative in project controlling.

Table 6-1: Essential tasks of Project Controlling[46]

	Task
Project management	Coordination of the parties that are involved in the project
	Documentation of the construction process, including functional and performance test

[46] (HOAI, 2013)

	Task
	Preparation, updating, and monitoring of the schedules (time management)
Project controlling	Monitoring of the project execution in terms of compliance with the approval, the contract with the executing company, the execution documents, the assembly and workshop plans, the relevant guidelines, and the generally recognized rules of technology
	Control whether the health & safety standards are being followed by all parties involved in the project.
	Supervise the contractor for the protection of the marine ecology and the environment
	Cost control by examining the services of the executing companies in comparison to the contract prices and the cost estimate
	Examining and evaluating the necessity of changed or additional services and the adequacy of prices
	Inspection of revised documents for completeness, integrity, and random testing for compliance with the state of construction
	Examining and approval of the final invoice
Inspection of equipment	Auditing from a computational as well as technical point of view with inspection and certification of the service state based on verifiable service records
	Assisting with the performance and function tests
	In-house acceptance at the plant manufacturers site
	Identification of faults and shortcomings during construction
	Monitoring the rectification of faults or shortcomings before the final acceptance
Preparation of final acceptance	Technical acceptance of the services based on the presented documentation, creation of an acceptance protocol, documentation of faults and shortcomings, and issuing of the final acceptance
	Listing of the limitation periods for warranty claims

	Task
	Systematic compilation of all necessary documents and results of the project
	Preparation of official acceptances and inspections

Take Away Messages – Essential tasks for control and supervision:

- The project participants should agree on some general rules that are applied during the project and fix these in a protocol, in particular deadlines and the project control
- To have reasonable control of all process steps during the construction phase, different essential tasks need to be performed by the employer or their authorized representative. These tasks include project management, project controlling, the inspection of equipment and the preparation and implementation of the final acceptance

6.2 Measures for project controlling

In the construction phase, good cooperation with and good surveillance of the plant manufacturer is necessary. The various measures for project controlling are presented and explained in more detail in the following chapter.

6.2.1 Organization chart and project participants list

Organization chart:

The persons or groups of persons involved in a project are represented graphically in a project organization chart. In addition, the responsibilities are named, and the relationships between the companies or persons are visualized. A project organization chart is, therefore, a graphical diagram that displays the hierarchic structure of the project, including all project team members with their authority and the superordinate project management. Figure 6-3 shows a schematic diagram of a simple organizational chart.

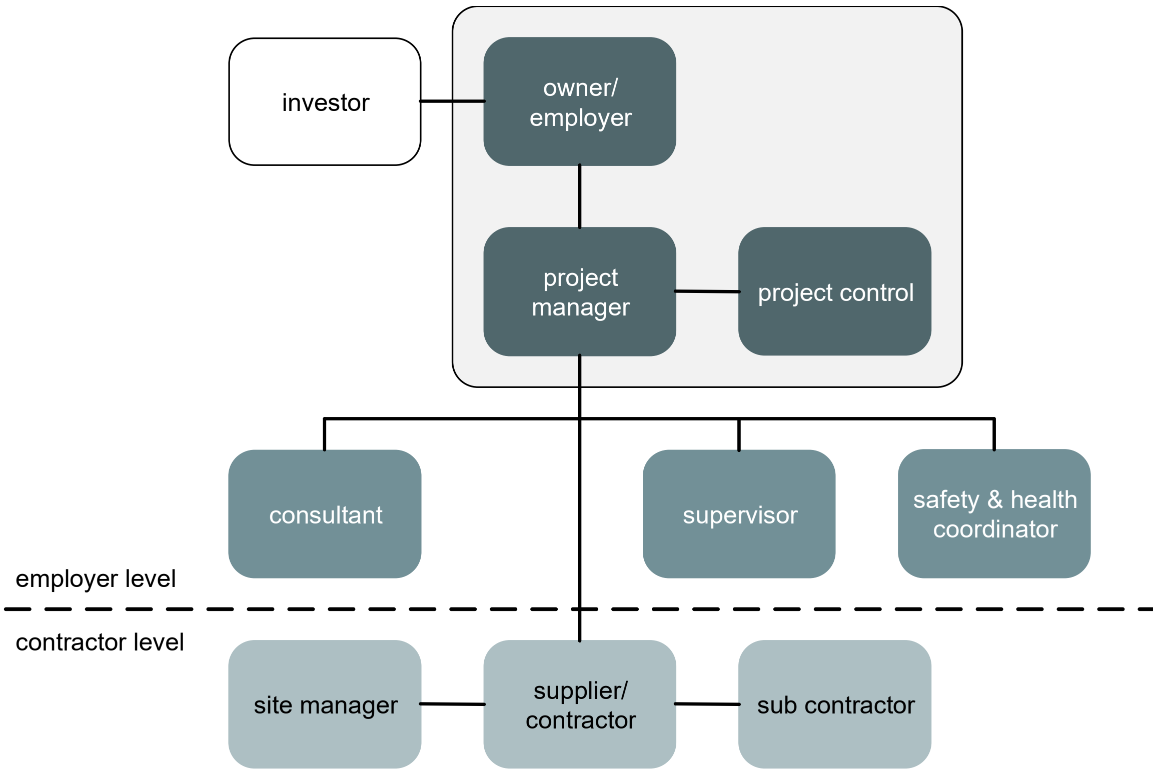


Figure 6-3: Principle of a basic organization chart

Figure 6-4 presents an example of a very detailed organizational chart. The connecting lines between the blocks represent a contractual relationship between the connected project partners.

In a SWRO desalination project, a possible project organization chart can be created in analogy to the following chart.

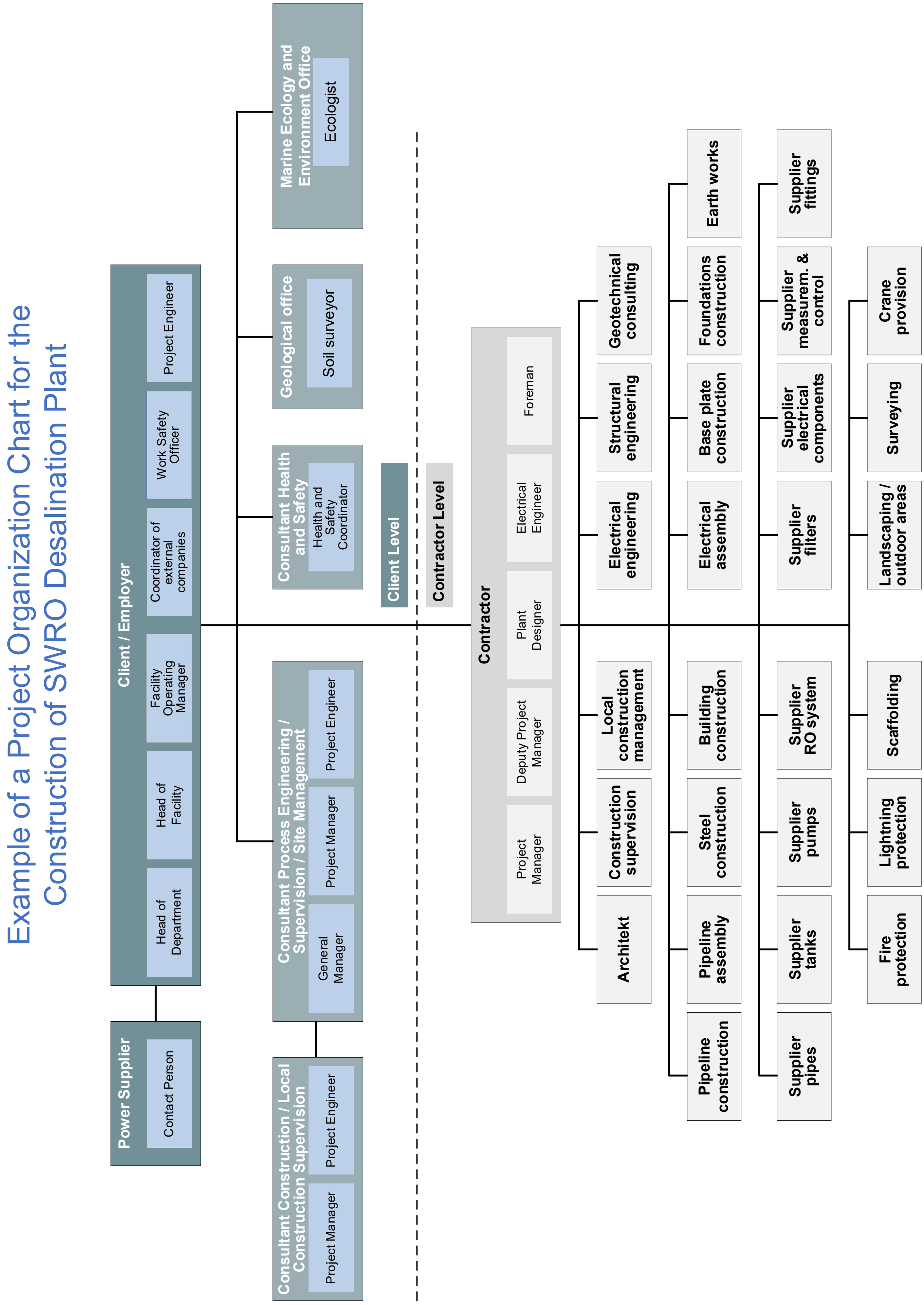


Figure 6-4: Example of a detailed organization chart

An example of an information box and the including contact details is shown in Figure 6-5.

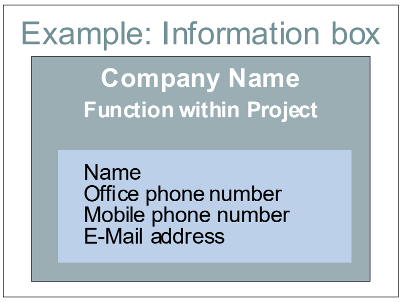


Figure 6-5: Detail of organization chart

Project participants list:

Table 6-2 shows an example of a detailed project participants list. A participants list can contain the same information as an organizational chart but does not display any hierarchial structures or contractual connections. For a quick overview, it is much easier to use than an organization chart. Additionally, a participants list can be sorted to get brief information without a time-consuming search.

A project participants list should contain at least the following information:

- Company name
- Responsibility/scope of tasks in the project
- Form of address, last name, first name, and title
- Function/role in the project
- Landline telephone number, mobile telephone number, e-mail address

Table 6-2: Example of a detailed project participants list

Company	Function within the project / Area of responsibility	Mr / Mrs	Name	First name	Function	Telefon	Mobile	E-Mail
...								
STEP Consulting GmbH	Project supervision / site management	Mr	Dr. Yüce	Süleyman	General manager	+49 241 90199-96	+49 171 1451086	yuece@stepconsulting.de
STEP Consulting GmbH	Project supervision / site management	Mr	Rams	Christoph	Project manager	+49 241 90199-97	+49 171 6873462	rams@stepconsulting.de
...								

6.2.2 Meeting's schedule

During the construction phase, scheduled project meetings, construction meetings, and health & safety meetings are held on agreed and fixed dates (jour-fix weekly or biweekly). Each project organization, company, or authority, must be represented by at least one authorized staff member in the construction meetings. In intensive construction phases, construction and project meetings must be held more frequently.

Project meetings

In the project meeting, the project managers of each participating organization discuss subjects related to the progress in the project, project costs, and their development, schedule, and issues that cannot be solved in the construction meetings. The project meetings can take place online.

Each project meeting has at least the following standard agenda points:

1. Review and reconcile the record of results of the previous project or construction meeting.
2. Short progress reports of the project managers on the construction status (deadlines, costs, dependencies)

The table of contents for a progress report of a project is shown as an example in the image below:

PROGRESS REPORT PROJECT **DATE:**

Content

Figure 6-6: Project progress report table of contents example

3. Further points regarding coordination, scheduling, and distribution of tasks
4. Review of schedules, revise if necessary, determination of intermediate steps, review of final dates
5. Examination of the cost plan, presentation of the interim cost status, examination of the budget
6. Setting a date for the next meeting

Construction meetings

In the construction meeting, the specialists of the project members (e.g., construction manager and supervisor, specialists, foremen, etc.) meet to discuss the project progress in detail and solve minor problems during construction or testing. Additionally, the next project steps are discussed in detail and pre-planned. Possible troubles, bottlenecks, and open questions can be examined and solved on the spot. The construction meeting can take place on-site or online, depending on the actual agenda.

Safety & health meetings

The safety & health meetings are held by the relevant specialists of the project members. They are organized by the safety & health coordinator of the employer. The pertinent issues for safety and health on the construction site are checked, and compliance with the safety regulations on the construction site is controlled. The safety & health coordinator can temporarily or permanently expel individual workers or companies from the site and shut down the entire site if serious deficiencies are found concerning site safety. The safety and health meeting must take place on-site.

Table 6-3: Example for a schedule for meetings

Type à	**Project meeting (PM)**	**Construction meeting (CM)**	**Safety and health meeting (SH)**
Frequency à	**monthly**	**biweekly**	**biweekly**
Tasks à	**project control (costs, time schedule)**	**control of scope of supply**	**on-site control of safety & health**
21.06.2021	PM1	-	-
23.06.2021	-	CM1	-
30.06.2021	-	-	SH1
07.07.2021	-	CM2	-

12.07.2021	PM2	-	-
14.07.2021	-	-	SH2

6.2.3 Structure of meeting and minute taking

Usually, a meeting is structured as follows:

- Welcoming/ Introduction
- List of participants
- Discussion of important points
  - Taking minutes including the clarification who does what and when
- Determination of next meeting

Every meeting must be recorded by a minute taker. Minutes of meeting are an essential part of project controlling. The minutes of the project meetings are written by the employer or his authorized representative. At least the following points must be recorded:

- the factual situation regarding the project progress
- causes for possible problems, delays, extra costs, etc.
- (suggested) solutions for the above mentioned
- responsible organizations and persons
- deadlines (for example, for the solution of problems)
- cost relevance of possible problems, delays, etc.
- a list of open points (LOP) to be followed until their settlements

The minutes of meeting are sent by e-mail as a draft within three working days after the meeting to all participants according to the agreed information distribution key. Any suggestions for corrections or additions will be sent to the employer or his authorized representative by e-mail within another three working days. The minutes of meeting should preferably be sent in PDF file format that cannot be changed easily.

If possible, it is recommended that minutes of meeting be taken during the meeting and reviewed/signed by the participants prior to leaving. This will negate the possibility of interpretation after the fact or of participants changing their mind.

Table 6-4 shows an example for a structure of minutes of meeting, including the main contents of a protocol.

Table 6-4: Structure of minutes of meeting

HEADER OF PROTOCOL

General information

No.	Topic	Date	Resp.
1.	Welcome/Introduction/Objectives: • …		
2.	Project Organization Chart/Project Participants: • …		
3.	Project execution: • …		
4.	Construction site & equipment: • …		
5.	Subcontractors/Proofs/Health & safety: • …		
6.	Approvals: • …		
7.	Site & construction plans: • …		
8.	Costs: • …		
9.	Schedules & Dates: • …		
10.	Miscellanious: • …		
11.	Annexes to the protocol • …		

Name and signature of minute taker

FOOTER OF PROTOCOL

The <u>header</u> should consist of the following points:

- Name and number of protocols,
- (Date,)

- (Logo of minute taker.)

The general information of the minute contains the following:

- Name of project,
- (Project number),
- Topic,
- Date,
- Place of meeting
- Name and company of participants

The protocol itself can include the following topics:

- Welcome/Introduction/Objectives
- Consultant or minute taker updates and provides to the project participants by e-mail information about the project execution
- Construction site equipment
- Subcontractors / Proofs / Health & safety
- Approvals:
  - Necessary permissions for working on the site,
  - Application for permissions.
- Site & construction plans
- Costs
- Schedules & Dates
- Listing of annexes to the protocol

Name and signature of the minute taker are placed at the end of the protocol.

The footer of the protocol should contain:

- Name of the file
- Number of the page

The annexes of the minutes of meeting should at least consist of:

- Participants list with name, company, and signature,
- List of open points (LOP)
  - Including discussed points (tasks) that could not be finished in the meeting,
  - Responsibility for execution of open points,
  - Fixed date by which a task must be completed.
- Other documents, plans, certificates, lists for clarification of the meeting's topics

6.2.4 Site supervision

To have an overview and control over the project's execution, it is necessary to monitor the construction site. As shown in Figure 6-7, site supervision is divided into 4 phases[47]

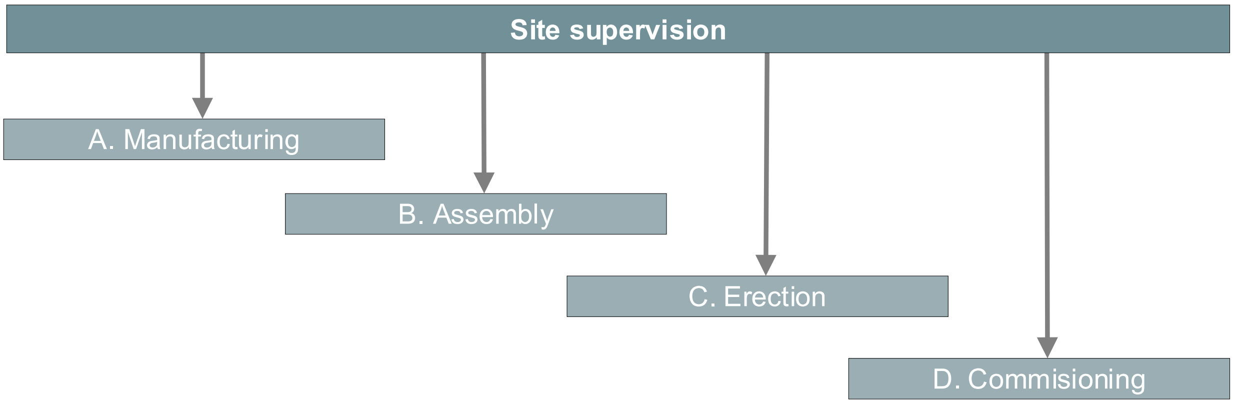


Figure 6-7: Site supervision

A. Site supervision during manufacturing

- Supervision of the execution of the project for conformance with the working drawings, project specifications, or schedule of work and with the generally accepted standard rules of technology and applicable regulations
- Supervision and correction of details by the manufacturer

B. Site supervision during assembly

- Supervision of the assembly of the components at the manufacturer's workshop
- On-site inspection of the plant to identify defects
- Supervision of correction of defects

C. Site supervision during erection

- Supervision the on-site execution
- On-site inspection of the plant to identify faults, deficiencies and lacks
- Supervision of the clearing and remediation of the faults, deficiencies, and lacks

D. Site supervision during commissioning

- Functional checks of sub-systems as pre-commissioning checks
- Commissioning of the complete plant begins when all pre-commissioning checks have been completed.

[47] Yüce, S.; Gebel, J. An Engineer´s Guide to Desalination

Take Away Messages – Measures for project controlling:

- An organization chart should be created to have an overview of the projects participants and to display the hierarchic structures or contractual connections. For a quick overview, a project participants list is also useful
- A meeting schedule should be created to ensure meetings are held regularly
- All meetings should be documented by a minute taker
- To have an overview and control over the project's execution, the employer should supervise the site during manufacturing, assembly, erection and commisioning

6.3 Essential steps in the construction phase

Several essential steps in the construction phase ensure a smooth and fair commissioning and transfer of ownership. Figure 6-8 shows these essential steps until the final acceptance. (The figure is also found in a larger size in chapter 4.3.2)

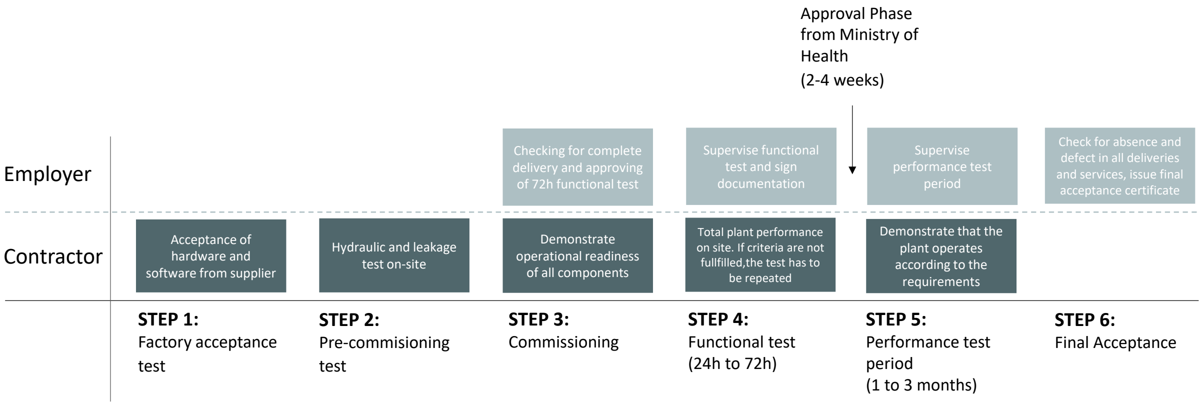


Figure 6-8: Essential steps until final acceptance

6.3.1 Factory acceptance tests & commissioning

Factory acceptance tests are equipment tests at the supplier's workshop at the end of the manufacturing phase before the equipment is delivered to the site. The aim of the tests is to confirm the completeness and the functionality of the tested equipment. The tests are performed and documented by the manufacturer in the presence of the employer. After successful tests, a “Ready for Shipment” certificate must be issued and signed by the supplier and the employer and/or his authorized representative

- The certificate should contain at least the following items:
    - Name and contact data of the supplier
    - Name and contact data of the employer
    - Object of certificate
    - Date and place of factory acceptance tests
    - Name and contact data of attendees during factory acceptance tests
    - Short description of the testing procedure
    - Recording of performance data of the tested equipment, if appropriate
    - Results of the factory acceptance tests
    - Signatures of the attendees

After the factory acceptance test, the contractor should do a pre-commissioning test, where the equipment is checked for any leakage and hydraulic problems.

If the factory acceptance and the pre-commissioning test have been completed successfully, the commission phase can start. During commissioning, the employer and/or his authorized representative must inspect the plant or its main utilities regarding their completeness, check the scope of delivery for compliance with the contract, and assess the actual condition of the plant before the final assessment.

In particular, the following must be compared and checked:

- Tender documents (= contract & offered equipment) vs delivered documents (process descriptions, parts lists, technical drawings, P&I diagrams, materials, etc.)
- Delivered documents vs installed technology
  - Equipment (quality, quantity, manufacturers, etc.)
  - P&I diagrams (kind of equipment, positioning of equipment, functionality, etc.)
- Plant condition (rust, dirt, leaks, damages, loose screws or pipe connections, etc.)

After the check for completeness has been conducted, a report should be established by the employer and/or his authorized representative.

Table 6-5 shows an example of the table of contents for a report of completeness tests.

It could happen that the P&I diagram was checked and approved in an earlier stage of the project. If the execution of the technology differs from the approved P&I diagram, the supplier needs to correct the installed technology.

Table 6-5: Example of a table of content for a report of completeness checks

Table of contents

The following Figure 6-9 shows an example of a P&I diagram, which was checked for compliance with the execution of the plant at the site. The red markings show places where the P&ID diagram did not match the actual execution on site. Here, the system manufacturer must correct the P&ID flow diagram for correct "as-built" documentation (or adapt the system technology to the P&I diagram).

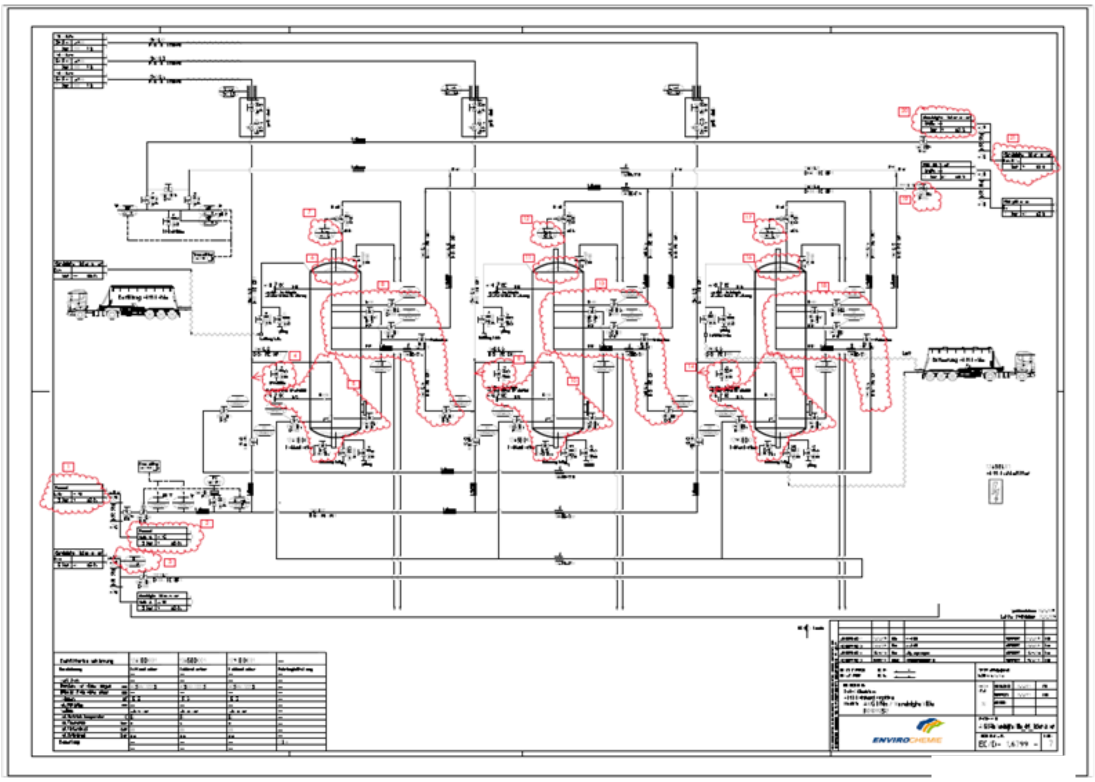


Figure 6-9: Example of a checked P&I diagram

Figure 6-10 shows a section from the example P&I diagram in Figure 6-9.

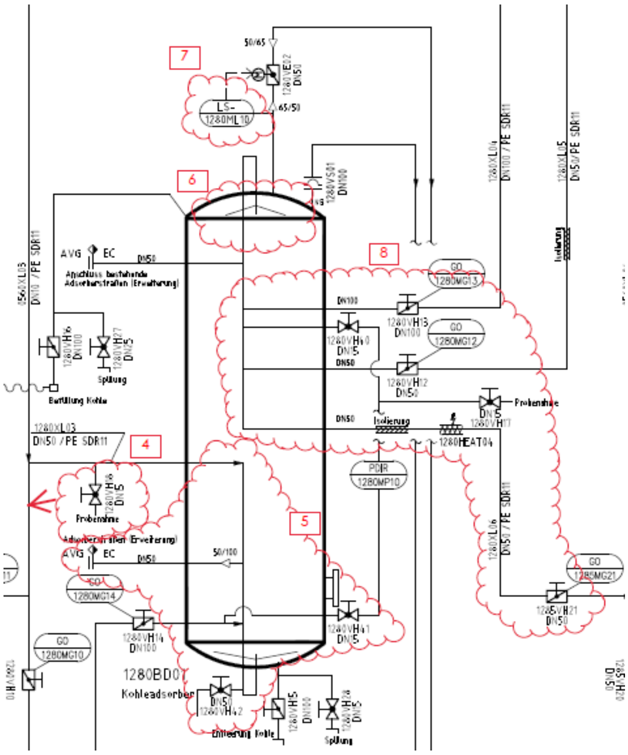


Figure 6-10: Extract from Figure 6-9

6.3.2 Functional test

The contractor must undertake a functional test run in the presence of the owner's representative and/or engineer/consultant on behalf of the owner. The performance and the procedure shall be fully documented and duly signed by all representatives participating. In case that the specified criteria are not fulfilled during the period, the functional test must be repeated. It is highly recommend doing the functional test for at least 72 h. If any failure or unscheduled shutdown occurs during the test, the entire test must be repeated.

Prerequisites for the start of the functional test are:

- Commissioning is completed.
- The proper functioning of all equipment was demonstrated.
- The plant is running in accordance with the contract, at the contracted, operating point and in accordance with all contracted specifications.

The functional test can be regarded as successful when

- the plant produces the contracted amount of product water during the test period,
- the plant has been operated for an agreed number of hours (for example 72 h),
- without interruption, and
- without any defects or malfunctions which prevent or significantly restrict proper operation or endanger the plant.
- Simulated interruptions do not extend the functional test.
- Proper data registration, evaluation, and documentation (report) is a condition for the acceptance of the functional test.

The functional test must be repeated (possibly multiple times), if it was not successful.

Figure 6-11 (pressure) and Figure 6-12 (flow rate) show examples for data registration and presentation.

These values originate from the process control system and have been recorded automatically during the functional test. The diagrams show, that the plant (or the data recorder) had problems at the beginning of 14.02.2020 and further on, which needed to be discussed before accepting the success of the functional test.

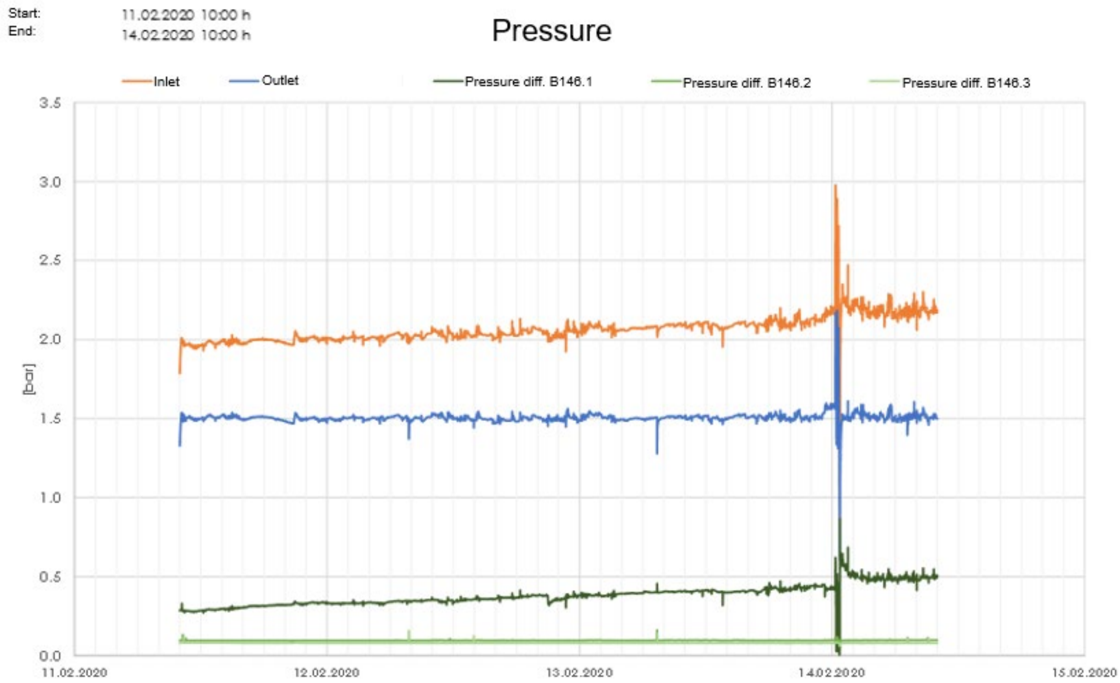


Figure 6-11: Example of performance documentation during the functional test

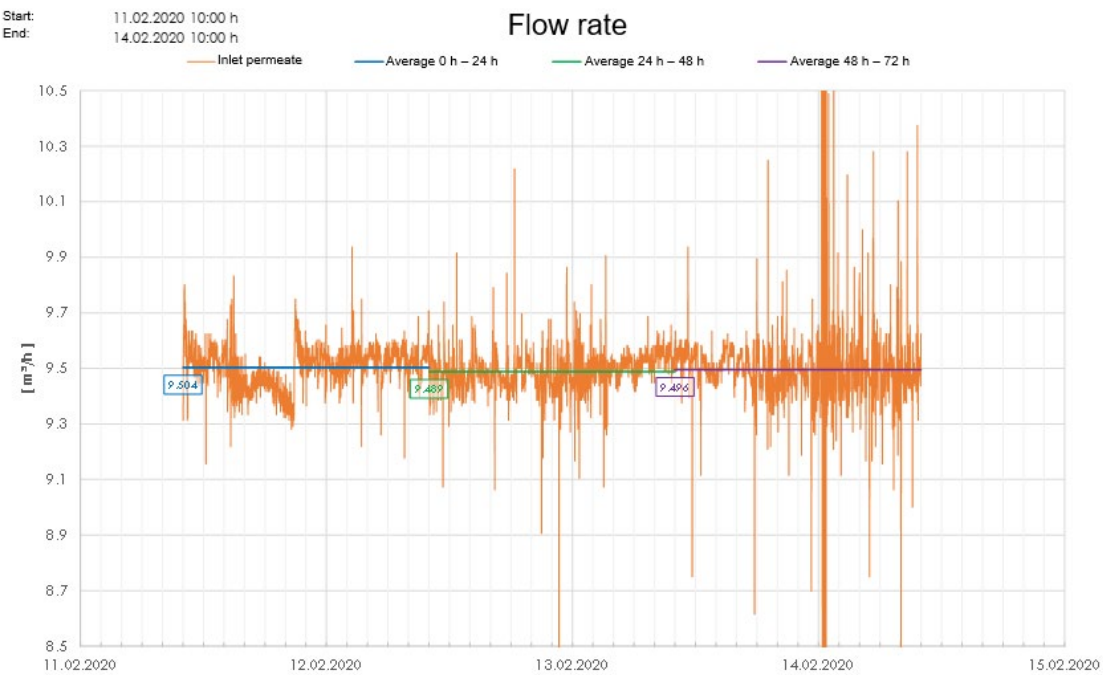


Figure 6-12: Example of performance documentation during the functional test

6.3.3 Performance test & on-site training

After the successful functional test, the performance test can start immediately.

The implementation of the SWRO plant performance test is addressed in the tender documents and must be offered by the system supplier and carried out under his own responsibility. The duration of the performance test must be a representative period and contractually agreed on in advance (for example, 3 months).

The performance test of a SWRO plant has the following purposes:

- Proof of performance (among others: contractually guaranteed water production rate, product water quality, water recovery rate, and plant availability)
- Proof of compliance with the contractually guaranteed consumption data (e.g., for electricity, chemicals, freshwater, etc.)
- Instruction of operating personnel,
- Optimization of operation.

The performance test can be accepted as successful, when

- The above-listed criteria are fulfilled,
- The plant has been operated for the agreed time (for example, 3 months),
- Without significant interruption and
- Without defects or malfunctions preventing or significantly restricting proper operation or endangering the plant. and the marine environment.
- Simulated interruptions do not extend the functional test.
- Proper data registration, evaluation, and documentation (report) is a condition for the acceptance of the performance test.

If the criteria listed above are not fulfilled, the performance test must be extended or repeated.

The successful performance test is the prerequisite for the final acceptance.

Figure 6-13 shows an example for data registration and presentation.

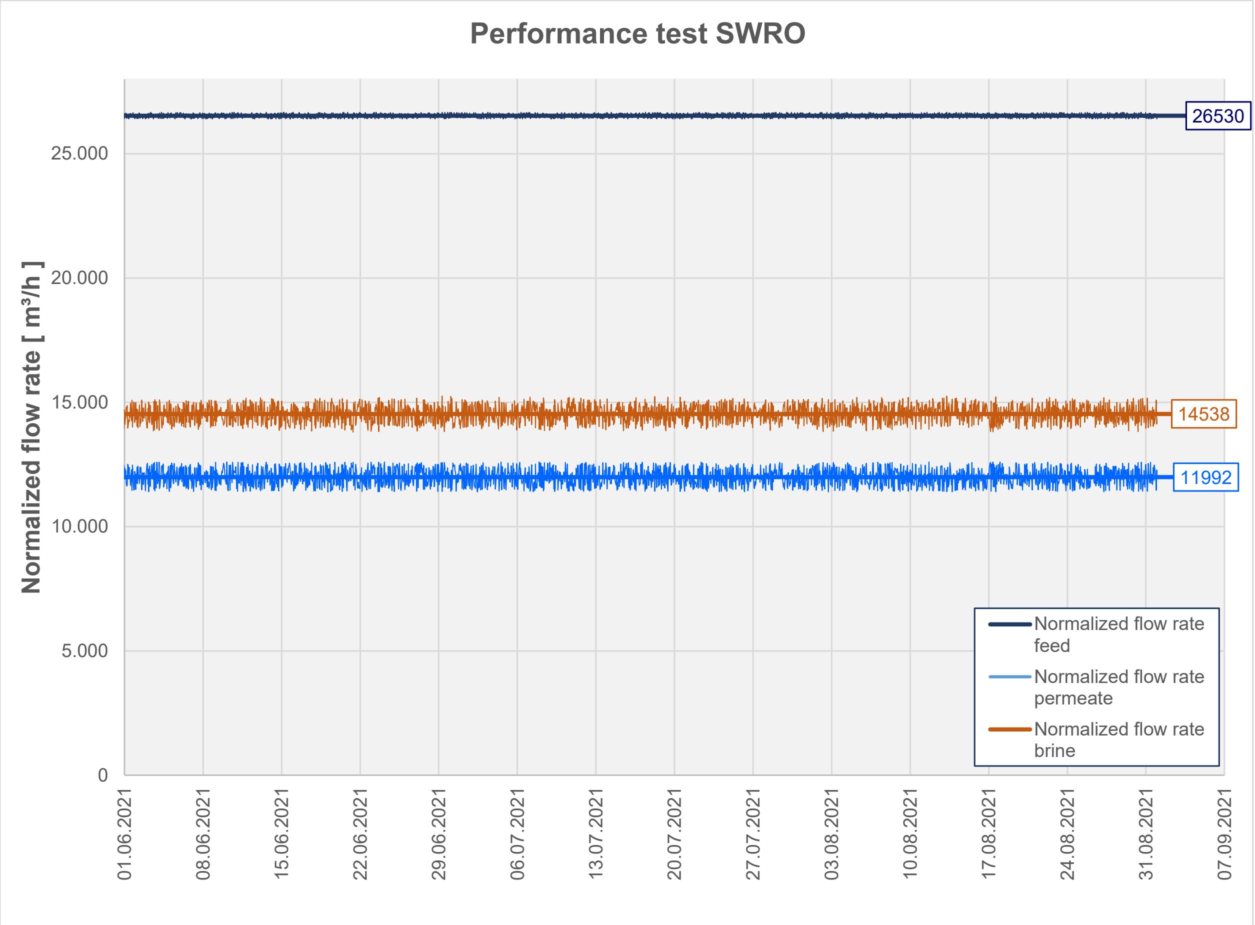


Figure 6-13: Example for data recording and presentation for the final report of the performance test

<u>On-site training</u>:

During erection, commissioning, and performance tests, the future staff of the desalination plant should get on-site training, which has to be supplied by the contractor. The duration of training depends on the complexity and size of the plant.

A training plan should include the following:

- Aim of the training
- Place of training
- Schedule and duration of training
- Requirements for trainees
- List of trainees
- The naming of trainers & training companies
- Description of theoretical and practical training in the context of the user manual
- Troubleshooting and safety instructions
- Maintenance plan

Before starting training, the supplier has to present a training plan that has to be confirmed and accepted by the employer.

The trainers must provide the trainees with sufficient training material of good quality. The training material must be checked and approved by the employer before training starts.

Following positions should be taken into consideration with the training participants

- Determination of who will participate in the training
- Small groups dependent on the workplace at the desalination plant
- Determination of team leader/s who can instruct new personal in future

Take Away Messages – Essential steps in the construction phase:

- Define checkpoints at which the contractor is controlled. The contractor has to prove that the delivery is complete and the plant works within the target values.
- A function test (72h) significanty reduces the risk for critical problems during the performance test period (3 months).
- The future staff of the desalination plant should receive on-site training from the contractor during the perfomance test

6.4 Final acceptance

The final acceptance should only be issued after satisfactory completion of the tests mentioned above. In addition, the as-built drawings, the design manual, and the maintenance manual must be provided by the contractor in good quality in paper and electronic versions. The manuals must also include a list of the suppliers and their correspondence addresses. As part of the technical acceptance, the absence of defects in all deliveries and services must be checked by the employer or the engineer on behalf of the employer. The final payment is usually linked to the issue of the final acceptance certificate. The employer will take over the desalination plant after the final acceptance. In the case of BOT and BOO contracts, the ownership remains with the contractor.

The final acceptance is documented by an acceptance certificate or protocol, including the listing of shortcomings. The previously agreed upon warranty period starts after the final acceptance.

The final acceptance certificate should contain at least the following:

- The name of the project
- Data of client, supplier, consultant, and minute-taker
- Relevant project data (location, plant name, order numbers)
- Operation date(s)
- A declaration, whether the performance and the state of the plant is free of defects
- A list of minor defects or open points which have to be corrected by the supplier in an agreed time frame
- Date, signature, and stamp of the contract parties and consulting engineers

The following tables show an example of an acceptance protocol.

Table 6-6: Example for a final assessment protocol, 1

Client Contractor Consultant

Title

Final acceptance protocol

In accordance with § 12 Para. 2 VOB/B

(Includes x pages)

Client:

Contractor:

Consultant:

Created by: STEP Consulting GmbH
Aachen, 29. October 2021

29.10.2021 1- 3 Titel

Table 6-7: Example for a final assessment protocol, 2

Client Contractor Consultant

Final acceptance protocol

Project:			
Order date:			
Location:		Plant:	
Client:		Client order no.:	
Contractor:		Contractor order no.:	
In operation since: Date	Trial operation: from to	Proof of performance: from to	Acceptance since: Date

Partial acceptance and warranty are limited to the following scope of delivery:

The scope of supply and services was delivered and installed in accordance with the above order. All technical documents according to the plant documentation ... were delivered according to the status at the time of acceptance. The plant facilities and equipment used by the contractor were handed over or de- livered in proper condition.
Upon acceptance, it was found:

☐ The performance is free of defects

☒ Apart from the defects and remaining work listed below, the service is in a condition in accordance with the contract

The liability for defects shall commence on the date of acceptance and shall end on expiry of the contractually agreed period of liability for defects, unless the limitation period is interrupted or suspended. The period for rectification is six weeks after acceptance.

Defects of an insignificant nature which are to be remedied and technical documents which are to be supplemented as well as missing technical documents, on account of which the Client reserves all rights in respect of defects:

(If necessary, further findings of deficiencies are to be attached)

ID	Description of the residual and shortage work	Request according to	Time limit for rectification

29.10.2021 2- 3 Titel

Table 6-8: Example for a final assessment protocol, 3

Estimated value for payment retention a) In the case of rectification of defects by the client: ____ € b) In the case of procurement of missing technical documents by the client: ____ €	
All claims of the client for warranty and damages according to order confirmation x as well as service specifications remain unaffected. The Client reserves the right to claim any contractual penalties incurred until payment has been made in full. Acceptance is hereby pronounced. The duration of the warranty period is up to 5 years when a maintenance contract is concluded. It shall be determined retroactively to the beginning of the trial operation (beginning of the economic benefit) after the end of the trial operation. The limitation periods and the scope of warranty are as follows:	
<u>2 years warranty:</u> Warranty components (mechanical, plant and electrical engineering) Warranty spare parts and wear parts	
Start of warranty: Date	End of warranty: Date
<u>5 years warranty:</u> guarantee of structures (foundations, basin, hall and steel structures) Guarantee of media resistance (pipelines, containers, basin linings and rubber linings) Guarantee of corrosion resistance (e.g., against weather influences) Guarantee of function and availability (8000 h/a when operated according to operating instructions and maintenance contract)	
Start of warranty: Date	End of warranty: Date
Other comments and additional arrangements:	

Participants:		
Client:	Contractor:	Consultant:

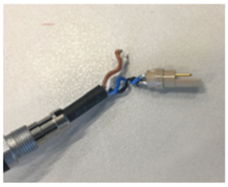
Signature client Signature contractor Signature consultant

As stated above, a list of shortcomings has to be created with defects and other points where the new system does not meet the order's requirements. This list should include details of the criticized equipment or performance, a description of the defect, photos, and the deadline for repair. Table 6-9 shows an example of a list of defects (extract).

Table 6-9: Example: extract of a list of shortcomings

ANNEX II: Final Acceptance Test
List of defects and damaged equipment
Desalination pilot plant

Project:	Desalination Pilot Plant	**Date:**	14.06.2021	Editor: DD
Action:	Final Acceptance Test	**Location:**	Kuwait	STEP Consulting GmbH

Pos.	Unit	Component	Component No.	Description	Photo	Deadline / Remarks
1.	Lot 1	JULABO FP51-SL		The cable of external Pt100 sensor is defect (Alarm code 15) - Noted damage after plant erection at site		26.07.2021
2.	Lot 2	Pt100	CT-D-010	The temperature sensor Pt100 is bend - Noted damage after plant erection at supplier		26.07.2021
3.	MED	Vacuum pump	MED AN-N-006	The vacuum pump is damaged and isn´t working – Noted damage at supplier		26.07.2019 Supplier will send a new vacuum pump to client

2021-06-14 List of defects Desalination Pilot Plant.docx   Page 1 of 4

Take Away Messages – Final acceptance:

- The final acceptance should only be issued after the satisfactory completion of the performance test period. In addition, the as-built drawings, the design manual and maintenance manual must be prior provided by the contractor in good quality.
- The final acceptance certificate should include a list of all shortcomings

6.5 Checklist for Project Controlling

Table 6-10: Checklist for project controlling

Checklist for project controlling		*Drawn by:*	
		Checked by:	
NO.	DESCRIPTION	CHECKED	REMARKS
6.1	**Essential tasks for control and supervision**		
	a) Have the general rules been fixed in a protocol?		
	b) Is the employer's project team aware of the essential tasks?		
6.2	**Measures for project controlling**		
	a) Did you create an organization chart?		
	b) Did you create a project participants list?		
	c) Did you create a meetings schedule including project, construction and safety & health meetings?		
	d) Are minutes taken at every project meeting?		
	e) Did you decide who is responsible for taking minutes?		
	e) Have you decided on critical milestones in the project where supervision on the site is essential?		
6.3	**Essential steps in the construction phase**		
	a) Did the contractor conduct a factory acceptance test, where the completeness and functionality of the equipment has been checked?		
	b) Did the contractor conduct a pre-commisioning test, where the equipment has been checked for any leakage or hydraulic problems?		
	c) Have you checked the plant for completeness and compliance with scope of supply?		
	d) Do you regularly assess the condition of the plant?		
	e) Did you supervise the functional test?		
	1. Check and accept the documentation of the functional test		
	2. Declare the test successful		
	f) Did you supervise the performance test?		
	g) Did you receive a detailed trainingplan for on-site training?		
	h) Did you determine who will participate in the training?		
6.4	**Final acceptance**		
	a) Have you carried out a final plant inspection?		
	b) Are there any shortcomings that need to be fixed before the final acceptance?		
	c) Have you issued the final acceptance certificate?		

Ministry of Water & Irrigation
وزارة المياه والري

سلطة المياه
WATER AUTHORITY

Guideline for the Management of Seawater Reverse Osmosis Desalination Plants in Jordan

التعاون الألماني
DEUTSCHE ZUSAMMENARBEIT

Facilitated by
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Table of Contents

List of Figures

List of Tables

Introduction

Several factors are hindering Jordan from harnessing seawater and brackish water for covering its ever-growing water deficit. Jordan has a very short coastline along the Red Sea near Aqaba. In addition, the salt content of the Red Sea, up to 43,000 ppm, is significantly (by ~10 %) higher than the salt content in the Mediterranean. The major demand center, Amman, is located around 350 km away from Aqaba to the north with a hydrostatic head difference of approx. 1,000 m.

The demand for drinking water is rising with population growth. The figure below shows the population distribution (2015) across the regions of Jordan. It is immediately noticeable that about two-thirds of the population live in the central region, around Amman. The immediate consequence is that a large part of the drinking water requirement is in the central area. Conversely, decentralized solutions must be found for sparsely populated regions. In the central region as well as in the North and South regions in Jordan, the surface water is by far not sufficient as a source for drinking water production. Thus, groundwater resources were until now largely used to cover demand. However, groundwater overexploitation has led to significant water level declines so that the aquifers are increasingly falling dry, and extraction is becoming problematic in many areas.

Map of Jordan

ID	Governorate	Capital	Population
	Northern region		29 %
1	Irbid	Irbid	2,003,800
2	Mafraq	Mafraq	622,500
3	Jerash	Jerash	268,300
4	Ajloun	Ajloun	199,400
	Central region		63 %
5	Amman	Amman	4,536,500
6	Zarqa	Zarqa	1,545,100
7	Balqa	Al-Salt	556,600
8	Madaba	Madaba	214,100
	Southern region		8 %
9	Karak	Al-Karak	358,400
10	Aqaba	Aqaba	213,000
11	Ma´an	Ma´an	179,300
12	Tafila	Tafila	109,000
	Total population		10,806,055

Figure 1-1: Estimated population of the Kingdom of Jordan by Governate for the end of 2020[1]

[1]Directorate of Family and Population Surveys (2020). Estimated Population of the Kingdom by Governate, Locality, Sex and Households.

With the upper parts of the groundwater system falling dry, the government and farmers have resorted to tap deeper layers. However, with increasing depths of extraction, groundwater is becoming

- saltier,
- more radioactive, and
- warmer.

Such deep groundwater is mostly brackish and needs to be treated in a “brackish water desalination plant.”

Within the contract Preparation of Guidelines for Planning and Management of Desalination Plants, contract number 81266072, the following documents will be prepared:

- Guideline for the Planning of Brackish Water Reverse Osmosis Desalination Plants in Jordan
- Guideline for the Management of Brackish Water Reverse Osmosis Desalination Plants in Jordan
- Guideline for the Planning of Seawater Reverse Osmosis Desalination Plants in Jordan
- Guideline for the Management of Seawater Reverse Osmosis Desalination Plants in Jordan

Objectives of the Guideline

The overall goal of this guideline is to assist the supervisors and operators of a desalination plant in ensuring stable performance over the lifetime of the plant with minimal operating cost. While the individual chapters are addressing the plant operator, they can be used by the plant contractor/employer as a basis for contractual agreements and aspects to keep in mind. Additionally, important aspects regarding quality control of product water and plant operation for the employer are included.

Chapter 1 will discuss key issues and strategies in managing Seawater Reverse Osmosis Desalination plants (SWRO plants). The principles of organizational structures, cost management, training courses, quality control, and plant documentation will be explained.

The proper and stable operation of the plant is an important requirement to ensure economic water production. The exact meaning behind this more abstract definition as well as a short description of plant operation modes will be explained in Chapter 2.

The plant operation lies on two pillars, which are equally important to guarantee safe and economical water production.

The first pillar, shown in Figure 1-2 on the left, represents the physical aspects of plant operation. This includes the provision of all material needed (see Chapter 3), the monitoring and control of the running process (see Chapter 4), and all aspects regarding maintenance operations (Chapter 5).

The pillar on the right are all concerns regarding the Environment, health, and safety (Chapter 6). This important topic relates to all parts of plant operation, from the management of consumables with the correct storage of chemicals to working with machinery during maintenance operations.

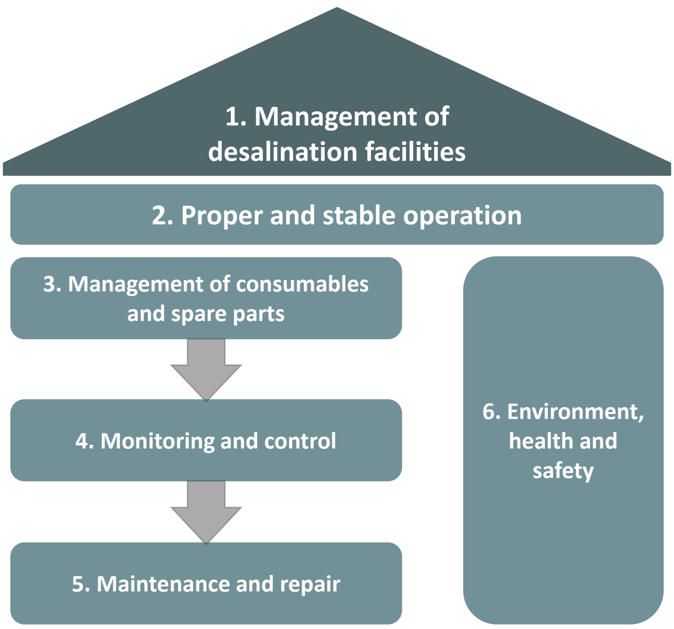


Figure 1-2: Chapter structure of SWRO Management Guidelines

How to use the SW Management Guideline

Both “brackish water desalination” and “seawater desalination” sound similar. However, there are crucial differences between both types of desalination technologies that make it necessary to consider them in two separate planning and management guidelines. The following chapters of these guidelines are dedicated to the management and operation of the “seawater desalination plant” in Jordan.

The Guideline for the Management of Desalination Plants comprises the major aspects of plant operation from the supervising management to specific information regarding monitoring and control, maintenance tasks and environment, health and safety requirements. These aspects and their dependencies are depicted in Figure 1-3, which will be shown at the beginning of each chapter so that the reader can go directly to the point of interest.

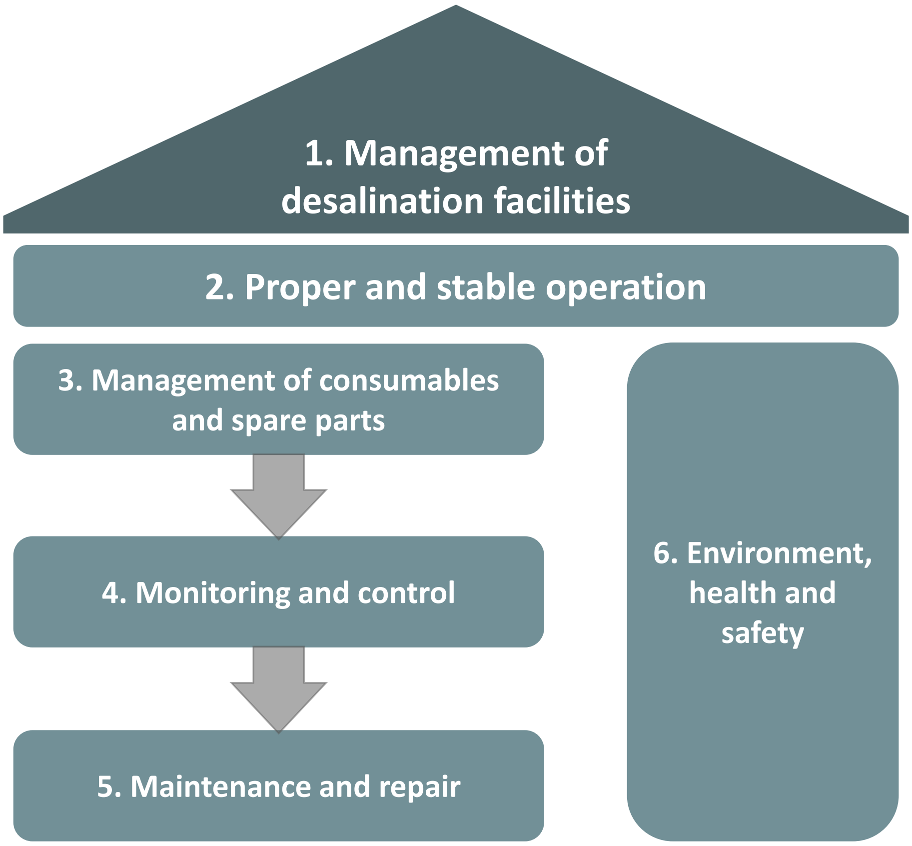
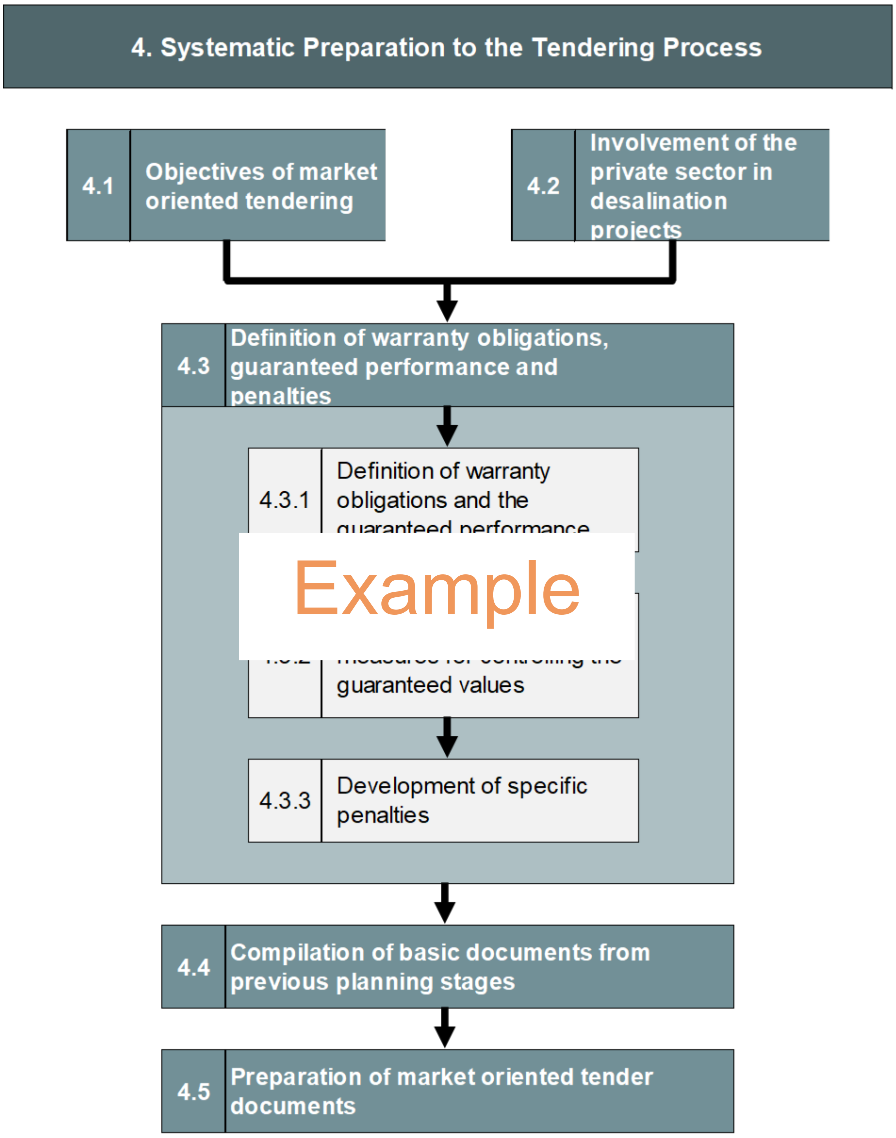


Figure 1-3: Structure of guideline at the beginning of each chapter

Each chapter contains the following structure and some elements to reinforce the understanding and application of the guidelines. Below, the elements from Chapter 4 of the Seawater Reverse Osmosis Planning Guidelines are exemplarily shown.

1. **The structure** that leads through the chapter:



2. **Take away messages** summarize the most important facts:

Take Away Messages – Objectives of market-oriented tendering:

- “Market orientation" must be applied to all required equipment, materials and services in all proj Example y study to the tendering process
- Apply the common contracting processes, be aware of the fact that a low price of a good may indicate that the producer compromised quality and that in the long run low prices may be more expensive..

3. **Checklist** for the application of the topics:

Preparation of tender documents		*Drawn by:* *Checked by:*	
ITEM No.	DESCRIPTION OF ITEMS THAT NEED TO BE INCLUDED IN THE TENDER DOCUMENTS	CHECKED	REMARKS
4.1	**Market-oriented tender**		
	a) Did you apply market-orientation to create a broad competition?		
	b) Did you apply the law of business to ensure that you get adequate quality?		
4.2	**Involvement of private sector**		
	a) Is the right contract type selected? ... financial risk?)		
	b) In case of B(O)OT: Is the water tari...		
4.3	**Warranty obligations**		
	a) Are the warranty obligations defined?		
	b) Is the warranty period of specific components realistic and on a fair level?		
	c) Did you include the essential steps until the final acceptance of the desalination plant?		
	d) Have specific penalties been developed? (Indicator, Value)		

1. Management of desalination facilities

In Figure 1-4, the chapter structure of these guidelines is depicted. Chapter 1 will discuss key issues and strategies in managing SWRO plants that are newly commissioned and already in operation. This chapter is the overarching umbrella that stands controllingly above the other contents of Chapters 2-7.

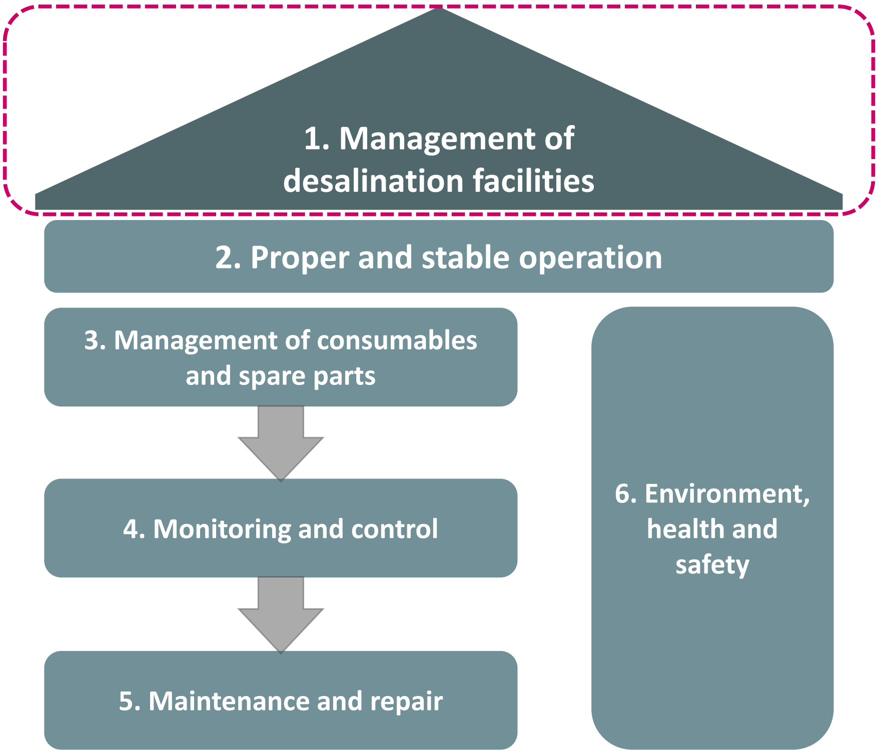


Figure 1-4: Chapter structure of SWRO Management Guidelines

The effective management of newly commissioned plants and plants already in operation is the focus of the entire management guideline.

The first chapter aims to show major challenges when starting the operation of a desalination facility and to guide into efficient operations and, when followed carefully, avoid costly waste of resources and unnecessary shutdown times or accidents and damage of plant equipment.

In this respect, topics such as organizational structure, human resources (HR), processes, cost management and the principles of environment, health and safety and quality control are addressed to form the basis of an efficiently operated desalination plant. The outline of this chapter is shown in Figure 1-5. In Chapter 1.1, the most important matters regarding the organizational structure are discussed. Chapter 1.2 focuses on the importance of adequate selection, training of plant personnel and suitable working conditions. Chapter 1.3 will give an overview of essential management processes, Chapter 1.4 deals with cost control. Environment, health and safety management is discussed in Chapter 1.5. Chapters 1.6 shows effective quality assurance and quality control strategies, whereas Chapter 1.7 deals with the important topic of suitable documentation management.

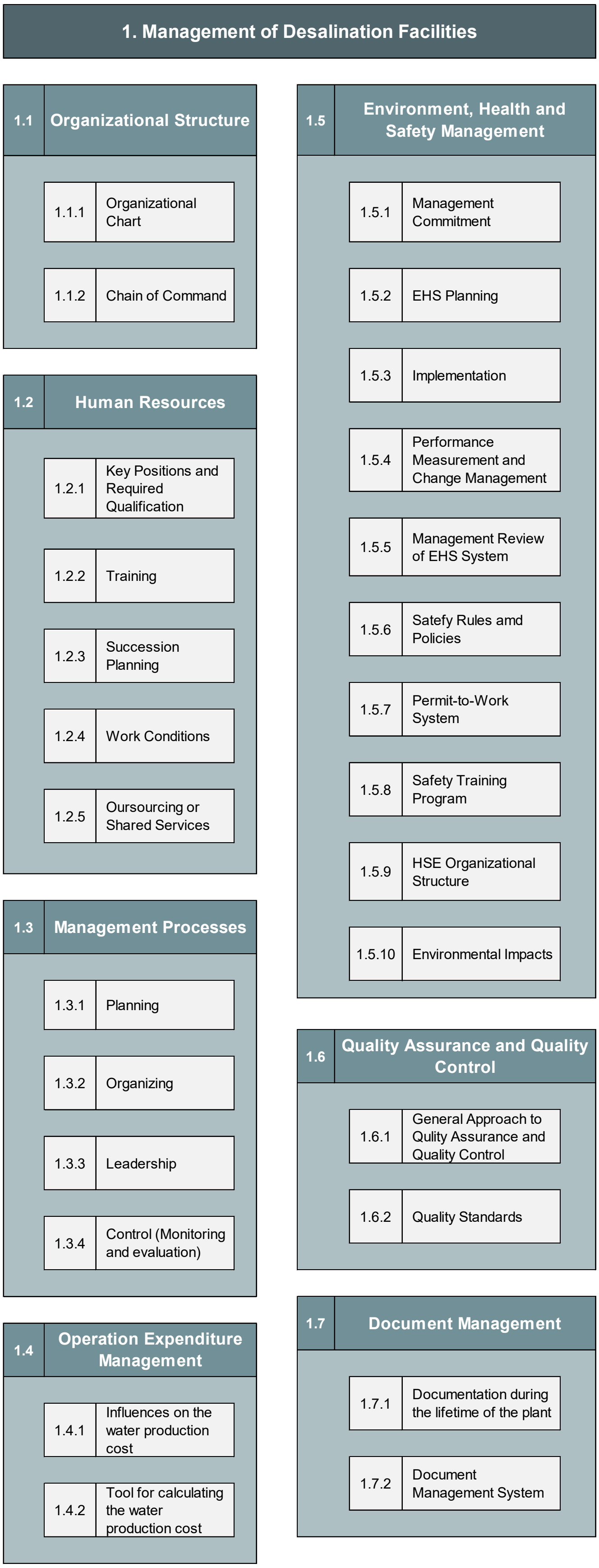


Figure 1-5: Structure of Chapter 1: Management of desalination facilities

1.1 Organizational structure

The purpose of a desalination plant operation is to efficiently use the available resources and technologies to produce quality drinking and potable water at the lowest price possible. The management and organizational structure shall support this purpose by optimizing and structuring the tasks and workflows. Therefore, the organizational structure allows groups to work together effectively within their individual functions to manage tasks.

The supervising function of the employer of a seawater desalination plant should keep this in mind and follow up on the organizational structure making sure that the chosen contractor lays the foundation of an efficient structure for the management of the operation contract.

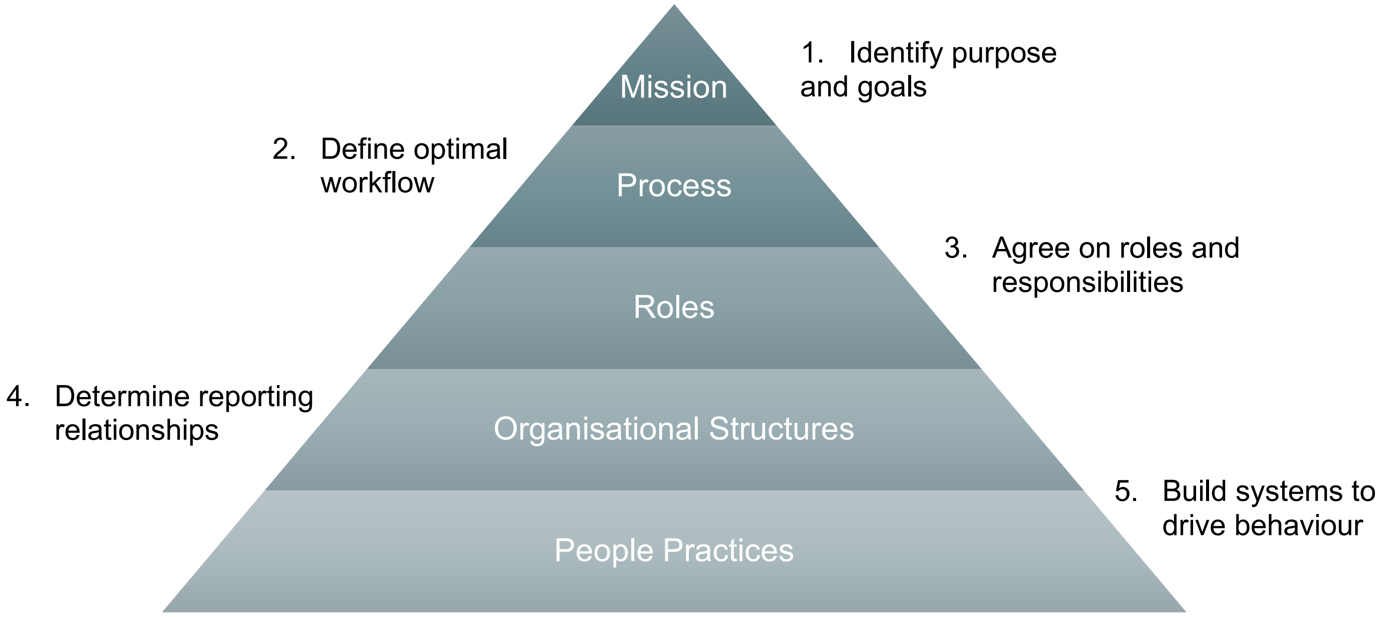


Figure 1-6: Composition of Organizational Structure

Sustainable organizational structures define the following:

- Which work is mission-critical, can be scaled back, or should be eliminated,
- Existing role requirements, while identifying necessary new or modified roles,
- Key metrics and accountabilities,
- Critical information flows,
- Decision-making authority by organization level.

Five elements create an organizational structure:

1. Job design,
2. Departmentation,
3. Delegation,
4. Span of control and
5. Chain of command.

These elements comprise an organizational chart and create the organizational structure itself. "Departmentation" refers to how an organization structures its jobs to coordinate work. "Span of control" means the number of individuals who report to a manager. "Chain of command" refers to a line of authority.

In desalination plants, vertical structures are typically applied as they fit best to the requirements of the plant management. This traditional type of organization forms departments such as management, administration, operation, technical, maintenance & repair, laboratory, safety, and training. Each department has a separate function and specializes in that area. For example, all human resources (HR) professionals are part of the same function and report to a senior leader of HR. The same reporting process would be true for other functions, such as operations or safety. In smaller structures, some departments may be grouped together or be taken over by an overseeing governmental department or be outsourced to an external contractor.

Some of the work can be grouped over a geographical area such as maintenance and inspection, purchasing, or laboratory to optimise efficiency and cost. As such specialized and trained employees can efficiently work on their dedicated geographically grouped plants rather than having employed part-time workers or not using the available capacities of one worker. Given the centralized decision-making, the organization can take advantage of economies of scale, i.e., centralized purchasing functions.

Avoid frequent changes in the organizational structure, as this makes workflows and processes inefficient and creates additional costs. Frequent changes can lead to ambiguities in authority and responsibility. Likewise, it is advisable to design the structure in such a way that the decision-making structure can be maintained if one person is absent. Time delays, especially in decision-making in the water sector, can lead to significant blockages and make communication with desalination contractors difficult. Sufficient staff must be recruited to fill the critical positions in the organizational structure.

1.1.1 Organizational chart

The vertical (functional) organizational structure foresees central coordination of the specialized departments.

Advantages of this functional structure are:

- The organization develops experts in its respective areas,
- Individuals perform only tasks in which they are most proficient,
- The organization has a clear direction; the structure is logical and easy to understand,
- Operations and decisions are closely controlled and managed,
- The chain of command and accountability is clear.

Disadvantages center on coordination or lack thereof:

- People are in specialized "compartments" and often fail to coordinate or communicate with other departments,
- Cross-functional activity is more difficult to promote,
- The structure tends to be resistant to change,
- It can demotivate employees and lower productivity.

This structure works best for organizations that remain centralized (i.e., a majority of the decision-making occurs at higher levels of the organization) because there are few shared concerns or objectives between functional areas (e.g., operation, administration). Appropriate management to coordinate the departments is essential.

The personnel on desalination plants can be divided into seven groups. According to the size, it can be useful to add a technical department and to outsource the training:

- Management,
- Administration,
- Operation,
- Technical,
- Maintenance & repair,
- Laboratory/safety,
- Training.

Depending on the requirements and plant size, there is flexibility in grouping departments. According to the size of the desalination plant, the number of employees varies. An example of an organizational chart for a plant of more than 50,000 m³/d is depicted in Figure 1-7: Example of Organizational Chart.

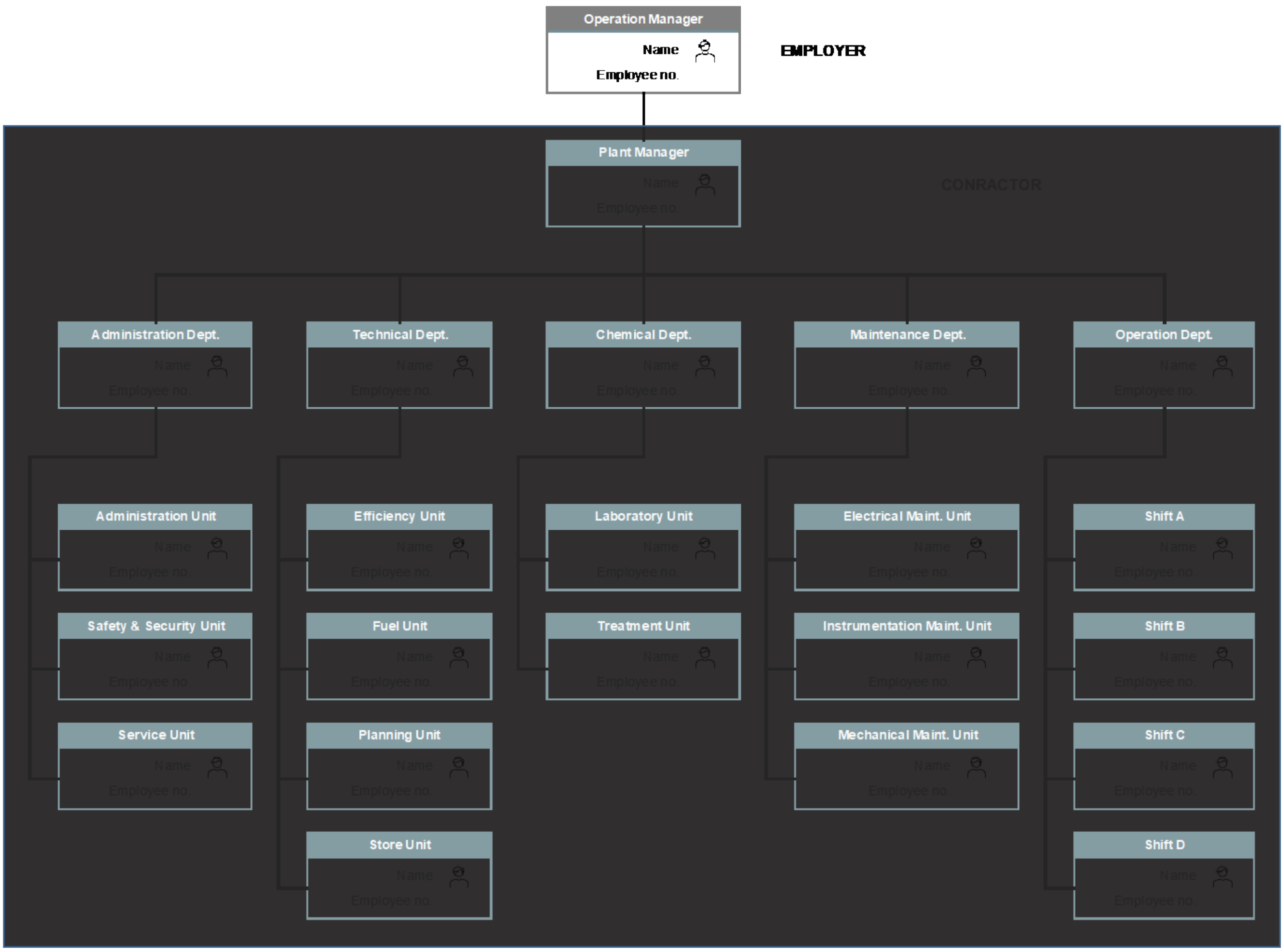


Figure 1-7: Example of Organizational Chart

The appointed supervisor from the employer's side takes the role of the Operation Manager responsible for the supervision of the operation and control of conformity regarding the contract implementation. The contractor should set up an organizational structure that fits the plant type and size and conforms with the contractual obligations.

This organizational chart is an example. The teams' compositions and department names may vary according to the size of the plant. For better visibility, please refer to annex 7.1. The following organizational principles shall be applied to the contractor's organization and will be monitored by the employer's appointed Operation Manager.

1.1.2 Chain of command

In an organizational structure, the chain of command refers to a company's hierarchy of reporting relationships – from the bottom to the top of an organization, who must answer to whom. The chain of command not only establishes accountability but also lays out the lines of authority and decision-making power.

A proper chain of command ensures that every task, job position, and the department has one person assuming responsibility for performance.

The chain of command is laid out in the organizational chart and includes the reporting relationship. Starting at the bottom, each position is connected to the one above by a line. Following the line vertically from position to position reveals the chain of command. Each person is one link in the chain. The chain of command is important and is used to exert control from the top. Many rules govern activities. Vertical organization structures are rather rigid and mechanistic, leaving little room for innovation and creativity.

It is also important to establish a clear chain of command line between desalination plants and the overseeing agency WAJ. In addition, there must be a reporting mechanism that is implemented and required within the chain of command. This can best be done by setting up a reporting mechanism (e.g. monthly submission of reports), creating report templates, setting up a document management system and initial constant demand from supervisors.

Today's digital world can simplify reporting by setting up a protected online website where operators digitally enter plant data. The data can be entered anywhere, even using the operator's mobile phone. Simple software can then automatically enter the data in the background into a database from which supervisors can check and verify. Such a possibility is cost-effective and solves many problems, especially for decentralized desalination plants.

Take away message: organizational structure

- Adapt the organization according to the needs and size of the desalination plant.
- Organize the activities in a lean way, consider outsourcing/subcontracting where appropriate.
- Define a clear chain of command in line with the organizational chart.
- Each centralized structure consisting of several SWRO must have its own overarching organizational chart.
- Clearly defined organizational charts and chains of command avoid organizational problems.

1.2 Human resources

Without an adequate standard of management, operation, maintenance, and training, it is impossible to maximize the availability and performance of any facility.

Either the employer or his operating contractor has to ensure that the personnel employed on the plant are adequately qualified and sufficiently experienced. All personnel employed on the facility must be able to carry out their specified duties efficiently and effectively under all conditions of the normal plant operation as well as in emergency situations. At such times, they should be capable of responding to and coping with unexpected problems and emergency breakdown situations in a calm and efficient manner, avoiding panic and any compulsive action that might endanger lives and equipment. A systematic approach to such problems should produce the best results in the least time and with the least interruption to productivity.

In addition to the general management and administrative skills necessary for the day-to-day operation of any major facility, the various desalination processes involve a broad spectrum of scientific and engineering technologies complemented by a number of trade crafts required for ongoing operation and maintenance. It is vital that the personnel have sufficient theoretical and practical knowledge of chemical and physical sciences, as well as mechanical, electrical, and chemical engineering, for the diagnostic control, chemical conditioning, and general operation of the various processes.

Successful operation and maintenance of desalination facilities require skilled mechanics, pipe fitters, electricians, instrument technicians, electronic technicians, and computer programmers to operate and maintain the equipment and the sophisticated control systems and computerized recorders and controllers.

In many countries, the required skill set can be a challenge in terms of recruitment from the local labor market. It is therefore of particular importance for any major desalination facility owner or operator to include a comprehensive training program to train new employees and to upgrade the skills of existing personnel. Such training may be in-house with company-employed instructors, by contractual arrangement with specialist training organizations, or a combination of both these options. A typical combination program would include in-house training comprising practical work, theoretical classroom lectures, and "on-the-job" training under the supervision of professional instructors and qualified working engineers and technicians. Theoretical training for engineers and chemists would be accomplished by an external degree or diploma courses operated by either universities or technical colleges.[2]

When setting up a human resources structure, the following leading questions help to determine the needs for skilled team members:

- Who is able to operate these plants so that the pre-set conditions of the cost-benefit calculation are fulfilled?
- What number of personnel are needed for managing and operating the desalination plant at a given capacity?
- What should the employees' structure look like?
- What kind of entry qualifications should be requested?
- How will operational personnel be acquired that are needed for these jobs?
- Where will they come from?

[2] Plant Operation, Maintenance and Management, 2010 EOLSS Publishers/ UNESCO, Tom Temperley

- Who should train them?

A desalination plant needs to perform services twenty-four hours per day, seven days per week. Therefore, it is required that the scope of services encompasses the operation service of all equipment, instrumentation, processes, facilities, systems, structures, and utilities that are acquired or created.

Therefore, human resources encompass topics such as employees, skills, training, recruiting, performance, leadership, and potential.

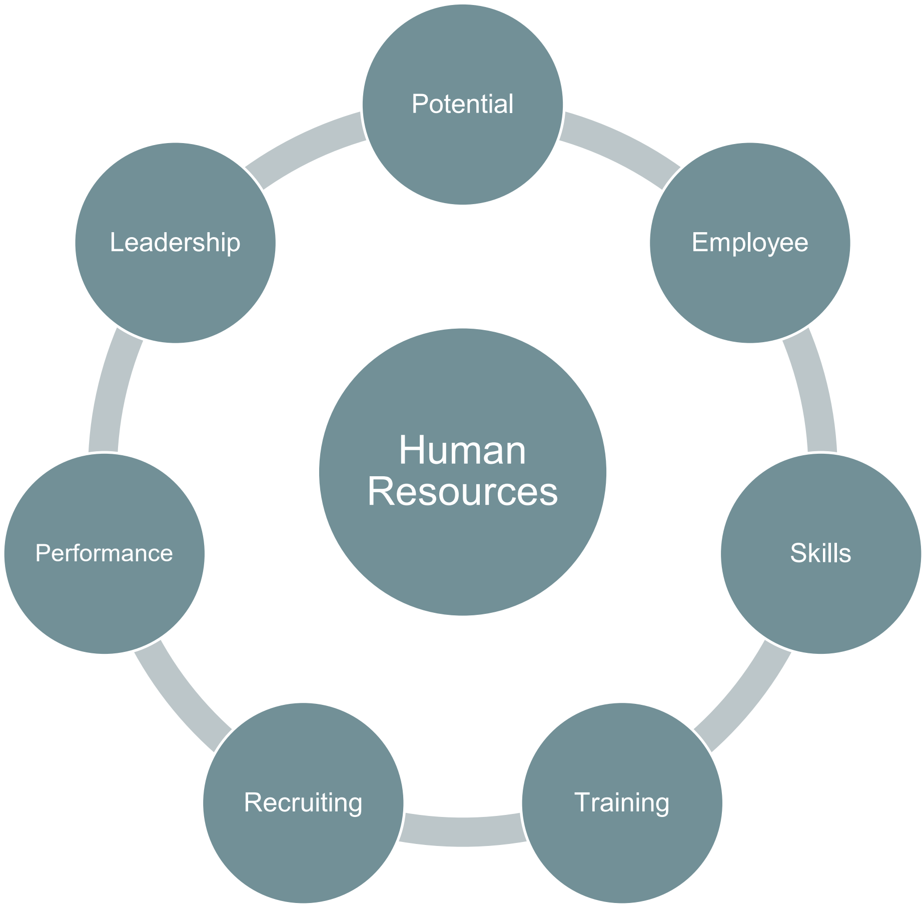


Figure 1-8: Definition of Human Resources

1.2.1 Key positions and required qualification

A well-running operation of a desalination plant at a given capacity requires a certain number of well-qualified staff. This includes the general management and administrative staff and a broad range of skilled technicians and crafts covering the spectrum of scientific and engineering technologies and operation and maintenance. It is vital that the personnel have sufficient theoretical and practical knowledge of chemical and physical sciences, as well as mechanical, electrical, and chemical engineering, for the diagnostic control, chemical conditioning, and general operations of the various processes. The number of staff depends very much on the size of the plant.

In a general approach to the necessary job postings, Table 1-1 suggests a typical staff composition that needs to be implemented by the contractor and monitored by the employer.

Table 1-1: Typical Plant Positions

Management	Chemical Team	Technical Team	Operations Team	Maintenance Team
Key Positions				
▪ Plant Manager ▪ Quality Manager	▪ Technical Team Lead	▪ Mechanical Team Lead ▪ Electrical Team Lead	▪ Operation Manager	▪ Maintenance Team Lead
Support Positions				
▪ Senior Administrator ▪ Finance and Procurement Officer ▪ Administration Officer ▪ IT Officer ▪ Driver ▪ Groundsman	▪ Process Engineer	▪ Mechanical Technician ▪ Electrical Technician	▪ Senior Operator ▪ Operators ▪ SCADA Officer ▪ Lab Technician	▪ Maintenance Technicians

For mid and large-size, requirements for the key positions could be identified as shown below:

Table 1-2: Example key positions mid- and large size seawater plants

Position	Minimum qualification	Total work experience (years)	Experience in similar work (years)
Plant Manager	▪ Professional qualification with bachelor's degree or equivalent in mechanical/chemical engineering	15	**7**
Maintenance Manager	▪ Professional qualification with bachelor's degree or equivalent in mechanical/chemical engineering	10	**3**
Operations Manager	▪ Professional qualification with bachelor's degree or equivalent in mechanical/chemical engineering	10	**7**
Shift Managers	▪ Professional qualification with bachelor's degree or equivalent in mechanical/chemical engineering	8	**4**
Instrumentation Technician	▪ Diploma or equivalent in relevant engineering	8	**3**

Position	Minimum qualification	Total work experience (years)	Experience in similar work (years)
Electrical Technician	▪ Diploma or equivalent in electrical engineering	8	**3**
Mechanical Technician	▪ Diploma or equivalent in mechanical engineering	8	**3**
Health and Safety Officer	▪ Suitable qualification or equivalent experience, registration as a workplace health and safety officer	5	**3**

Staff requirements change over the course of the time of operations, especially when the BOT contract ends and the employer takes over the plant with more responsibility for operations. In that case, some experienced existing staff can be taken over, or if this is not possible or desired, they need to be recruited from the local labor market.

A selection of examples of detailed job descriptions can be found in the annex. Job titles and the requirements of each position need to be adapted to the overall organization and size and type of the desalination plant.

The examples of the Plant General Manager and Operation Manager are depicted in Table 1-3 and

Table 1-4. For bigger sized plants it is advisable to put in place the position of an operations manager. The contract implementation should be carefully supervised and monitored from the employer side. A suitable position for this task is an Operation Manager as described in table 1-4. An example for a job description of the contractor's Operation Manager can be found in the annex.

Table 1-3: Example Job Description for General Plant Manager

Job Description
Job Title: Plant General Manager
Situation in Organization
▪ Reports to director
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
▪ Responsible for plant operation and maintenance. Establish plant policies and procedures. ▪ Responsible for plant production goals. Establish and maintain community relations. Foster a well-trained and motivated staff. ▪ Assure the safety of the plant.
Responsibilities
As Plant General Manager, the responsibilities would include, but are not limited to the following:

▪ Ensure implementation of established effective and economical operating methods and techniques and identify new technological changes in the business field which can be implemented to advance the operating methods and techniques.
▪ Develop and ensure implementation of plans and procedures to achieve the optimum utilization and operating efficiency of power and desalination plant.
▪ Ensure and direct implementation of efficient and effective maintenance methods and techniques.
▪ Analyze and study operating maintenance costs and take necessary measures as required.
▪ Establish and ensure maintenance of effective monitoring and reporting system.
▪ Ensure that adequate and trained personnel are available to effectively carry out plant activities.
▪ Coordinate and control necessary relations with the Owner necessary for theaccomplishment of the function sees that the staff are kept informed of scientific and technical developments in fields of present or potential interest.
▪ Co-ordinate and control necessary relations with Government officials necessary for the accomplishment of the function.
▪ Co-ordinate for new extensions with appointed Contractors and Consultants by Owner and communicate to concerned Sections.
▪ Reporting to the Owner, incident reports with causes and remedy actions to the Owner, summary of daily log sheet, daily performance report, weekly status report, monthly performance as well as operation and maintenance activities with any recommendations of modification and annual report.
▪ Confirm and approve all purchase requisitions initiated by Section Heads before submission for action.
▪ Confirm, approve and raise the recommended spares for Owner, reported by Planning with Section Heads. Verify and approve the technical recommendations by Section Heads before requesting Owner to place purchase order.
▪ Weekly meetings arranged with Section Heads to discuss operating conditions, maintenance progress work and difficulties and solution with plan for next week.
▪ Ensure Environmental Aspect-Impact and Hazard Risk Assessment are carried out, controlled, and updated.
▪ Identify, establish and monitor Information Management System objectives, targets, and programs.
▪ Provide necessary resources for effective implementation and sustenance of IMS.
▪ Report IMS performance to the management periodically.
▪ Ensure legal compliance with respect to their scope of activities.
▪ Ensure identification of root cause for the identified non-conformances/ deviations and to implement corrective actions/Preventive actions
▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
▪ Carry out annual performance evaluation of reporting employees.
▪ Facilitate the emergency drills planned.
▪ Provide adequate support to carry out the internal audits in the plant.
▪ Ensure systematic closing of identified non-conformances/deviation.
▪ Necessary coordination with the external agencies/interested parties for environmental and safety related matters.
▪ Receive, resolve, and respond to Owner complaints/feedback.
▪ Ensure to secure the premises and the facilities.
▪ Facilitate adequate training for the personnel.
▪ Ensure monitoring and control of contractors & subcontractors' activities within the premises.
▪ Receive security breaches and coordinate further actions.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Bachelor Degree in Engineering, preferred Master Degree
▪ Minimum 15 years of experience
Required skills-set: ▪ Awareness of Quality, Occupational Health & Safety and Environment Management system principles ▪ Knowledge of applicable legal requirements ▪ Hazard Risk assessment ▪ Aspect Impact assessment ▪ Leadership and communication skills ▪ Direction of plant operations and community relations requires significant technical knowledge as well as advanced interpersonal and supervisory skills. ▪ Time management ▪ Negotiating skills ▪ Computer Skills ▪ Communication skills **Desired certifications and skills:** ▪ Achievement Orientation; Concern for Order, Quality and Accuracy; Impact and Influence; Relationship Building; Teamwork and cooperation. ▪ ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred. ▪ Electrical safety.

Work Location: Plant

Table 1-4: Example Job Description for General Plant Manager

Job Description
Job Title: Operations Manager (employer side)
Situation in Organization
Reports to employer
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Ensure effective management and control of plant operating functions/all desalination plant operation & maintenance and laboratory activities in accordance with established and contractual requirements, schedules, quality cost and time objectives given to the contractor.
Responsibilities
As Operations Manager, the responsibilities would include, but are not limited to the following:
▪ Supervision, monitoring and control of the overall plant operations according to the contractual requirements.
▪ Participate in and concur all decisions regarding new design criteria, technical specifications and operating methods related to the plant and according to the contractual requirements.
▪ Supervise the plant operating budget and cost control system.
▪ Conduct regular follow-up meetings to discuss work progress, schedules, problems, interferences, priorities etc.
▪ Responsible for the approval of changes in methods, schedules and procedures needed to meet specific exigencies of the plant operations.
▪ Maintain reporting system which provides sufficient data to ensure that operations are being accomplished within the specified limits, schedules and technical parameters.
▪ Supervise and control proper and effective allocation and development of human resources to ensure maximum efficiency.
▪ Control Environmental Aspect-Impact and Hazard Risk Assessments.
▪ Follow-up on IMS performance.
▪ Control legal compliance with respect to their scope of activities.
▪ Control and approve root cause for the identified non-conformances/ deviations and the implementation of corrective actions/Preventive actions.
▪ Monitor and control contractors' & subcontractors' activities within the premises with respect to IMS.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Minimum: Bachelor of Engineering is a must, preferred post-graduation in engineering with power plant engineering specialization.
▪ 10 years in desalination, minimum 7 years in RO desalination plant.
Required skills-set: 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of applicable legal requirements 3. Hazard Risk assessment 4. Aspect Impact assessment 5. Investigating skills 6. Knowledge of spillage containment 7. Knowledge of managing HSE emergencies 8. Knowledge of identification, classification, and disposal of waste 9. Should be well conversed with Desalination/RO Operational activities. 10. Leadership and communication skills 11. Decision making and analytical skills. 12. Teamwork and problem-solving skills. **Desired certifications and skills:** SAP working knowledge is preferred, if SAP system available). ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred.
Work Location: Employer

Please note that the job descriptions must be considered for each individual SWRO system specifically. In particular, a distinction must be made whether the SWRO plant is operated as a single plant or in combination with several plants. In any case, each Job Description must meet the position's requirements to be assigned. However, it must also be an integral part of the overall operating team and be suitable for the organizational chart of the SWRO plant.

1.2.2 Training

Ideas behind Training

Training is a crucial activity that is needed to effectively run a desalination plant. The employer needs to monitor that the contractor’s personnel is skilled according to the operational requirements. When planning training, three key questions should be considered:

- Who should know what?
- Where could the training be held?
- How much would the training cost?

Based on the requirements of the employed personnel, the training of desalination plants can be defined as follows:

- Various professionals must be trained (engineers, technicians, and craftsmen),
- The training must cover various aspects of engineering and various professions,
- The complexity of the plants must require a high level of specialized knowledge and a high standard of training,
- All aspects of the training, as well as the certification, must be recognized without reservation by the plant operators,
- Good basic knowledge in chemistry and physics must be required from the outset.

Initial training at university level (bachelor's or master's degrees) is expected to be relevant. When it comes to professional training, the prevailing technical vocational educational schools (TVET schools) may not be able to provide training with the required qualifications. It is therefore important to provide initial training upon arrival and specialized and to the plant's needs adapted training courses.

It should also be verified if and which external training sources are available and match the training needs of the employed staff. The construction company of the desalination plant should provide initial training and training manuals on the different technologies and equipment.

Not only theory-based technical training courses in topics such as water chemistry, thermodynamics, basics of desalination, and maintenance are important to include in the offered training programs. Practical training such as job shadowing is necessary to learn on-the-job tasks.

Besides the above-mentioned training programs, many short courses, intensive courses, workshops, and conferences are offered on the free market to upgrade knowledge in the field of thermal and mechanical desalination process technologies. [3]

[3] A new approach to meet the growing demand of professional training for the operating and management staff of desalination plants, Joachim Gebel, Süleyman Yüce, STEP, 2006

Systematic Approach to Training

It is recommended to develop the training concept according to the SAT (Systematic Approach to Training) Methodology. The training steps include:

1. **Analysis**: Personal Screening of the personnel to be trained from MWI and WAJ,
2. **Design:** Converting competencies to training objectives, how can be trained best,
3. **Development:** New concepts for online assessment and online training that will accompany the on-site workshops for increasing the training efficiency according to European standards,
4. **Implementation**: The implementation of training workshops on-site or as webinars. Providing online training through distant learning complementary to the workshops (video class, E-test, forum),
5. **Evaluation:** Evaluation of training results based on the data collected during each of the phases.

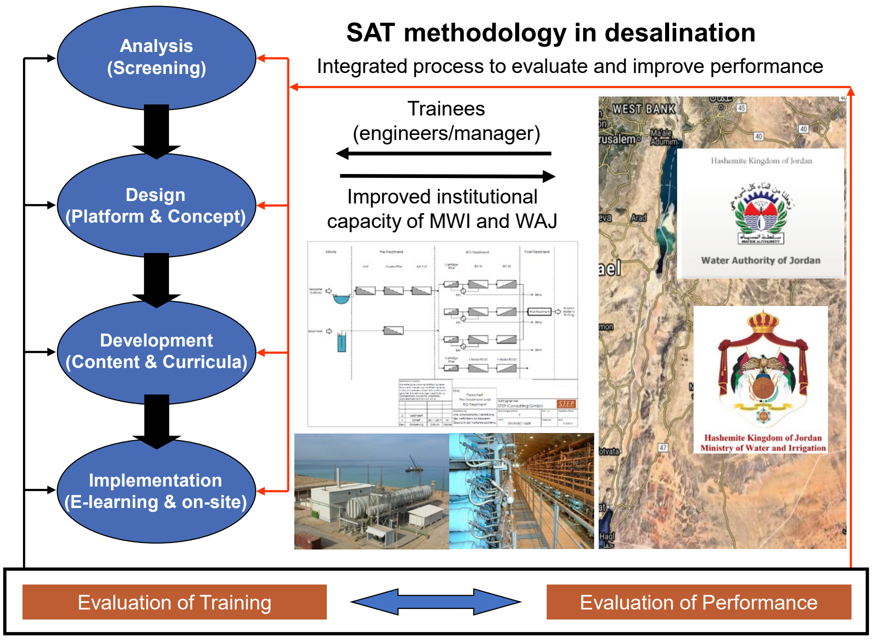


Figure 1-9: SAT Methodology

A central training department based at the contractor's premises or a shared training center (common training center to a certain number of desalination plants) can be set up in the case that the desalination plant does not have the necessary resources to organize and deliver training programs.[4]

Challenges in training

For the expected installation and operation of additional desalination plants, manpower is needed. Besides the financing and the manufacturing of these plants, the training of the future staff is a big challenge. The present and future lack of experienced and specialized personnel also imply that there is a lack of instructors. The best and most experienced plant operators or constructors are, because of their exposed position, not really interested in turning to full-time teaching. However, there might be a chance that these experts are available for a short

[4] A new approach to meet the growing demand of professional training for the operating and management staff of desalination plants, Joachim Gebel, Süleyman Yüce, STEP, 2006

intervention, i.e., a training course lasting a few days, as would be necessary for a training center.

When talking about training programs, the question of how to finance these measurements emerges directly. The solution can be found in an improvement in the availability of the plants.

A higher availability resulting in a higher freshwater production rate could be obtained by well-trained staff able to react correctly to any disturbances or unstable operation modes of the plant. Rough calculations prove that prevention of a 4 to 5-day plant standstill each year equals the cost for the required training courses. It is therefore highly recommended to integrate the training of staff into the operations plan.[5]

Site-specific training

All Operation Service personnel should undergo on-the-job training (OJT) exercises with various equipment manufacturers or the in-house training department. This OJT program requires the signature of the employee and their trainer to verify that the employee has received and understands the operation, maintenance, and safety aspects of the equipment/material. This section of the plan will outline specific training on the proper operation. This training includes, but is not limited to, the following parts of the plant:

Health and Safety

- General Health and Safety Training,
- Security Training,
- Evacuation Plan,
- Accident Reporting Procedures,
- Using Hand and Power Tools,
- Hazard Communication,
- Fire Prevention/Suppression,
- First Aid,
- Spill Containment/Slug Control Plan,
- Chemical Dosing System,
- Laboratory Safety.

System Operation

- SWRO Intake Pumping station,
- Pre-treatment System,
- Post-treatment system,
- Concentrate discharge
- Membrane Clean-In-Place System,
- RO System and equipment,
- Instrumentation and control,
- Electrical facilities on the RO plant,
- Water Quality Assurance/Compliance,
- Operations Monitoring and Trouble Shooting.

Project Management and Supervision

- Cost control (Estimation and Calculation) of desalination plants,

[5] A new approach to meet the growing demand of professional training for the operating and management staff of desalination plants, Joachim Gebel, Süleyman Yüce, STEP, 2006

- Project management principles, strategies and tools,
- Risk assessment,
- Project auditing,
- FIDIC contracting and contractual management,

Training needs depend on the skills levels of the team members and the technical requirements of the plant itself. A certificate system can be an excellent way to motivate and increase the effect of the training.

1.2.3 Succession planning

Succession planning is a process that constantly identifies and develops future workers in an organization. The contractor should plan for succession accordingly. Replacements become necessary when the following occurs:

- Departure of current employees (e.g., for retirement, because they move to another region, or they wish to change employment),
- New positions are created when the organization grows or changes.

Figure 1-10: Succession Planning

Some positions are easier to replace than others. It is important to keep in mind critical roles to be able to act fast when needed and not to jeopardize operations and risk disruption or a shutdown of the plant. Being proactive avoids future difficulties. Two questions help identify the critical roles:

- What is the day-to-day impact of X position on the plant's operation or specific department?
- If the person currently in X position left, how would that affect our operations?

Identifying employees capable of stepping into those positions leads to continuity and avoids disruption. External recruiting processes are long and costly. Questions to identify internal succession candidates include:

- If we were to hire for X position internally, which employees would be the strongest candidates for stepping into this role?
- Would those candidates need training? And, if so, what type?

External recruitment may be necessary when an internal employee fills the gap of a leaving employee or when the position itself cannot be filled with an internal employee. The recruitment process can be accelerated when candidates who already participated in a recruiting process can be contacted again or constantly contact potential candidates for specific key positions.

Knowledge Transfer Process

Staff succession requires a well-organized knowledge transfer process. The following elements are part of a robust knowledge-sharing culture and involve several key steps, such as identifying and collecting information, capturing, and saving knowledge, transferring and sharing the information, and applying that knowledge. This is an important process when it comes to the transfer from the contractor to the employer after termination of the contracting period to ensure a smooth transition and to avoid disruptions of operations.

- Training: Training is paramount for duplicating the existing employee's knowledge. It helps keep the knowledge alive if an employee were to depart and the company does not have a ready replacement. Organizations need to operate with a backup plan, especially for key positions with experienced employees.
- Using formal documentation: Transferring key information in the organization is an intricate step-by-step process. There are several tools such as Word documents, Excel spreadsheets, and PowerPoint presentations that can be used. It is advisable to have ready-made templates at the disposal for employees to track their goals and document processes. This also concerns contractors or consultants not directly employed by the desalination plant.
- Collecting data: Accurate data and information is critical when creating efficient knowledge-sharing systems. Spreadsheets can be used to collect vital information.
- Mentoring systems: Mentors, whether short or long-term, play a critical role in disseminating key information in your organization. Mentorship is a great avenue for organizations to transfer implied and underlying information from one generation to the next.
- Enabling employees to gain experience: Getting hands-on experience from a more experienced team member is a simple way to learn about an organization's history and culture. Guided experiences are perfect for transferring those skills that require a more practical approach.

Knowledge transfer systems facilitate the capturing and eventual dissemination of key knowledge across the organization. Employees obtain better access to the saved information as the system streamlines communication in an organization. These practices boost confidence and productivity in employees and facilitate succession.

1.2.4 Work conditions

Some plants may not have a 24-hour operator presence. Such plants are only operated during normal working hours, while some of them are just visited regularly, without any operators being present full-time. Therefore, remote operation and maintenance is a major challenge in most plants.

With the exception of shift personnel and the "on-call" management and maintenance staff, working hours will be governed by local labor laws and work conditions. Consequently, the working week will vary from location to location, but most working conditions allow for a 5- or 6-day working week of 8 h per day.

Many small-scale plants are fully automated and capable of operating for long periods without supervision, but the majority of large facilities require continuous operational supervision and the presence of full-time operation and maintenance personnel.

In such facilities, the operating personnel will be required to provide 24 h cover for the plant. A commonly used routine for ensuring staff coverage is the "Four Shift - Three Cycle System", although there are a number of other variations to the shift system, such as having five shifts and three cycles. The following is probably the simplest and most popular system in common use. It involves dividing the workforce into four equal shifts - A, B, C and D. The shifts work in sequence as follows:

Two morning shifts (06.00-14.00 h) Two afternoon shifts (14.00-22.00 h) Two nightshifts (22.00-06.00 h)

This cycle is then followed by two full days off.

Another example for the organization of a 24-hour operation is the slow rotating shift pattern that uses four teams and three 8-hour shifts to provide 24/7 coverage. Each team rotates through the following sequence every 28 days: 7-day shifts, 2 days off, 7 swing shifts, 2 days off, 7 night shifts, 3 days off[6].

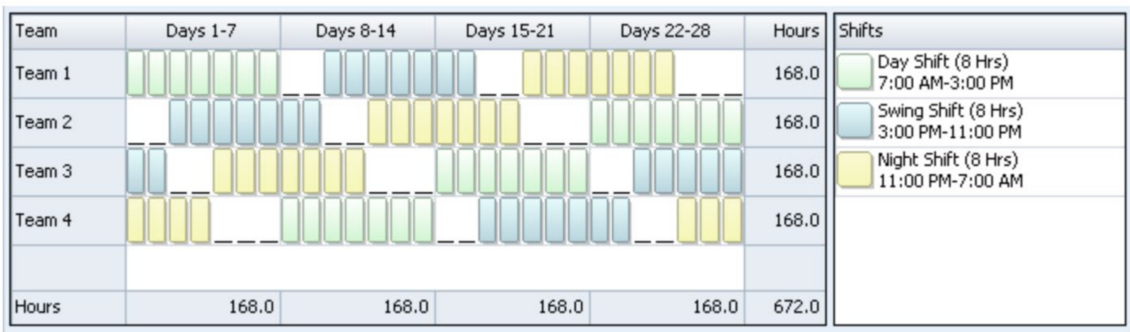


Figure 1-11: Rotating 8-hour shift schedule

The maintenance section will also provide a complete 24 h service in order to respond to emergency breakdowns etc. The Chief Maintenance Engineer will arrange a duty roster of maintenance personnel to be available on an "as required" basis after normal working hours. The various personnel assigned to this duty will remain on call throughout a specified period.

[6] https://www.bmscentral.com/learn-employee-scheduling/rotating-8-shift-schedule/

The roster will then change to include a second group of people, each member of the maintenance department serving on the roster in turn.

The duty shift engineer will be provided with the contact telephone numbers and full details of how the particular duty members of the roster may be reached in an emergency. Similarly, the duty shift engineer will be provided with the current details and whereabouts of key management personnel and how and where they may be contacted after normal working hours.[7]

In Jordan, the labor law is represented by Labor Code, Law No. 8 of 1996. Dated 2nd March 1996 and needs to be checked regularly for updates and changes.

1.2.5 Outsourcing or shared services

Outsourcing (subcontracting certain activities or services to third-party companies) can be an effective way to control costs and concentrate on the organization's core operations. In HR, service providers typically intervene in recruiting, payroll administration, or training. In operation, outsourcing may be considered for maintenance or laboratory services as long as they are subcontracted to independent service providers.

Outsourcing is also a way to optimize plant performance, improve water quality and reduce energy and consumables consumption. This saves personnel time and operational costs.

Examples for outsourced services are:

- Services for general cleaning/painting
- Site Inspection and troubleshooting,
- Comprehensive design review,
- Operation and maintenance review,
- Preparation of techno-economic optimization analysis,
- Practical recommendations report for the improvement of plant performance and operation costs,
- Engineering design and construction,
- Equipment delivery,
- Laboratory, jar tests and pilot services,
- Operator training.

[7] Plant Operation, Maintenance and Management, 2010 EOLSS Publishers/ UNESCO, Tom Temperley

Take away message: Human Resources

- Adequately qualified and experienced personnel is a pre-requisite for a smooth and efficient plant operation.
- Key positions and needed qualifications must be clearly defined in accordance with the required tasks and equipment.
- Training is crucial for maintaining and updating skillsets.
- Training avoids unnecessary shut-down times and assures a cost efficient and safe operation of the plant.
- Succession plammiimg assures a smooth operation of the plant and avoids costs related to disrupted services caused by non occupied positions.
- Apply the relevant labor laws and be aware of changes and updates.
- Outsourcing, sub-contracting or shared services can be an efficient way to optimise costs.

1.3 Management processes

A prerequisite of successful plant operation is to ensure that management and operating personnel are fully qualified and experienced in their various disciplines. The plant must at all times be operated in strict conformity with the manufacturer's recommended operating procedures. A successful and experienced operating team would supplement these procedures by including any additional procedural safeguards and improvements in operation and maintenance that their previous experience indicates would improve either the safety, efficiency, availability, or longevity of the plant and equipment. All procedures need to be approved by the management before they are incorporated into the general operation practices of the facility and monitored by the employer.

The key objectives governing the overall management processes for a successful plant operation are:[8]

- Meeting of drinking water production goals and performance warrantees,
- Protection of the health and safety of the operating staff and any sub-contractors or service providers,
- Protection of the environment in compliance with local guidelines,
- Protection and preservation of the equipment and structures of the plant in good working order such that all equipment and assets achieve their design lives; and
- Maximization of operational efficiency.

In order to meet these key objectives, the management should meet the performance standards of the successful operation of the plant and establish appropriate policies, including:

- Management and oversight of day-to-day operations,
- Process control and testing,
- Management and oversight of sampling and monitoring associated with compliance with all performance standards, applicable permits, potable water quality standards, and applicable laws,
- Analysis of faults and performance issues, determining their root cause, and taking actions to prevent reoccurrences,
- Safety and process training,
- Employee training and certification,
- Selection of type, quantity, and quality of all chemicals needed for plant operation service and purchase of such chemicals,
- Purchase of materials, supplies, and services associated with works operation service,
- Preventative maintenance, replacement, and repair of all equipment, instrumentation, systems, pipelines, and structures of the works,
- Maintaining of all equipment, process, membrane, and other warranties and guarantees provided by equipment suppliers,
- Management and oversight of works waste handling and disposal,
- Emergency response,
- Preparation of reports and data for regulatory reporting and monitoring.

[8] Plant Operation, Maintenance and Management, 2010 EOLSS Publishers/ UNESCO, Tom Temperley

The functions of management comprise planning and decision-making, organizing, leading, and controlling, as depicted in Figure 1-12.

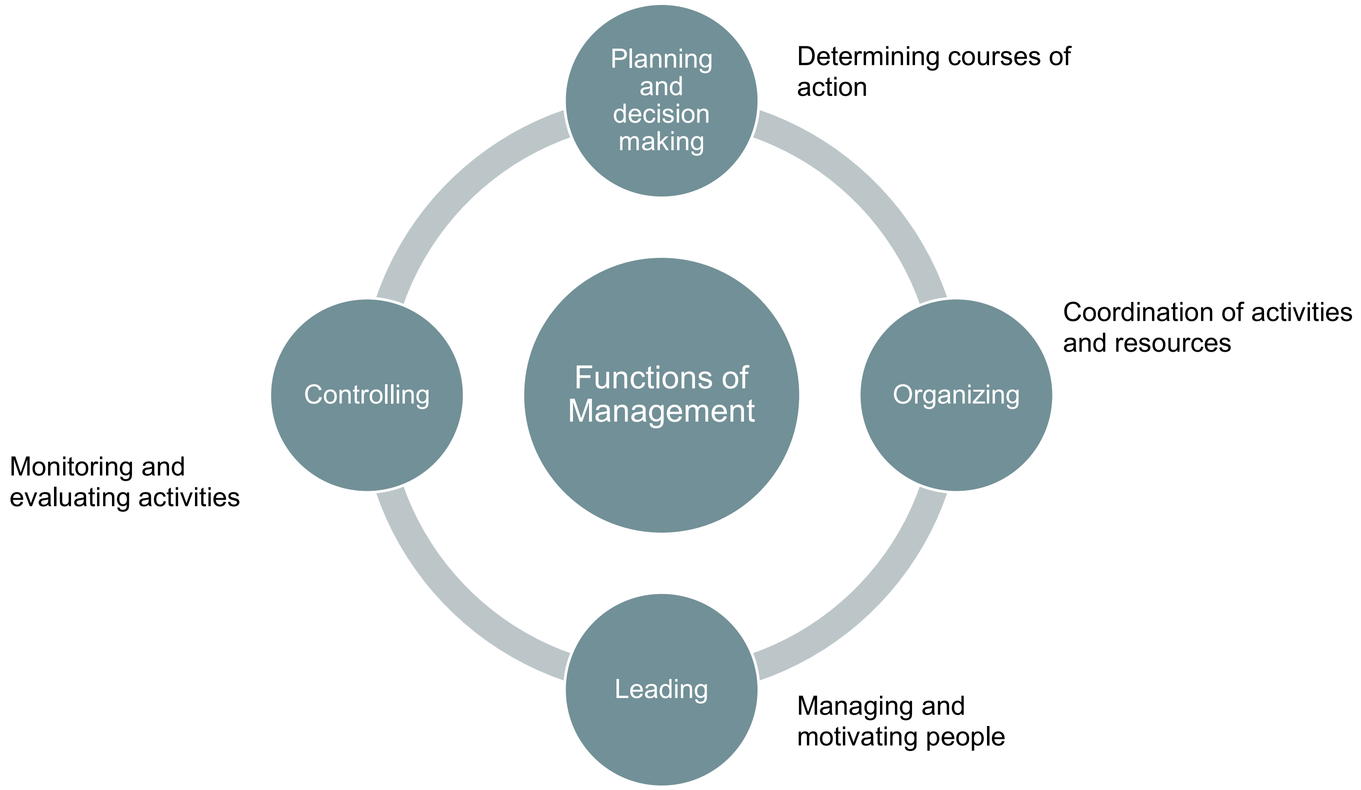


Figure 1-12: Functions of Management

1.3.1 Planning

It is the basic function of management. Planning defines and determines the strategic, tactical, and operational goals of an organization, department, or team. It deals with determining your team or department's goals, how and when they will be achieved and what resources will be allocated to them. The goal of running a successful desalination plant is to treat high salinity water and produce water acceptable for potable use and/or other intended uses with the lowest possible cost and the least environmental deterioration.

Planning is the determination of courses of action to achieve the desired goals necessary to ensure proper utilization of economic, technical, and environmental resources.

Planning tools include but are not limited to annual operating plans, annual preventative, responsive maintenance, asset condition monitoring plans, monthly and annual financial reports. Examples for planning reports are:

- Asset Management Plan,
- Code of Conduct,
- Communications Plan,
- Compliance Register,
- Corrosion Protection Plan,
- Data and Information Management System,
- Durability Plan,

- Emergency Management Plan: to eliminate or minimize personal injuries or property damage that could potentially be the consequence of an emergency,
- Incident Management Plan,
- Information Management System,
- Maintenance Management System,
- Membrane Preservation Plan,
- Monitoring and Reporting Plan,
- Staff Capacity Building Plan,
- Operation Service Plan: includes procedures, maintenance manuals, and trouble-shooting guidelines, system overviews, process descriptions, standard operating procedures,
- Quality Management Plan,
- Risk Management Plan,
- Safety Management Plan,
- Security Management Plan,
- Site Plan,
- Staff Roster,
- Standard Operating Procedures,
- Potable Water Quality Monitoring and Reporting Manual.

Monthly reports should be monitored by the employer.

1.3.2 Organizing

The organizing function is centered on the acquisition and deployment of resources to achieve operational goals. It determines an organization's division of labor into specific departments and teams, as well as what tasks are to be done, by whom, and how they will be grouped. Organizing also encompasses deciding the formal chain of command, operational processes, reporting structures, and decision-making authority that will be used.

The manager's role is to ensure continued competitiveness and create an efficient and productive organization with the right people with the right skills in the right roles at the right time to achieve maximum productivity and performance. See also chapters 1.1.1, 1.1.2 and 1.2.

1.3.3 Leadership

Leadership creates and determines the culture and values of an organization, department, or team. Quality leadership is also an integral component in creating and maintaining a high-performance work environment.

Successful leadership combines the authority of title – positional power with the leader's own personal power, which is based on the respect and trust earned from those they lead. The communication of the organization's vision, mission, values, and goals provides clear direction to all employees and fosters motivation and performance.

1.3.4 Control (Monitoring and evaluation)

Controlling involves the continuous monitoring of actual performance against planned performance. This function entails the constant and systematic monitoring and regulating of organizational activities and processes to ensure they are consistent with predetermined goals, plans, and key performance indicators. The operation needs a thorough control mechanism from the contractor's side and the employment side (fulfillment of contract).

Systems and processes should be put in place that establishes required standards of performance, measure the actual performance, compare it with the pre-set standards and initiate gap resolution actions when and if required:

- Establishment of standard performance,
- Measurement of actual performance,
- Comparison of actual performance with the standards and finding out possible deviations,
- Corrective action.

It is recommended to issue monthly operating reports, including data pertaining to performance compliance with applicable permit requirements, performance standards, potable water and source water flows, and any other information deemed necessary. The monthly operating report shall also include a description of maintenance activities and emergency services performed during the previous month. The monthly operating report shall include as a minimum the following and need to be prepared depending on the contract type, either from contractors or from own plant staff:

Water quantities, water qualities and inspections:

- Monthly average potable water flow supplied,
- Monthly average inflow water flow,
- Compilation of the daily flow rates: All Inlet and Outlet flows
  (optional, how many days per month are sufficient is project-dependent),
- A compilation of all test reports received during the month relating to the water quality of the potable water
  (minimum number and contents of the monthly examination are determined according to the specifications of the Ministry of Health),
- A summary of all test reports prepared during the month concerning the inlet water quality characteristics and parameters
  (project-dependent, depending on the reliability of the feed water source),
- The results of inspections carried out by state supervisory authorities during the current month, including recommended follow-up actions,
- A description of all incidents wherein the potable water quality standards and/or quantity standards were not met, including the follow-up actions for elimination and avoidance of the reoccurrence.

Maintenance, operation and plant-shutdowns

- A description of recommended works or unit shutdowns for maintenance and repairs during the current month and anticipated during the following month Monthly average inflow water flow,
- Description of the unscheduled repairs,
- A list of the main preventive maintenance work carried out this month on the main equipment and plants, and similar work expected for the next month,
- A summary of all test reports prepared during the month concerning the inlet water quality characteristics and parameters,
  (project-dependent, depending on the reliability of the feed water source),
- Semi-annually: an update of the spare parts inventory,
- A description of any incidents (hazardous materials emergencies, security breaches, etc.) that adversely impacted operations and endangered the lives of the workers.

Additional parameters that are essential for cost control

- Meter readings of the electricity consumption of the entire plant, preferably divided into the most important plant components (pre-treatment, RO desalination system, post-treatment, pumping, utilities),
- All chemical consumption data (pre-treatment, RO desalination system, post-treatment), preferably in an Excel sheet, at least monthly values.

The plant management needs to decide on the daily (i.e. reading and measurement), monthly and yearly reports to be established and which position should be responsible for the production and approval of these reports.

Besides the reporting within one desalination plant, there also needs to be established a formal reporting mechanism between the plant and the relevant governmental agencies (i.e. WAJ)

An example of a water quality monitoring requirements table for raw and potable water is given in chapter 4.

The minimum required frequency of measurement and type of samples of the potable water parameters needed to determine compliance with the potable water quality standards shall be established based on the requirements defined in the potable water quality specifications and performance standards. All sampling and testing shall be completed according to all applicable regulatory requirements and approved testing methods.

Once it is clear what is being evaluated and checked, however, the framework conditions within the monitoring organization must also be created to fulfil the monitoring tasks efficiently and reliably. For this, sufficient staff must be available, and working materials such as laptops and cars must be provided.

Take away message: management processes

- The plant must at all times opertate in strict conformity with the manufacturer’s recommended operating procedures.
- Apply planning tools that ensure the proper utilization of economical, technical and evironmental resources.
- Quality leadership is an integral component in creating and maintaining a high-performance work environment.
- Systematic monitoring and regulating organizational activities and processes ensures consistency with pre-determined goals, plans and key performance indicators.

1.4 Cost control

Continuous and detailed cost control in desalination plants is advisable and helps to detect deviations from the design values of the plant. In this way, increases in water production costs can be seen early and counteracted with appropriate measures. Chapter .1.4.1 shows the most important influences on the water production costs of SWRO plants. In Chapter 1.4.2, a tool for calculating water production costs is presented, with the necessary process data that must be available to evaluate the plants. It should be emphasized that the first thing to do is to take stock of the costs of all existing plants. We recommend that a new cost control system be set up with data from the existing facilities, to which new facilities can be added.

The water production cost is expressed in a currency unit per m³ of product water. For example, this could be JOD/m³, $/m³ or €/m³. Water production cost can be calculated from hourly, daily, monthly, or annual operating data, whereby values averaged over a longer period are more meaningful. In 2018, a comparison of cost data from 50 SWRO plants showed that SW desalination plants lie in water production cost between 0.5 $/m³ to 3 $/m³ with an average of 1.1 $/m³.

1.4.1 Influences on the water production cost

Several cost items have an impact on water production cost (WPC). The most important categories are the specific capital costs of the investment and the fixed and variable costs of operation.

Specific capital costs of the investment

Direct and indirect capital costs significantly impact the WPC via the annuity from the financing structure. Therefore, the calculation requires knowledge of the specific investment costs, the financing period and the interest and repayment rate. This detailed calculation can be crucial for DBO and EPC installations to estimate the impact of different interest rates and financing periods on the WPC.

Fixed & variable costs from Operation & Maintenance

- Fixed O&M costs are based on costs for maintenance and repair, insurance costs of the plant and infrastructure and personnel costs.
- Variable O&M costs are only incurred if seawater is also desalinated. Energy costs are an important part, as are costs for chemicals and additives and the replacement of membranes and cartridge filters. In the energy mix, the future costs of on-site renewable energies during the day, such as photovoltaics, must be taken into account in combination with deviating grid costs.

Possible cost drivers of a desalination plant that directly or indirectly affect the above cost items are listed below:

- Corrosion of metal equipment
- Scale formation and fouling,
- The efficiency of power source,
- Raw water specifications,
- The efficiency of pumping devices,

- Operating practices,
- Maintenance strategy adoption
- Lack of data collection,
- Level of skills of operating personnel.

1.4.2 Tool for calculating the water production cost (WPC)

Regardless of the number and size of desalination plants, the water production cost (WPC) should be reviewed periodically. Depending on the plant's capacity, the feed source TDS, or the technologies used, a comparison can be made. For example, a very detailed cost calculation could compare the operating costs of the pre-treatment units of several comparable plants. This could create a database for future projects and evaluation of ongoing desalination projects. MS-Excel is well suited for this purpose, as it is easy to use and adjustable.

However, the calculation of the WPC depending on the plant capacity is a good start from which further more detailed cost analyses can be carried out. We recommend that a database be established to allow monthly cost monitoring of all SWRO plants in Jordan. For this purpose, data from all desalination plants that have not yet been integrated must be collected, and measuring devices such as electricity meters may have to be retrofitted. The design values with indication of the year due to inflationary cost increases should be added, if available.

Figure 1-13 shows an example tool that can be used for a quick higher-level calculation of WPC. If not already available, we recommend creating such a tool e.g. MS-Excel and extending it as needed. It should be noted that the tool must be clear and allow easy repeated input. From an Excel tool, either the calculations themselves or screenshots of the calculations can be saved separately for documentation purposes.

According to Figure 1-13, the tool should start with a superior indication of the most important data. This should be at least the name of the plant, including the location, the capacity and the feed and outlet TDS (Circle 1 in Figure 1-13).

In the next step, the investment costs of the system must be entered. The unit $/(m³/day) has proven itself, as comparable values can easily be found in the literature. All information on the financing structure must be entered, such as funding period and interest rates. The possibility can also be given to include sponsored parts of the investment costs in the calculation. If no data on the plant is available, comparable data (capacity, source TDS, technology) on plants from the literature should be used. (Circle 2 in Figure 1-13).

A detailed breakdown of the fixed and variable O&M costs is useful in order to be able to track sensitive changes to the water production costs. As an example, the fixed O&M costs can be calculated first, such as maintenance and repair, insurance and staff costs. Then the variable O&M costs can be listed (Circle 3 in Figure 1-13). The calculation of energy costs should also include a distinction between renewable energy/fossil energy or grid. For example, future plants could be supplied by photovoltaics at plant location on the day and by the grid in the evening hours. It is also interesting to track and monitor the CO2 emissions, which are primarily based on the energy costs of the desalination plants in operation (Circle 4 in Figure 1-13).

Finally, the specific water costs should be clearly presented in JOD/m³, $/m³ or €/m³. (Circle 5)

WPC - Calculation Tool for Seawater Water Desalination plants

Plant Location:	**SW Plant - XXX**							
Product water (Permeate)	12016.3 m^3/h		=	288,392 m^3/d	=	100,000,000 m^3/a		
yield	0.45							
salt content feed	42,000 ppm		=	4.2 w%				1
max. salt content permeat	300 ppm		=	0.03 w%				
feed	26703.0 m^3/h		=	640,872 m^3/d	=	222,222,222 m^3/a		
brine	14686.6 m^3/h		=	352,479 m^3/d	=	122,222,222 m^3/a		
operating hours	8,322 h/a	0.95 availability						
Energy Mix Renewable/Grid	25.0%							
Total Capital Costs								
Specific Total Investment Costs	1250 $/(m^3/d)						360490267 $	2
Annual fixed costs from Investment								
From direct & indirect capital costs							25,577,670.26 $/a	
Funding Period [a]:	25	Total interest rate and repayment rate [%]:	5	r [-]: 0.071				
total capital costs							**25,577,670.26** $/a	
specific capital costs of the investment (product water)							**0.256** $/m^3	
Annual fixed & variable costs from Operation & Maintenance								3
maintenance & repair						21.39%	10,814,708.00 $/a	
	3	% of investment					0.11 $/m^3	
Insurance						3.56%	1,802,451.33 $/a	
	0.5	of capital costs [%]:					0.02 $/m^3	
staff						3.96%	2,000,000.00 $/a	
costs [$/person/a]:	20000	staff [person]	100				0.02 $/m^3	
chemicals and additives						5.93%	3,000,000.00 $/a	
	0.030	$/m^3 product water					0.03 $/m^3	
replacement of membranes and cartridge filters						3.96%	2,000,000.00 $/a	
	0.020	$/m^3 product water					0.02 $/m^3	
Variable costs from Energy Mix								4
[electr. energy] kWh/m^3	3	total consumption [kW]:	36049					
Greenhouse Gas Emissions for electricity production from Grid								
	0.400	kgCO2/kWh	90000 tCO2/a					
energy (electrical) from Renewable Energy						4.45%	2,250,000.00 $/a	
spec. costs [$/kWh]:	0.030	consumption [kW]:	9012				0.02 $/m^3	
energy (electrical) from Grid						53.39%	27,000,000.00 $/a	
spec. costs [$/kWh]:	0.120	consumption [kW]:	27037				0.27 $/m^3	
waste disposal/others						3.36%	1,700,000.00 $/a	
	0.017	$/m^3 product water					0.02 $/m^3	
total fixed & variable costs						100%	**50,567,159.34 $/a**	
specific variable costs (product water)							**0.506 $/m^3**	
annual capital costs and variable costs							**76,144,829.60 $/a**	
specific costs (product water)							**0.761 $/m^3**	5
specific carbon dioxide emissions (product water)							0.90 kg CO2/m^3	

Figure 1-13: Example tool that can be used for a quick higher-level calculation of WPC

Take away message: cost control

- Use the parameter of water production costs to perform cost control at least monthly.
- Retrofit existing systems with low-cost metering technology, e.g. electricity meters, to obtain all data for cost control. Consider this also in the planning of new desalination plants.
- Build up a cost database that enables a comparison of different plants according to parameters such as capacity and serves as a basis for cost estimates of the WPC in planning.
- Establish management structures that facilitate the recording of data, e.g. in monthly reports, through which the process engineers can evaluate the WPC.

1.5 Environmental, health and safety management

Any industrial plant or facility that involves rotating or reciprocating equipment, cutting machines, high temperatures, high-pressure liquids and vapors, corrosive and poisonous chemicals, together with high and medium voltage electrical systems, provides a dangerous environment for the unwary or the unprotected. A desalination plant is no exception. High temperature and pressure water and steam systems, high electrical voltages, inflammable fuels and materials, storage, and the use of corrosive and poisonous chemicals are all potential hazards.

In membrane desalination processes, corrosive chemicals, high pressures, rotating machinery, and high voltages present a constant hazard to operators and maintenance personnel. The safety and well-being of personnel working in such facilities must take precedence over all other aspects of plant operation and maintenance.

Detailed safety procedures and a "Permit to Work" system must be implemented and enforced in full throughout the facility's operational life. The "Permit to Work" system should be inaugurated when the plant equipment is being commissioned or immediately the electrical systems are energized[9].

Overall operations and maintenance shall be based on the following key objectives:

- Meeting the works processes and drinking water production goals and performance warrantees,
- Protection of health and safety of the operating staff and any sub-contractors or service providers,
- Protection of the environment in compliance with the local regulations,
- Protection and preservation of the equipment and structures of the works in good working order such that all equipment and assets achieve their design lives; and,
- Maximization of operational efficiency.

The contractor shall send monthly EHS monitoring reports to the employer.

[9] Plant Operation, Maintenance and Management, 2010 EOLSS Publishers/ UNESCO, Tom Temperley

An overview of the principles of an EHS system is depicted in Figure 1-14.

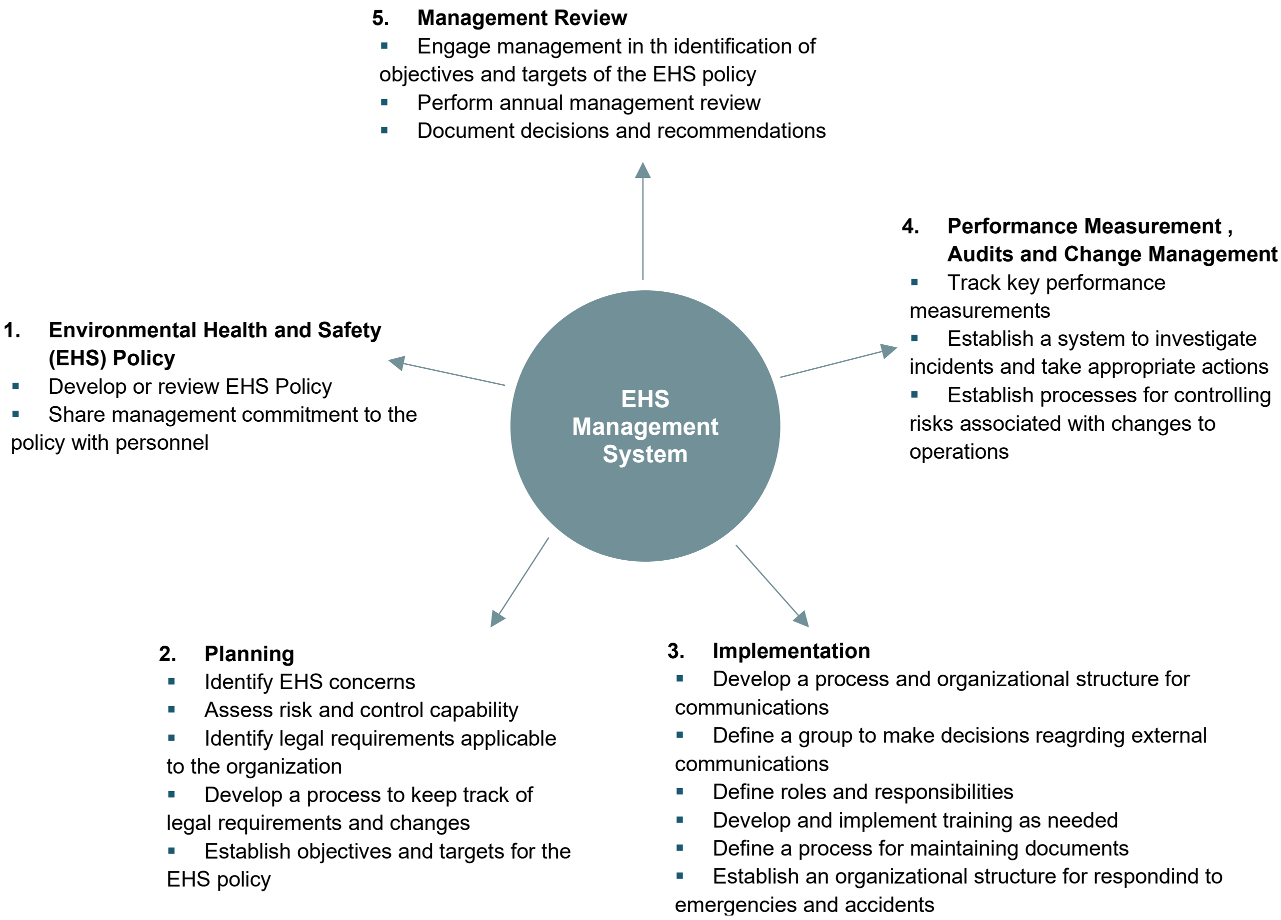


Figure 1-14: EHS Management System

Top management should set in place procedures to define, document, and endorse a formal EHS policy for an organization. The policy should clearly outline the roles and expectations for the plant and its personnel. It should be developed in communication with representatives from the operations team so that all major concerns are adequately addressed.

The EHS policy should state an intent to prevent or mitigate both human and economic losses arising from accidents, adverse occupational exposures, and environmental events. Build EHS considerations into all phases of the operations, including laboratory discovery and development environments; achieve and maintain compliance with laws and regulations. In addition, continually improve EHS performance.

The EHS policy and policy statement should be reviewed, revalidated, and, where necessary, revised by top management as often as necessary. It should be communicated and made readily accessible to all employees and made available to relevant interested parties, as appropriate.

1.5.1 Management commitment

Management commitment to EHS performance is widely recognized as one of the elements most critical to EHS program success and to the development of a strong culture of safety within an organization. Therefore, the management system document establishes management commitment with a formal statement of intent, which defines examples of how performance goals are supported. Examples of how this commitment is supported include the following:

- Establish methods to use energy more efficiently, reduce waste, and prevent accidents.
- Comply with laws, regulations, and organizational requirements applicable to their operations.
- Improve EHS performance continually.
- Conduct periodic assessments to verify and validate EHS performance.

1.5.2 EHS planning

Planning is an integral part of all elements of the management system and to be effective involves the design and development of suitable processes and organizational structure to manage EHS aspects and their associated risk control systems proportionately to the needs, hazards, and risks of the organization. Planning is equally important to deal with health risks that might only become apparent after a long latency period. It also establishes objectives that define the criteria for judging the success or failure of the management system. Objectives are identified on the basis of either the results of the initial status review, subsequent periodic reviews, or other available data.

Various sources of information are used to identify applicable EHS aspects and to assess the risk associated with each. Examples include, but are not limited to, information obtained from the following:

- Hazard/exposure assessment,
- Risk assessment,
- Inspections,
- Permits,
- Event investigations (injury and illness investigations, environmental incident investigations, root-cause analysis, trend analysis),
- Internal audits and/or external agency audits,
- Fire and building codes,
- Employee feedback concerning unsafe work conditions or situations,
- Emerging issues,
- Corporate/institution goals, and
- Emergency management.

Once applicable EHS aspects are identified, a risk-based evaluation is performed to determine the potential impact and adequacy of existing control measures. If additional controls or corrective actions are needed to reduce risks to acceptable levels, they are integrated into business planning. Categorizing each item in this manner allows gaps that are identified to be prioritized and incorporated based on level of importance and available resources. Please also refer to chapter 2.3.

Care should be taken when developing and disseminating new controls and corrective actions. If requirements are perceived by laboratory personnel as unnecessarily onerous, there is potential for lower compliance within the organization and a loss of credibility on the part of EHS personnel. While understanding that some individuals will never be convinced of the need for new controls, it is important to provide clear, supported justifications for changes to existing protocols to encourage the adoption of the new policies and procedures.

1.5.3 Implementation

The design of management arrangements should reflect the organization's business needs and the nature of their risks. However, there should be appropriate activity across all elements of the model (policy; planning; implementation; performance measurement, audits, and change management; and management review).

Specifically, the organization should make arrangements to cover the following key areas:

- Overall plans and objectives, including employees and resources, for the organization to implement its policy;
- Operational plans to implement arrangements to control the risks identified;
- Contingency plans for foreseeable emergencies and to mitigate their effects (e.g., prevention, preparedness, and response procedures);
- Plans covering the management of change of either a permanent or a temporary nature (e.g., associated with new processes or plant working procedures, production fluctuations, legal requirements, and organizational and staffing changes);
- Plans covering interactions with other interested parties (e.g., control, selection, and management of contractors; liaison with emergency services; visitor control);
- Performance measures, audits, and status reviews;
- Corrective action implementation;
- Plans for assisting recovery and return to work of any staff member who is injured or becomes ill through work activities;
- Communication networks to management, employees, and the public;
- Clear performance and measurement criteria defining what is to be done, who is responsible, when it is to be done, and the desired outcome;
- Education and training requirements associated with EHS;
- Document control system; and
- Contractors should have written safety plans and qualified staff whose qualifications are thoroughly reviewed before a contract is awarded. All contractor personnel should be required to comply with the sponsoring organization's safety policies and plans.

Although each individual is responsible for ensuring that work is carried out prudently and safely, achieving a safe operating environment is a joint effort between management, EHS personnel and operations personnel. In addition, regulations, policies, and plans will never cover every contingency, so communication is essential to ensure that new situations can be handled appropriately, i.e., by creating safety committees consisting of representatives from each part of an organization. Please see also chapter 2.2 for technical details.

1.5.4 Performance measurement and change management

The primary purpose of measuring EHS performance is to judge the implementation and effectiveness of the processes established for controlling risk. Performance measurement provides information on the progress and current status of the arrangements (strategies, processes, and activities) used by an organization to control risks to EHS. Measurement information includes data to judge the management system by

- gathering information on how the system operates in practice,
- identifying areas where corrective action is necessary, and
- providing a basis for continual improvement.

All of the components of the EHS management system should be adequately inspected, evaluated, maintained, and monitored to ensure continued effective operation. Risk assessment and risk control should be reviewed in the light of modifications or technological developments. Results of evaluation activities are used as part of the planning process and management review to improve performance and correct deficiencies over time.

Periodic audits that enable a deeper and more critical appraisal of all of the elements of the EHS management system should be scheduled and should reflect the nature of the organization's hazards and risks. To maximize benefits, competent persons independent of the area or activity should conduct the audits. The use of external, impartial auditors should be considered to assist in the evaluation of the EHS management system. When performing these reviews, it is important that the organization have a plan for following up on the results of the audit to ensure that problems are addressed, and that recognition is given where it is deserved.

1.5.5 Management review of EHS Management System

Top management should review the organization's EHS management system at regular intervals to ensure its continuing suitability, adequacy, and effectiveness. This review includes assessing opportunities for improvement and the need for changes in the management system, including the EHS policy and objectives. The results of the management review should be documented.

Among other information, a management review should include the following:

- results of EHS management system audits,
- results from any external audits,
- communications from interested parties,
- extent to which objectives have been met,
- status of corrective and preventive actions,
- follow-up actions from previous management reviews, and
- recommendations for improvement based on changing circumstances.

The outputs from management review should include any decisions and actions related to a possible change to EHS policy, objectives, and other management system elements, consistent with the commitment to continual improvement.

The management system review ensures a regular process that evaluates the EHS management system in order to identify deficiencies and modify them. Systemic gaps, evidence that targets are not being met, or compliance issues that are discovered during compliance or risk assessments indicate a possible need for revision to the management system or its implementation.

1.5.6 Safety rules and policies

Safety rules and regulations are created to protect plant personnel from unsafe work practices and exposure to hazardous materials. Consistently following and enforcing the safety rules in order to create a safe and healthful laboratory environment in which to work will help encourage a culture of safety within the workplace. What follows is a description of laboratory safety rules, but these will not cover every contingency. Part of the culture of safety is communication and discussion about safety hazards within the plant so that new concerns can be addressed as quickly as possible.

Please see also chapter 6.

1.5.7 Permit-to-Work system

A "Permit-to-Work" system should be applied wherever possible to any work carried out on plant equipment that involves electricity, pressure, or temperature.

In some circumstances, it may not be possible to completely isolate a particular piece of equipment or section of the plant in order to allow work to be carried out. Under this circumstance, although a full "Permit to Work" may not be issued, it may be possible for the Operations Engineer to provide a "Certificate of Permission to Work". This means that although the equipment is not isolated, it may be considered safe to work, providing certain conditions and procedures are adopted. Such a procedure requires that extreme care be taken at all times when carrying out such work.

The "Permit-to-Work" system will involve the following steps:

- The Maintenance Engineer or his representative issues a written request for permission to work on a particular item of equipment or section of the plant.
- Providing that there is no objection to the work being carried out at the time, the Operations Engineer or Shift Supervisor will arrange for the isolation of the equipment.
- The system is isolated. Isolating valves will be chained and padlocked; electrical switchgear and isolators will be racked out and chained and padlocked in position.
- When the isolation is completed and inspected to the satisfaction of the responsible operation engineer, a "Permit to Work" in two copies is issued. One copy is given to the Maintenance Engineer with permission to commence work on the isolated section. The second copy, together with the keys to the isolating padlocks, will be locked away in a special locker. The key to this locker is held by the Maintenance Engineer until the work is completed.
- When the work is completed and inspected by the Maintenance Engineer, the locker key will be returned to the Operations Engineer, who will open the locker. Both copies of the "Permit to Work" will then be canceled and filed. Only when this procedure is completed will the isolation be broken, and the system tested and returned to normal operation.

An extract of an exemplarily permit to work can be found in Figure 1-15. The complete document is attached in the annex.

Permit to Work Form

Permit to Work/Work Order Number :	

This Permit To Work is the formal way of tracking the authorisation and communication of all specified high-risk tasks involved with a work activity.

Section 1: General Details				
Work Activity Title: (As per Work Activity Risk Assessment)				
Location of Work Site:				
Company/Entity doing the work:				
Estimated Duration of Work:	From / / to / / (Max 3 weeks)			
Specified High-Risk Work Tasks Covered by this Permit To Work:	Tick appropriate boxes and attach a copy of the required Form/s			
	☐	Hot Work	☐	Excavation
	☐	Confined Space	☐	Plant Isolation
	☐	Work at Heights	☐	Live Electrical Maintenance Work
	☐	HV Switching Sheet and associated Access and Test Permits		

Section 2: Permit Request *(On-Site Supervisor of the contractor/workers who have been engaged to perform the work):*

This acknowledgement signifies a formal request to commence a work activity involving one or more specified high-risk tasks. As the person requesting this permit, I hereby certify that:

- ☐ I have developed and/or reviewed the Risk Assessment and required Control Form/s relevant to this work activity.
- ☐ I have consulted with relevant people to ensure that controls are adequate.
- ☐ I am competent to coordinate this work activity in accordance with the attached Risk Assessment and Control Form/s.
- ☐ I shall undertake to implement all planned and necessary controls to ensure the health and safety of those completing or impacted by the activity.
- ☐ I shall ensure that the persons required to carry out the work are advised of and understand the requirements of the Risk Assessment and Control Form/s, and the Permit To Work / Access Instructions in Section 4 below.
- ☐ I shall monitor hazards and control methods throughout the work activity.
- ☐ I am requesting this Permit to be reviewed, registered and numbered by the PBPL Permit to Work Authorised Person.

Name:		**Signature:**		**Date:**		**Time:**	

Section 3: PBPL Person Engaging Contractor /Worker Review:

This sign off is to signify that the PBPL person who engaged the contractor/worker has reviewed all documentation and provided comments.

- ☐ I have reviewed the content of all related documents including the Risk Assessment and required Control Form/s and provided feedback to the contractor/workers.
- ☐ I confirm as the PBPL person who engaged the contractor/worker, I will monitor the methods of work and the implementation of the proposed controls to ensure that PBPL standards for health and safety are being achieved throughout the works.
- ☐ I have informed the relevant person/s for the area that the work is being performed in, the full scope of works to be completed by the contractor/workers and the processes developed for supervising and enforcing the works.

Name:		**Signature:**		**Date:**		**Time:**	

Figure 1-15: Extract of a permit to work form

1.5.8 Safety training program

All employees (existing and newly hired) should be required to attend basic safety training prior to their first day. Additional training should be provided to operation and laboratory personnel as they advance in their laboratory duties or when they are required to handle a chemical or use equipment for the first time.

Safety training should be viewed as a vital component of the plant safety program. The organization should provide ongoing safety activities that serve to promote a culture of safety in the workplace that will begin when the person begins work and will continue for the length of their tenure. Personnel should be encouraged to suggest or request training if they feel it would be beneficial. The training should be recorded and related documents maintained in accordance with organizational requirements.

Training sessions may be provided in-house by professional trainers or may be provided via online training courses. Hands-on, scenario-based training should be incorporated whenever possible. More technical details can be found in chapter 6. Safety training topics that may prove to be helpful to plant personnel include

- Working with chemicals,
- Electrical Safety Training,
- Disaster Preparedness and Awareness,
- Lock-Out/Tag-Out Training,
- Anti-scalant Handling,
- Emergency Response Planning,
- Use of Chemicals Hazard Information and Packaging for Supply (CHIPs) and material safety data sheets (MSDS)s,
- Personal protection equipment (PPE),
- Safety showers and eyewash units,
- First aid and cardiopulmonary resuscitation,
- Gas cylinder use,
- Fire extinguisher training,
- Laser safety, and
- Emergency procedures.

1.5.9 HSE organizational structure

A safe work environment can only be achieved if the responsibilities are made clear to everyone at the plant. Roles, responsibilities, and accountabilities must be defined, documented, and communicated. The most important roles are listed below:

Senior Management: The senior management makes sure the environment, health, and safety (EHS) system is implemented, maintained, and fully functional. This includes reporting hierarchies. The performance of the EHS management system is presented to Senior Management.

Safety officer: A safety officer has to be appointed by the senior management. He or she has authority in health, safety, and environmental questions. His or her authority cannot be overruled by higher-ranking management.

Supervisor: Supervisors are responsible for making workers fully aware of the hazards that may be encountered on the job or in the workplace. In addition, supervisors ensure that plant operators work safely, responding to any of the hazards brought to their attention, including taking every precaution reasonable in the circumstances for the protection of a worker.

Employees: The responsibilities of employees include:

- Reporting hazards in the workplace,
- Working safely and following safe work practices,
- Using the required personal protective equipment for the job at hand, and
- Participating in health and safety programs established for the workplace.

The involvement of employees at all levels is needed for the effective performance of EHS-related tasks. All employees are asked to practice good housekeeping, participate in training, report hazards and injuries, use personal protective equipment, and practice safe work habits. Each employee is expected to participate actively and take ownership of Environmental, Health, and Safety Policy, goals, and objectives. The safety officer will be accountable for implementing this policy. Senior management will be visibly committed and actively supportive of this policy.

1.5.10 Environmental impacts

Saline water desalination provides safe drinking water for regions with severe freshwater shortages and can help to protect and relieve the groundwater resources from extensive usage. However, desalination is also accompanied by some negative main effects on the environment:

- Air pollution,
- Water/soil pollution,
- Noise pollution,
- Resource depletion.

The plant management must integrate and achieve the defined in the environmental management plan (EMP) documented environmental assessment outcomes, commitments, and approval obligations. The EMP also includes instructions for environmental incidents and environmental monitoring.

The environmental performance shall be reported in a monthly, quarterly and annual report.

Take away message: Environment, Health and Safety Management

- Detailed safety procedures and a permit-to-work system must be implemented and enforced in full throuout the operational life of the plant.
- The management puts in place the EHS policy developed jointly with operational representatives of th eplant.
- The EHS policy should clearly outline the roles and expectations for the plant and it's perssonnel.
- The EHS policy should be reviewed, revalidated and revized by the management as often as necessary.
- Develop a strong culture of safety.
- Perform risk-based evauationsto determine the potential impact and adequacy of existing control measures.
- Safety rules need to be communicated clearly.
- A permit-to-work system should be applied to any work carried out on plant equipment.
- All new and existing employees should attend safety training. Safety training is a vital component of the plant safety program.
- Roles, responsibilities including reporting hierarchies need to be clear to all staff members.
- An environmental management plan needs to be implemented to reduce environmental risks.

1.6 Quality assurance and quality control

To assure the quality of the plant's operations and produced water quality in compliance with all regulatory requirements, the management needs to prepare a quality management plan containing quality assurance and quality control aspects of the plant's operations. Depending on the size of the plant, a team or a person should be dedicated to implementing and following up on quality measures.

Effective quality assurance and quality control (QA/QC) measures are important for safeguarding budgets and timelines, identifying reliable suppliers, managing conflicts between different parties, and ensuring what is planned and built matches the needs of stakeholders.

1.6.1 General approach to quality assurance and quality control

Whether the plant is being operated by the owner or by a contractor, it is essential that it is managed, operated, and maintained in accordance with detailed Operation and Maintenance Procedures approved by the plant manufacturers, in accordance with local employment regulations and the local hazard regulations. Such procedures ensure that the highest standards of operation, maintenance, and safety are implemented at all times.

These procedures should be fully detailed and descriptive. In order to be fully effective, they must cover all aspects of plant management, administration, accountancy, purchasing, stores purchasing and management, operation, maintenance, safety, and record-keeping. Standard forms should be generated by the various departments and sections for all reporting and recording activities.

There should be a philosophy of continuous upgrading and improvement in safety and general efficiency. Such procedures will be subject to revision and updating in accordance with recommendations made from time to time by a committee composed of section managers. Copies of the most recent editions of these procedures will be kept in each department, each section, and the relevant manager's office. All personnel should have direct access to them as required.

The quality management systems contain two aspects: quality assurance and quality control, often used interchangeably.

Figure 1-16: Quality Assurance versus Quality Control

While quality assurance relates to how a process is performed or how a product is made, quality control is more the inspection aspect of quality management.

Table 1-5: Quality control and quality assurance comparison chart

Quality Control and Quality Assurance Comparison Chart

QA	QC
A managing tool	A corrective tool
Process-oriented	Product-oriented
Proactive strategy	Reactive strategy
Prevention of defects	Detection of defects
Everyone's responsibility	Testing team's responsibility
Performed in parallel with a project	Performed after the final product is ready

1.6.2 Quality standards

Standards underpin any quality system. The following list of standards are commonly used in the field of water desalination:

Table 1-6: Relevant quality standards

ISO	Year	Description
ISO 10006	2003	Quality Management Systems
ISO 14000	2015	Environmental Management
ISO 21500	2012	Guidance on Project Management
ISO 31000	2018	Risk Management
ISO 45001	2016	Occupational Health and Safety
ISO 55000	2014	Asset Management
		Standard Methods for the Examination of Water and Wastewater: Published by American Public Health Association, American Water Works Association, Water Environment Federation
		IFC Environment Health and Safety Guidelines
		IFC Environment Health and Safety Guidelines for Water and Sanitation Projects

Audits are a critical component of a continuous improvement process. The management team should use audits as a means of continuous improvement and not as a punitive measure. Audits have the purpose of addressing the following:

- That business systems are functional and efficient
- That processes are fit-for-purpose and efficient
- That reports are comprehensive and accurate
- That non-conformances are reported and addressed

Take away message: Quality Assurance and Quality Control

- Implementing and controlling quality standards support the operation and maintaince in accordance with detailed Operation and Maintenance Procedures approved by the plant manufacturers.
- Quality assurance and quality control go hand in hand with the EHS management system.
- Appropriate quality standards need to be implemented and audited.

1.7 Document management

Chapter 1.7 introduces the structure of classical plant documentation, including its maintenance and management. The aim is to emphasize the importance of proper plant documentation and keeping documents up to date. Correct documenting and data management are required for many processes in plant operation, starting with the final acceptance of the new plant through to different aspects during the plant runtime.

The documentation is part of the contractor's operation team and shall be monitored by the employer.

Chapter 1.7.1 deals with the life-cycle of the documents during the lifetime of desalination plants. Comments on the document management system are given in Chapter 1.7.2.

1.7.1 Documentation during the lifetime of the plant

The document management of a desalination plant serves to store and pass on essential plant information. The main purpose is to ensure safe, simple and cost-effective operation. This can ensure comprehensive knowledge of the condition of the desalination plant over longer periods of time and an efficient flow of information to the operators. Therefore, a systematic approach to document management needs to be implemented.

Document management has a significant impact on the economic efficiency of the desalination plant, as inconsistent documentation and data can increase maintenance and operating costs. However, its importance is often underestimated in practice because the necessary knowledge for successful and systematic document management is lacking.

Existing documents of desalination plants are also subject to constant change due to market and product developments, new international or national legal regulations, conversion and expansion measures. This means that the managers and operators of desalination plants must adapt the documents within the document management system promptly and consistently.

During the life of the desalination plant, various documents need to be stored in an organized way, starting from the As Build Documentation after plant construction until the decommissioning. It is recommended to keep the plant documentation at least digitally for future projects and training purposes even after decommissioning. The following is a list of important documents that should be saved:

- **Planning documents desalination project:**
  Feasibility studies, engineering design reports, documentation of permits, tendering documents, documentation of the tendering and procurement process, offers from the bidders
- **Construction documents desalination plant:**
  As-Built documentation: The As-Built documentation is a comprehensive documentation of the installation that wholly and correctly reflects the state of affairs at the time of its approval. The preparation and handover of the as-built documentation takes place after the installation and commissioning phase and is within the contractually guaranteed services of the contractor.

As -build documentation shall include: Declarations of conformity, Commissioning reports, Drawings, Component's list (additional as Excel file), Supplier documentation, Test reports

Manuals: Operating manuals, Maintenance manuals, Safety instructions

- **Contractual documentation**
- **Deconstruction documentation**

1.7.2 Document Management System

The importance of gathering reliable data and recording data has already been discussed throughout this guideline. However, to be able to make data-driven decisions for plant operation, the gathered data has to be accessible and readily available for use as well. A document management system (DMS) should be implemented to ensure easy and quick access to documents. In this guideline, the term document management system is used to describe the systematic naming and to store of all documents and digital assets, with this guideline focusing mostly on digital documents.

Regardless of the plant size, type of contract, and the number of documents, a systematic approach to document storage is highly recommended. Companies that manage records and documents casually often find it difficult to access and retrieve information when needed. Inefficient record keeping can be costly in terms of wasted memory space and time spent searching for records. It can even lead to high monetary expenses if documents that are needed due to legal requirements or for contract compliance cannot be provided. Lastly, the systematic management of documents helps monitor the performance and cost development of the SWRO plant and facilitates budgeting.

The first step is to set up an overall structure with a definition of which documents must be collected and governed and for which period. Generally, the digital DMS should provide a digital version of each physical document. All stored and governed data must have a purpose and a defined use. For best results, the DMS should be implemented organization-wide in a standardized manner, and each employee who creates and stores data should know about the correct way to do so.

With a typical Microsoft folder structure, files can only be found via their title, file type, or modification date. Therefore, if the documents are managed using such a folder structure, a naming convention for documents and folders is recommended. For example, the naming of engineering documents might be:

Type – Item document description – Equipment/asset number (– Quantifier)

The type of document can be defined in a list similar to Table 1-7.

Table 1-7: Possible shortcuts to organized data structuring[10]

Type	Description
GEN	Document not covered by any other classification
REP	Report
RES	Measurements/ Results
WIN	Work Instructions
CIV	Civil Drawing
ELC	Electrical Drawing
MCH	Mechanical Drawing
PID	Process & Instrumentation Diagram
EPD	Exploded Diagram
GPH	Graph
PTG	Photograph
MTC	Maintenance Manual
OPT	Operating Manual
TRG	Training Manual
PIN	Project Initation
PLN	Project Plans
DFN	Defect Notice
NCN	Non-conformance Notice
NCR	Non-conformance Report
HSD	Health & Safety Document
PTW	Permit to Work
SMS	Safety Management Systems
SSW	Safe System of Work
WSI	Written Scheme of Inspection
DSH	Data Sheet & Technical Specifications
PLT	Parts List

The item document description should be short and comprehensive. The equipment/asset number is a unique number assigned to each part of equipment or asset in the plant. Additionally, a quantifier might be used if multiple documents exist (for example, damage reports on a certain part of the equipment like shaft damage of a pump).

The final document name might look like this:

MTC – High-Pressure Pump Maintenance Manual – 865732 – 01.

This naming convention ensures all documentation can be found more quickly based on the variety of information. Additionally, the use of a standardized document template and format (.docx, .pdf, .xls, etc.) is recommended where applicable to ensure easy access on different computers or servers.

A more sophisticated approach especially for larger plants or associations of single plants is the use of DMS software, such as OpenText, EQMS, and eFileCabinet. With a typical folder structure, files can only be found via their title, file type, or modification date. A DMS provides more detailed search options and a visualized folder structure.

[10] https://www.reliableplant.com/Read/31622/digital-asset-management

Most systems are capable of keeping a record of the various versions created and modified by different users (history tracking) while also offering a method of change control and editing restrictions. That way, different levels of access can be implemented throughout the staff, which could not be easily realized in a simple folder structure. Also, the existence of double entries and possibly contradicting documents is avoided.

DMS software hosts all documents and integrates them within other systems such as CMMS (Computerized Maintenance Management System, see Chapter 5) or CAD software. For example, electronic engineering documents may be linked within the CMMS to the appropriate equipment, functional locations, or materials through the approved document management system. Other applications for DMS software (in this context also called Enterprise resource planning, ERP) include inventory management for spare parts and consumables and management of procurement processes.

We recommend that the status of the inventory is kept up to date and can be viewed by the supervisor to have the possibility to perform supply chain management in the future. Successful implementation could save costs and avoid plant downtime in the longer term.

DMS software mostly uses automatic cloud backups, but for folder structures, the implementation of a backup strategy is necessary to avoid data loss. The following aspects regarding backup strategies should be kept in mind:

- Where is the backup stored? If the backup is stored onsite, onsite catastrophes such as floodings or fires might destroy the backup infrastructure and lead to data loss.
- How often is a backup necessary? It is recommended to implement a backup schedule at regular intervals.
- How is the backup data restored in case of data loss?

2. Proper and stable operation

The chapter structure of these guidelines is presented in Figure 2-1. Chapter 2 is considered an introduction to the operational issues of a SWRO plant. There will be a brief overview of the process with links to Chapters 3-6 elaborating on the different aspects of plant operation in more detail.

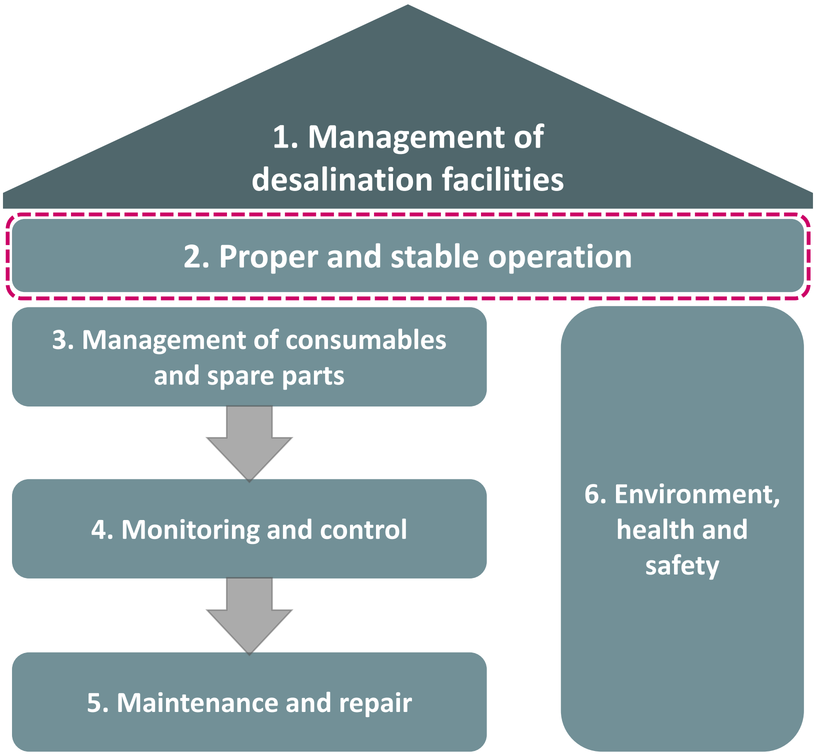


Figure 2-1: Chapter structure of SWRO Management Guidelines

This chapter aims to provide the reader with the general steps of operating a SWRO plant and present measures to evaluate the quality of the process.

Figure 2-2 shows an outline of Chapter 2. This chapter states the essential criteria to assess the performance of a RO plant. Chapter 2.2 gives an overview of the different plant operation modes. Finally, the basics of risk management will be explained, including possible risk management applications in a SWRO plant and a detailed example of how to perform a risk assessment. The importance of process redundancy and some best practice concerning redundant equipment will be the topic of Chapter 2.3.3.

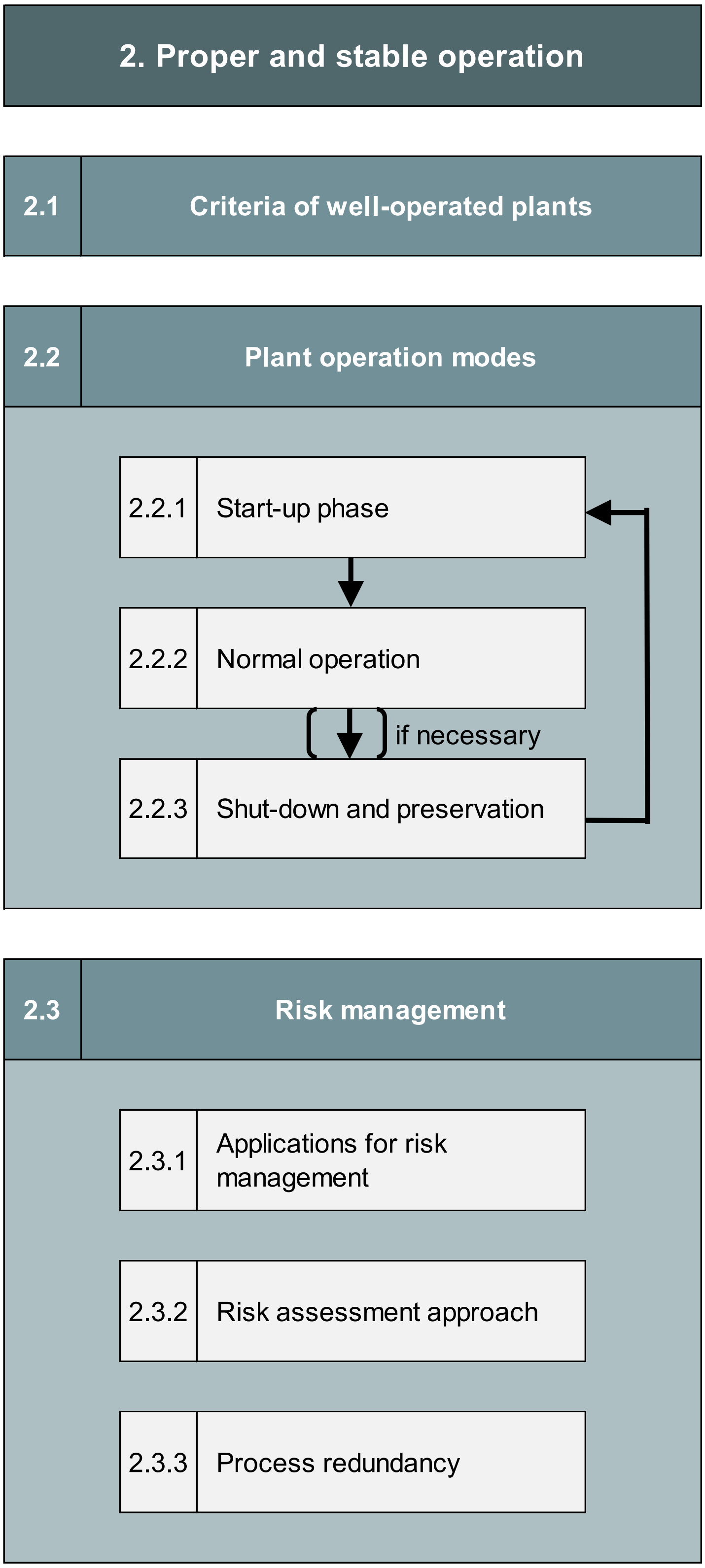


Figure 2-2: Structure of Chapter 2: Proper and stable operation

2.1 Criteria of well-operated plants

The objective to operate a SWRO properly and stably is a very abstract one. Figure 2-3 depicts more specific technical parameters, which define whether a SWRO plant is run properly.

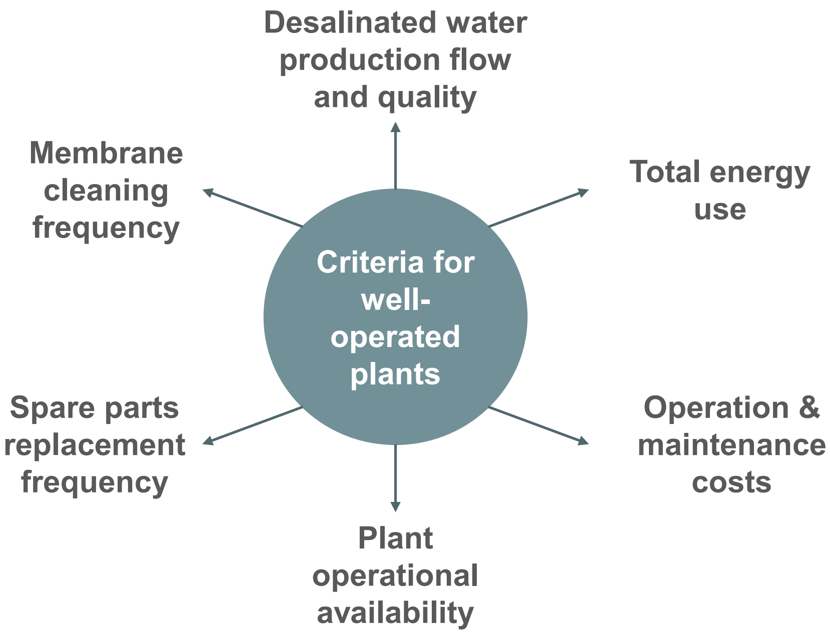


Figure 2-3: Criteria of well-operated plants

The **desalinated water quality and quantity** are the essential parameters defining the desalination plant's performance. If the targeted amount and quality are not met, the SWRO plant cannot be classified as well-operating. However, as the amount of the product water is dependent on the quality and availability of raw water, the responsibility of producing the target amount does not lie entirely in the hands of the operator. On the other hand, the quality must be ensured by the operator of the RO plant in accordance with the drinking water regulations and demands of the contract.

The plant has to be **available** at or above its specified capacity for the majority of the time. The classification index OEE (=*Overall Equipment Effectiveness*) identifies the percentage of operating time that is truly productive with:

OEE = Availability * Performance rate * Quality rate

The number and duration of downtime due to maintenance or unplanned shut-downs have to be minimized to maximize the plant efficiency. During the runtime, both the produced quality and quantity have to be sufficient. The OEE index is a practical, and helpful tool to compare the plant performance with its design data or other plants and gives an overview of plant performance during the plant's lifetime.

Another critical ecological criterion is the **drain percentage** of a SWRO plant. This parameter describes all outgoing flows that are not the product flow, for example, brine, filter backwash water and permeate flows during the flushing period. Drain percentage should be minimized to ensure a sustainable operation of the plant, both to gain the most from valuable raw water as well as reduce the amount of contaminated water discharged into the environment.

The **operation and maintenance costs** are the overall economic criterion, as they relate all expenses to the amount of drinking water produced. Energy consumption, spare parts replacement frequency, membrane replacement, and cleaning frequency are the significant parameters that substantially influence these costs.

As energy in the form of electricity makes up a large portion of the operational costs of any desalination plant, monitoring the **electricity consumption** is highly important. Otherwise, the actual specific water production cost of the plant cannot be controlled. The "specific energy consumption", kWh/m³, includes all power consumed from the raw water pumps to the final water storage tank.

Spare part replacement is another big part of operational costs, mainly caused by replacing the membrane elements and cartridge filters. Replacements result in expenses for the spare parts themselves, maintenance workers, and production stops.

High spare parts replacement frequencies and frequent membrane cleaning are strong indicators for the operation of the plant at suboptimal parameters. The last statement refers primarily to the cartridge filters in the pre-treatment section. While they require little expertise for operation and can be simply replaced when clogged, they are relatively expensive and should not be used to remove high amounts of solids from the raw water inlet. Efficiently running plants should not require cartridge filter replacement more than once every two to three months. If the exchange frequency exceeds the design limits, the SDI (=*Silt Density Index*, see Chapter 4) before and after the filter and the differential pressure should be measured. If the differences between the design and real values are abnormally high, the previous pre-treatment steps should be checked for their full functionality. Other sources of high particle concentrations clogging the filter might include changes in source water quality, algal bloom, corrosion in pipelines between pre-treatment and cartridge filters, or antiscalants reacting with coagulants, usually because of excessive usage. Backflushing cartridge filters is not advisable since it increases the risk of particle breakthrough and thus damage to the RO membranes[11].

The aforementioned aspects are of crucial importance for the economic operating of the plant and result to a high degree from decisions made during the planning period. Because of that, they are often included in the warranty obligations between employer and contractor, see also Planning Guidelines Chapter 4.

Table 2-1 summarizes those plant performance parameters together with appropriate boundaries for each parameter. Those values are based on a review of more than 50 desalination plants worldwide[12]. For some parameters, the range of values is relatively large because of site-specific differences between the different plants and their operating cost components. Cost positions like energy, chemicals, and labor vary significantly from one plant location to another. Nevertheless, the table might give an impression of how the SWRO plant performs in comparison to others and state-of-the-art plants.

[11] DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7.
[12] N. Voutchkov (2014). Desalination Engineering – Operation and Maintenance.

Table 2-1: Criteria of well-operated SWRO plants and their assigned limits[13]

Plant performance parameter	Criteria for well-operated plant
Desalinated water production flow and quality	▪ Meet plant design specifications ▪ Do not change significantly with changes in source water quality and time
Total desalination plant energy use (w/o product water delivery) [kWh/m³]	▪ 3.0 - 3.5 kWh/m³ (TDS < 36 parts per thousand, ppt) ▪ 3.6 - 4.0 kWh/m³ (TDS = 36-42 ppt) ▪ 4.1 - 4.5 kWh/m³ (TDS > 42 ppt) Note that seawater temperature and the use of PV in the power supply scheme can affect these values
Operation and maintenance costs [USD/m³]	▪ 0.35 - 0.5 USD/m³ (TDS < 36 parts per thousand, ppt) ▪ 0.6 - 0.8 USD/m³ (TDS = 36-42 ppt) ▪ 0.9 - 2.2 USD/m³ (TDS > 42 ppt)
Plant operational availability (% of the time per year at or above the plant's designed production capacity)	▪ Minimum 95% ▪ Best-in-class plants >98% ▪ Downtime <10-15 days per year
Cartridge filter replacement frequency (in weeks)	▪ Once every 6-8 weeks
SWRO membrane train cleaning frequency (in months)	▪ Once every 3-4 months
Annual RO membrane replacement rate (% of total installed RO membranes)	▪ None during first 2 years ▪ 15-20% thereafter

[13] N. Voutchkov (2014). Desalination Engineering – Operation and Maintenance.

Take Away Messages – Important performance criteria:

- The RO plant should be operating at specified water production for at least 95% of the time.
- Keeping record of costs and plant performance (availability, product quality and quantity, spare part replacement frequency etc.) helps to spot anomalies in plant behaviour early. Thereby, costly troubleshooting can be avoided.
- Some performance criteria can be included in the warranty obligations between employer and contractor.

2.2 Plant operation modes

This chapter will provide a brief description of the different operation modes. The exact start-up and shut-down sequences may vary from plant to plant, so this is only a general outline. Always follow the manufacturers' instructions regarding specifics to ensure the correct handling and operation of the machinery.

The sequence of the different modes is depicted in Figure 2-4. After the start-up sequence, the plant will run in normal operation mode. Only when necessary, a shut-down with subsequent preservation should be performed.

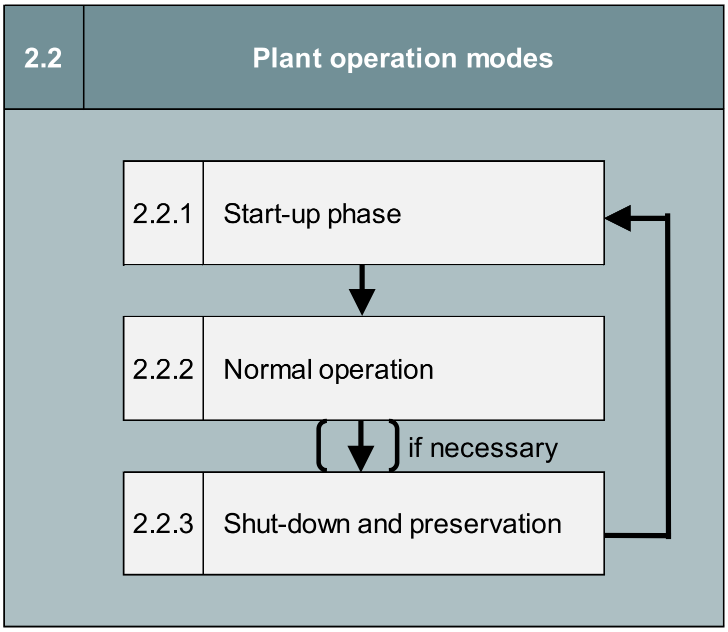


Figure 2-4: Plant operation sequence

2.2.1 Start-up phase

In general, frequent shut-downs and start-ups are undesirable for several reasons:

- **Wasted raw water** during the flushing period
- **Corrosion** in steel equipment due to stagnant water
- Formation of **bacterial growth**
- Building of (organic) **deposit**
- Increased wear and tear in machinery leading to an **increased production cost**
- **Blocking of membranes** due to increased particle concentration in raw water after a stagnant period
- Risk of **damaged membranes** due to pressure peaks (if the start-up process is not performed correctly)

During a start-up, the pre-treatment section must be flushed to prevent any contamination of the membrane trains. Special attention must be paid to the water quality entering the membrane trains after the pre-treatment section. The feedwater entering the RO system must be stable regarding flow, temperature, and conductivity. The turbidity must be within the designed limits. The feedwater also has to be free from free chlorine or any other chemical agent which might damage the membrane material. More detailed information regarding important characteristics is given in Chapter 4.

Next, the remaining air inside the pressure vessels must be flushed out at low pressure (less than 4 bar) and flow rate, according to the manufacturer's specifics. All permeate and concentrate flows have to be directed to the drain during this time. Check pipes and valves for any leaks and tighten connections if necessary. If the system is started after a long-term shutdown or for the first time at all, during this time also the preservation solution is flushed out from the membranes, using a low-pressure flush for approximately 90 minutes.

Never start up the plant against a closed concentrate valve as the recovery would be too high, and scaling might occur. The RO membrane train is highly sensitive against pressure peaks. The pressure should only be increased slowly to avoid excessive forces which might damage the membranes or their housing.

When the design permeate and concentrate flows are reached, the system should run until full membrane performance is reached. Until then, the permeate has to be discarded to ensure the required quality. This is necessary for safe drinking water production; however, the waste of raw water is an important reason to avoid unnecessary production stops.

After start-up, document all operating parameters of feedwater, concentrate and permeate. Compare the measurements from the different membrane trains to spot irregularities caused by leakages within trains. Take samples according to sample documentation and keep all data as a reference to evaluate future plant performance.

2.2.2 Normal operation

The continuous operation of the plant in normal mode is highly desirable. Only during this period, the target flow rate of quality drinking water can be produced, and the plant operates in an economical and resourceful way.

If the capacity needs to be reduced, instead of shutting down the plant, it is advisable to reduce the flow rate by reducing the feed pressure. In this case, monitor system and single element recovery to stay within limits stated during the plant design process.

In the case of changing feed water quality which might lead to increased fouling or scaling potential, the system recovery might have to be reduced.

Keep operation in normal mode as long as possible using switching over to redundant systems, following preventive maintenance schedules, and thereby avoiding downtime due to troubleshooting.

2.2.3 Shut-down and preservation

From time to time, the plant has to be shut down for maintenance reasons, or an unplanned shut-down occurs. Most importantly, no saline water should remain in the pressure vessel to avoid fouling or blocking through settling particles. Please refer to your plant's manual for exact specifications regarding the shut-down procedures.

As a first step, the high-pressure pump and chemical injection must be stopped. The permeate tank level has to be checked because when the high-pressure pump is switched off, backflow through the membranes caused by osmotic pressure can occur depending on the system specifics (if the permeate piping is submerged in the permeate tank). This reverse flow can have a favorable cleaning effect and will stop once equilibrium is reached. However, if the tank level is too low, the air is sucked into the pressure vessel, which should be avoided.

After the high-pressure pump is switched off, the back pressure from the following stages might become too high and lead to membrane damage. In this case, safety valves or atmospheric drains have to be used to keep backpressure within safe limits stated by the membranes' manufacturer. **The differential pressure between permeate side and feed side should never exceed 0.3 bar**.

The membrane train has to be flushed at low pressure until the conductivity measured in the feed equals the concentrate flow conductivity. For short-term shutdown, flushing with chemically untreated feedwater is sufficient. This should be part of the normal procedure every time the SWRO plant is shut down. For longer shutdowns that exceed 48 hours, permeate water should be used for flushing. Monitor pressure drops and compare the values with the limits stated in the membrane product information sheet. After flushing, the feed valves must be closed.

Check for any leakages or partially open concentrate or permeate lines to avoid the drying out of membranes!

In the case of planned short-term preservation (less than 48 hours), it is sufficient to repeat the flushing process with feedwater at least every 24h.

For long-term preservation, the membranes first must be flushed with permeate. It is recommended to flush membrane trains for 30 to 60 minutes or longer in case of warmer water with higher fouling potential. After the flushing, the membranes should be preserved in an SMBS solution according to the manufacturer's recommendations.

Take appropriate precautions when working with SMBS solutions. Refer to Chapter 6 Working with chemicals.

Check the pH of the SMBS solution in the membrane system weekly. If it drops to 3.2 or lower, change the SMBS solution. It is advisable to flush RO membranes and change SMBS bi-weekly, regardless of pH values.

If the planned shutdown exceeds one month, the membrane trains should be cleaned using the CIP procedure and long-term storage procedures should be performed according to the manufacturer's instructions.

Take Away Messages – Plant operation modes:

- Continuous plant operation is the most cost effective and most ecologic. Frequent and unnecessary shutdowns should be avoided.
- The correct start-up sequence of the plant is mandatory to prevent damages due to pressure peaks, debris or chemical contamination.
- Permeate produced during the start-up period cannot be used as drinking water as the specified quality cannot be ensured.
- Specifics regarding start-up and shut-down can be found in the respective manuals for each plant, which have to be provided by the manufacturer.

2.3 Risk management

Many risks might endanger the continued successful operation of a SWRO plant. Therefore, it is necessary to monitor these risks and find strategic ways to overcome them. This process is called risk management. Possible risks for SWRO plants, as well as the general procedure when performing a risk assessment, are presented in the following chapter.

2.3.1 Applications for risk management

The most important general risks in the operation of a RO plant are shown in Figure 2-5. They can be divided into three categories: economic, environmental, health, and safety risks. Risks can be based on internal factors, meaning processes inside of the SWRO plant operation, as well as external factors, for example, force majeure events like algal bloom or another decline in source water quality.

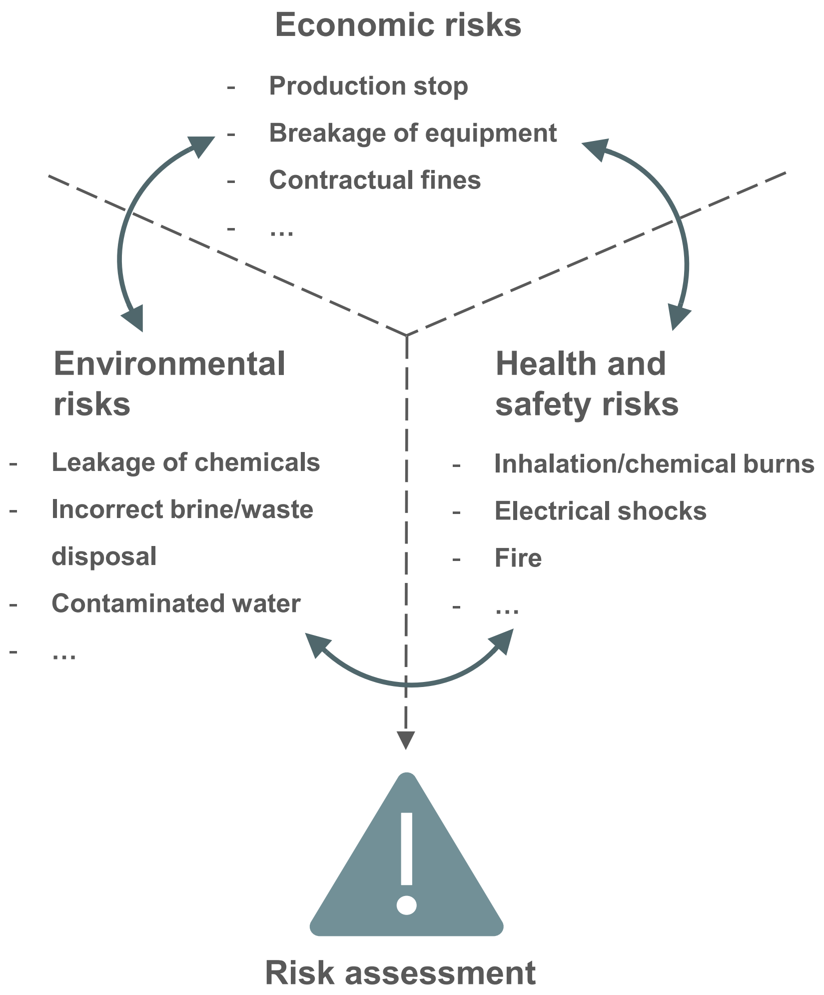


Figure 2-5: Possible risks in operating a SWRO plant

All risks that either generate unplanned expenses or result in a stop of payment are considered to be economic risks. These might include, among others, the unplanned stoppage of water production, for example, due to quality problems in the source water, resulting in contractual fines and loss of income, breakage of equipment, or compensation to injured or sick workers.

Risks that negatively impact either close by or remote areas and beings are called environmental risks. The most serious of those risks would be contamination of soil, sea- or groundwater either because of faulty plant operation, a chemical leakage, or incorrect waste disposal.

The third category are health and safety risks. In RO plants, where different chemicals are used frequently and in high amounts, there is a high possibility for chemical burns or inhalation of toxic fumes. Other safety risks might include injuries due to trips or falls, electrical shock, and injuries caused by heavy machinery, e.g., trucks or cranes. Injury to a trained worker could then result in a production stop, i.e., economic consequences.

This is by no means an exhaustive list of possible risks in RO plants but shows that all these risk categories can be linked to each other and result in unpredictable consequences.

There are some important psychological aspects to be considered while implementing risk management in an organization:

- **Attitude towards risks:**
  The scope of risk management is not only to overcome risks on individual occasions but to implement a general awareness and methodology throughout the organization. Too often, an indifferent attitude towards risks leads to problems that could have been avoided.

- **Learning from previous lessons:**
  Efficient and sustainable risk management is strongly based on communication and documentation. It is important to learn from previous experiences not to repeat past mistakes. Therefore, incidents must be recorded and consulted when they become relevant in current situations. The process of documentation is described in more detail in Chapter 1.7.

- **Responsibility:**
  Risk management has to be performed and supervised by the management for the whole operating process (see Chapter 1). But it also has to be included on a smaller scale in each employee's everyday work. An example would be the consideration of their personal health and safety while working.

2.3.2 Risk assessment approach

Primarily, most hazards need to be identified and regulated during the planning process in the HAZOP studies (for more information, please refer to SWRO Planning Guidelines). Both of the HAZOP studies (planning and operation) provide a safe system design as well as regulations for safe operation. However, since hazards can occur in all aspects and at all times during plant operation, risk management is a never-ending process escorting the entire plant lifespan. The continuous cycle of a general risk assessment approach is presented in Figure 2-6.

Detailed principles on risk management can be found in the ISO 31000:2018 norm.

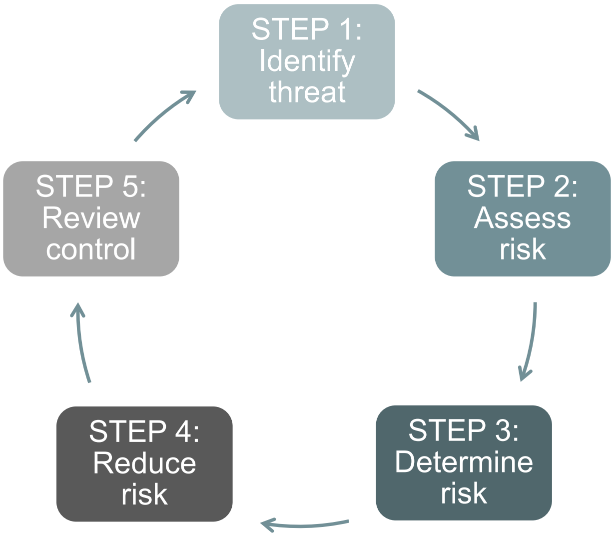


Figure 2-6 Continuous cycle of risk assessment[14]

The necessary steps are described in the following:

- **STEP 1: Identify the possible threat**
  This step aims to find, recognize, and describe risks that might prevent the organization from achieving its targets. This applies both to internal risks that are under the control of the organization, such as the working schedule, and external risks like a global supply risk. Several tools can help in this step, such as:

  - **List of common risks:** In every industry, there are common risks concerning specific areas of operation. The respective management officers should sum up these common risks for their field of work. This is only the first part since this is a more generic approach.

  - **Lessons-learned approach:** This approach includes learning from previous incidents from either the specific facility or other facilities from the same or similar organizations. This is especially valuable for health and safety incidents but may also be applied to different areas like mistakes in maintenance operations. Open and trustful communication between employees across the hierarchy is necessary to perform this step effectively. It should always be made clear that it is about not overseeing or repeating mistakes rather than assigning the blame. The incidents can be presented, for example, in training sessions or via memos anonymously.

  - **Scenario-based:** The approach of listing the common risks and lessons learned is identifying risks based on past incidents. The scenario-based identification goes further. It is a tool to identify risks that have not happened yet but may happen in the future. Scenario-based risk identification is commonly performed by expert groups in audits or during site inspections. On a smaller scale, it can also be performed by each employee. An example will be presented later in this chapter.

[14] After ISO 31000:2018.

The whole plant and interactions between components have to be fully understood to identify possible risks. When performing a risk analysis for a bigger system, the system is often divided into subsystems, and risks are identified for each subsystem. This minimizes the danger of overlooking possible risks.

- **STEP 2: Assess the risk**

  In this step, the Likelihood and the impact of the risk are determined to estimate the level of the risk.

  Risk Level = Likelihood x Severity

  In STEP 2, the following questions have to be answered:

  - Who might be harmed and how?
  - Which damages might affect process equipment?
  - How likely is it that things go wrong?
  - How severe would the outcomes be?

- **STEP 3: Determine the risk**

Standards and norms have to be established to evaluate the consequences of a risk. This is important to categorize the consequences stringently. Otherwise, the consequences of the same risk would be considered differently by different persons based on their subjective perception of risks. For many applications, there are limiting risks that can be found in their respective norms, for example, the IEC norms for electrical components. For other applications, the management (see Chapter 1) has to decide on a risk philosophy and define those limiting risks themselves. In general, the necessary actions to be taken according to the risk level are shown in

Table 2-2.

Table 2-2: Control actions based on risk level[15]

Risk level	Action
▪ 20 – 25	Stop – stop the activity until immediate action is taken to control and reduce the risk
▪ 15 – 16	Urgent action – take immediate and rigorous action without stopping the activity if practicable
▪ 8 – 12	Action – take suitable action within a specified time scale to improve the existing control to reduce the risk level
▪ 3 – 6	Monitor – continuously monitor the existing control measures to ensure they are still effective and improve if required
▪ 1 – 2	No action – no further action is needed, but the assessment should be reviewed periodically

- **STEP 4: Find means to mitigate the risk**
  There are several potential ways to treat risks which can be chosen:

  - **Risk avoidance/elimination:** This includes not performing an activity that could present a risk. Avoidance can sometimes be an option, for example, as a basis for Safety Instructions that prohibit certain actions in a specific area. However, avoidance is not the solution to all risks, simply because increasing risk avoidance might stop operation altogether.

  - **Risk reduction:** This strategy is based on reducing the negative impact or the likelihood of a certain event. An example would be using the appropriate personal protective equipment while working with chemicals.

  - **Risk sharing:** This includes insurances or contracts. For example, a contractual fine with a supplier should supply risks occur and hinder the continuous operation.

  - **Risk bearing:** This is a viable strategy for minor risks, where the cost of insuring against the risk would be greater over time than the total losses sustained.

[15] A. Awwad et al. (2018). Risk Assessment and Control for Main Hazards in Reverse Osmosis Desalination Plants.

- **STEP 5: Periodically review the applied control mechanisms**
  Control measures have to be checked periodically whether they are still applicable and effective and still necessary because of a change in risk level.

Since these steps are deliberately vague to apply to all aspects, a more specific example of a risk assessment in a SWRO plant is presented in the following[16].

Risk assessment topic: Electrical hazards

- **STEP 1: Identify threat**
  As electricity is the main power supply of the plant, all maintenance, and even operation activities include dealing with electricity which introduces the risk of electric shock to workers especially because of poorly maintained equipment, poorly isolated electric cables, or charged static electricity.

- **STEP 2: Assess risk**
  As dealing with electricity is a repeated and usual activity, the likelihood that something can go wrong is estimated as high (**4**). Because of a wide range of voltage (low, medium & high) in addition to wet environment and based on the historical records for fatal accidents, the severity of consequence is estimated as very high (**5**). Based on the likelihood and consequence estimation, the risk level is **20**, which is considered a very high-risk level with a red color code.

- **STEP 3: Determine the risk**
  The risk rate is estimated as very high risk with red color code, so any unsafe operation should be stopped, and urgent action must be taken to protect workers and ensure their safety.

- **STEP 4: Risk mitigation**
  Recommended actions:
  a) Regular and comprehensive check for all electrical connections, cables, plugs, and outlets to ensure they are well insulated and do not introduce any risk in addition to changing any deteriorated one.
  b) Issue clear instructions for energy isolation before starting working with electricity and strictly apply lockout - tagout system.
  c) Ensure that all workers are qualified enough and trained to deal with different ranges of voltage.
  d) Provide suitable equipment and tools, for example, insulated ladders, electric resistant gloves, safety shoes, and voltage tester.
  e) Relocate all electric cables that could contact with water in case of water leakage to be far from water.
  f) Check all electric equipment to ensure it is effectively grounded.

[16] A. Awwad et al. (2018). Risk Assessment and Control for Main Hazards in Reverse Osmosis Desalination Plants.

g) Develop preventive maintenance and inspection procedures and schedules for all equipment to detect any sign of damage.

By implementing these control measures, the risk level is supposed to be reduced from high to moderate with a light green color code that requires continuous monitoring, checking, inspection, and improvement (see Figure 2-7).

Severity / Likelihood	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Very likely (5)	5	10	15	20	25
Likely (4)	4	8	12	16	Before (20)
Fairly likely (3)	3	6	9	12	15
Unlikely (2)	2	4	After (6)	8	10
Very unlikely (1)	1	2	3	4	5

Figure 2-7: Risk matrix for electrical hazards[17]

This example illustrates that risk assessment and mitigation is the responsibility of both the management and the individual employee. The management has to provide access to protective equipment and tools, but it is in the employee's responsibility to properly wear those, follow safety instructions, and only perform work he or she is qualified for.

Take Away Messages – Risk management:

- Different risks are linked to each other and may thus become more severe. It is mandatory to have a good understandig of the whole system to be able to identify and assess different hazards and their consequences.
- Risk management is a responsibility of both, the management as well as each individual worker.
- Risk mitigation often does not cost much but can prevent high expenses and accidents and should therefore be included throughout the organization.
- Many risks can be avoided by simply following best practice guidelines.
- Low-risk events can trigger a chain reaction that can lead to serious accidents and mistakes. It is essential to stop the chain reaction early on.
- Do not forget that bad luck and human error play a big part in any incidents. Better to stay safe than sorry!

[17] A. Awwad et al. (2018). Risk Assessment and Control for Main Hazards in Reverse Osmosis Desalination Plants.

2.3.3 Process redundancy

Process redundancy describes the duplication of critical components or functions of a system to increase the reliability of the system.

It is an important risk mitigation tool and can be integrated into several aspects at a SWRO plant, as shown in Figure 2-8.

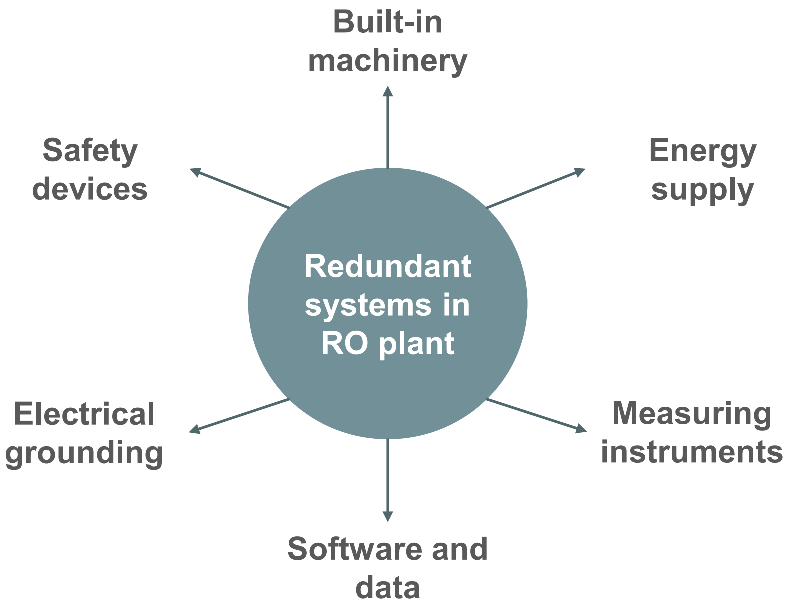


Figure 2-8: Examples for redundant systems in a SWRO plant

Most aspects of the SWRO plant are realized redundantly from the planning phase of the facility.

The first aspect is the **built-in machinery**. It is recommended to install at least the following items of equipment redundantly:

- Low-pressure feed pumps
- High-pressure pumps
- Chemical metering pumps
- Media filters
- Cartridge filters
- Other, possibly minor equipment where a blackout would lead to severe operating problems (for example the vacuum priming system)

The recommended redundancy level for these items is **N+1**, where **N** is the quantity required for operation. The additional standby installation helps continuing operation in case of a broken part or a part that requires frequent shut-down for maintenance.

The significant dependency on the **energy supply** makes SWRO plants vulnerable. Suppose the public electrical grid supplies the plant. In that case, the installation of an emergency Diesel engine might be an option to ensure at least some functionality of the most critical aspects during blackouts, for example, to flush out saline water from the membranes, as well as safe shut-downs. Furthermore, the offtake priority of the electricity should be included in contact with the external supplier.

Other pre-installed instruments can be designed redundantly because of safety reasons discussed in the HAZOP studies. Examples can be **electrical grounding** and **safety devices** like level switches or emergency eye shower flasks.

Some redundancy refers to a redundant way of working. An important aspect is the continuous creation of **software backups and data**. Please refer to Chapter 1.7 for more information on plant documentation and data management.

Redundant **measuring instruments** ensure correct data because differences can be spotted easily. Either the instruments are redundant directly online or in the form of handheld instruments for periodical checks.

General handling of installed redundant systems

The reliability of the installed redundant systems can only work if they are maintained just like the rest of the equipment.

- Keep all parts of redundant systems in good shape
- Perform regularly visual inspections and necessary maintenance
- Change over to redundant installation for maintenance operations to prevent downtime of plant
- Rather use the redundant path than bypassing, especially with filters, to avoid debris in downstream machine parts.
- Do not change/bypass redundant systems!
- Do not use redundant equipment as spare parts!

Take Away Messages – Process redundancy:

- Process redundancy is decided during the planning period to mitigate risks in plant operation.
- Redundant equipment should not be dismantled afterwards or used for other purposes.
- Redundancy can even save lives, data and equipment, but only if maintained properly.

3. Management of consumables and spare parts

This chapter will focus on the management of consumables, like chemicals and single-use equipment, and spare parts. The reliable availability of materials used for plant operation is mandatory for continuous operation and a prerequisite for maintenance tasks (Chapter 5).

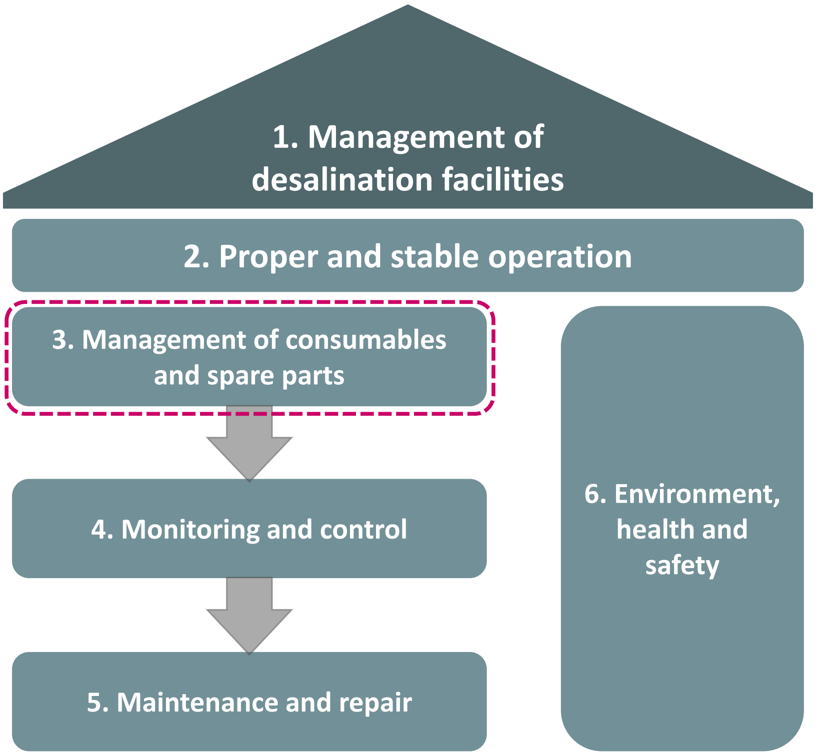


Figure 3-1: Chapter structure of SWRO Management Guidelines

The aim and purpose of this chapter are to emphasize the importance of cost reduction in procurement while maintaining the necessary quality level and the relevance of correct storage to avoid value loss or additional expenses.

In Chapter 3.1, the basics of supply chain management and procurement processes will be presented. Ideas for possible ways to reduce costs like component standardization will be proposed in Chapter 3.2. Furthermore, the general best practices of storing spare parts and chemicals used in RO plants and the basics of inventory management will be explained in Chapter 3.3.

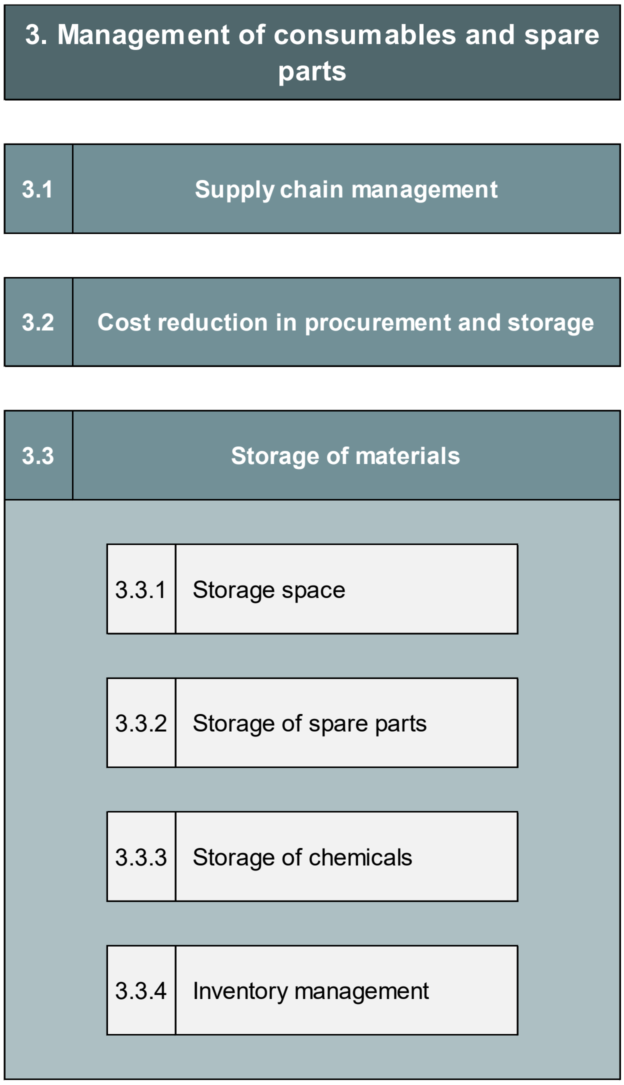


Figure 3-2: Structure of Chapter 3: Management of consumables and spare parts

3.1 Supply chain management

The importance of supply chain management has become more and more visible during the last decades. In particular, the interdependency of markets all around the globe combined with international transport leads to logistical challenges.

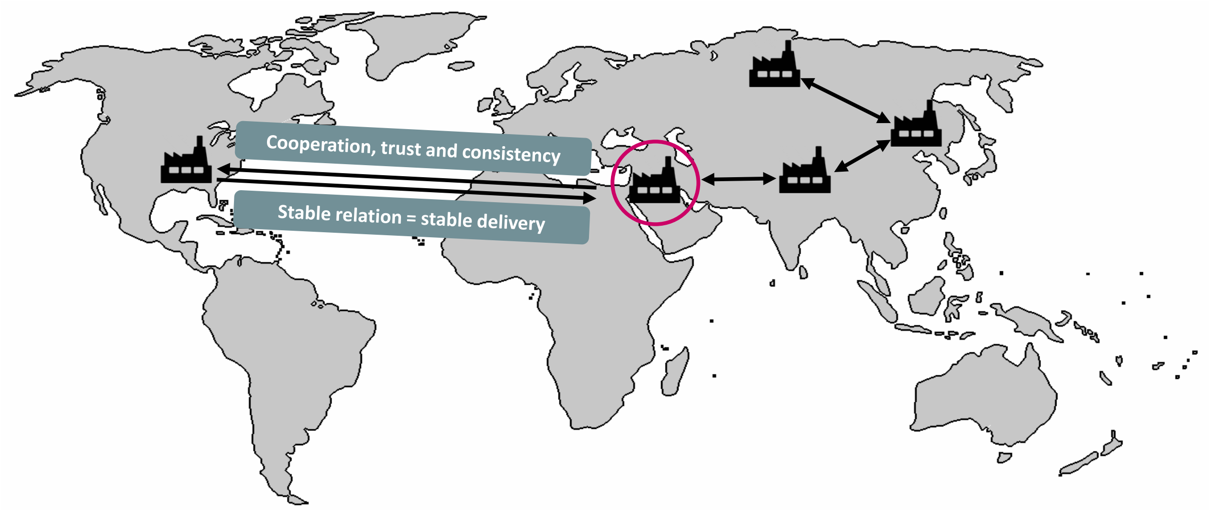


Figure 3-3: Global supply characteristics

Figure 3-4 shows general supply risks, resulting in supply gaps concerning RO facilities and their consumables and spare parts.

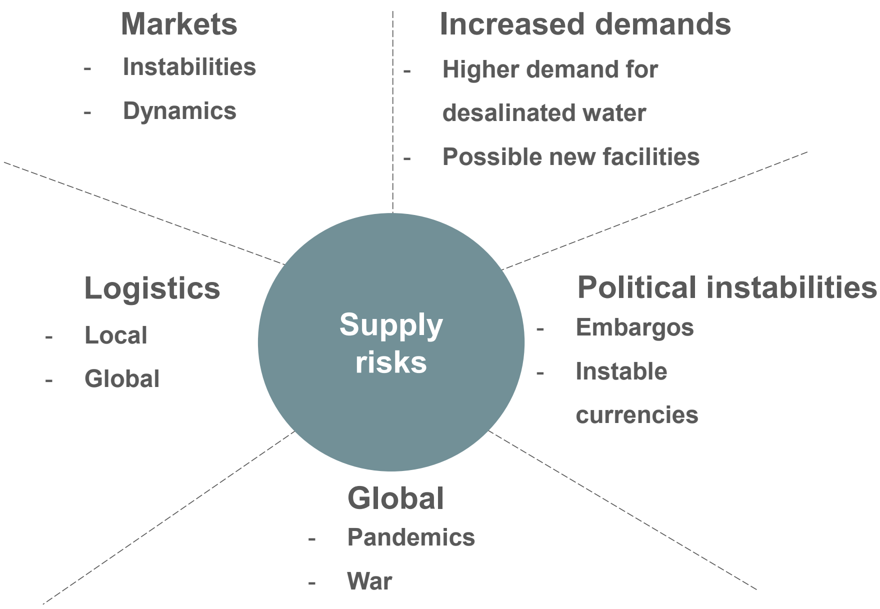


Figure 3-4: Possible reasons for supply gaps

Supply risks exist both primarily, for example, shortage of RO membranes due to increased demands as more desalination facilities are built around the world and secondary, for example, shortage of raw materials. The causes and consequences of shortages can hardly be overviewed and much less managed. Efficient supply management is crucial to bridge possible supply gaps and to gain time to find alternatives if certain materials are not available promptly.

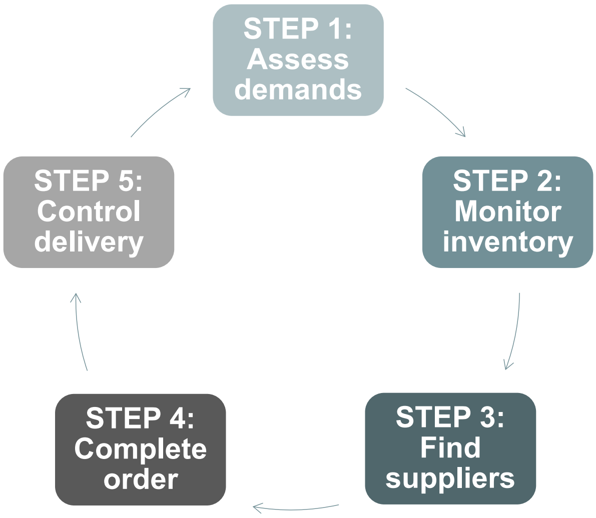


Figure 3-5: General steps of the procurement cycle

STEP 1 in the procurement process cycle, shown in Figure 3-5, is to assess the demands. This can be done by referring to previous demands or consumption data that must be provided from the desalination plant's supplier. According to the planning guidelines, the chemical consumptions have been pre-calculated during the planning period. Future changes in production quantity should be considered in this step, especially for the use of chemicals. If necessary, prioritize the demands by assessing the financial consequences of the shortage.

STEP 2 focuses on the importance of continuous monitoring of inventory to avoid self-inflicted shortages. All purchases and consumptions have to be documented. This step is also important for the correct assessment of demands (see Chapter 1.7 for more details on plant documentation). Excessive inventory leads to unnecessary binding of capital and increases the risk of damages of spare parts during the storage period. Also, most chemicals should be consumed within one year. Good monitoring also helps to see possibilities for combined orders which can be executed less frequently.

STEP 3 is to find reliable suppliers. The basics of this step are similar to the tendering process presented in the Planning Guidelines. Finding suppliers mostly has to be performed during the planning period and at the beginning of plant operation.

Some questions should be answered before ordering:

- Can the supplier meet the quality demands?
- How long are the delivery times?
- Does the supplier meet delivery dates?
- Are there inexplicable price fluctuations in his products?
- How do his prices compare to competitors?
- Is there one permanent and reliable contact person?
- Is the supplier flexible and can react promptly?
- Are there possible discounts for larger orders or long-time contracts?

It is desirable to have fallback suppliers if one supplier falls out.

STEP 4 is to complete the order. In this step, attention should be paid to the exact specifics of quantity, payments, and delivery dates which have to be documented to avoid misunderstandings.

In STEP 5, the state of the order on delivery has to be documented as well as any delays. Do not accept deliveries that contain wrong quantities or faulty equipment and compare the delivery note with the invoice before clearing the payment.

Take Away Messages – Supply chain management:

- Supply gaps can happen anytime and for various reasons. Good supply management is necessary to bridge those supply gaps.
- Choose suppliers with care. Evaluate suppliers over time and change supplier if issues have occurred.
- Good monitoring of inventory is essential to save money during the ordering process. Orders can possibly be executed bundled and less frequent.

3.2 Cost reduction in procurement and storage

Together with employees' wages and energy costs, consumables and spare parts account for a large part of operating costs. Some means of possible cost reduction are presented in this chapter.

The first measure is **price comparison** in procurement, already mentioned in the previous Chapter 3.1 as well as in the planning guidelines. Always buy spare parts and consumables in a market-orientated way whilst only buying quality equipment as recommended in the manufacturers' manuals from reliable suppliers. Buying quality equipment made from the right material is especially important in SWRO plants due to the harsh and corrosive environment.

Spare parts and equipment for unscheduled reactive maintenance must be available at the SWRO plant promptly. To save time and money, the installation of a warehouse directly at the plant is recommended. Also, transport ways and thereby costs, as well as CO2 emissions, might be reduced that way. When the procurement is planned ahead, **bulk orders** for consumables and spare parts can be placed, which reduces costs. This is even more effective when **standardization of components** throughout the SWRO plant was to be implemented. This would lead to fewer suppliers, known equipment quality, and established maintenance procedures.

Some common items in RO plants where standardization would be advisable are listed below:

- RO membranes
- Cartridge and bag filter elements
- Pumps (e.g., chemical dosing pumps)
- Control components and instrumentation
- Valves, taps, and fittings
- …

When standardized equipment such as pumps is used, the staff would also gain more experience in maintenance, which will shorten the time needed for each operation and reduce mistakes. It would also enable the exchange of equipment throughout the facility.

Take Away Messages – Cost reduction in procurement and storage:

- It is important to purchase high quality materials. They might cost more at the beginning, but save money in the long run.
- Always purchase materials in a market-oriented way. Do price comparisons between, at least three, suppliers.
- If standardized equipment is used in the plant, do not replace them by not standardized equipment, just due to their cheaper prices.

3.3 Storage of materials

The correct material storage is crucial to avoid damage to stored equipment leading to unnecessary expenses and dangers to the environment, health, and safety. Best practices for storing chemicals and spare parts used in SWRO plants as well as the basics of inventory management will be presented in this chapter.

3.3.1 Storage space

The dimensions and specifics of the storage spaces have been defined in the planning process, for example, ventilation, collection trays for chemicals, explosion- or fire protection. But during plant operation, some general requirements for the use of storage spaces must be defined, as seen in Figure 3-6. These requirements apply to all storage spaces, regardless of space and stored materials.

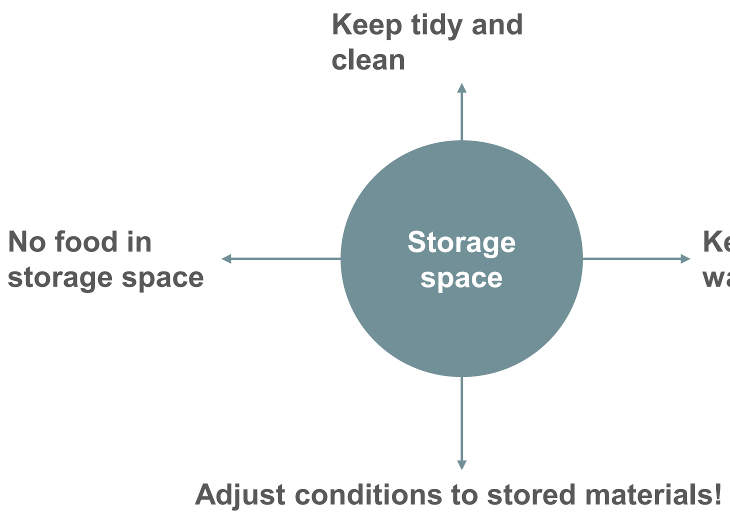


Figure 3-6: Requirements for storage spaces

The storage space has to be kept tidy and clean at all times. This applies especially to the walkways and emergency exits. Thereby falls and trips, which are two of the most common safety risks in industrial plants, are minimized and quick access in emergencies possible. Also, keep the unloading area free and accessible for deliveries.

No food or personal items should be stored in storage rooms to avoid contamination, especially in chemical stores.

Keep stored items at their assigned places and keep smaller items in labeled bins. Shelves should also be labeled. That way, inventory can be monitored more easily.

Use shadow boards for tools, as shown in Figure 3-7. This is even more important for special tools, which might be harder to reorder.

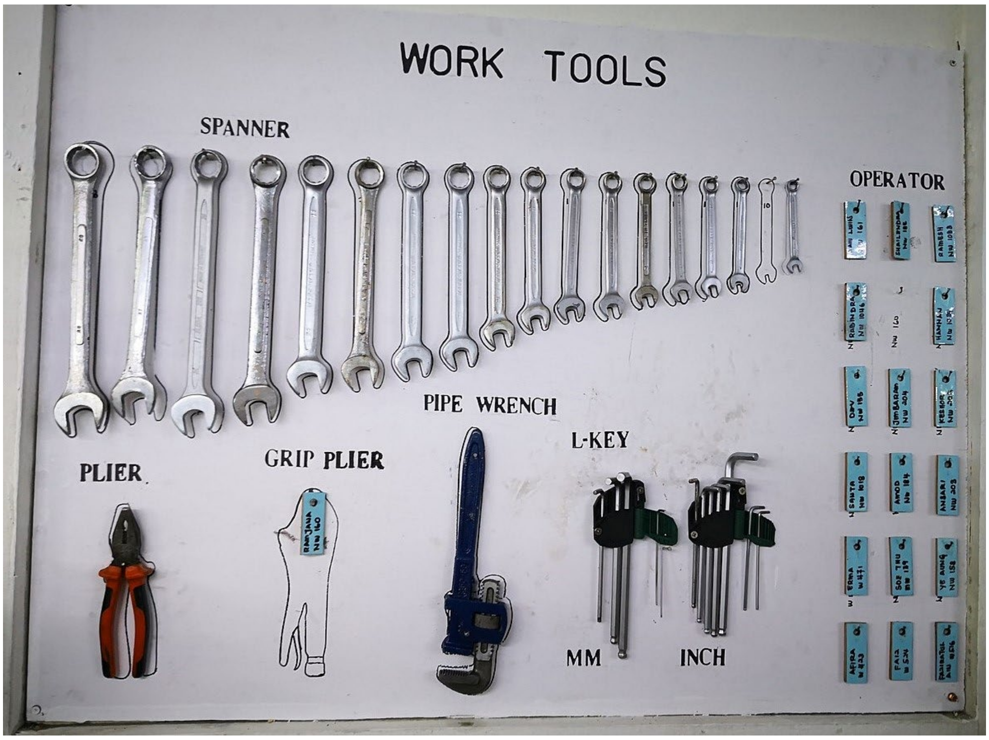


Figure 3-7: Example for work tool shadow board[18]

Make sure that **safety systems**, for example, air ventilation, are working properly at all times. Chemical fumes and lack of oxygen due to metal corrosion can lead to serious health problems.

Most importantly, adjust the conditions (temperature, humidity) inside the storage room to the specifications of the stored materials.

3.3.2 Storage of spare parts

Instructions for the correct spare parts storage can usually be found in their original packaging. Some general rules apply for all manners of SWRO spare parts and are shown in Figure 3-8.

[18]https://en.wikipedia.org/wiki/Shadow_board

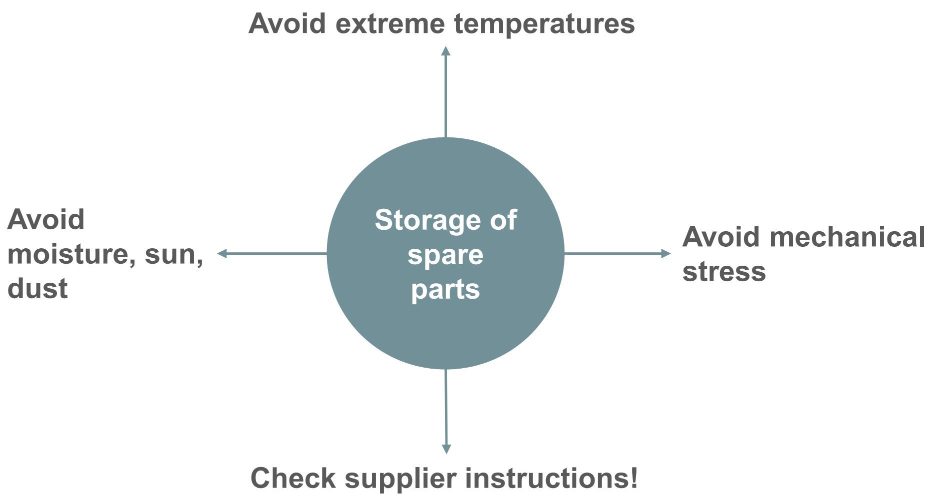


Figure 3-8: General best practice for the storage of spare parts

All spare parts must be stored clean and protected from moisture or dust. Especially polymer materials, for example, membrane elements, must be protected from direct sunlight or extreme temperatures. For these reasons and to avoid theft, spare parts always must be stored **inside of the warehouse** and not outside.

Mechanical stress, induced during loading and unloading operations or storage, must be avoided. In general, high stacks of materials should be avoided both to protect the parts as well as to prevent accidents.

A more detailed list of spare parts and recommendations for their storage can be found in Table 3-1.

Table 3-1: Correct storage of spare parts

Components	Material	Risks	Correct storage
Membranes	Polymers	▪ Biological growth	▪ Virgin: dry or in storage solution, sealed in original packaging ▪ Used: in storage solution according to manual
		▪ Mechanical stress	▪ Properly stacked and secured
		▪ Deterioration	▪ Protected from direct sunlight ▪ Temperatures 5-30°C
Pumps, pipes, valves	(Stainless) Steel	▪ Corrosion	▪ Clean and dry
		▪ Dirt	▪ In original packaging or wrapped in PE sheets
		▪ Mechanical stress, bending	▪ Properly stacked and secured

Components	Material	Risks	Correct storage
			▪ On a level ground
Pipes, hoses	Polymers	▪ Embrittlement, deterioration	▪ Protected from direct sunlight ▪ Protected from chemical gases
		▪ Mechanical stress	▪ Kept away from sharp objects or edges ▪ Stored in a stable pyramid shape on ground level and fixed with stoppers
Cartridge filters	Polymers (Polypropylene)	▪ Deformation	▪ Do not stack filters
		▪ Deterioration	▪ Protected from direct sunlight and extreme temperatures
		▪ Contamination	▪ Kept in separate bags
Electrical equipment	Various	▪ Corrosion	▪ Dry
		▪ Dirt	▪ Protectively packaged
		▪ Mechanical stress	▪ Do not stack electrical equipment

3.3.3 Storage of chemicals

This chapter focuses on the correct storage of chemicals. As mentioned before, chemicals are one of the most significant sources of hazard when operating a RO plant. Hazards in the storage of chemicals mainly occur when chemicals are released due to leakage. There are several possible causes for the release of chemicals:

- **Mechanical damage**
  During transport, due to excessive or risky stacking, overloading of shelves, or tipping due to storage on uneven floors
- **Aging**
  Embrittlement of plastic containers due to long storage or UV radiation from sunlight, softening of plastics due to heat, corrosion of metallic containers, interactions between chemical and container
- **Effects in stored goods**
  Increased pressure due to vaporization in a warm environment, degradation of the product during long storage, UV radiation from sunlight triggering reactions
- **Open handling**
- **External factors**
  Chemicals must be kept inside locked stores and protected from unauthorized access as well as severe weather conditions such as flash floods.

The possible effects are:

- **Fire or explosion**
- **Health hazards** (immediate or chronic)
- **Environmental damage**
- **Property damage**

Special attention concerning the chemical storage spaces must be paid during the planning period additionally to the general requirements on storage spaces listed in Chapter 3.3.1.

Chemicals always have to be stored indoors in appropriate chemicals stores!

Sunlight and moisture lead to embrittlement and corrosion of containers, increasing the risk of leakages. Chemical containers have to be protected from those harsh environmental impacts without losing their protective barriers. Any harmful chemicals stored outside could directly pollute the environment in the event of leakage.

Introduce a storage concept for larger chemical stores!

A risk assessment according to the procedure described in Chapter 2.3 should be performed if more significant quantities of chemicals are stored together. The basis of the risk assessment is the Material Safety Data Sheets (MSDS) (see below) as well as supplementary information from the manufacturer or relevant databases. Derived from these risks, the necessary protective measures are defined. The risk assessment documentation can then be integrated into the storage concept. The storage concept will help keep track of stored quantities, ensure a higher level of safety and simplify, for example, firefighting measures in case of emergency.

General advice on storing different chemicals together:

- Implement the recommendations listed in the MSDS.
- Always store chemicals according to storage plan, if available.
- Do not store chemicals together where the simultaneous release and interaction may result in the formation of flammable or toxic gases.
- Do not store acids and bases together.
- Do not store chemicals together, which need different temperature conditions.
- Take care not to store chemicals together, which need different extinguishing agents.
- Take special care of uncleaned empty containers and partially empty containers as, for instance, explosive air-gas mixtures can be formed when flammable liquids are within these containers. Therefore, the empty vessels must be handled as full but should be stored separately from other containers and clearly labeled.

Supposing adequate storage spaces and plans exist, some general rules for the storage of chemicals are stated in Figure 3-9.

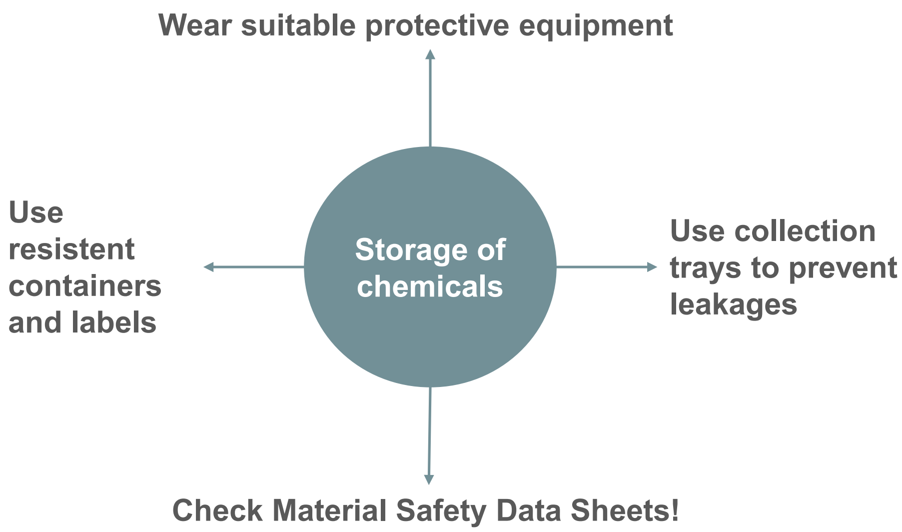


Figure 3-9: General best practice for the storage of chemicals

Material Safety Data Sheets

The most important source of information regarding the correct handling and storage of chemicals is the Material Safety Data Sheet (MSDS) of a chemical. If the supplier did not provide them for the delivery, they can be found on websites of any chemical manufacturer. They include the following aspects:

- **Name and CAS-number**
  Every chemical can be clearly identified by its CAS number (*Chemical Abstracts Service*). While there are often several names for the same substance, either for chemical or marketing reasons, the CAS number stays always identical.
- **Emergency phone number of the supplier company as well as general contact information**
- **Hazard identification**
  This includes the internationally standardized GHS pictograms (*Globally Harmonized System of Classification and Labelling of Chemicals*) as well as the Hazard statements, a set of standardized phrases about the hazards of chemical substances and mixtures, and the Precautionary statements, which advise about the correct handling of chemical substances and mixtures.
  A list of all GHS pictograms of chemicals used in RO plants and their respective description can be found in Figure 3-10.
- **First-aid measures**
- **Firefighting measures**
  Here, appropriate extinguishing equipment, special hazards, and advice for firefighters are listed. These properties have to be considered in the storage plan.
- **Accidental release measures**
- **Handling and storage**
  This section also includes incompatibilities between different chemicals.
- **Exposure control and Personal Protective Equipment**
  This section lists the protective equipment needed for handling this chemical sorted by body parts, for example, eye or respiratory protection.
- **Information regarding physical properties, stability, and reactivity**

- **Toxicological and ecological information**
- **Disposal considerations**

An example of an MSDS can be found in the Appendix (Figure 7-1).

It is mandatory to keep the corresponding MSDS updated and accessible to anyone working with or handling chemicals. They have to be located near the chemicals. The best option would be an online library with a search function, although physical copies of the MSDS will do as well.

Pictogram	GHS	Chemicals	Description - Handling
 Flammable	GHS02	Na-DDS	Flammable; substances produce explosive mixtures when in contact with air or water or are self-inflammatory. Keep away from open fire or heat; seal containers tightly; store fireproof
 Oxidizing	GHS03	$Ca(OCl)_2$	Has an oxidizing effect and fuels fire. Mixing with flammable substances produces explosive mixtures. Keep away from flammables and do not mix with them; keep stored clean.
 Compressed gas	GHS04	N_2	Gas cylinders under pressure can explode when heated; cryogenic gases produce cold burns. Do not heat; wear protective gloves and goggles for cryogenic gases.
 Corrosive	GHS05	HCl, $Ca(OCl)_2$, $Ca(OH)_2$, H_2SO_4, NaOH, NaClO, $Na_2S_2O_5$, Na-DDS	Destroys metals and corrode body tissue; heavy eye damage possible. Avoid contact; wear protective googles and gloves; in case of contact rinse eyes or skin with water.
 Toxic	GHS06	Na-DDS	In small quantities causes immediate serious damage to health or death. Do not inhale, touch or swallow. Wear personal protective equipment. Contact immediatly poison control center or doctor.
 Harmful	GHS07	HCl, $Ca(OCl)_2$, $CaCl_2$, $Ca(OH)_2$, $Na_2S_2O_5$, $C_3H_3NaO_2$	Causes damage to health, irritates eyes, skin or airways. In larger quantities leads to death. Do not inhale, touch or swallow. Wear personal protective equipment. In case of skin irritation or eye contact, rinse with water or suitable agent.
 Health hazard	GHS08	$(C_2H_2O_4)$	Has an allergenic effect, causes cancer, mutagenic, toxic for reproduction and fertility damaging or organ-damaging Before working with such substaces, you must be well informed; wear protective clothes, gloves, eye and mouth protection or breathing protection
 Environmental hazard	GHS09	$Ca(OCl)_2$, NaClO	Harmful to aquatic organisms, toxic or very toxic, acute or with long-term effects. Only dispose of in hazardous waste, never allow to enter the environment.

Figure 3-10: GHS pictograms of frequently used chemicals.

Chemical symbols in order used: Na-DDS is sodium salt of dodecyl sulfate; $Ca(OCl)_2$ is calcium hypochlorite; N_2 is nitrogen; HCl is hydrochloric acid; $Ca(OH)_2$ is calcium hydroxide; H_2SO_4 is sulphuric acid; NaOH is sodium hydroxide or lime; NaClO is sodium hypochlorite or bleach; $Na_2S_2O_5$ is sodium metabisulfite; $CaCl_2$ is calcium chloride; $C_3H_3NaO_2$ is sodium acrylate; $C_2H_2O_4$ is oxalic acid.

Resistant containers and labels

Each chemical has its requirements for precautions to avoid hazards. Therefore, every chemical has to be adequately labeled at any time. **Any chance of mixing up chemicals in containers with other substances or water has to be prevented**. Never leave chemicals in a container without a label, not even for a short while.

The label has to include at least the following data:

- Name of substance (and CAS-number)
- Hazard pictogram
- Hazard statements (H-statements)
- Precautionary statements (P-phrases)

The label must be easily legible and resistant to liquids like water and the substance inside the container. Use waterproof markers if handwritten labels are used. **The equipment in the chemical dosing system should also be tagged and marked to make it easy to tell which pumps or pipes carry which chemical!**
Uncleaned empty containers, as well as partially empty containers, have to be clearly labeled as well. After cleaning, labels and hazard symbols on empty containers must be removed before disposal to avoid confusion.

Containers and packaging for chemicals must be sufficiently resistant against mechanical, thermal, and chemical impact related to (internal) transport and storage. Chemicals mustn't be stored in containers that might be mixed up due to their form or labels with food containers.
Harsh conditions attack the material of the container and increase the risk of damages over time. Therefore, it is advisable to **use up chemicals within one year**. Also, always use up older chemicals before new ones,

The easiest way to ensure resistant containers and labels is to store chemicals in their original packaging. If this is not possible, for example, if smaller amounts of a chemical are transported and used somewhere else, keep the forementioned requirements in mind. The recommendations for resistant containers and labels apply to chemicals in their pure form as well as to mixtures, chemical waste, or materials contaminated with chemicals.

Collection trays

All chemical containers should be stored on top of collection trays, which can hold the whole liquid volume in case of leaks. This holds true for all hazardous substances but foremost for water-hazardous substances. For single or empty containers which must be stored separately for a short time, drip trays are another option (see Figure 3-11).

Figure 3-11: Chemical storage on collection tray and in drip tray

Stationary safety equipment and Personal Protective Equipment

Depending on the chemicals to be stored, stationary equipment is necessary to implement in the storage spaces. This might include emergency showers, eye showers, or eyewash bottles, as well as spill-absorbing materials.

When working with chemicals, always wear suitable Personal Protective Equipment (PPE). This also applies to transport and loading/unloading operations since leakages can always happen when damaged containers. Pay special attention if chemical containers have been opened before as they might not be closing correctly or traces of chemicals remaining on the canister. **Since this is an essential topic on its own, detailed information regarding PPE and safe working with chemicals can be found in Chapter 6: Environment, health, and safety.**

Take Away Messages – Storage of chemicals:

- All chemicals must be stored inside on collection trays.
- Take care when storing chemicals together. Consult storage plan or Material Safety Data Sheets for possible incompatibilities.
- Make sure that all containers are chemical-resistant and properly labelled according to GHS regulations.
- Provide adequate Personal Protective Equipment close to the stored chemicals.

3.3.4 Inventory management

Inventory management is an essential systematic approach to sourcing, storing, and keeping track of components and materials in a desalination plant. It benefits operational efficiency and longevity, leading to a more cost-efficient operation of the plant.

It is crucial to have spare parts, tools, and consumables stored beforehand in the storage facilities of the plant. This is important to avoid placing unnecessary orders and having operational difficulties because of lacking consumables and spare parts. Additionally, by having spare parts and consumables stored in an organized manner, time (and thereby money) that would be spent for searching can be saved during plant operation or maintenance jobs.

To store items in an organized way, it is recommended to assign a specific location in the storage spaces to each sort of equipment. Items of the same type should be stored together, at least for long-time storage. Storage plans and labelled shelves make it easy for employees to find spare parts and equipment quickly. The so-called ABC system can help to assign places for equipment. Equipment of class A is used very frequently and should therefore be placed close to the entry at easy reach, whereas class B items can be stored for example in drawers. Class C items can be stored further away in closed boxes. Do not forget to keep the specifics of the material or chemical in mind, when assigning a storage location (see Chapter 3.3.2 and 3.3.3).

Storage space is used more efficiently in an organized storage system than if items are stored rather chaotically. It also helps to have an overview of the number of consumables at first glance. Lastly, theft of equipment or consumables can be spotted much earlier than in less tidy storage spaces.

Inventory management software can be used to track in- and outgoing consumables and spare parts. Inventory software helps to keep track of item attributes such as item name and description, number in stock, location in the facility, time of order, costs of order/shipping, etc., instead of doing this on paper. Small to medium-sized plants usually use Excel, Google Sheets, or other manual tools to keep track of inventory databases and make decisions about ordering. For large amounts of stored goods, there are various inventory tracking and editing tools which are suitable for small/medium scaled plants and businesses, such as Zoho Inventory, inFlow Inventory, or MS Access. These kinds of software require little training and smartphones or other scanning devices can be used to fulfill orders or update the inventory lists.

As with many aspects of proper plant operation, the theory cannot be implemented into daily operation if the employees are not motivated to stick to the recommendations. Make sure all employees concerned are trained in the storage system and inventory management software and understand the importance of proper plant appearance and tidy storage spaces.

Table 3-2: Checklist for Chapter 3

Management of consumables and spare parts		*Drawn by:*	
		Checked by:	
NO.	DESCRIPTION	CHECKED	REMARKS
3.1	**Supply chain management**		
	1) Do you document all ingoing and outgoing elements in your store? (Consumptions, purchases)		
	2) Do you have a good overview over your inventory?		
	3) Do you have reliable suppliers? (Check questions listed in chapter)		
	4) Do you have fall-back options if a supplier cannot deliver?		
	5) Do you document any issues or delays with deliveries?		
	6) Do you clear payments only after you have ensured about the state of the delivery?		
3.3.1	**Storage spaces**		
	1) Are your storage spaces clean and tidy?		
	2) Do all safety installations in the storage spaces work properly?		
	3) Are the passage ways and loading areas at the storage space clear?		
	4) Are the storage spaces protected against intruders?		
3.3.2	**Storage of spare parts**		
	1) Are all spare parts stored **inside**? (Protected from dirt, direct sunlight, …)		
	2) Are all sensitive spare parts packed in protective packing?		
	3) Did you ensure that no spare parts are submitted to mechanical stress?		
	4) Did you check the supplier's information regarding correct storage?		
3.3.3	**Storage of chemicals**		
	1) Are all chemicals stored **inside**? (Protected from direct sunlight)		
	2) Have you introduced a storage plan for your chemicals?		
	3) Do you follow the instructions about storing different chemicals together?		
	4) Are the Material Safety Data Sheets for all stored chemicals up-to-date and readily available for everyone working with those chemicals?		
	5) Are all chemicals stored in resistant containers?		
	6) Are all chemical containers labelled according to the GHS regulations?		
	7) Are all chemicals stored on collection trays to avoid environmental contamination?		
	8) Is adequate Personal Protective Equipment available?		

3.3.4	Inventory management		
	1) Are all storage spaces tidy and clearly laid out?		
	2) Do employees often lose time to search items?		
	3) Is there a storage plan?		
	4) Are all items of the same class stored together?		
	5) Are all items stored at their intended location?		
	6) Are all employees partaking in the task of inventory management and keeping storage spaces tidy?		

4. Monitoring and control

In Figure 4-1, the chapter structure of these guidelines is depicted. Chapter 4 will discuss key parameters in monitoring a SWRO plant, necessary measurement instruments, and control strategies for the plant operators.

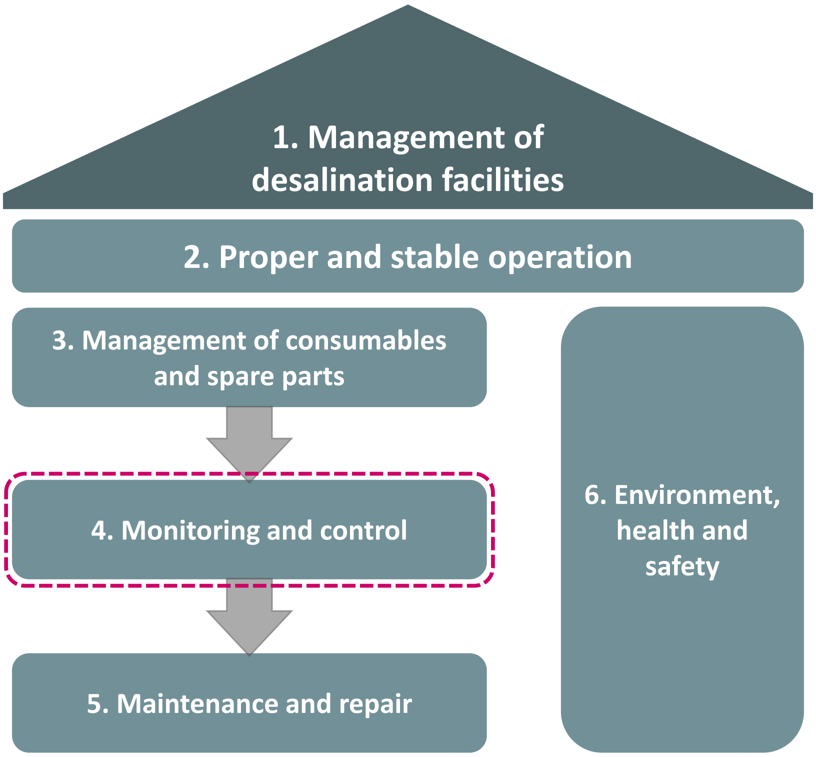


Figure 4-1: Chapter structure of SWRO Management Guidelines

This chapter aims to emphasize the importance of reliable measurements to check the current status of SWRO plants. Reliable measurements are essential as a basis for educated decision-making and to assess the plant's performance over long periods of operation.

The outline of this chapter is shown in Figure 4-2.

In Chapter 4.1, the most important parameters concerning plant status as well as water quality are defined. Chapter 4.2 focuses on the importance of gaining reliable and comparable data through calibration of measurement instruments, normalization of data, and a critical mindset towards recorded data. Chapter 4.3 will give an overview of the importance of record-keeping and control strategies for owners of externally operated SWRO plants.

4. Monitoring and control

4.1 Key indicators

- 4.1.1 RO membranes performance monitoring
- 4.1.2 Pretreatment monitoring
- 4.1.3 Water quality

4.2 Acquisition of reliable data

- 4.2.1 Measurement instruments and calibration
- 4.2.2 Normalization
- 4.2.3 Value assessment and plausibility

4.3 Record-keeping and control strategies

- 4.3.1 Control strategies for supervising SWRO plants

Figure 4-2: Structure of Chapter 4: Monitoring and control

4.1 Key parameters

In this chapter, the most important technical parameters for SWRO plant operation will be defined. They will be further divided into parameters regarding the RO membrane performance, the pre-treatment efficiency, and monitoring parameters in water samples.

4.1.1 RO membrane performance monitoring

The critical monitoring parameters to assess the performance of the RO membranes are

1. The (normalized) **permeate flow**,
2. **Trans-membrane pressure**, and
3. The **percent salt rejection**.

The **permeate flow** describes the volume of water passing through the membranes during a specified time unit, e.g., per second, minute, or hour. It is a target characteristic of the plant and the basis for the whole plant design process. The physical SI unit (internationally standardized unit, *système international d'unités*) for flows would be m^3/s (cubic meters per second), but most commonly m^3/h (cubic meters per hour) or gpm (gallons per minute) are used. It is advantageous to use the same unit in each desalination plant so that misunderstandings can be avoided. Membrane manufacturers often use the permeate flux instead of the permeate flow, which gives the permeate volume per time and membrane surface unit (in lmh, liters per square meter and hour, or gfd, gallons per square foot per day). As the permeate flow is influenced by trans-membrane pressure, temperature, and feedwater composition, normalization has to be performed as described in Chapter 4.2.2.

Salt rejection is the percentage of salt that has been removed from the feedwater TDS (see Chapter 4.1.2). Salt rejection is a membrane property influenced by temperature, pressure, and feedwater TDS and has to be normalized similarly to the permeate flow. Salt rejection can be calculated using the TDS of feed and permeate (Equation 4-1) or, if the TDS is not monitored directly, using the conductivity of said flows instead (Equation 4-2). The manufacturers state the salt rejection of RO membranes as higher than 99% and even around 99.8% for NaCl.

Equation 4-1

$$\%\,Salt\ rejection = \frac{TDS_{Feed} - TDS_{Permeate}}{TDS_{Feed}} * 100$$

Equation 4-2

$$\%\,Salt\ rejection = \frac{Conductivity_{Feed} - Conductivity_{Permeate}}{Conductivity_{Feed}} * 100$$

The **salt passage** is the counterpart to salt rejection, namely the percentage of feedwater TDS that passes through the membrane.

The driving force for the desalination process is the pressure difference between feed and permeate pressure, called **trans-membrane pressure (TMP)**. Another pressure difference that is sometimes used is the **net differential pressure** between feed and concentrate.

The **recovery** of membranes describes the ratio of product water flow (product quantity) over the feed flow (input quantity). A high recovery is desirable to use the source water as efficiently as possible but comes with a higher risk of scaling due to higher salt concentrations. Commonly, SWRO plants operate with recoveries around 40-65%.

4.1.2 Pre-treatment monitoring

To ensure a high RO performance, it is the task of the pre-treatment section to reliably provide pre-cleaned feed water for the RO section to avoid fouling, scaling, or membrane degradation. The parameters listed below should be monitored continuously in the RO feed.

The **temperature**, **pH,** and **pressure** of flows are monitored at different positions throughout the plant sections and probably do not need further explanation.

Particulate foulants

An important parameter to monitor is the total amount of dissolved organic and inorganic matter in a specified volume of water, called **TDS (Total dissolved solids)**. It is often calculated from the **conductivity** of the fluid by multiplying the conductivity with a correlation factor k which is dependent on the water composition. As the conductivity of the water is dependent on the temperature, the conductivity at standard temperature (25°C) must be used for this calculation. This conductivity value is called EC25. Most conductivity meters have an internal compensation for temperature. If this is not the case, the temperature of the fluid has to be documented with the measured conductivity. The exact TDS can also be determined in a laboratory using gravimetric methods.

The main parameters characterizing the feed water regarding fouling are the turbidity and the Silt Density Index, SDI.

The **turbidity** is a measure of the quantity of silt particles, clay, and suspended organic matter in a fluid. It is determined by measuring the amount of light that is scattered by the particles. Turbidity is measured in a nephelometer. The corresponding unit most commonly used in desalination is NTU (nephelometric turbidity unit). As the turbidity shows only the overall number of suspended particles and does not provide information on the type, shape, and size of particles, additional parameters have to be monitored to assess the fouling potential of the feed water.

The **Silt Density Index (SDI)** is a parameter that indicates the fouling potential of the source and feed water to the reverse osmosis unit. It can be used to check whether the pre-treatment section is working properly. The SDI can be determined by filtering a water sample through a 0.45-micron filter with standardized dimensions using a standardized driving pressure. The time it takes to collect 500 mL of filtrate is measured first with a new filter pad (t_0) and again after usually 15 min (t_n). The SDI can then be calculated using Equation 4-3 with n being the total test run time.

Equation 4-3

$$SDI = \frac{1 - (\frac{t_0}{t_n})}{n} * 100$$

This is technically not a continuous monitoring process. However, as the procedure is quite simple and does not involve elaborate laboratory analysis, it is included in this chapter.

In addition to determining the SDI, the color and appearance of the filter pads can be indicative of which foulants are suspended in the water source.

The SDI and turbidity are used to determine the effectiveness of pre-treatment filters by comparing the values before and after filtration. Both parameters should not exceed the thresholds specified by the membrane manufacturer before entering the RO membranes.

Typical requirements from membrane manufacturers can be found in the SWRO Planning Guidelines.

Mineral-scaling foulants

The saline source water contains minerals such as calcium, magnesium, barium, strontium, sulfate, and carbonate. Their concentration increases in the RO trains and peaks at the last stages. In higher concentrations, these mineral ions can form salts that precipitate on the membrane surface ("scaling") and negatively impact the flow through the membranes. The most prevalent mineral salts in SWRO plants are typically calcium sulfate ($CaSO_4$), calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$. The scaling potential is calculated using the solubility of $CaCO_3$. For source water with a TDS value higher than 4000 mg/l the **Stiff-Davis Saturation Index (SDSI)** is used to indicate the scaling potential of the source water. The SDSI is defined as the difference between the actual pH value and the pH value of a calcite calcium carbonate saturated solution. The SDIS is calculated using Equation 4-4.

Equation 4-4

$$SDSI = pH_{measured} - p_{Ca} - p_{Alk} - K$$

$pH_{measured}$ indicates the actual pH of the source water, p_{Ca} equals -Log(Ca^{2+}) with Ca in mg/l as $CaCO_3$ and p_{Alk} equals Log_{10}(Total Alkalinity) with the total alkalinity in mg/l as $CaCO_3$. K is a constant based on ionic strength and temperature. The calculation of the SDSI is similar to the calculation of the Langelier Saturation Index (LSI), which is used for brackish water with lower TDS values, but a different constant K is used.

If the SDSI is above 0, the source water will likely cause scaling. If the SDSI is negative, the water is corrosive and tends to dissolve scale. The SDSI of the feed water, together with the pH, is used to adjust and supervise the dosing of antiscalant chemicals.

Further parameters

Chlorination is commonly used to treat raw water to inactivate microorganisms. But free chlorine in the RO membrane trains can quickly lead to membrane oxidation and irreversible damage. The **Oxidation Reduction Potential (ORP)** is measured to ensure that the dechlorination works properly and no free chlorine enters the RO train. Free chlorine must be removed so that the RO membranes are not damaged.

4.1.3 Water quality

In addition to the parameters presented in this chapter, some important parameters cannot be monitored continuously. Samples must be taken and analyzed for these parameters. Water analysis might be performed in an internal or independent external laboratory.

Particulate foulants

Particulate foulants describe organic and inorganic particles contained in the source water such as fine debris, plankton, detritus, and silt that cannot pass the RO membranes. The **TSS (Total suspended solids)** quantifies the total weight of solid residuals in the source water in mg/L (milligram per liter). The TSS is determined through gravimetric methods, where a defined volume of source water is filtered through a pre-weighed glass-fiber filter. Afterwards, the filter is sprayed with deionized water to remove all dissolved solids that would crystallize in the drying process and thereby corrupt the TSS value. Then the filter is dried at 103°C. The weight difference between the clean and dried filter represents the TSS value.

The ratio of TSS to turbidity is also a good indicator of a shift in the size of the particles suspended in the source water. An increase in the TSS/turbidity ratio is indicative of a shift of particulate solids toward smaller-size particles, for example during an algal bloom, when smaller-sized algae dominate over larger particles.

Colloidal foulants

Colloidal foulants are organic or inorganic suspended compounds that may precipitate on the membrane surface. **Iron, manganese, and silica compounds** exist naturally in seawater sources, but only in very low concentrations. Elevated values can result from over-dosing or poor mixing of flocculation or coagulation chemicals. **(Total) hydrocarbons**, as well as oil and grease in raw water analysis, are indicators that the source water is contaminated with oil-based waste, for example from oil leaks from ships. Hydrocarbons can only be reduced via Dissolved Air Flotation (DAF) clarification.

Natural organic foulants

The presence of organic compounds or microorganisms is monitored by measuring the amount of **Total Organic Carbon (TOC)**. The TOC is an important factor to indicate the fouling potential of the source water. Usually, open seawater does not contain critical amounts of organic matter. Higher contents of natural organic matter can originate from algal bloom or rivers or freshwater sources close to the intake. Other indicators for algal bloom can be an elevated **Chlorophyll *a*** value, which quantifies the number of algae with green pigmentation using light transmission, or an elevated **Total algal count**.

For health reasons, no **E. Coli bacteria or other coliforms** are allowed to be present in the drinking water, which must also be monitored.

The **Chemical Oxygen Demand (COD)** is a parameter to quantify the organics and inorganics in water. It measures the amount of oxygen required to decompose organic and inorganic constituents in the water by chemical reaction. The **Biological Oxygen Demand (BOD)** is a similar parameter also to quantify organics in water, but it measures more specifically the oxygen amount needed by aerobic biological organisms to break down biodegradable organic material. They are both used to quantify the organic load in water as there are strict regulations in many countries to avoid negative environmental impacts.

The thresholds for all substances and parameters mentioned depend on the acceptable levels from the membrane manufacturers, the national drinking water requirements as well as end users' individual perceptions. Additionally, the concentrations of several ions, heavy metals, or radioactive materials should be monitored depending on source water characteristics and drinking water regulations. This is especially important when the clean RO permeate is blended with water from other sources, for example, brackish water.

When performing the drinking analysis, special attention must be paid to the correct procedures, starting with taking the sample up to conducting the measurements. Differences in temperature or measurement insecurities must be avoided in taking the samples. When documenting the analysis results, it is essential to document the unit of the parameter that was analyzed. As for some parameters, different units may be used depending on testing equipment or laboratory standards.

A full raw water analysis must be performed before designing the plant. It is recommended to repeat the raw water analysis at regular intervals during operation (e.g., monthly). The drinking water analysis must be performed in accordance with local regulations to ensure safe and high-quality drinking water at all times. The concentrate water should also be analyzed both to ensure no harmful substances are released into the environment as well as to give insight on possible problems in the plant.

Table 7-2 to Table 7-5 in the appendix give examples of which parameters might be relevant for water analysis. However, these tables are only meant for general guidance. Many parameters are site-dependent, and the inclusion of further data might be necessary, while in other instances, some parameters might be less relevant.

4.2 Acquisition of reliable data

It is essential not just to gather any data when it comes to data acquisition. The data taken from the measurement instruments and the automation system has to be correct, reliable, and comparable to provide knowledge about the plant's status. A common mistake is trusting the automation and measurement instruments blindly without questioning the readings or even trusting system alarms to prevent damage instead of close and active monitoring of parameters. This chapter includes the necessary general steps to collect and prepare informative and reliable data and how to assess values critically, both from manual measurements as well as from the SCADA system.

4.2.1 Measurement instruments and calibration

The only way to gather data from inside the process is through monitoring instruments and sample analysis. The type and position of measurement instruments are decided during the design phase of the SWRO plant. Ideally, all instruments are of high quality and positioned in a way so that they can provide all data necessary for plant operation. Special attention should be paid to the positioning of the measurement instruments, as instruments are subject to external influences like temperature as well as internal influences, such as flow conditions inside the system. Instruments without connection to a computerized monitoring system have to be installed so that values can easily be taken, and that the instruments can easily be dismantled for calibration purposes.

Table 4-1 provides a list of essential monitoring equipment for a SWRO plant. Depending on the size, pre- and post-treatment processes, and general layout of the plant, additional measurement instruments might be installed.

In addition to the installed measurement instruments, some hand-held instruments should be used to compare values and quick sample analysis. Manual instruments to check the temperature, pH value, conductivity, and ORP are recommended.

A laboratory for more detailed water sample analysis should be available at the plant.

Table 4-1: Essential monitoring instruments

Essential monitoring instruments			
System	**Instrument**	**Position**	**Specifications & Comments**
Intake	**Flow meter**		
	Water meter		**To log total volume of treated water**
Chemical Dosing Systems	**Flow switch**		
	Low-level switch		
Cartridge Filters	**Pressure gauge**	**Before and after filter As close to filter as possible Not too close to valves (turbulences)**	**Also for other filter types or UF membrane if used for pretreatment**
RO Feed Line	**Flow meter**		
	Water meter		**If not installed directly after intake**
	Conductivity meter		**To determine water quality and salt rejection**
	pH meter	**After acidification**	**To assess scaling potential**
	Pressure gauge		
	ORP sensor		
	Temperature sensor		**May also be included with conductivity meter**
	Sample port		
RO Membrane Trains	**Pressure gauge**	**At feed, permeate and concentrate side for each stage, feed pump discharge pressures**	**To monitor pressure drop for each stage individually**
	Flow meter	**Concentrate flow of each stage, total permeate flow**	
	Water meter	**Permeate line to log total water volume produced**	
	Conductivity meter	**At permeate and concentrate side for each stage**	**To assess water quality and salt rejection**
	Temperature sensor	**At permeate side of each stage and at permeate line**	
	Sample port	**On permeate and concentrate line as well as on each pressure vessel permeate outlet**	**To facilitate monitoring and troubleshooting**
Desalinated water tank	**Level indicator**		
CIP System	**pH meter**		
	Flow meter		
General	**Hour meter**		**To log total operational hours or running time of equipment**

Measurement instruments, both installed and hand-held, have to be maintained according to their manufacturers' recommendations, just as all other equipment at the SWRO plant. Additionally, to ensure the data they provide is accurate and therefore can be used for decision-making in the operating process in the SWRO plant, the measurement instruments need to be calibrated at regular intervals. Without accurate readings, problems might be detected too late, equipment might get damaged or the product quality does not comply with the contractual requirements. Regular calibration is one step towards an optimized process.

Calibration generally describes the process of comparing a device with unknown accuracy to a known standard. Through this process, any deviation from the predefined value can be documented and adjusted. The calibration should be performed by an accredited organization; regular verification for the instruments can be done internally by the operators. The calibration should be carried out at intervals according to the manufacturers' specifications, but at least once every three months[19]. The frequency of calibration should be chosen reasonably. It is advised to calibrate more frequently rather than too rarely. Calibration of online equipment can be scheduled to be performed during maintenance operations to avoid additional downtime.

To ensure adherence to the recommended calibration schedule, calibrations should be documented in a similar way to maintenance works (described in Chapter 5.2.4). The installation of small calibration record tags (similar to Figure 4-3) on each piece of equipment that has to be calibrated can help to keep a good overview. The calibration schedule and the calibration curves can be documented in either a separate logbook or in the maintenance logbook.

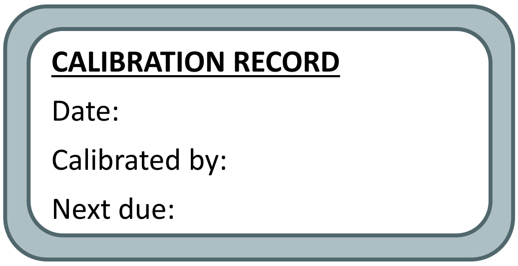


Figure 4-3: Exemplary calibration tag

4.2.2 Normalization

To be able to spot tendencies and developments in plant performance, the recorded data must be monitored over a longer period. But influences resulting from a change in the RO system overlap with other influences resulting from a change in temperature, recovery, feed pressure, and feed water composition. For example, an increase in feed water temperature of 4°C causes an increase of the permeate flow of about 10%[20]. Therefore, recorded parameters cannot be compared directly to each other. Normalization excludes the overlapping operational influences so that the only remaining change that can be seen on the normalized data is caused by fouling, scaling, or membrane degradation. A qualitative example is shown in Figure 4-4. On the left, the permeate flow seems to be constant over time, which indicates no problems with fouling, scaling, or degradation. However, it is not apparent that the plant operators steadily increased the feed pressure to achieve said constant permeate flow. The right diagram shows the actual normalized permeate flow rate, which is constantly decreasing

[19] Recommendation from DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7
[20] DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7

up to the point where cleaning must be performed (usually at around a 10-15% decrease in normalized permeate flow).

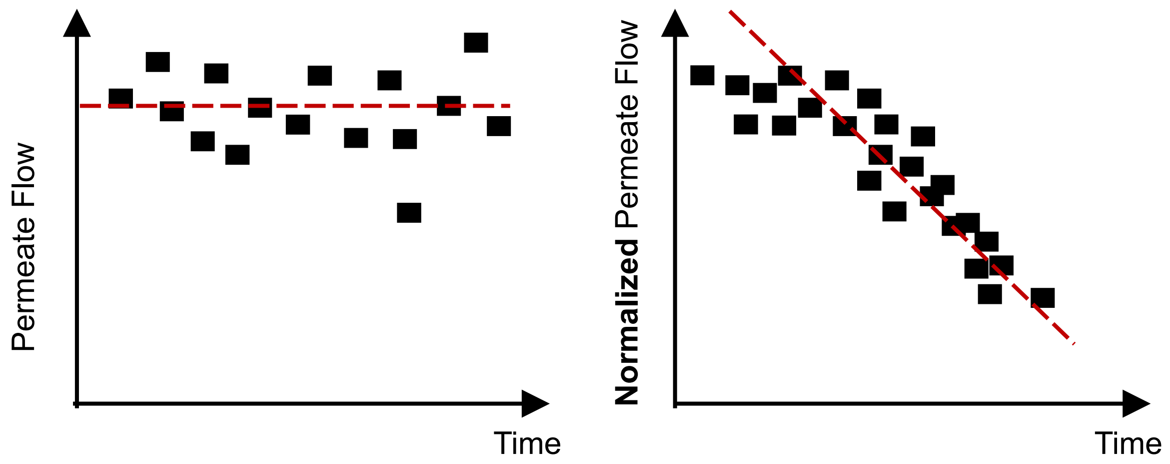


Figure 4-4: Example for the development in permeate flow and normalized permeate flow over time[21]

This elimination of the influences of the operating parameters is done by comparing the actual performance to a reference performance. This reference performance can be the designed system performance to check whether the system reaches its designed performance. Alternatively, it can also be compared to the initial system performance to show performance changes over time.

Normalization is sometimes automatically included in measurement instruments. For example, most conductivity meters have an internal temperature sensor to consider temperature changes. However, normalization has to be performed separately for the permeate flow, the percent salt rejection, and the differential pressure. The most common way to normalize data is using manufacturer software (for example, FTNORM from DuPont). Ideally, the system directly imports and normalizes data, maybe even real-time and continuously. In this respect, possible mistakes from manually copying data can be avoided.

4.2.3 Value assessment and plausibility

The last aspect of acquiring reliable data is a critical mindset towards recorded data. There is a tendency to rely too much on automation instead of checking the recorded data for plausibility. To avoid mistakes and to make values comparable throughout periods, the following steps should be performed:

- **Always measure the correct way (Correctness).**
  Ensure that the instruments are working properly, are calibrated and maintained according to the manufacturers' specifications. Conduct any measurement correctly and not hastily. For some instruments, it is necessary to wait a designed period for the value to stabilize. For other instruments, readings change after a while to an incorrect value (for example, hand-held conductivity meters in stagnant water).
- **Always measure the same way (Reproducibility).**

[21] After J. Kucera (2010). Reverse Osmosis: Design, Processes, and Application for Engineers

Use the same instrument and the same settings. Take samples and measure values at the same position, ideally at the designed position specified in the planning phase. Measuring, for example, the feed pressure too far away from the inlet to the RO train can lead to incorrect readings due to pressure loss through friction in the piping. Measure only when the whole system is in a stable operating condition.

- **Always document the same way (Traceability).**

  Document the same amount of digits. Always document recorded data together with its respective unit. Use a standardized unit throughout plant operation to easily compare values and avoid misinterpretations.

- **Always check the value for plausibility (Validity).**

  Do not trust automation blindly. Check whether the value is somewhere in the expected range. If it is not, check the unit and settings of the measurement instrument. Check readings for inexplicable jumps. Compare the value to previous recorded data and, if applicable, conduct measurement with a hand-held meter to compare readings.

  The plausibility of flow and conductivity meter readings can be checked using simple mass balances. sThe generalized flows at a membrane element are shown in Figure 4-5.

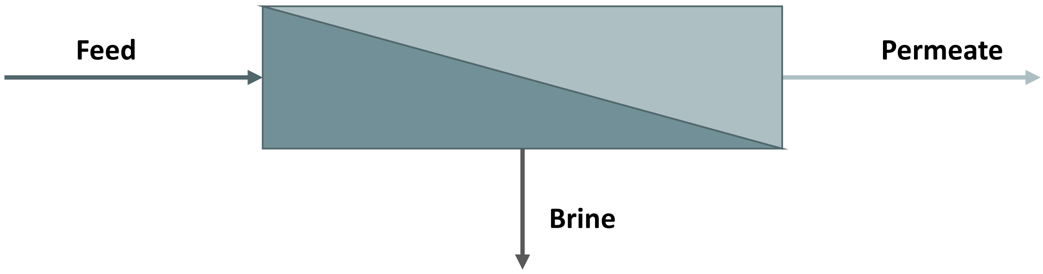


Figure 4-5: Generalized flows at membrane element

To confirm the accuracy of flow meters, Equation 4-5 can be used. It states that the sum of all incoming flows (here: feed flow) must equal the sum of all outgoing flows (permeate flow plus concentrate flow). Small deviations can result from the inevitable measurement inaccuracy or changes in fluid density, but it is still an easy way to check these readings.

Equation 4-5

$$Feed\ flow = Permeate\ flow + Concentrate\ flow$$

Equation 4-6

Equation 4-6 can be used to roughly check the accuracy of flow and conductivity meters[22]. If

$$\frac{(Feed\ flow) * (Feed\ conductivity)}{(Permeate\ flow) * (Permeate\ conductivity) + (Conc.\ flow) * (Conc.\ conductivity)} = 1 \pm 0.05$$

the result from the equation deviates more than 0.05 from 1, one of the meters is compromised and calibration should be performed.

The equations can either be calculated roughly in the head or using an Excel spreadsheet. For more in-depth calculations regarding mass and energy balances, software provided from membrane manufacturers, for example, WAVE (DuPont), LewaPlus (Lanxess), or IMSDesign (Nitto Group) may be used.

[22] DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7

SCADA system and reliability

SCADA systems collect and transform data from multiple sensors and controllers throughout the plant. This data is presented to an operator using a Human Machine Interface (HMI). The HMI allows the operator to see what is going on in the plant in real time, including custom mimic displays, alarms, trends, etc., to make decisions to adjust any machine controls or settings. In addition to real time operation, SCADA systems can also be used to prepare data archives that show trends and developments in equipment performance and can be used as the basis for improved maintenance schedules. Depending on the level of automation, the SCADA system will also adjust the pressure and flow control valves to achieve the desired productivity and recovery of the system during automated start-up or control valves in the feed stream to prevent free chlorine from entering the RO membrane trains.

The same principles for the collection of reliable and comparable data that have been presented in this chapter also apply to data from SCADA systems. As said before, there is a tendency to trust the shown values, especially from automatic systems, blindly. However, SCADA systems are highly complex and there are many interdependencies between the used equipment. Several factors can lead to incorrect data, including

- Sensor failure
- Unreliable communication paths between the system components
- Intermittent power supply
- Incorrect configuration
- External manipulation

Data gaps or inaccurate readings are almost a certainty when these failures occur. Graphs become choppy or unreadable and false alarm notifications, both positives, and negatives, are likely.

To minimize the risk of sensor failure, sensors and other equipment of the SCADA system must be checked, calibrated, and maintained regularly. As for configuration, typically the basic configurations are made by the manufacturer of the system during installations as most SCADA systems are difficult to configure. Smaller adjustments such as the unit used for values can be made by the operating personnel and might lead to incorrect values and confusion. The risk of external manipulation through system security breaches must be met by regular, in-depth training programs for employees.

Not all SCADA systems are equipped with automatic normalization software. Just as with manually gathered data, it must be ensured that data is comparable throughout time and different environmental conditions which can only be achieved through normalization.

Lastly, critically review data as underlying and undetected mistakes in configuration or wiring can lead to wrongful data. Check values for plausibility as stated above in this chapter.

Take Away Messages – Acquisition of reliable data

- Close monitoring is indispensable to operate SWRO plants in an efficient and informed way.
- Only maintained and calibrated measurement instruments can provide reliable data. Perform calibrations in intervals recommended by manufacturer and document results.
- Data must be comparable over longer time periods. Always document data in a systematic way. Use the standardized units and normalize data if necessary.
- Do not blindly trust readings and monitoring systems! Check values for plausibility.

4.3 Record-keeping and control strategies

Monitoring and controlling a system does not only consist of observing the current plant status. It also involves keeping records from previous status parameters. Record keeping is an additional step in the work process and it might be tempting to neglect it. However, the importance of record-keeping is immense to keep the plant reliably in continuous operation. Reasons for record-keeping are shown in Figure 4-6.

Figure 4-6: Reasons for record-keeping

Good records provide the basis for educated decision-making. The performance of the plant can be monitored closely and changes in parameters can be detected early. With records throughout a plant's lifetime, experience and knowledge on occurring issues grow. Systems, as well as maintenance schedules, can then be optimized. When critical changes in plant parameters are spotted, maintenance can be performed before equipment fails. Thus, damage to equipment and resulting downtime can be prevented, which keeps water production efficient and cost-effective. Lastly, records provide transparency, for example concerning maintenance jobs that have or have not been performed or the quality of the produced drinking water, which can help when warranty problems arise.

The plant operators are responsible for monitoring the SWRO plant, while the supervising authority is mainly controlling the quality of the product as well as other aspects of plant operation such as procurement and health and safety concerns. As SWRO plants are typically operated by external O&M companies, this guideline will focus on the necessary strategies for quality control.

As a basis for any plant, a comprehensive system performance reference set must be provided after the commissioning of the plant. This includes amongst others

- All results of performed equipment checks
- Calibration curves of all instruments according to manufacturer recommendations
- A list of all set points and values of all instruments of the initial performance

Refer to Chapter 1.7 for more information on plant documents after plant commissioning and during the plant's lifetime.

4.3.1 Control strategies for supervising SWRO plants

When supervising SWRO plants that are operated and maintained by an external contractor, the focus of monitoring and control strategies lies in product quality, the product water capacity and the water production cost. Most importantly, an overview of the amount and quality of the produced drinking water must be provided by the contractor to check whether contractual specifications have been met. The exact intervals and contents of said reports must be specified in the contract.

Standardized forms and communication channels should be established to ensure smooth and efficient communication between the employer and contractor. It should be made clear who is responsible for which part of the reporting process. The contractor is obliged to provide any information stated in the contract truthfully and to the best of his knowledge and abilities. Nevertheless, the employer must check on the state of the plant from time to time and perform independent inspections and audits. Additionally, the employer should also draw samples and have them analysed at either an owned or an independent external laboratory. If the contractor does not comply with his reporting responsibilities, the employer must check on him promptly. Penalties for insufficient reporting might be included in the contract. Again, refer to Chapter 1 for more detailed information regarding monthly operating report content.

SWRO plants are usually equipped with advanced SCADA systems. For full transparency, (reading) access for the employer might be contractually included. This also provides a possibility to train new personnel when the plant is handed over at the end of the contract.

It lies in the responsibility of the contractor to ensure stable and economically profitable water production. The contractor is responsible for the safe operation of the plant. The contract should include HSE requirements that the contractor has to comply with to meet the employer’s standards regarding HSE. See Chapter 6 for more information on health and safety standards.

As the O&M contracts do not include the whole expected lifetime of the plant, it must be ensured that the plant is maintained properly with the entire lifetime in mind and not just shorter intervals. Neglected maintenance can be cheaper for the operator in the short run and become a major issue for the future plant owner in the long run as previous experiences have shown. Refer to Chapter 5 for more information on maintenance for a reliable and sustainable plant operation.

5. Maintenance and repair

Figure 5-1 shows the chapter structure of these guidelines. Chapter 5 will elaborate on maintenance strategies and different aspects of maintenance at SWRO plants.

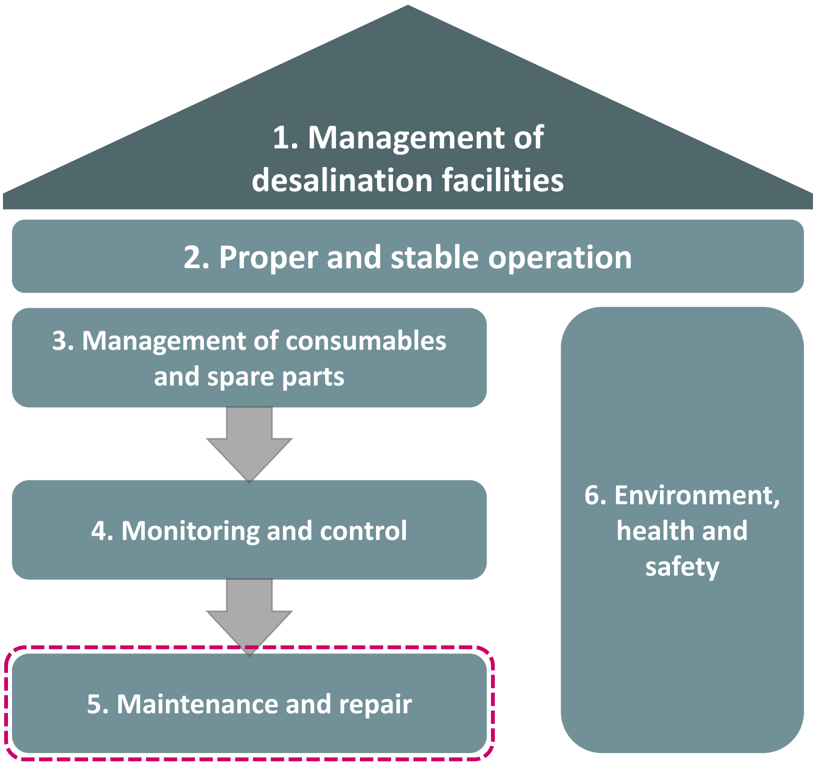


Figure 5-1: Chapter structure of SWRO Management Guidelines

This chapter aims to provide insight on different maintenance strategies to enable the plant operator to choose a maintenance strategy that protects the plant's capital value and ensures reliable and sustainable operation.

In general terms, the contractor is required to operate the desalination plant in strict conformity with the manufacturer's operating and maintenance procedures. These may be supplemented with special procedures dictated either by local ambient conditions or the operator's specialized experience. The operation and maintenance contract may include financial penalties for below-standard performance. This ensures that throughout the lifetime of the plant, the optimum performance of the equipment, as well as maximum availability of the plant, will be achieved and that at the end of the contract term, the plant and all equipment will be returned to the owner in fully maintained and functional condition.

The outline of this chapter is shown in Figure 5-2. Chapter 5.1 will present the three most common maintenance strategies and make recommendations for SWRO plants. In Chapter 5.2, the cycle of maintenance from scheduling to documentation is explained. Subchapter 5.2.4 will give an overview of the necessary documentation for maintenance works. Subchapter 5.2.5 will talk briefly about troubleshooting and adjustment of operational parameters at SWRO plants. Chapter 5.3 will emphasize hazards that can occur during maintenance work.

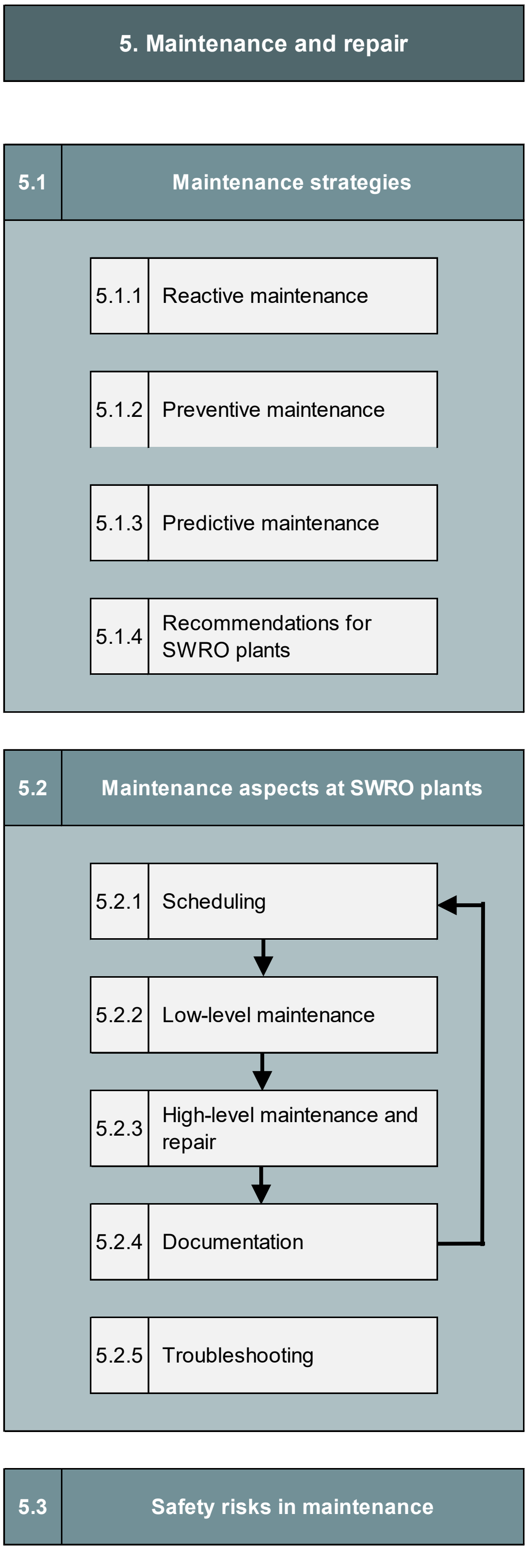


Figure 5-2: Structure of Chapter 5: Maintenance and repair

5.1 Maintenance strategies

Over time, any SWRO plant's condition is impaired by degradation processes. To maintain production, the negative changes caused by normal wear and tear as well as stress through overload must be eliminated by countermeasures. Maintenance aims to restore operability to its original level.

In general, maintenance strategies can be divided into two groups: Reactive maintenance, also known as breakdown maintenance or troubleshooting, and proactive strategies, including preventive and predictive maintenance. These common maintenance strategies and some of their characteristics are depicted in Table 5-1.

Table 5-1: Different maintenance strategies

Maintenance strategies		
Reactive maintenance	**Preventive maintenance**	**Predictive maintenance**
• **Run-to-failure maintenance** • **Total service life of equipment is used** • **Sudden and unpredictable failures** • **Possible additional damage to other machinery parts**	• **Maintenance intervals for items based on theoretical rate of failure** • **Prevents unexpected failures and unscheduled downtime** • **Additional workload due to inspections**	• **Prediction of equipment failure based on continuous sensor data monitoring** • **Total service life of equipment is used without sudden failures** • **Need for complex and costly monitoring system**

5.1.1 Reactive maintenance

Reactive maintenance is **based on running equipment until it breaks** and carrying out emergency repairs to restore the equipment to operation. At first glance, this strategy seems to be the most cost-efficient one, as repairs are only performed when necessary, and the total service life of the equipment is used up.

However, this strategy has several disadvantages. Firstly, failures occur suddenly and unpredictably, resulting in unscheduled downtime. To then be able to repair the equipment promptly, all spare parts for vital equipment have to be kept in stock. Otherwise, critical spares would have to be ordered individually and on short notice, which prevents cost reduction through bulk orders and price comparison.

Secondly, an unscheduled emergency job often takes 3-9 times longer than a planned one[23]. Because of time pressure and reduced planning, more mistakes during the maintenance job might be made and even safety hazards might arise.

Thirdly, a failure in upstream equipment can cause additional damage to other machinery parts. That way, a minor defect can result in increased repair costs. Added to the loss of income during an unscheduled downtime and the increased expenses for spare part storage or ordering, reactive maintenance becomes the most expensive strategy throughout industries.

Additionally, environmental hazards might arise, for example, if equipment failure leads to the uncontrolled discharge of chemicals or chemically treated or otherwise polluted fluids.

Nevertheless, reactive maintenance can be a viable strategy for some plant equipment. Examples would include non-critical machinery as well as short-life or disposable equipment with enough spares in stock. Still, reactive maintenance should always be used combined with proactive measures and never as the default maintenance strategy.

5.1.2 Preventive maintenance

Preventive maintenance, also preventative maintenance, is a proactive strategy. It aims to keep the plant in peak shape throughout the plant's lifetime. It is based on **carrying out inspections and maintenance jobs in defined, constant intervals.** The intervals are provided by the manufacturers and are derived from probability statistics regarding estimated failures. These intervals can either be time-based or usage-based (running hours of equipment).

Some unwanted issues that can be prevented by preventive maintenance are shown in Figure 5-3.

[23] https://www.reliableplant.com/Read/32032/how-to-reduce-maintenance-costs-right-way

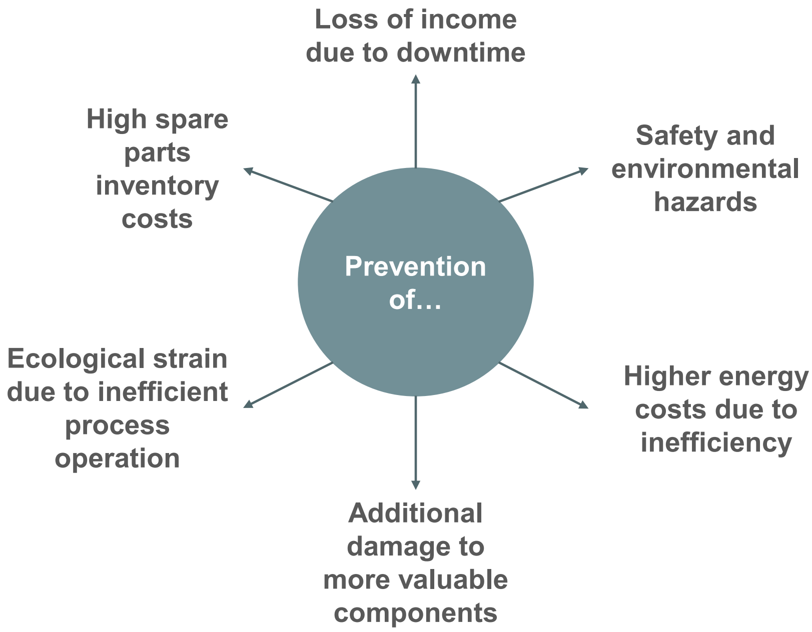


Figure 5-3: Advantages of preventive maintenance

Some disadvantages of reactive maintenance compared to preventive maintenance have already been stated above, for example, possibly occurring safety and environmental hazards, high costs for spare parts, and possible damage to downstream equipment. Additionally, preventive maintenance also reduces energy costs and thereby environmental strain, as well-functioning equipment uses less energy than inefficient equipment.

Another advantage of preventive maintenance is the possibility to combine maintenance cycles of different equipment to reduce downtime further. That way, for example, annual or semi-annual inspections and maintenance operations can all be done in a few weeks and thereby require fewer shutdowns. The scheduling of maintenance operations would be especially profitable for Jordan, as the shutdown of the SWRO plant could be scheduled for the winter season when less water is needed than during summer.

While preventive maintenance has many advantages and ensures high reliability, it can be cost-intensive because of labor costs and expenses for spare parts. As the inspection and maintenance intervals are based on general statistics from the manufacturers, they might not be ideal for each individual SWRO plant as feedwater quality and environmental influences differ from location to location. The wear reserve of equipment might not be fully exploited in case of a too-short cycle, while in other cases, too many faults are permitted to occur due to a too-long cycle.

5.1.3 Predictive maintenance

Predictive maintenance attempts to schedule maintenance **based on the condition of the actual equipment** rather than on statistics. The current condition of the plant is determined by performing tests, inspections, periodic offline diagnostic measurements, or online diagnosis via continuous sensor data. As failures seldom happen instantaneously, changes and trends in the data can indicate imminent failures. Predictive maintenance aims to provide high plant reliability while exploiting the wear reserve of equipment.

Predictive maintenance aims to combine the advantages of both reactive and preventive maintenance. However, purposeful and reliable test and diagnosis methods are not necessarily available or applicable, depending on the layout of the plant. Installing and managing sensors and software is a major investment and adds workload, especially during the implementation. Predictive maintenance takes operational data provided by flow meters or pressure gauges, which normally are already installed at a SWRO plant, into account. But often, additional sensors like accelerometers to measure vibration, which can result from an upcoming bearing failure, or corrosion monitoring systems might have to be installed.

Predictive maintenance can never be performed without both properly knowing the current condition as well as having monitored the long-term development of equipment performance.

5.1.4 Recommendations for SWRO plants

It is generally of the highest priority to preserve the capital value of the SWRO plant and ensure reliable operation. As typical SWRO plants are designed to provide from 100,000 to over 1,000,000 m^3 of fresh water per day, it is nearly impossible to substitute this amount of water ad hoc from other desalination plants or freshwater sources. **An unplanned, prolonged breakdown can therefore lead to serious water shortage and must be avoided at all times.**

While maintenance work is a cost factor, whichever strategy is chosen, neglecting maintenance almost definitely becomes even more expensive. **Therefore, a valid maintenance job cannot be avoided.** Delaying it will only increase the cost and lead to a plant in quite a bad shape. Performing the maintenance job according to the schedule will cost a calculated amount of money, but performing it later can only increase and never decrease the costs.

Maintenance cost is an important factor in assessing plant performance. But depending on contract, company, or laws, different aspects may or may not be included in maintenance cost, for example, lubrication or consumables. No two plants are completely alike regarding equipment, age, past maintenance performed, or raw water quality. Comparisons between plants based solely on absolute maintenance costs are therefore incomplete. It is, however, important to monitor the development of maintenance costs over the plant's lifetime.

When trying to cut maintenance costs, it should not be done by focusing on the maintenance cost itself. The total cost per m^3 of produced water is the far more informative and relevant number. Cutting maintenance costs by simply deferring or canceling maintenance jobs never works in the long run. Understanding and implementing the correct work processes for good maintenance will generate improved plant reliability and thereby lower total costs per m^3 of produced fresh water.

As the contracts for operating and maintaining an SWRO plant often are limited to a certain period, contractors might tend to cut expenses for maintenance jobs as they might not be interested in the plant's condition after their contract. Neglecting maintenance might work for a while (around 12–18 months), but after that time, the expenses for maintenance work will rise again due to the worse overall state of the plant[24]. The commitment to perform maintenance jobs should be included in any contract to ensure a sustainable operation of the SWRO plant throughout its designed lifetime, which can be assumed to be around 25 years. The implementation of maintenance work has to be controlled by the operating contractor and the contractor has to document any jobs performed to ensure transparency in accounting. **At the end of the contract term, the plant must be handed over to the employer in impeccable condition, allowing for normal wear and tear and the expected deterioration of the facility due to age.**

The different maintenance strategies and their characteristics have been described in the previous chapters. A summary of which strategy can be applied for which equipment is given in Table 5-2.

Table 5-2: Combination of maintenance strategies

Strategy	Summary	Cost to implement	Equipment
Reactive	Fix equipment when it breaks	Low	• Low-priority equipment • Disposable items with enough spares in stock • Never for critical or safety-relevant equipment
Preventive	Maintenance on a predetermined schedule provided by manufacturers	Average	• The best strategy to implement without expertise
Predictive	Monitoring of plant condition triggers work orders	High	• For the largest and costliest equipment

Generally, when it comes to choosing the right maintenance strategy for a plant, factors like the size and layout of a plant have to be taken into account. Whilst predictive maintenance might be too costly and elaborate for smaller plants, it can lead to an even more efficient operation of a large SWRO plant. But for all proactive strategies, **record-keeping** is essential.

With preventive maintenance, there is a risk of “overdoing” maintenance. When a maintenance job has been performed, its documentation must include the date the maintenance was carried out (see Chapter 5.2.4). This holds true both for scheduled maintenance as well as emergency changes. Otherwise, a maintenance job might be performed more often than scheduled.

[24] https://www.reliableplant.com/Read/32032/how-to-reduce-maintenance-costs-right-way

Emergency repairs, when done properly, can (but do not have to) be used to initiate a new maintenance cycle (see Figure 5-4). This saves a shutdown but might disturb the regularity of the cycle and cause the annual shutdown to shift into a different season.

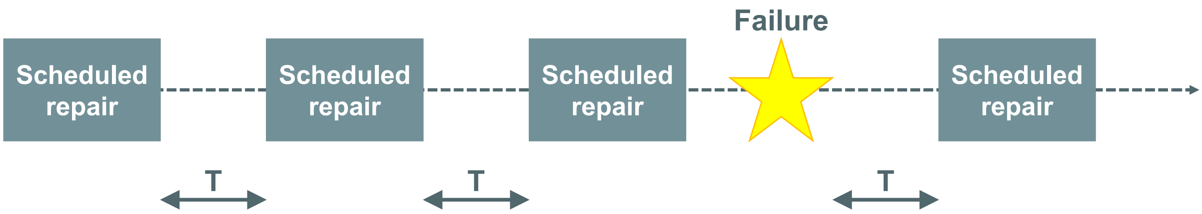


Figure 5-4: Cycle of preventive maintenance[25]. T is the designed interval between scheduled repairs.

Keeping records of maintenance works is especially important to learn from previous experience. Comments may help to improve workflows and can be used to document any unusual findings or problems which might be prevented in future maintenance.

The intervals between schedules can be adjusted after careful assessment. As said before, the manufacturers' recommendations might not fit perfectly for each SWRO plant as they are based on probability statistics, which are thorough but cannot take plant specifications into account. Due to the close proximity of the plant to the sea and saline aerosols being present in the air, some maintenance jobs, such as oil changes or refurbishing layers of protective paint, might have to be performed more often than suggested. On the other hand, if it becomes clear after a longer period of thorough maintenance that an item is found in good shape during every inspection, the specific stress for the item at a plant might be lower than presumed in the manufacturers' calculations. However, major changes should only be done with the utmost care and after consultation with the manufacturer.

Take Away Messages – Maintenance strategies

- Reactive maintenance, or troubleshooting, is not advisable as the sole maintenance strategy as it increases the risk of elevated costs and accidents and fails to keep the plant in perfectly working condition.
- Preventive maintenance is a good strategy to combine different maintenance tasks and perform them together to avoid more frequent shutdowns.
- Predictive maintenance is an ideal strategy for most valuable equipment.
- Different maintenance strategies should be combined for different parts of equipment, based on their importance to continuous safe operation.
- Record keeping is essential to assess the plant's condition, to be able to learn from previous experiences and to make adjustments to the maintenance schedule.

[25] After F. Sturm (2003). Efficient Operations – Intelligent Diagnosis and Maintenance of Plants

5.2 Maintenance aspects at SWRO plants

In this chapter, the different parts of maintenance work that have to be performed at SWRO plants will be discussed. The subchapters each refer to one aspect, starting with the scheduling of maintenance tasks to low- and high-level maintenance and the correct documentation. These four aspects can be seen as a cycle of maintenance. The last subchapter will give some insight on troubleshooting and adjustment of operational parameters in certain situations.

5.2.1 Scheduling

As discussed in Chapter 5.1.4, a maintenance strategy solely based on reactive maintenance is not recommended if reliable plant operation is desired. The first step in proactive maintenance is scheduling. Usually, the maintenance schedule for larger plants is already created during the planning phase by the plant's manufacturer and handed over to the plant operator. Still, the basic process on how to create a maintenance schedule is shown in Figure 5-5 and described in this chapter.

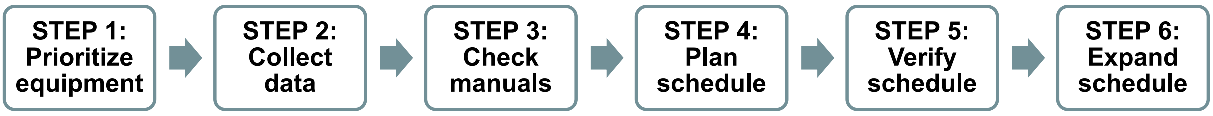


Figure 5-5: Steps in creating a maintenance schedule

If there is no proactive maintenance schedule yet, STEP 1 is to prioritize the equipment. This allows for a step-by-step implementation of a new maintenance schedule. The equipment is ranked with regards to the following aspects:

- Vital to operation
- High repair and replacement costs if they fail unexpectedly
- Failures in this equipment occur mostly through wear and tear and not randomly
- Availability and delivery time for spare parts
- Age of equipment (after the first four aspects have been ranked, new equipment should be maintained with a higher priority than older equipment to ensure better protection of capital value).
- ….

STEP 2 is to collect historical data about all the work and unplanned downtime that each piece of equipment went through in the past few years.

STEP 3 is to check the manuals of the equipment on which maintenance is necessary and at what intervals.

In STEP 4, the initial maintenance schedule can be put together. When the initial plan is ready, the implementation can start.

After that in STEP 5, adjustments to the initial schedule might have to be made based on experiences with the schedule. If an item has experienced breakdowns between maintenance intervals, the source of this problem must be localized. If the breakdowns result from unavoidable wear and tear, the intervals between maintenance works should be shortened. On the other hand, maintenance might also be scheduled too often (see Chapter 5.1.2).

The last step (STEP 6) is to expand the maintenance schedule to items that have not yet been included.

To create this schedule and document maintenance work, the use of maintenance software is advisable. In Computerized Maintenance Management Systems (CMMS) or Enterprise Asset Management (EAM) software, the aspects regarding maintenance and inventories are combined:

- Schedules for maintenance and inspection
- Manuals, checklists, contracts, and guarantees of equipment
- Inventory of spare parts, tools, and consumables
- Documentation of maintenance works
- Statistical analysis of previous maintenance works and reports to improve the maintenance system continuously

In the appendix of this guideline, a list of minimum requirements regarding a preventive maintenance schedule is included (see Table 7-6). It can be used as an overview or if manuals or recommendations from manufacturers are not available. Keep in mind that not all items of this list might be installed at each respective SWRO plant depending on the exact layout of the pre- and post-treatment section. As these are only general and minimum requirements, always maintain equipment according to manufacturers' instructions firstly.

Electrical equipment is not included in this schedule but should also be inspected ever so often to ensure safe functionality. In addition to the visual checks performed by the user before every use, an inspection by a trained electrician is recommended. The intervals must be adjusted to the conditions the electrical equipment is used. As the conditions at a SWRO plant are typically quite harsh in some areas, more frequent checks might be in order. In some countries, laws regulate the maintenance intervals of electrical equipment. Additional information can be found, for example, at websites for occupational health and safety administration[26] or insurance companies[27]

[26] https://www.hse.gov.uk/electricity/faq.htm#q7
[27] munichre.com or other

5.2.2 Low-level maintenance

Low-level maintenance describes all smaller aspects of maintenance, which might have to be performed daily and do not include larger replacements. They are performed both scheduled and when necessary (reactive). An overview is given in Figure 5-6.

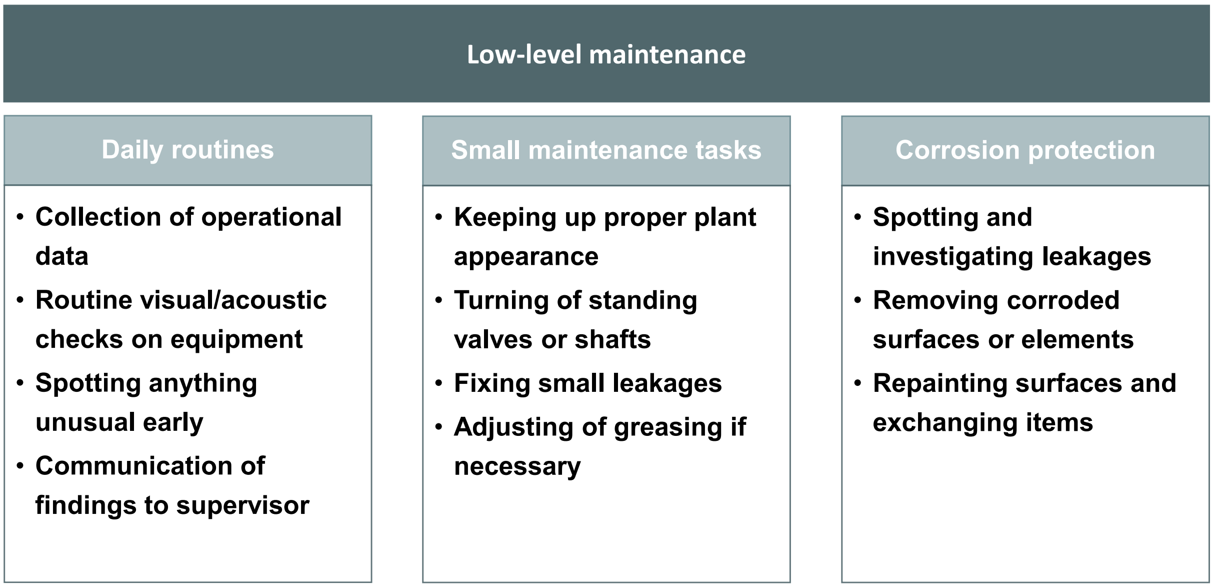


Figure 5-6: Aspects of low-level maintenance

Daily routines include collecting the operational data needed for plant monitoring. This step might be required once per shift or daily. More information regarding important parameters can be found in Chapter 4.

Visual and/or acoustic checks might be required for some equipment and can be included in the maintenance schedule. But it has proven helpful for the whole plant equipment to perform routine inspection tours through the facility to spot anything unusual as early as possible. Simple human senses can pick up oddities before a measurement instrument might show a significant change. Any findings should be communicated, for example, via documenting them in the daily operational datasheet and remedied shortly.

Small maintenance tasks should be performed when necessary and not only according to a strict schedule. This aspect is sometimes also referred to as good housekeeping and includes, among others, the following works:

- Opening and turning standing valves to avoid blocking
- Turning shafts of standby pumps to avoid flat areas developing on bearings and deformation of the shaft
- Fixing smaller leakages by adjusting or replacing seals on valves or pumps
- Greasing bearings if necessary
- Removing clutter or spills, keeping working areas neat and orderly, and keeping the floors free from trip or slip hazards.

That way, a proper plant appearance can be kept up more easily, which leads to better control of tools and machinery, easier inventory, and better workflows because less time is spent on searching and cleaning before work. Also, more serious damage to equipment or trouble during a larger maintenance operation, caused, for example, by blocking valves that prevent isolation of equipment, might be avoided. These small maintenance tasks, especially the last, should be performed throughout work and by all workers.

Another important aspect of low-level maintenance includes corrosion protection. Corrosion can occur inside the system in pipes and pumps or on the surface of equipment or the floor.

As to **interior corrosion**, the right choice of material is highly important. Since the material is already specified in the planning period, interior corrosion is only partly discussed in this guideline. It is important to keep the aspect of material compatibility in mind when exchanging parts or to perform maintenance.

- Stick to the predefined materials by using the recommended spare parts.
- Take the exact specifics of alloys into account as corrosion resistance varies strongly between alloys.
- Preserve the protective surface of alloyed or galvanized steel. Avoid scratches.
- When welding pipes, use the appropriate Welding Procedure Specifications (WPS) and Procedure Qualification Record (PQR) for the type of weld and piping material. Use backing gas and avoid gaps in the welding seam where water could enter.

Stagnant brackish water increases the risk of corrosion inside of the RO system. When a shutdown is unavoidable, make sure to properly flush the system with clean water. If a plant is taken out of service, flush the system with clean water and use air to dry it, according to the manufacturer. Use drainage points to empty pipes or tanks.

If a cathodic protection system is installed, make sure it is running properly at all times and keep it maintained.

The corrosivity of the water inside the pipes is influenced by the concentration of dissolved salts and the pH value. The Langelier-Saturation-Index (LSI) is used to evaluate the corrosivity as well as the scaling potential. Refer to Chapter 4 for a detailed explanation of the LSI. Make sure the LSI is in the designed range and that the pre-and post-treatment sections are working properly to avoid elevated corrosivity.

Preventing **surface corrosion** is much easier than protecting the insides of the system. The development of corrosion damage is depicted in a simplified way in Figure 5-7.

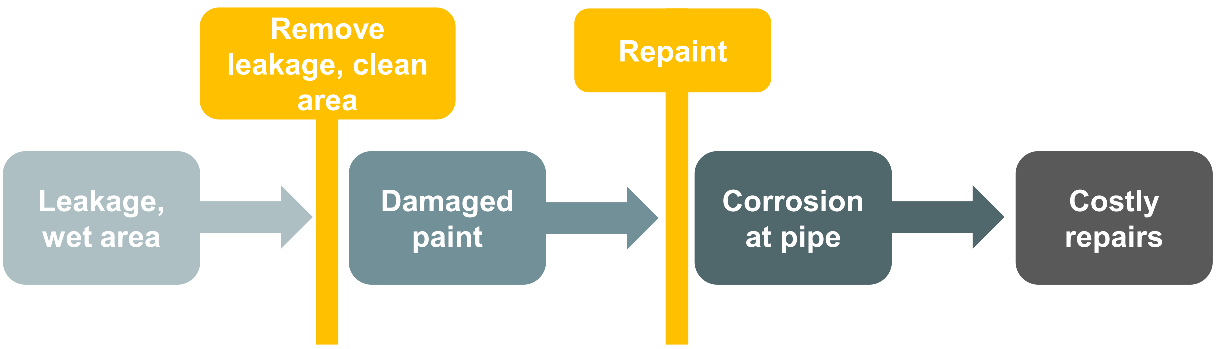


Figure 5-7: Development of corrosion damage

Protecting any surfaces in a SWRO plant from corrosion mainly focuses on keeping the protective paint coating intact. A small leakage can, if not remedied, lead to a constantly wet area which increases the risk of damage in the protective paint layer. Corrosion at a pipe or housing and probably costly repairs are the natural consequences. This development can be stopped by removing the leakage, drying up the area, and, if necessary, refreshing the paint layer. This includes cleaning and preparing the surface, applying a rust inhibitor, and a corrosion-protective coat of primer and finishing coat.

Drains in areas where larger amounts of water are spilled regularly must be installed and working. Make sure to keep drains free. If it becomes clear that in a certain area, a drain is missing, try to reinstall one if the spilled fluids are harmless and do not have to be discharged separately.

Chemical dosing areas, especially when dosing acids or bases, are affected by corrosion even more. Always clean up any spills on the floor or housing of pumps etc., immediately. It is advisable to cover concrete floors with corrosion-protective paint. The installation of protective curtains around the acid dosing area might be an option.

5.2.3 High-level maintenance and replacement

High-level maintenance in this guideline refers both to actual repair and exchange of parts as well as in-depth inspections of equipment. The specific instructions on how to change parts or perform inspections must be taken from the manual of the item. There is, however, a general procedure to safely carry out maintenance work, shown in Figure 5-8.

In case of unscheduled emergency maintenance, this basic procedure should also be followed as far as possible. The implementation of a schedule that ensures the availability of a maintenance team around the clock can be considered.

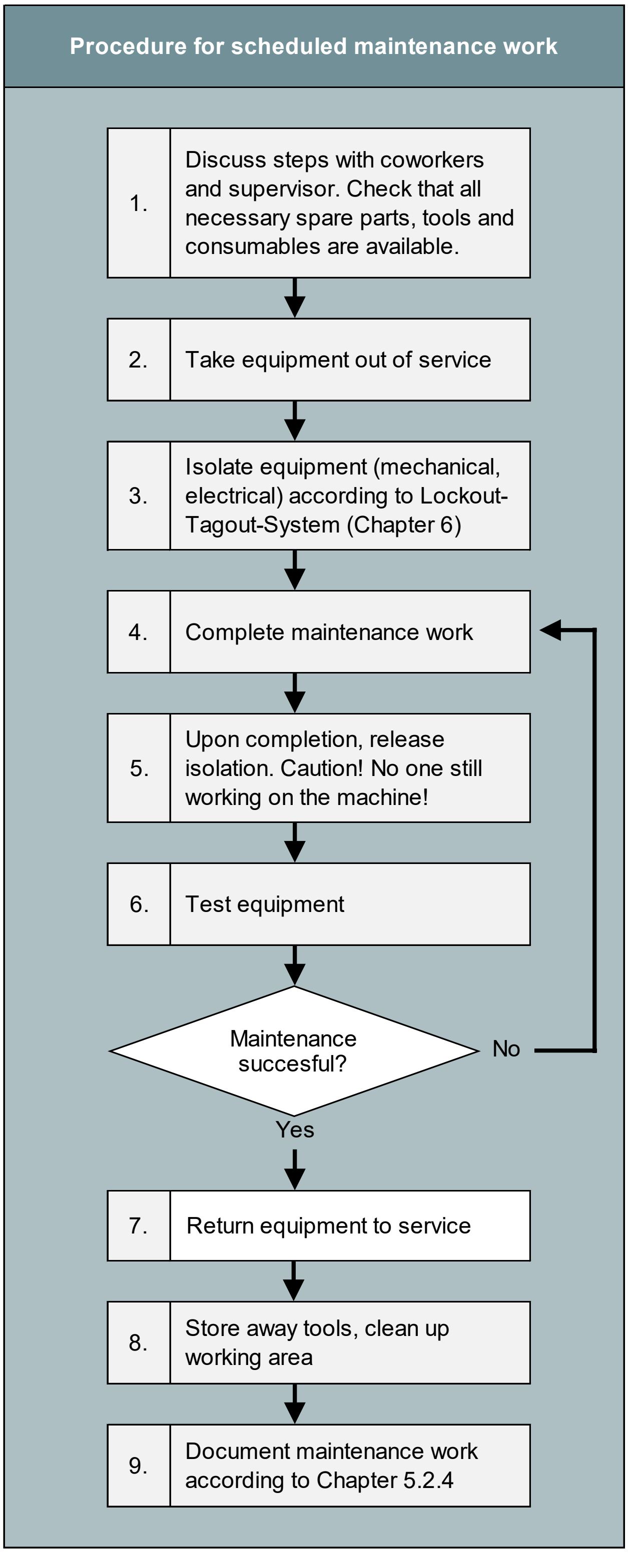


Figure 5-8: General steps for maintenance work

Before starting the maintenance work, it has to be discussed with and cleared by the supervisor and, in case of hazards, the Safety Officer and engineers concerned (see Chapter 6). Coworkers should then be informed about the different steps that will be performed. All necessary tools, spare parts, and consumables must be available and can be laid ready at the site if practicable (Step 1).

The equipment then will be taken out of service and isolated by locking valves, earthing the unit, hanging signs at the switch cabinet, or whichever steps are necessary to render the equipment safe for maintenance work (Step 2,3). Refer to Chapter 6 for additional information regarding Lockout-Tagout-System and safety procedures for maintenance in hazardous environments.

Upon completion of the maintenance work, the isolation must be released to test the equipment (Step 5). **Good communication is highly important in this step.** Make sure no one is still working at the machine and might be endangered by the start-up of the equipment.

After returning the equipment to service, all tools and exchanged spare parts must be stored away, and the maintenance work must be documented according to Chapter 5.2.4 (Step 8,9).

For critical tasks, the creation of step-by-step **Standard Work Instructions (SWI, also Standard Operating Procedures)** can be helpful. Working from manuals can sometimes be tricky if the manual is written in a language that is not fully understood by every employee or if the different steps are not laid out very clearly. If instructions are forwarded to other employees only orally, the procedure will differ from instructor to instructor. If there are questions that arise each time the task is performed or if plant-specific adjustments to the procedure described in the manual have been made, they can be taken into account in the SWIs.

Implementation of a standardized procedure brings consistency into maintenance tasks and ensures that no steps are being forgotten. Standard Work Instructions do not replace initial training but can reinforce what had been learned and might remind personnel of recent changes in the procedure. They can be seen as an addition to the Standardized Safety Instructions presented in Chapter 6.

SWIs work best if they are

- Simple and as short as possible
- Visual and include, for example, photos or graphics
- Consistent in layout and style throughout the plant
- Easily accessible, both in print and digital version

SWIs are more likely to be used by employees if they fulfill their needs. It is advisable to have the most experienced workers check the SWIs and provide their feedback. SWIs can be used both for maintenance tasks as well as for more frequent jobs that require precise action, for example, mixing of chemicals.

5.2.4 Documentation

After any maintenance work is conducted, it has to be documented. The documentation can ensure that maintenance jobs are neither forgotten nor repeated needlessly. When equipment has failed, and reactive maintenance has had to be performed, noting the date, the state of equipment, and the possible cause of failure can help detect underlying issues. In many operation and maintenance contracts, the contractor is required to provide the employer with records of planned and performed maintenance tasks for cost transparency. Refer to Chapter

1.3.4 for more information regarding formal reporting mechanisms. Lastly, some manufacturers will only accept warranty claims if maintenance has been performed in the way they recommend it. Good documentation can help to ward off warranty claim problems.

An overview of relevant documents regarding maintenance is given in Figure 5-9.

Maintenance and equipment documentation				
Currently installed equipment	**Spare parts inventory**	**Operation and maintenance manuals**	**Preventive maintenance schedule**	**Maintenance records**
• Manufacturer • Model and serial number • Capacity • Warranty information/ dates • Local representative	• Including inventory of special tools needed • Information on where to buy spare parts	• Revise manuals/ drawings if new equipment has been installed • If applicable: update Standard Work Instructions (SWIs)	• Based on manufacturer's manuals	• All works carried out (replacements, membrane cleaning, …) • Due date and actual date of maintenance • Persons performing work • Comments • …

Figure 5-9: Documentation for maintenance works and equipment

Firstly, each plant needs a reliable list of currently installed equipment. This must include the manufacturer, model number, serial number, capacity, and local representative. If this list is not existing at a plant, a review should be conducted to create it. If new equipment was installed during maintenance, the list must be updated.

Keeping an up-to-date spare parts inventory helps streamline spare part management and to detect missing spare parts for future maintenance work. If special tools are needed for new equipment, those can be included in the inventory as well. The spare parts inventory can also contain helpful information on where to buy spare parts. Refer to Chapters 1.7 and 3 for more information regarding spare parts management and inventory software.

The operation and maintenance manuals for all equipment currently used in the SWRO plant must be available at each plant. Revise manuals if new equipment has been installed. Revise the As-built drawings if changes to the overall layout and structure have been made. If standard work instructions, SWIs, are used and affected by changes, they should also be updated. The changes to the SWIs should also include any possible future improvements regarding the procedures that were discovered during the maintenance work.

The preventive maintenance schedule has already been explained in the previous chapters. Lastly, the actual maintenance record for each job has to be written. The record should contain the following information:

- Due date of maintenance work and date it was actually performed
- All works performed and which particular parts or materials were repaired or replaced

- All people employed in the work
- The time required to complete the work
- Running hours of equipment
- Any comments relating to the performance and condition of the equipment

Especially the last point is highly important to learn from previous experiences and to adjust workflows. It helps to gain insight as to how the condition of the equipment develops over a longer period or possible reasons for failure.

5.2.5 Troubleshooting

The implementation of a maintenance schedule including inspections, low-level and preventive high-level repairs aims to minimize the occurrence of machine failure and thereby the necessity of reactive maintenance or troubleshooting. However, some failures are random or seemingly random, as the underlying problem is not yet detected. If reactive maintenance has to be performed, please remember to

- Perform troubleshooting in the same organized way as scheduled maintenance.
- Use quality spare parts and materials.
- Control work systematically. Inaccurate maintenance work can result in high costs and damage to equipment.
- Keep safe working in mind, especially when isolating equipment or returning it to service.

In Chapter 4, the importance of monitoring normalized performance parameters of the system, such as normalized permeate flow, salt passage, and differential pressure, has been discussed. If there is a rapid change in the parameters, this usually indicates damaged equipment, either in the RO trains or in the pre-treatment unit, or mishandling. A slow rise or decline in parameters indicates normal fouling or scaling processes.

Figure 5-10 shows a troubleshooting matrix that shows trends in normalized performance as well as direct and underlying causes. It also states corrective measures and adjustments in operational parameters that can be made.

Adjustment of operational parameters							
Case	Norm. Permeate Flow	Norm. Salt Passage	Norm. Differential Pressure	Location	Direct cause	Underlying cause	Corrective measure
1	+	++	0	1st Stage	Oxidation damage	Free chlorine, ozone, $KMnO_4$	Replacement element
2	+	++	0	All Stages	Membrane leak	Permeat backpressure, abrasion	Replace element, improve cartridge filtration
3	+	++	0	Random	O-ring leak	Improper installation	Replace O-ring
4	--	+	+	Last Stage	Scaling	Insufficient scale control	Cleaning, adjust scale control
5	-	0	++	All Stages	Biofouling	Contaminated raw water, insufficient pretreatment	Cleaning, disinfection, improve pretreatment
6	--	0	0	All Stages	Organic fouling	Oil; cationic polyelectrolytes water hammer	Cleaning, improve pretreatment
7	--	+	+	1st Stage	Colloidal fouling	Insufficient pretreatment	Cleaning, improve pretreatment
8	--	--	0	All Stages	Compaction	Water hammer	Replace element or add elements

Symbols:

+	increase
++	greatly increase
0	no change
-	decrease
--	greatly decrease

Figure 5-10: Changes in normalized performance, causes, and corrective measures[28]

[28] After J. Kucera (2010). Reverse Osmosis: Design, Processes, and Application for Engineers and DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7

As each part of the machinery can fail in different ways, detailed instructions on how to perform further investigative tests to find reasons for failure will not be part of this guideline. Check

- N. Voutchkov: Desalination Engineering: Operation and Maintenance (book, 2014),
- J. Kucera: Reverse Osmosis: Design, Processes, and Application for Engineers (book, 2010)
- DuPont: FilmTec™ Reverse Osmosis Membranes Technical Manual (manual, 2021, version 7)

for more information.

Take Away Messages – Maintenance at SWRO plants

- Small, low-level maintenance helps a lot to keep the plant in proper appearance and can prevent damage to equipment or structures.
- Standard Working Instructions can be created for critical maintenance or everyday tasks to ensure consistency in work.
- Writing and revisiting maintenance records is essential to improve maintenance work flows, detect underlying issues and ward off warranty claim problems with manufacturers.

5.3 Safety risks in maintenance

In the previous chapters, the risks resulting from lack of maintenance have been discussed. This chapter will focus on the hazards resulting from maintenance work itself. Maintenance is usually a higher-risk period than normal operation, for several reasons. Some hazards in maintenance works are shown in Figure 5-11.

Figure 5-11: Hazards in maintenance works

Maintenance often involves non-routine tasks and might have to be performed in exceptional and hazardous conditions, for example, at height or in confined spaces. For larger maintenance tasks, groups of plant workers and external specialists, who might not be familiar with plant specifics, might have to work together without misunderstandings. During maintenance work, the automation systems and safeguards which prevent direct contact between workers and machinery might be disabled. Other hazards arise from electrical power sources and tools.

Reactive maintenance, or troubleshooting, is even more hazardous than scheduled maintenance. The greatest problem therein lies in time pressure. Using shortcuts in safety and standard procedures might be tempting to allegedly save time. But working in a hurry and without being calm and focused on the work might lead to spare parts being mixed up, wrong parts being used, or parts being forgotten during reassembly. Lack of communication beforehand and during the work might result in misunderstandings leading to accidents.

Another hazard in troubleshooting arises from the sudden asset failure. Repairing faulty equipment without knowing the underlying issue might result in unexpected machinery or fluid movements. Make sure to properly isolate the equipment before starting the maintenance job.

As SWRO plants operate at high pressures of around 30 bar, special attention must be paid to all pressure vessels, pipes, and tanks. Pressure vessels must be labeled to indicate the maximum allowable working pressure and temperature. Pressure vessels should never be filled above the designed level. If maintenance works, especially welding jobs, have to be performed at pressure vessels, it must be ensured that all installed valves and flanges, and welds withhold the applied pressure. Follow the respective testing procedures and only let qualified personnel perform these maintenance jobs.

All pressure systems shall be protected with appropriate pressure-relief devices. The pressure-relief device shall be installed so that the discharge is directed away from the area where a person could be affected. Pressure-relief devices shall be inspected periodically by lab staff. Orifices on both sides of the pressure-relief device should be checked for obstruction. Never install a valve between a safety valve or similar device and the vessel being protected by it.

It is highly recommended to stay focused throughout maintenance jobs and to follow the instructions in the manufacturer's manual. Do not use unsafe shortcuts to save time or money. Always keep safety at the forefront of the mind. Please refer to Chapter 6 for information regarding health and safety in specific workplaces or situations.

Take Away Messages – Safety risks in maintenance

- Maintenance is a high-risk activity because of non-routine tasks and exceptional conditions.
- Communication between plant supervisor, internal employees and external specialists is crucial.
- Troubleshooting is even more hazardous than scheduled maintenance.
- Stay focused and don't operate under time-pressure. Working in a hurry only seems to reduce time but often results in mistakes and accidents.
- Refer to Chapter 6 for more information on Environment, Health and Safety.

6. Environment, health and safety

Figure 6-1 shows the chapter structure of these guidelines. Chapter 6 will discuss the aspects of the health and safety of employees at SWRO plants and environmental risks and responsibilities.

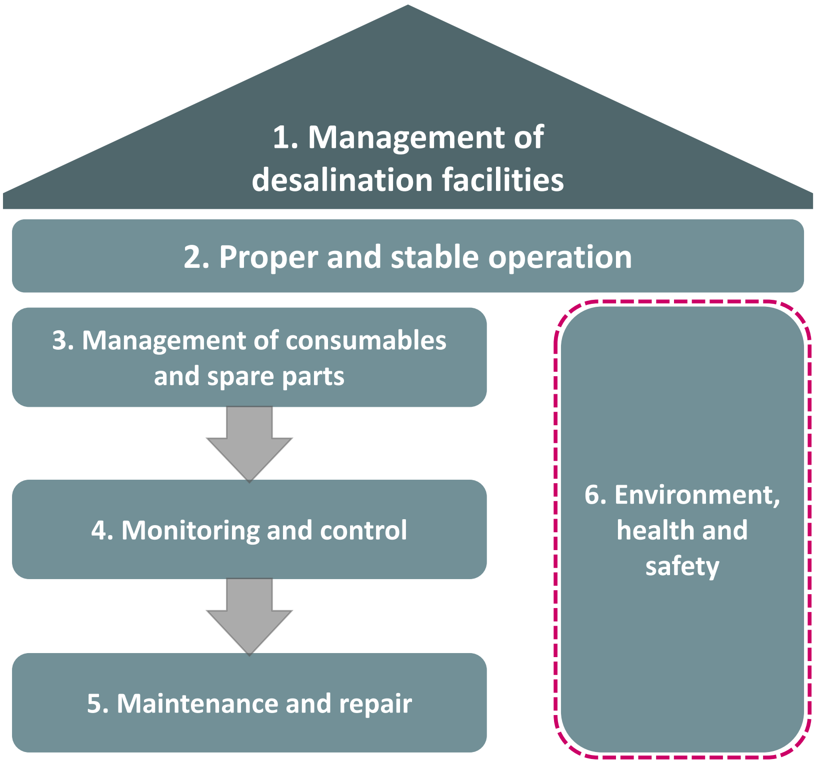


Figure 6-1: Chapter structure of SWRO Management Guidelines

The aim and purpose of this chapter are to emphasize the importance of safety systems to avoid accidents and injuries among workers or visitors at the SWRO plant.

It is recommended to include requirements regarding Environment, health, and safety (EHS) in the tendering for operation and maintenance contracts. That way, the employer can ensure that his contractors meet his own standards regarding EHS. The compliance with these standards should be controlled through documentation and audits, similar to other aspects of quality control. More information regarding reporting can be found in Chapter 1. The information regarding EHS in this chapter can be used as a basis for contractual requirements.

The outline of this chapter is depicted in Figure 6-2. In Chapter 6.1, the superordinate occupational health and safety measures, for example, the installed safety systems as well as standardized procedures for internal and external workers, will be presented. In Chapter 6.2, the individual safety measures for different hazardous tasks and workplaces at SWRO facilities will be explained. Finally, Chapter 6.3 will focus on various aspects of operating a SWRO plant, their influence on the Environment, and everyone's responsibility to act sustainably.

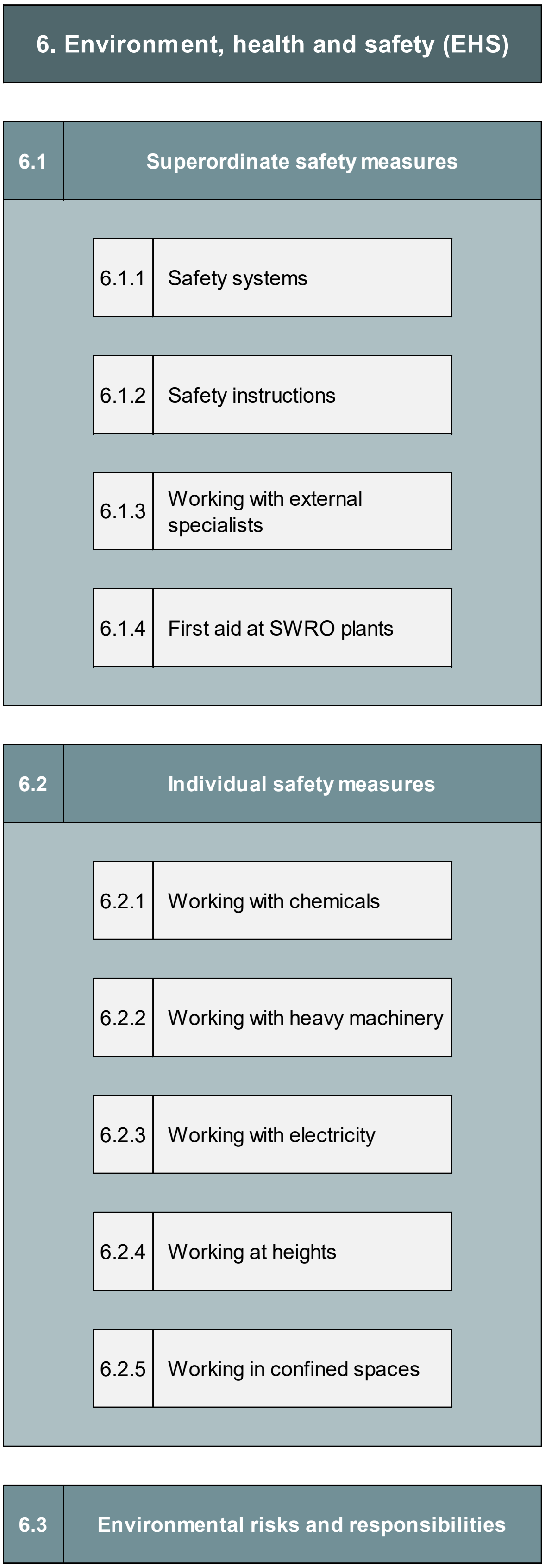


Figure 6-2: Structure of Chapter 6: Environment, health and safety (EHS)

Safety measures can be seen as different levels of a pyramid, depicted in Figure 6-3. All these measures must be applied together to mitigate health and safety risks effectively.

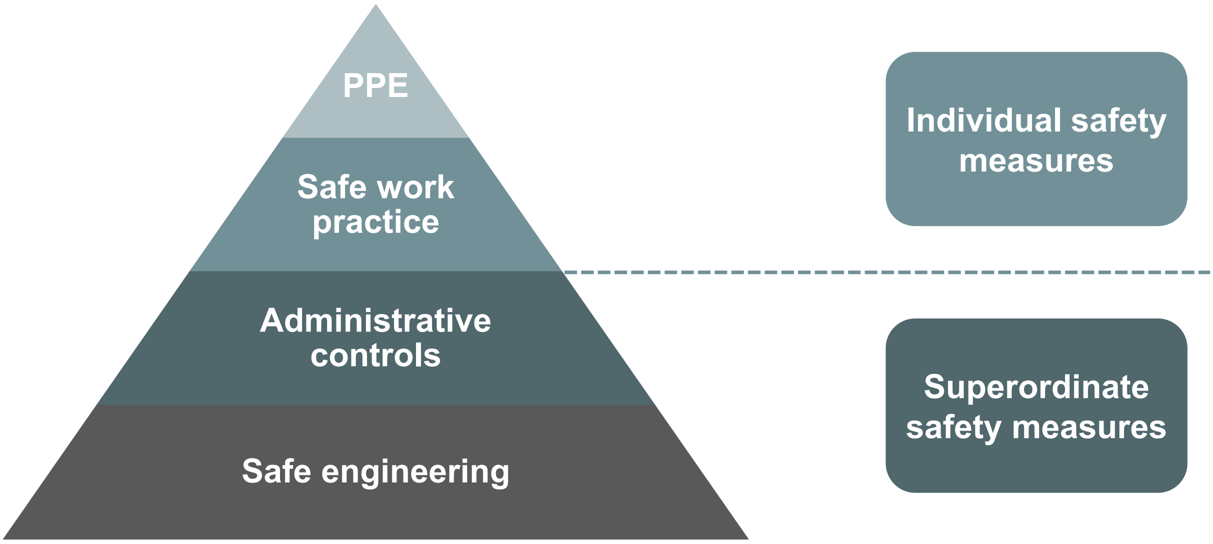


Figure 6-3: Pyramid of safety measures

The basis of safety measures is safe engineering and design. This relates to the design of the whole plant as well as of the individual machines. Safe engineering is an important aspect of the planning process, for example, stationary safety systems and redundant installations have to be included. In this guideline, those safety systems will be presented, but the responsibility for safe design lies with the manufacturers, planners, and contractors and will not be a part of these guidelines.

Administrative controls refer to the management side of safety. They include, among others, safety training, certificates, and the preparation of safety instructions as well as the provision of protective equipment, regular checks on safety installations, and documentation of incidents. Those controls lie in the responsibility of the assigned safety officer and have to be performed according to local or internal company regulations. Refer to Chapter 1 for general information on management structures, EHS management, and training procedures.

Safe work practice affects all employees and refers to the general awareness concerning hazards and compliance with safety measures. Every employee must participate in training and perform all tasks according to the safety training. Safe work practice also includes working together as a team, looking out for co-workers when performing critical tasks, and good communication.

The last step is Personal Protective Equipment (PPE). PPE is only the final tool to mitigate any residual risks which might persist after applying the aforementioned safety levels.

6.1 Superordinate safety measures

Superordinate safety measures refer to emergency systems that concern the safety of the facility as a whole. The two aspects therein are depicted in Figure 6-4 and will be discussed in their respective Chapters 6.1.1 and 6.1.2.

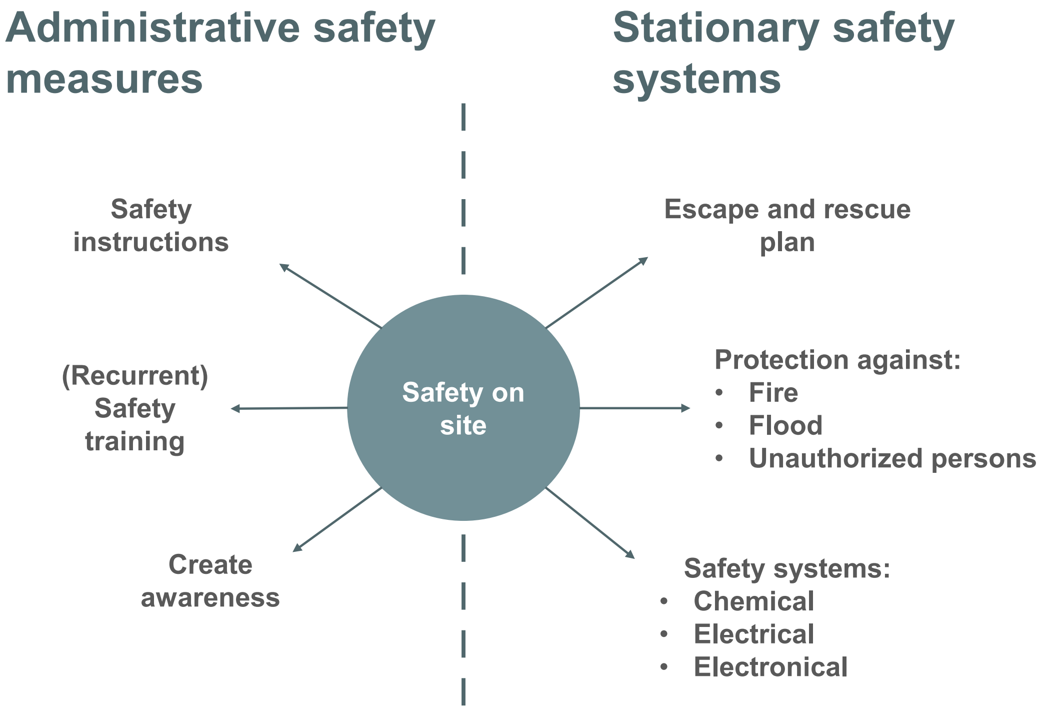


Figure 6-4: Administrative and stationary safety systems

A safe work environment can only be achieved if the responsibilities are made clear to everyone at the plant. Roles, responsibilities, and accountabilities must be defined, documented, and communicated. The most important roles are listed in Chapter 1.

The involvement of employees at all levels is needed for the effective performance of EHS-related tasks. All employees are asked to practice good housekeeping, participate in training, report hazards and injuries, use personal protective equipment, and practice safe work habits. Each employee is expected to actively participate in, and take ownership of Environmental, Health, and Safety Policy, goals, and objectives. Most importantly, the defined roles and responsibilities must be valued and accepted. **Decisions and recommendations from the safety management unit or responsible safety officer should not be ignored or overruled**.

6.1.1 Safety systems

Safety systems that are installed at SWRO plants to prevent fire or injuries from accidents with chemicals or electricity will be presented in this chapter. Due to the on average larger size of SWRO plants and the increased number of staff, a brief introduction to evacuation and safety at office buildings will be included. Lastly, measures for intrusion protection and IT security systems will be discussed.

If applicable, the recommended intervals for necessary tests and inspections for the safety systems will be listed at the end of each section. It is advisable to document the execution of these checks with the date, name, and signature of the person performing the tests, and any findings. For smaller, more frequent tasks, this can be done for example with a printed list in a protective sheet close to the location of the safety system. These signed documents serve as proof towards the employer for compliance with the EHS requirements stated in the operation and maintenance contract.

Fire-fighting measures

Constructional fire prevention and larger pre-installed fire-fighting systems, for example, sprinkler systems, fire protection doors, and fire alarm systems have to be considered in the planning phase according to national regulations and the size of the facility.

Fire-fighting equipment to fight small fires should be provided at the plant. Fire extinguishers have to be chosen according to their category (A, B, C, D, or E) as not all fire extinguishers can be used on every fire. Figure 6-5 shows the most common portable extinguishers, powder, and CO_2 extinguishers. The circles indicate the type and the fire category they can be used for.

Figure 6-5: Left: Powder extinguisher, right: CO_2 extinguisher[29].

[29] https://www.firefighter.com.my

The extinguishers have to be stored at their assigned position at all times. It has been proven useful to mark the position of extinguishers and other equipment with black and yellow striped tape on the floor.

For larger fires, fire extinguishers cannot be used as they only provide extinguishing material for a few minutes. The installation and provision of hydrants and fire hoses must be considered in the risk analysis in the planning period. If hydrants and hoses are provided, their location must be marked in the fire and rescue plan (see Figure 6-6).

The installation of fire and rescue plans is recommended. The fire and rescue plan has three main purposes. First, it shows the location of fire-fighting equipment. It also shows the emergency exits and the best way to get there from its location. In case of an emergency, the fire and rescue plan should be handed over to fire-fighters to give them a layout of the facility.

The fire and rescue plan should use the standardized safety signs presented in Chapter 6.1.2. An exemplary fire escape plan is depicted in Figure 6-6.

Employees must be trained in the correct behavior in case of fire, evacuation, and the use of fire-fighting equipment.

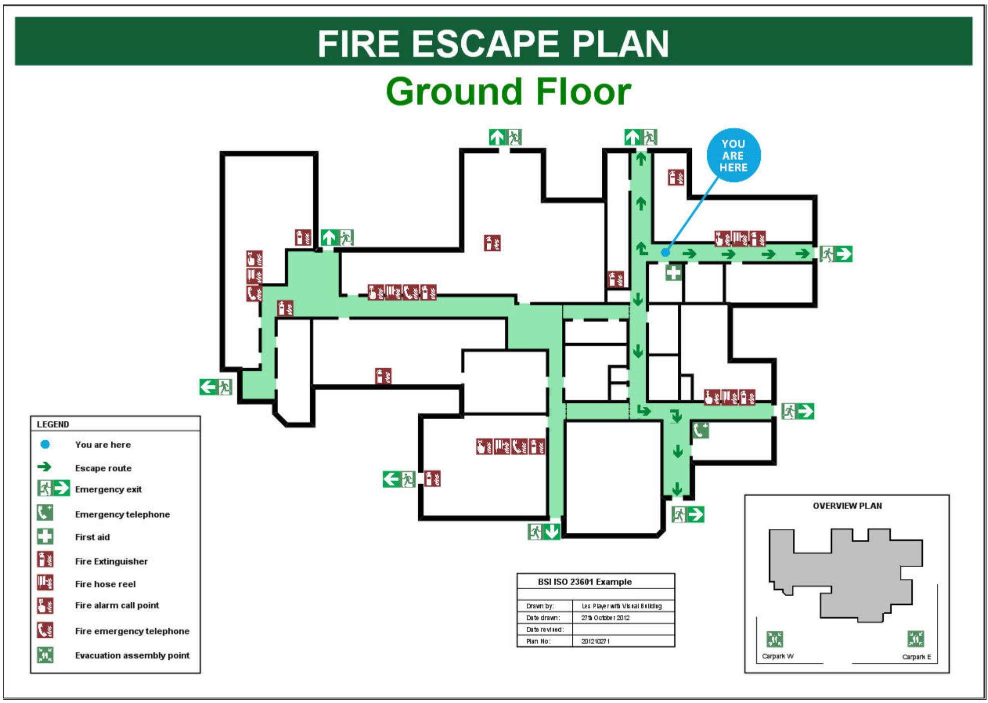


Figure 6-6: Exemplary escape and rescue plan[30]

Inspection of fire-fighting systems

In general, follow the local regulations and the instructions from the manual regarding the test and inspection of safety systems.

Emergency ways and exits must be free and accessible at all times. If any emergency doors are blocked by equipment or other items, make sure to immediately remove said items.

30 After https://www.visualbuilding.co.uk/guides/specials/fire-escape-plans

Fire extinguishers, hoses, and hydrants should be checked visually each month to identify the damage or misplaced equipment. The function and triggering of fire protection doors as well as the fire alarms should also be checked monthly. It is recommended to have professional inspections of immobile and mobile fire-fighting equipment at regular intervals according to local regulations or manufacturers' instructions, but at least annually for immobile equipment (fire hoses, hydrants) and biannually for mobile equipment (fire extinguishers).

Chemical emergency systems

In case of accidents with chemicals, the affected body parts have to be rinsed thoroughly with clean water. This can be done most effectively by using an emergency shower. They can provide around 30L of water per minute and often include a separate emergency eye shower. Additionally, emergency eye-wash bottles can be provided to allow immediate rinsing and thereby avoid damage to the eyes. Two bottles are recommended in case one is not sufficient or contaminated. The location of the eye-wash should be marked, and the bottles should not be removed!

Figure 6-7: Left: Emergency shower including eye-shower[31]; Right: Emergency eye-wash bottle

Inspection of emergency showers

Check monthly whether emergency (eye) showers are working properly and provide the designed water flow rate. Check water quality and whether any pores are blocked. This flushing also prevents microbiological growth in the emergency shower pipes and head. If eyewash bottles are used, make sure they are still placed at their designed location and that the seal is not damaged.

A more thorough inspection and cleaning of the emergency shower is recommended in annual intervals. The steps are presented in Figure 6-8. Check shower head for scale and clean with

[31] https://upload.wikimedia.org/wikipedia/commons/8/8d/Safety_Shower_and_Eye_Wash_Station.jpg

a mild citric acid solution, if necessary (STEP 1). The water should be under enough pressure to form a 10-30 cm fountain against gravity (STEP 2). The head should not leak after use (STEP 3). In STEP 4, check the hose and overall equipment for visible damage. Check whether the appropriate GHS sign is installed and visible at the shower station (STEP 5).

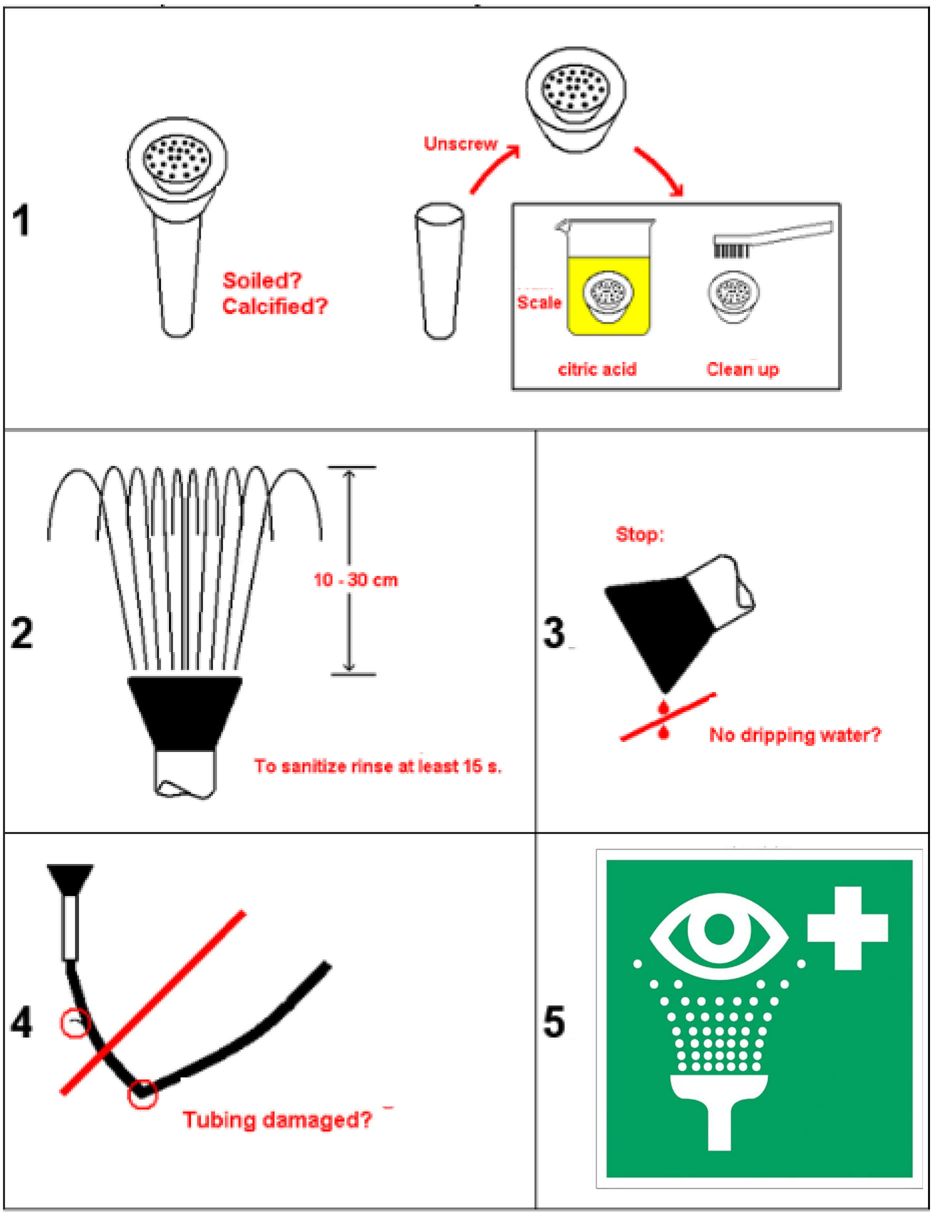


Figure 6-8: Extended inspection of emergency shower

Electrical emergency systems

Kill switches, or emergency stops, are a common safety mechanism to shut off machinery in an emergency. They are designed to abort an operation as quickly as possible and to be operated simply and quickly. Kill switches are usually designed to be noticeable so that every bystander can find and operate them (see Figure 6-9). They should never be manipulated or blocked!

Figure 6-9: Emergency stop[32]

Protective covers, or safeguards, block rotating or otherwise reaching into dangerous parts of machinery. Often the machinery cannot be started without the protective cover in place. Like kill switches, those safety installations should never be manipulated for easier handling or other reasons!

When maintenance work is carried out, the respective work area must be cordoned off and secured for the duration of the measure so that unauthorized persons cannot enter it. In addition, this is to prevent employees from accidentally turning on a machine that is still undergoing maintenance. Barriers and signs must be used to draw attention to the work. The signs should include information on who is performing the work and during which period. If necessary, for example, the power supply must be interrupted, the water turned off, or moving machine parts secured. In principle, it is important that shut-off inlets or systems remain switched off and are not switched on again by another employee while the maintenance person is still in the plant. Lockout – tagout systems, shown in Figure 6-10, are a tool to ensure that switches, valves, or other equipment cannot be operated accidentally.

[32] https://www.in-line.ltd.uk/warehouse-installations/warehouse-labelling/

Figure 6-10: Logout – tagout system in place[33]

<u>Inspection of electrical emergency systems</u>

Kill switches should be checked annually for functionality.

Safety at office buildings

Some hazards are also present in office buildings. Those typically include tripping and fall hazards arising from loose cables or items on the ground. Other hazards include the use of faulty electrical equipment which can lead to fires and damages to the equipment. Employees must not leave personnel electrical equipment on unsupervised.

Evacuation in case of emergencies

As a large number of staff is employed at SWRO plants, the correct behavior in case of an emergency is even more important than at, for example, smaller brackish water RO plants. In case of an evacuation, all persons must leave the buildings quickly but not hastily.

Different signals can indicate an alarm, such as fire alarms, gas sirens, or optical alarms. All employees must know the different signals and how to act accordingly.

Each employee must be familiar with the fire escape plans (see Figure 6-6) and the nearest emergency exit. If visitors without knowledge about the facility and emergency exits are at the plant, employees must assist them during evacuation.

Emergency exits must be marked with the GHS emergency exit sign (see Figure 6-12). They lead to designated assembly points. Assembly points must be at a safe distance from possible sites of emergency, easily accessible from all emergency exits, and must not block or hinder

[33] https://trdsf.com/blogs/news/top-10-lockout-tagout-violations-and-what-s-required-for-compliance

access of firefighters to the site of the emergency. At larger facilities, multiple assembly points might be necessary.

At the assembly point, supervisors or designated safety officers must check that the total count of employees and visitors has left the buildings and stays at the assembly point. If possible, first aid equipment and visitor lists (see below) should be brought to the assembly point. Employees who have further information regarding the type and location of the emergency must come forward and give the information to the firefighters. Employees must not leave the assembly point, hinder the firefighting or emergency works or reenter the building before the safety officer has permitted access.

It is highly recommended to perform regular exercises in emergency evacuation situations.

Intrusion protection and IT security

SWRO plants are critical assets in a country's drinking water infrastructure and therefore need protection against intrusion or manipulation. A security plan has to be worked out in the planning period to protect both physical assets as well as IT and SCADA systems. The intrusion protection will include both physical measures and policies and procedures.

Physical measures may include stable walls, incorporating intrusion prevention installations on windows and doors as well as fences and other barriers. Doors, gates, and hatches must be equipped with locks connected to a monitoring system with intrusion alarms. These alarms may utilize motion detectors, enhanced lighting, or closed-circuit TV surveillance, among others.

The access to the plant should be controlled through a hierarchical access card system or other means to maintain security. This also ensures that the exact number of persons currently at the facility is known and can be checked in case of an emergency. Staff should be required to display identification at all times. Visitors should never be allowed to wander alone, both to ensure their own and the plant's safety. Upon entry, visitors should be issued a temporary access permit and log into a visitor's logbook.

To ensure the safety of the produced drinking water, close monitoring and laboratory testing are necessary. That way, any chemical, biological or radiological contamination can be detected.

Another serious problem can be water theft. Theft directly at the SWRO plant is a minor concern compared to theft from the supply pipes to the residential areas. Still, storage tanks for fresh water should not be left open or unlocked if they are not supervised. There should be no easy access to sample points or valves where freshwater can be drawn easily. Fencing in the property helps against water theft as well as against theft of equipment.

It can be challenging to discover water theft in the first place. Water theft can be discovered more easily when reliable water meters are installed and monitored. Ideally, an online system facilitates monitoring and taking measurements. Pressure losses can help to identify theft of large amounts of water or severe leakages. Refer to Chapter 4 for more information regarding monitoring and control.

Establish good communication between water suppliers and customers to spot differences in produced and delivered quantities. When there are signs for water theft, even if it is not directly at the SWRO plant and therefore not in the direct responsibility of the plant management, inform police and responsible authorities and make sure that necessary repairs at pipes or monitoring instruments are carried out.

In the case of IT and SCADA systems, protection starts with installing and maintaining firewalls and systems for virus protection. Keep business and operational systems separated. Generally, only connect systems to the internet and larger networks if necessary. Do not let employees connect personal external devices such as hard drives and USB sticks to company computers. Use encryption technologies for safe data transfer. As for physical protection, secure SCADA equipment, and server locations. Make sure only authorized employees have access to servers. It is recommended to include IT security in the safety instructions for employees to enhance the awareness of risks in IT systems.

6.1.2 Safety instructions

Communication between safety officers and employees is essential to create a safe work environment and to raise awareness towards the correct use of equipment. This communication is held orally in the form of safety training and instructions on operating equipment safely. Those safety instructions must be given before the employee's first time performing the task and should be repeated at regular intervals, for example, yearly.

Safety instructions differ according to their topic:

- **General safety instructions:** They apply to all people working in an area or just passing through. They inform about general hazards and necessary precautions when being close to hazardous machines or materials without actually working with them. An example would be an area where forklifts are driving. The general safety instructions would include warnings, the obligation to stay on marked passageways and to wear PPE. Commonly, they are printed out and kept at entries to facilities or areas.

- **Task-specific safety instructions:** They apply, as the name suggests, to a specific hazardous task. They are only given to the concerned employees. Examples could include the demonstration of how to use a certain power tool correctly and safely or how to mix chemicals and which PPE to wear.

Additional to the safety instructions performed by the supervisors, **standardized written safety instructions** are a helpful tool to point out and remind workers of the task- or machinery-specific hazards. They do not replace the initial instruction through a supervisor or safety officer.

Safety instructions have to be written and updated by the safety officers for any critical task and machinery that may pose a health and safety risk. Safety instructions are not meant to give step-by-step instructions for tasks. Instead, the goal is to inform employees about the correct use of hazardous substances or machinery and to state the necessary precautions. This should be done clearly and concisely. The length of the safety instructions should not exceed one page. The use of standardized symbols to illustrate hazards as well as safety measures is advised (see Figure 6-11).

The basis of safety instructions for the use of chemicals are the Material Safety Data Sheets. The manufacturers' manuals or operating instructions should be consulted for hazardous machinery.

Safety instructions usually include the following information:

- Working area and task
- Dangers to humans and the Environment with standardized hazard symbols
- Necessary protective measures with mandatory signs
- Rules for safe work behavior
- Information regarding emergency contacts and first-aid measures
- Information on maintenance operations

An example of written safety instructions can be found in Figure 6-11. A blank template for safety instructions as well as safety instructions for working with ladders, forklifts, fall protection, loading/unloading operations, and working in confined spaces are included in the Appendix.

Applications for written safety instructions in a SWRO plant may include but are not limited to all tasks named in Chapter 6.3.1 – 6.2.5. A general safety instruction at the entry of plants might be a feasible option to warn about loud noise or trip hazards.

Safety instructions have to be readily available and easily understandable for any employee. The easiest way is to print the safety instructions and keep them in plastic sheets at the respective working area.

Employees should know about the safety instructions concerning their work, but employees don't need to know all safety instructions in the plant.

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

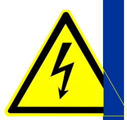
DESIGNATION

Electric hand tools

General operating instructions for handling electric hand tools

DANGERS TO HUMANS AND THE ENVIRNOMENT

- Dangers from electric shock!
- Dangers from tools or work pieces that get out of control!
- Dangers from catching clothing and hair!
- Dangers due to noise!
- Dangers from hand-arm vibrations!



PROTECTIVE MEASURES AND RULES OF CONDUCT

Hearing protection:	Wear ear protection when working at noise levels above 80dB(A)!
Eye protection:	Wear safety goggles!
Body protection:	Wear suitable tight working clothes
Foot protection:	Use safety shoes!

Conduct:

- The accident prevention regulations and the manufacturer's operating instructions must be complied with!
- When changing tools: Remove the mains plug!
- Use only approved tools in electric hand tools!
- Use tools only for their intended purpose!
- Check connecting cables for damage before switching on!
- Check that the safety devices are complete and functioning correctly before use!
- Do not dismantle or block protective devices!
- Guide electric hand tools with both hands and make sure that your foothold is stable!
- Use electrical hand tools only together with a mains supply protected by an RCD switch (30mA)!
- If you have long hair: Use a hairnet!
- Do not wear gloves when using drilling machines!

WHAT TO DO IN THE CASE OF MALFUNCTIONS

- Replace defective tools immediately!
- Have damage to electrical cables and components repaired by a specialist!

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

Carry out emergency measures at the scene of the accident!
Call an ambulance/doctor!
Inform supervisors and the occupational insurance association!

First aider: ....……………………..

MAINTENANCE

- Before each use, check the function and safety devices of the machine!
- Comply with the manufacturer's guidelines with respect to maintenance and care!
- Repairs must only be performed by qualified persons!
- Electric hand-held devices must be checked annually by a qualified electrician to ensure that they are in proper condition (keep test logbook).!

CONSEQUENCES OF NON-COMPLIANCE

- Health consequences: injuries and illness!
- Consequences under industrial law: warning, reprimand!

Figure 6-11: Example for safety instruction sheet for Electric hand tools[34]

The signs used in the safety instructions should be taken from the ISO 7010 norm. The ISO 7010 norm is an international technical standard for graphical hazard symbols (GHS) on hazard and safety signs. The symbols are intended to provide safety information that relies as little as possible on the use of words to achieve understanding. The ISO 7010 hazard symbols can be seen as an extension to the GHS system for the correct characterization and labeling of chemicals presented in Chapter 3.

Use the proper standardized symbols in SWRO plants both on the safety instructions as well as at hazardous workplaces. Indicating the position of important safety equipment and emergency exits is a cost-effective tool for a safe work environment.

Figure 6-12 shows the different types of hazard and safety signs with some common examples.

The first category includes the Safe condition signs (green rectangle with white symbols). They include the position of first aid equipment and the direction of emergency exits.

The second category includes Mandatory signs (blue circle with white symbol). They indicate the mandatory rules for a certain task or working area. The mandatory signs are most commonly used to show PPE that has to be worn or to indicate actions that have to be performed, for example, sign M011 – Wash your hands.

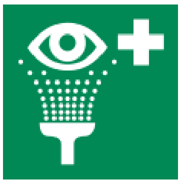
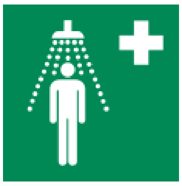
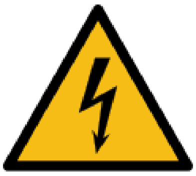
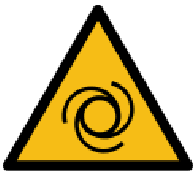
The Fire equipment signs are red rectangles with a white symbol and indicate the position of fire-fighting equipment.

The fourth category consists of Warning signs, black symbols on a yellow triangle. They warn of the hazards of operating a certain machine or handling materials.

Prohibition signs are in the last category. They show a black symbol in a red circle with a diagonal line and indicate items or actions prohibited in the assigned area.

Make sure the form and meaning of every hazard symbol used in the SWRO plant and on safety instruction sheets are known to every employee. The symbols are mostly self-explanatory; however, some depict more abstract processes and can therefore be more difficult to identify.

[34] Adapted from https://www.svlfg.de/betriebsanweisungen

Name	Pictogram	
Safe condition & first aid signs	 Emergency exit (right) **E001**	 First Aid **E003**
	 Eyewash station **E011**	 Safety shower **E012**
Warning signs	 General sign **W001**	 Electricity **W012**
	 Fork lift trucks and other industrial vehicles **W014**	 Automatic start-up **W018**
Fire equipment & fire action signs	 Fire extinguisher **F001**	 Fire protection door **F007**

Name	Pictogram	
Mandatory signs	 Wear ear protection **M003**	 Wear eye protection **M004**
	 Wear protective gloves **M009**	 Wash your hands **M011**
Prohibition signs	 No open flame; Fire open ignition source & smoking prohibited **P003**	 No reaching in **P015**
	 No eating or drinking **P022**	 Do not expose to direct sunlight or hot surface **P068**

Figure 6-12: Examples for hazard and safety signs according to ISO 7010[35]

6.1.3 Working with external specialists

On several occasions, workers or specialists from other companies might perform tasks at the plant. Therefore, it is important to state that the same safety measures and safe work practices apply in the same manner for all people working at the plant.

Good coordination between plant managers, safety officers, and external and internal workers is crucial to avoid misunderstandings. The safety officer should also feel responsible for the

[35] https://en.wikipedia.org/wiki/ISO_7010

health and safety of external workers, while the external workers should acknowledge the safety officer's authority.

First, the external workers should be instructed about the general safety measures at the plant. Afterward, the tasks that will be performed have to be discussed, particularly about safety hazards. The general steps for performing a risk assessment presented in Chapter 2.3 can be used as a guideline. The plant manager or safety officer and the external workers have to work together to perform this step since the external workers may not be familiar with plant specifics. In contrast, the safety officer cannot be expected to know all risks concerning those specialized tasks in detail.

The results of this risk assessment should then be documented together with the clearance of the safety officer (please also refer to Chapter 1 for more details on plant documentation). This way, the possibility of misunderstandings and resulting incidents can be minimized. A template for risk assessments can be found in Table 7-7 in the Appendix.

After clearance, the safety officer is responsible for informing other employees working in close vicinity to the external workers about the tasks being performed and coordinating the different workflows.

This is a recommendation, especially for larger plants or more complex maintenance operations. While a formal, written risk assessment might be too elaborate for smaller tasks, the aforementioned general steps should always be performed.

6.1.4 First aid at SWRO plants

EHS management ideally aims to prevent all accidents. However, medical emergencies and work accidents can always happen. The co-workers of the person in distress will be the first on-site and could ideally provide the medical supply until further medical help arrives. Employees who are specially trained in first aid are called first responders. First aid courses can train first responders both in theoretical knowledge as well as in practical application. The courses could also be customized for the work at water treatment plants. Refer to Chapter 1 for more information regarding training principles.

Due to the size of SWRO plants, nominating designated first responders is highly recommended. The first aid courses should be refreshed at regular intervals (annually or biannually). The courses might include the following aspects:

- Assessing the scene and the injury
- Calling for medical aid and informing supervisors
- General medical emergencies (Respiratory distress, shock, heart attacks, …)
- Work-related emergencies (Burns, wounds, eye injuries, exposure to hazardous chemicals, …)

First aid equipment should be provided for free and in good condition at every plant, including bandages, plasters, sterile gauze dressings, disposable gloves, and foil blankets against shock. Additionally, the installation of an automatized external defibrillator (AED) can be considered, if a larger number of elder employees is working at the plant and if first responders are trained in the use of AEDs.

At the end of Chapters 6.3.1 to 6.2.5, a summary of first aid measures for the respective working field is included. Those are included to give an overview and are not meant to replace more in-depth first aid training.

Take Away Messages – Superordinate safety measures

- Keep safety systems maintained! Never block access to safety equipment or remove it from its original location!
- Standardized written safety instructions are a valuable tool to warn of task-specific hazards. Written safety instructions do not replace oral safety instructions and trainings performed by the plant supervisor or safety officer.
- Safety measures apply in the same manner for internal as well as external. The safety officer’s authority has to be acknowledged by every worker.
- Before any task is performed by external workers, the operations have to be discussed with the plant’s safety officer. It is advisable to fill out a risk assessment sheet to document the tasks.

6.2 Individual safety measures

In Chapter 6.1, superordinate safety measures like stationary safety systems and administrative safety measures have been discussed. This chapter focuses on the individual safety measures for each worker performing a task. Thereby, safety equipment and safe work practices have to go hand in hand.

General safe work practices for hazardous tasks

For any hazardous tasks, some general best practices apply:

- **Inform supervisor!** The supervisor has to have an overview of who is working where. Establish a log in – log out system to inform the supervisor before workers start the task and after completion.
- **Do not work alone!** If needed, the co-worker can aid or call for help. Establish communication ways if a person is working out of sight of co-workers.
- **Do not perform tasks for which you are not trained.** Proper training is the basis of working safely. Please refer to Chapter 1 for more information regarding training.
- **Do not perform hazardous tasks if you are feeling unfit.**
- **Always perform tasks according to safety training and manufacturer's instructions.**
- **Check on co-workers!** Make sure co-workers inform each other when performing hazardous tasks in close vicinity and shut off hazardous areas like openings at the floor.

You can find detailed information regarding hazardous tasks and safe working procedures on websites for occupational health and safety, for example, www.osha.gov and www.hse.gov.uk.

Personal Protective Equipment

Personal Protective Equipment (PPE) describes protective clothing, helmets, goggles, or other equipment to reduce employee exposure to hazards. PPE is needed wherever hazards are still present after other safety measures like safe engineering and administrative safety measures have been applied.

The management is responsible for providing well-fitting safety equipment without additional cost to the employees. Smaller, frequently used safety equipment, for example, hearing protection and helmets, should also be provided for visitors or external workers. The equipment has to be accessible at all times; consider possible supply gaps when stocking. If a task requires PPE, it should never be performed without it, regardless of how short it might take.

PPE has the serious limitation that it does not eliminate the hazard at the source and may result in employees being exposed to the hazard if the equipment fails. Therefore, the employee working in a hazardous environment has to be trained to know the correct PPE for the task at hand and how to do it correctly. PPE has to be checked both at regular intervals by the safety officer as well as by the employee before use.

6.2.1 Working with chemicals

The correct labeling and storage of chemicals according to the Material Safety Data Sheets has already been presented in Chapter 3. This chapter will give an overview of different personal protective clothing and general advice on working with chemicals.

When working with chemicals, the Mandatory signs in the safety instructions (shown in Figure 6-12), as well as the GHS symbols on the container label (presented in Chapter 3), inform about possible hazards and mandatory PPE. But even if not all chemicals used are necessarily hazardous, it is advisable to wear some basic protective equipment.

- **Clothing**:
  Long clothing with long sleeves and a high cotton content is generally favorable to minimize splashes on the skin or the danger of burning.
- **Footwear**:
  Solid, closed shoes are recommended for the same reason.
- **Eyes:**
  Safety goggles with sufficient side protection should be worn when working with any chemical to avoid splashes getting into the eyes.
- **Hands:**
  There are different classes of protective gloves according to their penetration time for various chemicals. The correct glove for a chemical should be stated by the manufacturer of the chemical.
  The most common types are shown in Figure 6-13.
  Disposable nitrile gloves protect the skin for a short while against splashes of diluted acids and bases, but not against solvents. They are often thin and thereby provide a good grip.
  Butyl rubber gloves provide higher resistance against undiluted chemicals and can be reused when properly cleaned after being used.

There are other glove materials as well as combinations of materials, for example, latex-neoprene-mixtures, that protect chemical mixtures.

The gloves should not be worn permanently to avoid skin irritations. Take care when taking off gloves not to touch them with bare hands. Gloves must only be worn at the workstation! Do not touch light switches, door handles, water tabs, phones, food, or any other non-hazardous equipment with used gloves to avoid contamination.

Figure 6-13: Left: Nitrile gloves (Nitril-Butyl-Rubber, NBR)[36]; middle: Butyl gloves (IIR, IBR)[37]; right: Latex-Neoprene-Mix gloves[38]

Some general advice on working with chemicals:

- Only take the amount needed from the original storage container.
- Do not put any excess chemicals back into the original container to avoid contamination.
- Before loading into the tanks, mixing or diluting of chemicals should be done in a separate container to ensure a homogenous mixture.

First aid for working with chemicals

Detailed information regarding first aid measures for each substance as well as an emergency phone number, can be found in the Material Safety Data Sheets (MSDS). An example of an MSDS can be found in Figure 7-1 in the Appendix.

- Contact first responder and plant supervisor
- Contact medical aid if severe injury. Inform doctors about the substances.
- Help person **without endangering yourself or others**.
- Take off contaminated clothing.

[36] https://www.spsurgicals.com/product/nitrile-gloves/

[37] https://www.uvex-safety.com/en/products/safety-gloves/6677/uvex-profabutyl-b-05r-chemical-protection-glove/

[38] https://www.arbeitsschutz-express.de/de/mapa-duopolymer-chemie-handschuhe-duo-mix-27-000405-7?number=10001640000008

- Wash affected body parts immediately and thoroughly with clean water. Do not use solvents or other hazardous materials.
- If larger parts of the body are affected, use the emergency shower.
- If eyes are affected, best use an emergency eye shower or flasks. If those are not available, use clean water. Take care not to let the liquid enter the unaffected eye.

6.2.2 Working with heavy machinery

Heavy machinery at SWRO plants includes for example trucks during loading and unloading operations, forklifts, and indoor cranes for maintenance operations.

The resulting hazards depend on the type of machine used. For vehicles, there is a substantial risk of overlooking co-workers and overrunning them. Co-workers could be hit with a machinery part or the carried load. For cranes, the main hazard comes from the carried load. In case of wrongful loading or securing, the load could break free or swing unpredictably. Further hazards come from rotating machinery parts or falling from vehicles.

Working with heavy machinery is nearly always teamwork. Several workers, the operator of the machine, and the machine itself all have to operate and be operated safely to ensure safe work practice. Safe work practice in working with heavy machinery consists of safety measures for each worker, the communication between workers, and the actual operating machine. The interactions between the three aspects are shown in Figure 6-14.

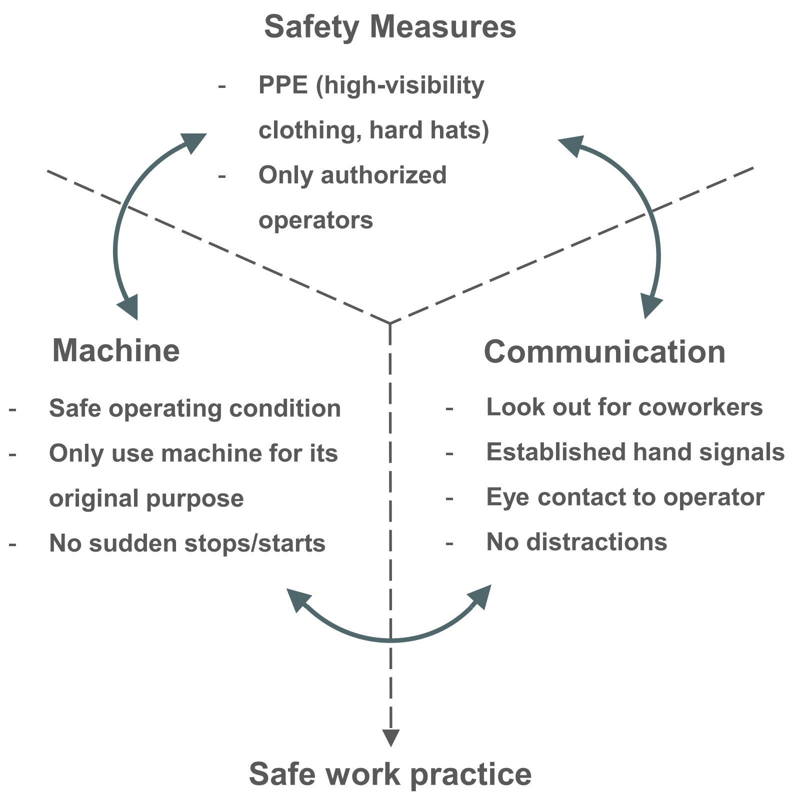


Figure 6-14: Interaction between operating and communicative safety measures

Safety measures

Only authorized persons with appropriate training should operate machines. The qualification of non-employees operating machinery at the plant site has to be controlled by the plant supervisor, and the tasks and specifications have to be discussed before the start of operation. The operator has to be healthy and stay concentrated throughout the operation. Never rush when operating a machine! Do not let yourself be distracted!

The operator is responsible for the state of the machine. The vehicle and, if existing, the operator's cab have to be kept clean and free from unnecessary lose items. Handrails, footholds, and any walking surfaces have to be free from grease, oil, or other substances.

The operator should perform a visual check before each use. Pay attention to warning lights, brakes, fluid levels, and possible leaks. Check lifting cables, loading hooks or tines, and other parts of lifting equipment. The machine's safeguards have to be in place and working.

The following PPE should be considered when working with heavy machinery at SWRO plants:

- **Ears:**
  Noise at work can cause hearing damage that is permanent and disabling. This can be gradual, from exposure to noise over time, but damage can also be caused by sudden, extremely loud noises.
  Hearing protection should be used when workers are subject to short-term high noise levels from heavy machinery or when there is a risk of sudden, loud noises due to impacts or explosive sources. Hearing protection should also be worn in an area of high background noise. The level of background noise can be assessed as follows: If two persons cannot hold a conversation over a distance of two meters without raising their voices, hearing protection is necessary[39].
  The type of hearing protection (earmuffs or earplugs) can be chosen according to the noise level and the comfort of workers. But remember that when wearing hearing protection, alarms or communication can be unheard!
- **Visibility:**
  High-visibility clothing should be worn around heavy machinery to minimize the risk of workers being overlooked by the machine operator.
- **Footwear:**
  As falls from vehicles are among the most common accidents when working with machinery, appropriate solid footwear should be worn. Steel-toe shoes are recommended against the danger of injuries caused by falling loads or overrunning.
- **Head:**
  High-visibility safety helmets for head protection should be worn when working with machines, especially lifting equipment.

Communication

Good communication between the operator and co-workers performing tasks near the machine is essential. The different tasks should be discussed between the operator and persons concerned before the start of operation.

[39] According to https://www.hse.gov.uk/toolbox/noise.htm

Make sure that all persons working nearby are familiar with the alarm for going in reverse. When workers are wearing hearing protection that obstructs the acoustic alarm, consider enabling an additional visual alarm.

Standardized hand signals should be used for lifting operations. Some basic signals are shown in Figure 6-15.

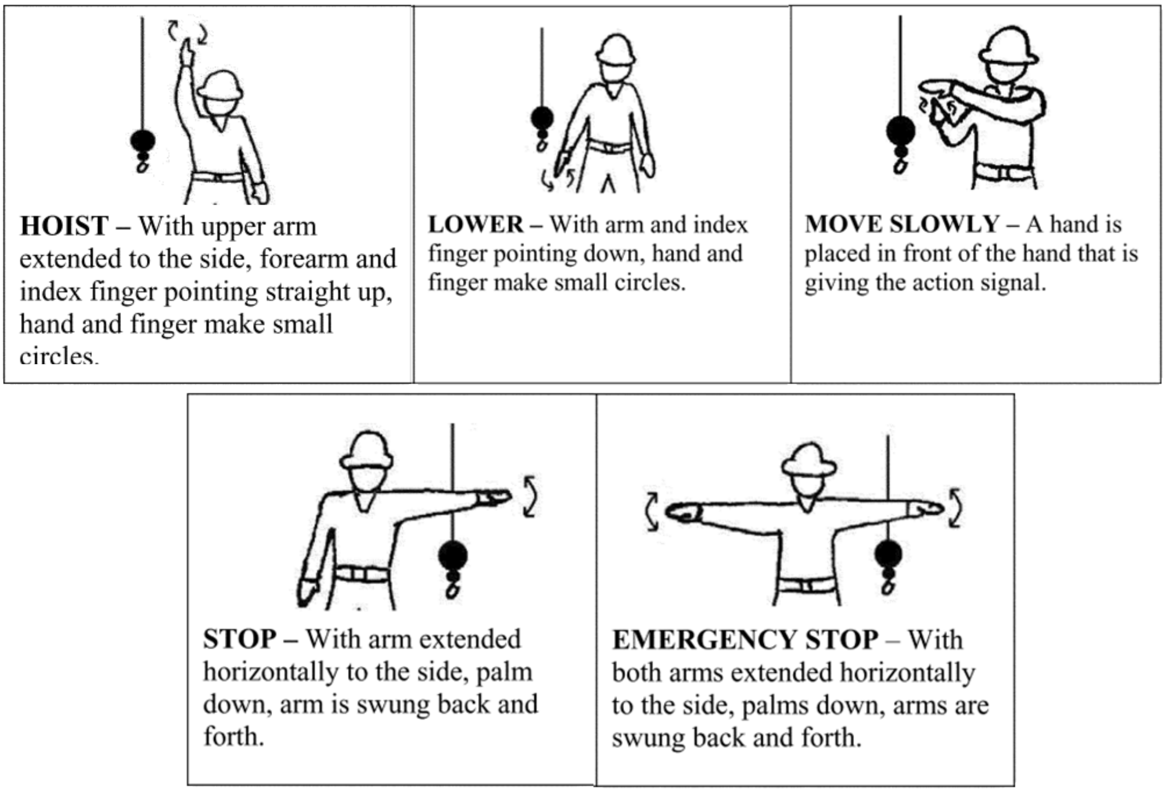


Figure 6-15: Standard hand signals for lifting operations[40]

To avoid confusion or when the operator cannot see properly because of the loaded goods, appoint a signaler who keeps eye contact with the operator and who gives the necessary signals. **An emergency stop signal from any worker must lead to an immediate stop of the machine!**

Machine

Most importantly, the proper use and limitations of the machine should be known and respected. Never use a machine for a task it is not meant to do! Always use the machine according to the safety instructions provided by the safety officer or the manufacturer.

Have the machines thoroughly inspected at regular intervals. Additionally, the operator should perform a visual check before use (see above).

Do not forget that falls from vehicles are amongst the most common accidents concerning heavy machinery. When entering a vehicle cabin, only use the safe entries, handrails, and steps. Do not climb onto machine parts that do not support your weight or do anything that

[40] Adapted from https://www.osha.gov/sites/default/files/2018-12/fy10_sh-21009-10_Hand_Signals_Cranes.pdf

could result in slipping and thereby activating vehicle controls. Use the three-point-hold explained in Chapter 6.2.4. Never try to mount or jump off a moving vehicle if it is not an emergency.

Never interfere with moving machinery. Any vehicles must not move when parked or during loading/unloading operations. Block the vehicle against running away or sinking in on softer grounds. Never restart the machine after stop/maintenance without all safety measures up and running. Never restart the machine with people still working at/close to the machine.

Put/keep safeguards in place to prevent people from reaching into rotating or otherwise dangerous parts. Do not modify or remove kill switches, shields, or control bars.

When loading, always balance loads to avoid tipping. Consider the maximum load and the center of gravity of the load. Never load any item of unknown weight! Make sure loads are properly secured to the vehicle. Persons should never walk or stand under carried loads! Never swing loads over anyone's head!

The operator of a machine must have a full-round view without blind spots. Do not put up objects that hinder the view. Watch out that the load on the forklift is not stacked too high. Eliminate the necessity for going in reverse as much as possible. If unavoidable, keep continuous eye contact and communication with the signaler. When going in reverse, always enable the acoustic (and visual) alarm.

First aid for working with heavy machinery

The means for first aid depend strongly on the situation. Try to stay calm and assess the situation at hand. Never endanger yourself or others when rescuing a person. Shut off moving parts immediately using the emergency switch.

Take Away Messages – Working with heavy machinery:

- Only trained and healthy workers are allowed to operate heavy machinery!
- Never use a machine for a task it is not meant for!
- Always wear high-visibility clothing around vehicles.
- Look out for your co-workers. Do not drive vehicles without a signaler if you have no full-round view.
- Talk through the operation beforehand and establish standardized hand signals to avoid misunderstandings.

6.2.3 Working with electricity

Working safely with electricity and electrical equipment is a top priority in every facility. It is crucial at desalination plants, as unsuitable equipment can become live in wet surroundings and make its surroundings live too. Everyone should look out for electrical wires, cables, or equipment near where they will work and check for signs warning of dangers from electricity or any other hazard.

The applications of working with electricity at a SWRO plant include working with power tools, welding, and maintaining powered equipment, for example, pumps or electrical aggregates and switchboards. The main hazards of working with electricity are electric shock or burns from contact with live parts. Electric shock can also lead to other injuries, for example, a fall from a ladder.

Faulty electrical equipment and installations pose a high fire risk. Never leave live parts accessible and never store flammable substances close to electrical equipment.

Repairs and changes of electrical installations must be performed by trained electricians only. Even wiring a plug incorrectly can have serious consequences. It must be ensured that all electrical installations and equipment are safe. Don't cut corners – electrical installations must be installed by someone who has the necessary training, skills, and experience to carry out the work safely.

When working with electrical equipment:

- Check equipment for visible damage before use. Check for damaged plugs and connectors, visible internal wires in the cable, repairs carried out with tape, burn marks that suggest overheating.
- Check for unusual smells after starting the equipment. This also indicates damage.
- Do not overload single sockets by using (unfused) adapters.
- Check that cables, plugs and sockets are robust enough for the working environment.
- Do not leave trailing cables as they can lead to falls.
- Always switch off and unplug equipment before cleaning or adjusting it.

Depending on the type of power tool, different body parts have to be protected.

- **Eye/face:**
  Visual protection should always be used when operating any power tool, as there are many flying particles that are capable of entering and damaging the eyes.
- **Ears:**
  Wear hearing protection (earmuffs or earplugs) when working with loud power tools.
- **Clothing:**
  Wear full-body clothing to protect the skin against sparks. **Clothing should be close-fitting when working with rotating power tools!**
- **Footwear:**
  Wear hard plastic- or steel toe boots with an insulated sole.

For working at electrical installations, additional PPE is necessary. However, as only trained electricians should perform such tasks, this guideline will not include PPE for working with live electrical equipment.

First aid for working with electricity

Symptoms of electric shock include seizures, burn marks, and possibly unconsciousness or cardiac arrest.

- Contact first responder and plant supervisor.
- Contact medical aid if severe injury.
- Help person **without endangering yourself or others**.
- Break the electric circuit by using the emergency switch, switching the equipment off in the normal way, or taking out the fuse.
- Pull or push the person in distress away from the electrical source using non-conductive materials (blankets, wooden sticks).
- Cover burns with sterile wound dressings.
- Check consciousness and breathing in intervals. If necessary, start resuscitation (CPR) until medical aid arrives.

Take Away Messages – Working with electricity:

- Damaged electrical equipment should never be used, not even for smaller tasks. Always check equipment before use.
- Electrical safety systems should never be bridged. Emergency switches have to be easily accessible.
- Only trained electricians should perform any work on electrical wiring.
- Always switch off and unplug equipment before cleaning or adjusting it.

6.2.4 Working at heights

Falls are among the most common causes of fatal work accidents. They can occur for example, off a ladder, through a fragile ceiling, or through openings in a floor. Especially falls from lower heights up to two meters are often underestimated but they can inflict severe injuries. These accidents can be prevented by following a few basic procedures and using the right equipment.

The first and most important basic rule is that, in general, **working at height should be avoided as much as possible**. Do as much work as possible from the ground, for example by using extendable tools. If working at heights cannot be avoided, the risk potential of the work task should be determined beforehand. In accordance with this, any person working at heights should have the necessary skill, knowledge, and experience required for the job.

There are various ways to perform work at height. Preferably, a scaffold or mobile elevated work platform can be used as they inherently provide railings against falls. Doing work with the help of a ladder should always be the second choice. Ladders should only be used when the use of scaffolds or elevated work platforms is impossible.

Take care that the scaffold has been installed completely and in accordance with the manufacturer's instructions. Before it can be accessed by personnel, it must be inspected for defects. Exceeding the load limit specified by the manufacturer or raising the height of scaffolds with the help of boxes or additional ladders is strictly prohibited. Workers on a scaffold must also keep themselves properly secured and watch out for each other while working.

The use of a ladder contains several hazards. The feet of the ladder could slip, the ladder could bend, or the worker could trip and fall off the ladder. Still, in many situations, a ladder can be the most suitable equipment for working at heights if properly used.

In wet conditions, the use of a ladder should be avoided. This only increases the already existing risk of slipping. In addition, you also need to know about the installation conditions and the maximum load of the ladder used. The choice of the ladder also depends on the type of work task that needs to be done. Always use any type of ladder in the correct way. Never use, for example, a stepladder folded together as a leaning ladder. Keep in mind that the top two to three steps of any ladder should not be used. Thus, a two-meter-high ladder cannot be used for a job that takes place at the height of two meters. Lean ladders to a solid wall with a height to distance ratio to the wall of about 4 to 1.

When working, the ladder may only be used on level and load-bearing ground. In addition, protection against slipping, for example, anti-slip feet on the ladder and falling over, must be provided. The ladder may only be used for temporary work. A ladder serves only as an interim solution. The worker should not lean over the ladder while he or she is standing on it or make horizontal pushing or thrusting movements in the opposite direction to the ladder. This could cause the ladder to tip or fall over. The so-called **three-point contact rule** on the ladder is important. This rule states that three points of the body, for example, both feet and one hand, must always be on the ladder. For a short time, the chest or knee can also be used as a contact point.

Safety equipment for ladders and scaffolds includes the following items:

- **Footwear:**
  Solid footwear is recommended to ensure a secure footing on the ladder or scaffold, especially in a wet environment.
- **Hands:**
  Likewise, gloves are recommended for a tight and secure grip.
- **Head:**
  Wearing a helmet is essential, as it protects against possible falling objects and may prevent more serious head injuries in the event of a fall.

Additional fall hazards exist at edges that have not been properly secured or at unsecured openings. Simple barriers and nets can avoid danger in these zones. Likewise, roof work should only be undertaken by trained personnel with the load-bearing capacity of the roof kept in mind.

In some scenarios, fall protection has to be worn. As usual, the use of PPE against falls should never be the only measure when working at heights. First, the risk of the fall itself has to be mitigated via barriers or performing the task from another point at the ground.

In principle, it can be stated that a safety harness should always be worn when the workplace is above water or other substances in which a person can sink in. At exposed stairways, openings in the ground, operating stands of machines, or working inside confined spaces like tanks, wearing a safety harness should be considered from a drop height of one or two meters. Remember, even small drop heights can result in severe injury. Also, when the safety harness is worn from the beginning of work, rescuing the person will be much easier in case of an emergency.

The safety harness must be donned properly to ensure full functionality. The steps are shown in Figure 6-16. Use only quality equipment and that any person working at heights is trained and fit for the task!

Figure 6-16: Steps to don a safety harness[41]

The safety harness is connected to an anchor point with an energy-absorbing rope. Check the ropes before use. Never reuse ropes after a fall! The anchor point is chosen according to the type of task. This point should prevent the person from hitting the ground in the event of a fall. A distinction is made between temporary and permanent anchors. For example, larger tanks sometimes have permanent anchor points built in. Two examples of temporary anchors are shown in Figure 6-17. Tripods can be used where there is no possibility to attach a mobile fall protection strap. These straps can only be suitably attached to firm structures that can support a multiple of a person's body weight. If necessary, protect the sling from abrasive edges.

[41] https://www.scaffolding-direct.co.uk/scaffolders-twin-leg-safety-harness-rghk4-2/

Figure 6-17: Left: Fall arrest tripod with rescue winch; right: Mobile fall protection strap

Figure 6-18 shows an illustration of how to select an anchor point. Generally, an anchor point should be chosen as high as possible to keep the fall short. During the work, it is necessary to pay attention to the position of the rope so that in the event of a fall, it cannot wrap around limbs.

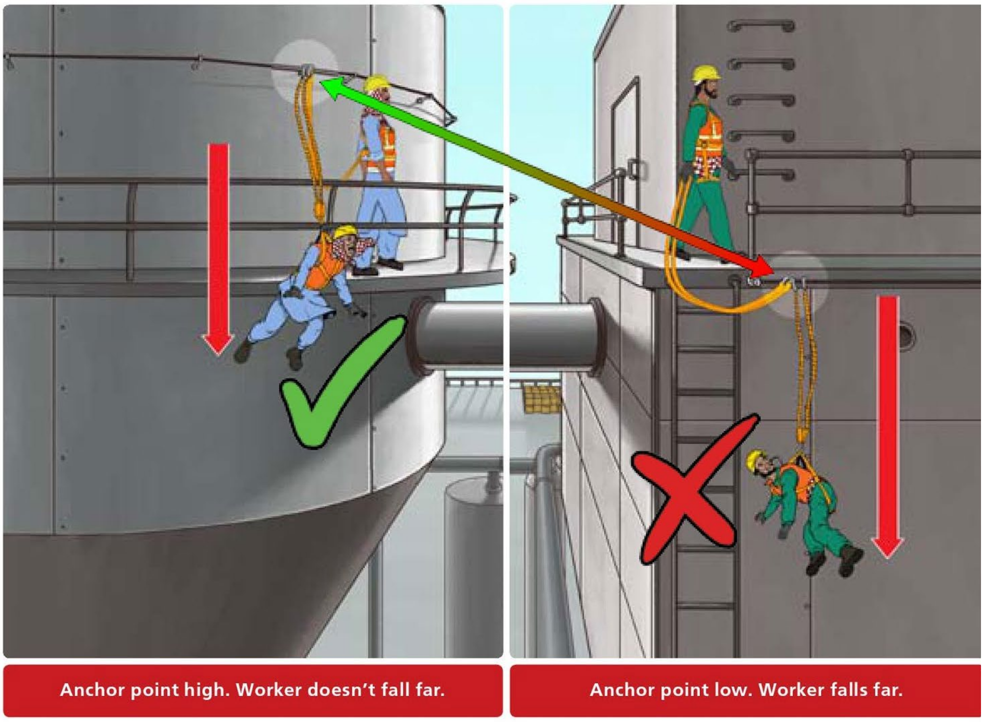


Figure 6-18: Correct choice of anchor point[42]

[42] After https://www.firstsafety.in/2020/10/work-at-height.html

When working at heights, keep in mind that loose items provide the hazard of injuring people on the ground. Secure any tools and materials.

First aid for working at heights

In case of an unsecured fall:

- Assess the injuries. Talk to the person calmly.
- Contact first responder and plant supervisor.
- Contact medical aid if severe injury.
- Proceed with necessary first aid measures. Stop bleedings and still broken bones.
- Keep the person warm and awake to avoid shock.

In case of fall into a safety harness:

- Assess the situation and establish communication with the person in distress.
- Contact first responder and plant supervisor.
- Contact medical aid if severe injury.
- Help person **without endangering yourself or others**.
- Calm the person in distress and ask the person to move arms and legs if possible. Hanging in a safety harness for a long time without moving can result in restricted blood circulation and danger for life!
- Try hoisting up a person using the winch of tripod or manpower.

Take Away Messages – Working at heights:

- Try to avoid working at heights. Look for another way to perform the task from ground level, for example using telescope equipment.
- Preferably use scaffolds and mobile elevated work platforms for working at heights.
- If using a ladder, only use it temporarily and in the correct manner.
- Do not forget: even falls from smaller heights can result in severe injury and possibly disability!

6.2.5 Working in confined spaces

A confined space can be any space of an enclosed nature where there is a risk of death or serious injury from hazardous substances or dangerous conditions. A confined space also has limited or restricted means for entry or exit and is not designed for continuous occupancy. Confined spaces include, but are not limited to, tanks, vessels, storage bins, pits, manholes, tunnels, equipment housings, ductwork, pipelines, and other poorly ventilated rooms.

Dangers in confined spaces can arise from a lack of oxygen due to oxygen consumption through corrosion of steel or reactions with the stored substances. In combination with water, Lime can release carbon dioxide, which is heavier than normal air and displaces it. Poisonous or flammable gases and vapors, as well as hot conditions resulting in overheating, are further risks. These hazardous conditions may already be present in the confined space or may arise from the tasks performed. Special attention has to be paid when volatile and often flammable substances like solvents are used. Petrol-fueled engines should never be allowed in confined spaces as the carbon monoxide in the exhaust is highly dangerous.

Do not work in confined spaces unless it is essential to do so. Try to avoid entering confined spaces by having the work done from outside if possible.

If works inside confined spaces have to be performed, make sure you have a safe system for the tasks at hand. All employees concerned have to be trained properly beforehand. **When working in confined spaces, the most important rule is not performing any tasks alone!** A supervisor of the work has to be appointed who discusses the tasks with the worker entering the confined space (entrant) beforehand. The supervisor does not have to stay right in the confined space throughout the work but should be close by. An attendant should also be appointed to stay outside of the confined space ensuring a constant communication line with the entrant if any hazardous situations might occur or if the entrant cannot leave the space without help.

PPE in confined spaces often includes safety equipment for working at heights (refer to Chapter 6.2.4). It is recommended that the entrant don a safety harness and connect it to the tripod before entering the space.

Using a ventilation system is the best option when working in confined spaces. If the hazardous atmosphere cannot be purged by ventilation, other PPE might include self-contained breathing apparatus (SCBA). SCBAs come with 30-60 minutes of air time, which can be worn during the work period, or as emergency escape devices with 5-10 minutes of air time. Make sure that entrants and attendants are trained in the use of SCBAs.

Safe work clothing, including steel-capped shoes and robust full-body clothing, is always advisable.

The following checklist (Table 6-1) includes many of the essential elements to help prepare a safe working system in confined spaces.

Table 6-1: Checklist for Working in confined spaces

6.2.5 Checklist for Working in confined spaces		*Drawn by:* *Checked by:*	
NO.	DESCRIPTION	CHECKED	REMARKS
1)	Is a responsible supervisor appointed who checks safety at each stage?		
2)	Are the people entering the confined space (Entrant) physically and psychologically suitable for the work?		
3)	Are mechanical and electrical isolations in place to avoid (inadvertent) operation?		
4)	Are all pipes isolated to avoid release of liquids or gases into the confined space?		
5)	Did you clean the space before entry if hazard from fumes from residues persists?		
6)	Did you check the size of the entrance? Is it big enough to provide ready access and exit in an emergency?		
7)	Did you increase the number of openings to improve ventilation? Did you install mechanical ventilation (without petrol-fueled engine) if necessary?		
8)	Did a competent person test the air with a properly calibrated gas detector to check that it is free from toxic and flammable vapours and fit to breathe?		
9)	Are breathing apparatuses provided if the air inside the space cannot be made fit to breathe?		
10)	Are emergency arrangements (equipment + trained people) in place?		
11)	Are adequate communication systems provided between people inside and outside the confined space and to summon help in an emergency?		
12)	Did you position someone outside to keep watch, to communicate with the person inside and to aid in case of emergency? (Attendant)		

First aid for working in confined spaces

Emergency arrangements will depend on the risks. You should consider communications and rescue and resuscitation equipment.

- All rescue equipment has to be available right at the entry of the confined space.
- Contact first responder and plant supervisor.
- Help person without endangering yourself or others. **Never enter a space with a potentially dangerous atmosphere without first checking the air inside with a gas detector or wearing proper breathing apparatuses!** Too often, the attendant climbs into the space to rescue the entrant and endangers him- or herself!

- If the person in distress is already wearing a safety harness, he or she can be carefully pulled out. Avoid bumping the person into edges or walls when pulling out of the space.

6.3 Environmental risks and responsibilities

Due to its geographic location and low water resources, Jordan is unavoidably struggling with the consequences of climate change. As a result of this situation, there is a growing interest in addressing and preventing the effects of climate change.

The Jordanian Ministry of Environment plays a formative role in this process. The "Ministry of Environment's strategy (2020-2022)" states the ultimate goal as follows:

"To protect the environment, preserve vital ecological systems through setting and enforcing legislative frameworks, prepare strategies and policies, disseminate environmental culture and transition toward a green economy through a supportive institutional structure. The ultimate goal is to achieve sustainable development and reduce pollution and the negative effects of climate change while pursuing a participatory approach." [43]

In addition to this quote, the Sustainable Development Goals (SDGs) are also addressed (see Figure 6-19). The SDGs were set up by the United Nations General Assembly and represent the endeavor of a united global alliance to work towards a world with prosperity and peace.

Jordan has set itself the task of focusing especially on four goals out of the total 17 listed. These include

- SDG 12 - Responsible Consumption and Production
- SDG 13 - Climate Action
- SDG 14 - Life Below Water, and
- SDG 15 - Life on Land.

Figure 6-19: UN Sustainable Development Goals

The consequences of environmental problems can be direct or indirect. A direct consequence may be contamination of the soil or water. Further influences can, for example, affect wildlife.

[43] Ministry of Environment Strategy 2020 – 2022, p. 21

The leakage of a gaseous, liquid, or solid substance can have serious consequences for humans, animals, and nature. SWRO plants are at a high risk to cause a widely spread contamination, as substances distribute quickly if discharged into the sea and thereby affect larger areas before they are sufficiently diluted. Safeguarding the aquatic environment and ecosystems in the vicinity of desalination plant discharges is an essential component of good operation practices by the desalination industry[44].

An indirect influence contributes to the increase of the Greenhouse effect and therefore causes an increased number of natural catastrophes. These may include anything from heavy rainfall events to long periods of drought.

During the feasibility study of any SWRO plant, an Environmental Impact Assessment (EIA) should be performed. An EIA is a project- and site-specific systematic procedure for identifying and evaluating all potential impacts of a proposed project. After identifying the impacts, appropriate mitigation measures and alternatives, such as modifications to the process or alternative project sites, can be developed. Performing a thorough EIA does not only benefit the environment but can also protect the SWRO plant from negative effects from the environment, such as bad source water quality and seasonal effects like algal bloom or jellyfish outbreaks[45]. Please refer to Chapter 1 in the SW Planning Guidelines for more information regarding environmental impacts.

Most important decisions regarding environmental impacts and mitigation of negative effects are made during the planning phase, such as the choice of site or outfall structures. Therefore, during the operational phase of the SWRO plant, the focus lies on maintaining all structures and equipment and sustainable use of resources, so that the plant operation can be carried out as designed in compliance with the EIA and environmental requirements.

It lies in the responsibility of the management as well as each worker at a SWRO plant to comply with these SDGs as far as possible. Environmental management procedures must be compiled for each of the major environmental issues of concern. Management decisions must be respected and carried out throughout plant operation. Each individual can make his or her contribution by using resources wisely and thoughtfully. In addition to official inspections carried out by authorities to check compliance with legal regulations, the compliance of the contractor with environmental commitments stated in the operating and maintenance contracts should be controlled by the employer.

The main aspects that have to be considered in everyday work at SWRO plants are depicted in Figure 6-20 and include but are not limited to

- Consumption of chemicals
- Management of liquid or solid wastes including concentrate discharge
- Potential seawater pollution
- Consumption of energy and the causation of CO_2 emissions
- Sustainable use of resources

If all of these aspects are considered and implemented with respect, this can contribute to an important part of the fight against direct and indirect impacts.

[44] N. Voutchkov (2019). Sustainable Management of Desalination Plant Concentrate
[45] S. Lattemann (2007). Environmental impact and impact assessment of seawater desalination

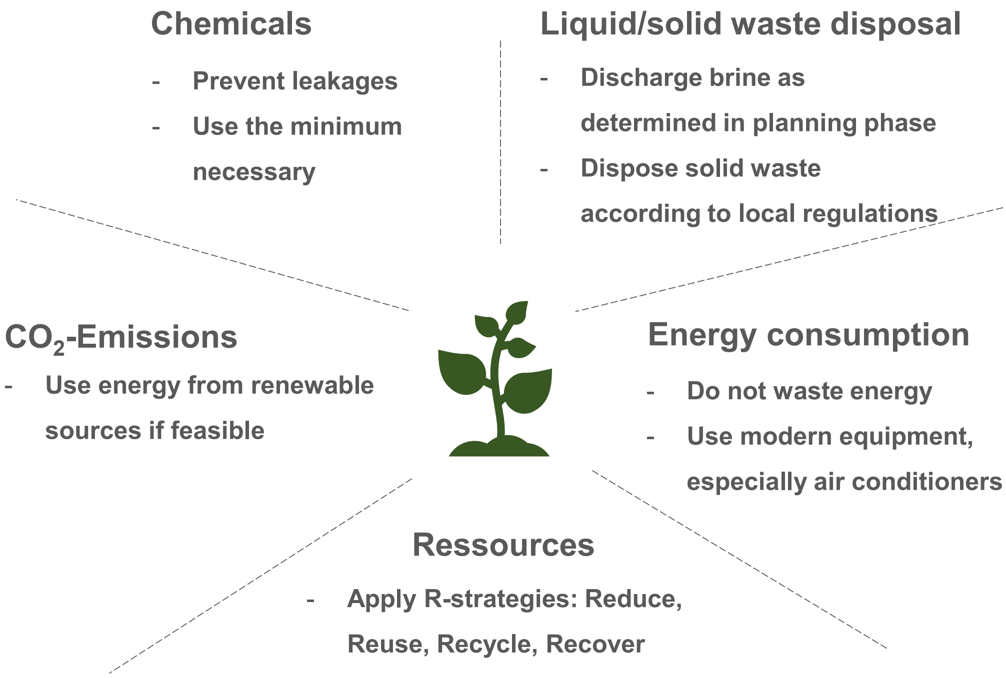


Figure 6-20: Environmental risks and responsibilities - Applications

Chemicals

Starting with the chemical impact: this has already been described in Chapter 3.3.3. To summarize from this chapter: Use only as much of a chemical as needed. Do not increase or overdose chemicals to achieve better plant operation or to make up for operational issues. This can lead to an increased potential for damage to membranes and other equipment as well as elevated harmful concentrations in brine or filter backwash water. Only use the intended chemicals as only they are tested for their environmental impact.

During daily work, watch out for damage that can lead to leakage and cause serious hazardous situations. If stored improperly, chemical spills can cause further sea- or groundwater and environmental damage. Such incidents are to be avoided. As discussed previously, chemicals must be stored inside in a chemical containment area with a ground, that is impervious to chemicals. Chemicals also must be stored in protective and chemically resistant containers with appropriate labelling.

Disposal of brine

Brine has to be disposed exactly as designed in the planning process. If environmentally less desirable discharge options such as direct and undiluted discharge of untreated brine are performed, more sustainable and advanced alternatives such as off-shore diffusers can be found in the SW Planning Guidelines. Incorrect brine discharge can lead to aquatic zones with a salt concentration (TDS) higher than what the affected aquatic organisms might tolerate. Therefore, keep the pipelines and installations needed for brine discharge maintained and in good shape. Do not alter brine discharge to avoid reparations! Always contact the assigned supervisor if unsure. Do not mix untreated filter backwash water or other contaminated liquid waste into brine unless the harmfulness of these flows has been proven.

Management of solid or liquid wastes

Special attention should also be paid to the disposal process of waste or residual materials. Clean waste from hazardous chemical residues before disposal. Always dispose solid waste according to local regulations. Used membrane elements can be disposed as municipal waste, provided no remnants of preservation solution or other hazardous substances remain in the elements[46]. If possible, separate the waste so that it can be more easily be recovered or recycled. Old spare parts and electrical equipment contain valuable materials that can be recycled. Do not store wastes outside, where they can be carried away by wind and washed into the sea!

As for liquid waste, this mostly refers to other discharge streams besides brine, including pre-treatment filter backwash water and membrane cleaning water. The most common treatment options before the discharge of these streams include equalization and neutralization of the streams or settling and sludge dewatering with the solid waste being discharged into landfills. Regardless of the exact specifics, it is important to not alter the discharge process to avoid any negative environmental impacts.

In general, close monitoring of any discharge water quality must be performed to ensure that the discharge water meets the requirements from the EIA as well as all local regulations.

Consumption of energy and the causation of CO_2 emissions

With the whole world facing challenges due to climate change, every action should be considered with the environmental impact in mind. CO_2 emissions can be reduced by using renewable energy sources when possible. Generally, try to consume as little energy as necessary. This can be achieved by using modern and therefore more efficient equipment, for example for air conditioning, as well as by simply not wasting energy in everyday life by leaving machinery or lights on when not needed.

Sustainable use of resources

Finally, one should take a special look at the resources and the general handling of them. For example, when disposing a material or spare part, one

ask oneself whether the simple disposal might have been avoidable or if they could be refashioned for another use. Consider the R-strategies: Reduce, Reuse, Recycle, Recover. However, these considerations must be made cautiously so that the technical and qualitative standards are still achieved.

[46] DuPont (2021). FilmTec™ Reverse Osmosis Membranes Technical Manual, Version 7

Take Away Messages – Environmental risks and responsibilities:

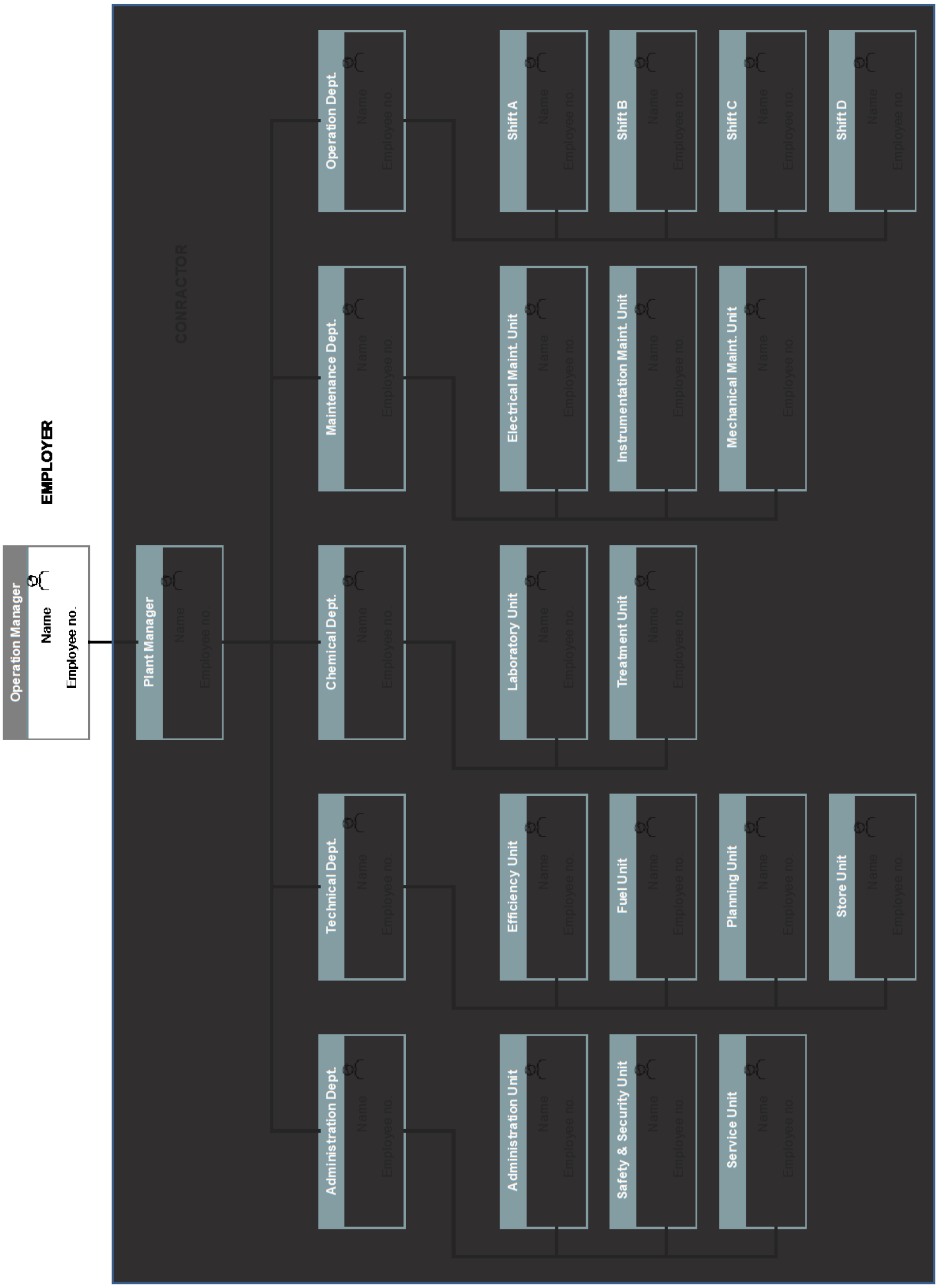
- Everyone is asked to do his or her part to reduce negative environmental impacts!
- Malpractice can result in direct consequences that affect the stable operation of a SWRO plant as well as long-term consequences.
- Always discharge liquid and solid waste in accordance with the regulations of the company and/or the local authorities.
- Try to minimize the consumption of energy, chemicals and materials as far as possible.

Table 6-2: Checklist for Chapter 6

Environment, health, and safety		*Drawn by:*	
		Checked by:	
NO.	DESCRIPTION	CHECKED	REMARKS
6.1	**Superordinate safety measures**		
	1) Are the roles and responsibilities defined and documented? Are the different authorities acknowledged by workers and management?		
	2) Is every worker at the SWRO plant aware of the importance of environment, health, and safety issues?		
	3) Is all safety equipment maintained and in its place?		
	4) Are all workers trained in the use of this safety equipment?		
	5) Are standardized written safety instructions available for hazardous machinery and tasks?		
	6) Do you discuss and document the tasks performed by external workers beforehand?		
	7) Is first aid equipment available at the plant? Are there trained first responders for emergencies?		
6.2	**Individual safety measures**		
	1) Are the recommendations for general safe work practices implemented throughout the facility? (Chapter 6.2)		
	2) Do you check whether the hazard of performing dangerous tasks can be reduced by performing the task in a different, safer way? (For example with telescope equipment, from outside instead of inside of confined spaces etc.)		
	3) Is appropriate Personal Protective Equipment available? Do workers know how to properly use the equipment?		
	4) Do supervisors have a good overview over who is working where?		
	5) Do supervisors regularly check on their employees performing hazardous tasks?		
	6) Do only trained and healthy workers perform any hazardous tasks?		
6.3	**Environmental risks and responsibilities**		
	1) Are all workers and the management aware of the necessity to protect the environment and to act sustainably?		
	2) Is all waste discharge performed according to local regulations and in the best possible way?		
	3) Do you ensure to minimize the consumption of chemicals and materials within the boundaries of safe and continuous operation of the SWRO plant?		

7. Appendix

7.1 Organizational chart



7.2 Job descriptions

Job Description
Job Title: HR Supervisor
Situation in Organization
Reports to personnel manager or plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Supervise the operational activities of the Personnel department. Enhance systems and procedures to improve the operating quality and efficiency of the department. Supervise staff in accordance with company policies and procedures.
Responsibilities
As HR Supervisor, the responsibilities would include, but are not limited to the following:
▪ Analyze and document business processes and problems. Enhance solutions to enhance efficiencies.
▪ Supervise staff in accordance with Division/dept Communication Matrix and conduct limited employee performance reviews.
▪ Responsible for staff scheduling to include work assignments/rotations, employee training, employee vacations, employee breaks, overtime assignment, back-up for absent employees, and shift rotations.
▪ Schedule and conduct department meetings and responsible to meet department productivity and quality goals.
▪ Maintain all personnel records at a high level of confidentiality and ensure the processing of all new employees, update employee's file to cope with official documents requirement.
▪ Communicate with Supervisors, Managers, on Department operations and follow-up latest issues of Jordanian Labor Law and future amendments.
▪ Monitor the in processing of all new employees.
▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
▪ Carry out annual performance evaluation of reporting employees.
▪ Provide on-the-job training to new employees and evaluate their OJT Performance
▪ Identification and control of hazards in assigned work area.
▪ Ensure aspects identified are monitored and operational controls are followed.
▪ Report deviations in Integrated Management System.
▪ Effective resource utilization.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Bachelor Degree in Engineering, preferred Master Degree
▪ Minimum of X years of experience in a similar position
Required skills-set: ▪ Awareness of Quality, Occupational Health & Safety and Environment Management system principles ▪ Knowledge of applicable legal requirements ▪ Hazard Risk assessment

- Aspect Impact assessment
- Interpersonal and supervisory skills.
- Computer literate
- Communications skills

Desired certifications and skills:
Perform a broad range of supervisory responsibilities over others.
Work under pressure (i.e., handling significant problems and tasks which come up simultaneously and/or unexpectedly).
Write reports and statistical data analysis.

Work Location: Plant or Supervising Organization

Job Description
Job Title: HSE Manager
Situation in Organization
Reports to plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Supports the Top Management in the HSE Policy and Guidelines issue, in the Organization roles and responsibilities definition, for what concerns safety aspects and in the HSE Management System standard issue.
Responsibilities
As HSE Manager, the responsibilities would include, but are not limited to the following:
▪ Manage and actively participating in plant activities while maintaining focus to overall company objectives and consistency through HSE management
▪ Ensures, in accordance with the management guidelines, the implementation, updating, review and auditing of the plant HSE Systems
▪ Maintain company policies and HSE program by providing education to all field employees and contractors
▪ Monitors the effective implementation of appropriate Safety and Environment System procedures and provide for their updating in line with changes in Legislation and Company Directives
▪ Provides for motivation and familiarization of all Company personnel respecting the importance of complying with Company system procedures and all Safety equipment provided.
▪ Assists the Engineering and Operations Department in all issues concerned with Health and Safety at work.
▪ Conducts safety audits both internal and external
▪ Carries out analysis of accident / incident statistics, identifying trends and suggesting improvement plans
▪ Provides technical support to Senior Management on any safety related subjects
▪ Carries out any in-house safety training.
▪ Carries out safety audits on Sub-contractors
▪ Safeties related engineering input into new projects and modification programs
▪ Participates to HAZOP meetings prior to procurement and installation activities
▪ Performs Risk Assessment

▪ Preparation of Health and Safety documentation
▪ Provides Safety support and advice, including supervision on preparation of plans and procedures for initial contract start up activities.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Bachelor Degree in Occupational Safety & Health or related disciplines, preferred Master Degree
▪ Valid registration as a Workplace Safety and Health Officer
▪ Minimum of 7 years of experience in a similar position, 5 years of experience on supervision level
▪ Certification as a Fire Safety Manager is an advantage
Required skills-set: ▪ Knowledge on Quality, Occupational Health & Safety and Environment Management system principles ▪ Knowledge of applicable legal requirements ▪ Hazard Risk assessment ▪ Aspect Impact assessment ▪ Interpersonal and supervisory skills. ▪ Computer literate ▪ Communications skills **Desired certifications and skills:** Perform a broad range of supervisory responsibilities over others. Work under pressure (i.e., handling significant problems and tasks which come up simultaneously and/or unexpectedly). Write reports and statistical data analysis.
Work Location: Plant or Supervising Organization

Job Description
Job Title: HSE Officer
Situation in Organization
Reports to the HSE Manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Supports the HSE Manager in the HSE Policy and Guidelines issue, in the Organization roles and responsibilities definition, for what concerns safety aspects and in the HSE Management System standard issue.
Responsibilities
As HSE Officer, the responsibilities would include, but are not limited to the following:
▪ Actively participating in plant activities while maintaining focus to overall company objectives and consistency through HSE management
▪ Ensures, in accordance with the management guidelines, the implementation, updating, review and auditing of the plant HSE Systems
▪ Monitors the effective implementation of appropriate Safety and Environment System procedures and provide for their updating in line with changes in Legislation and Company Directives.

▪ Responsible for recording and reporting of all worker injury documentation to plant HSE Manager.
▪ Conduct a training session for the employees about the HSE protocol.
▪ Identify non-compliant, incomplete, or substandard procedures, for activities involving employees and/or contractors in the plant
▪ Working with operations and maintenance employees to promote permit to work system and ensure safety of everyone involved in the processes
▪ Providing support in all aspects of post-accident / injury treatment process
▪ Participating in the continuous auditing of HSE management systems
▪ Carrying out investigation into major incidents and submitting an investigation report
▪ Leading on-site HSE training programs designed to motivate field personnel
▪ Ensure to conduct walk around checks regularly to monitor HSE controls
▪ Ensure availability of first aid measures at locations
▪ Ensure availability of firefighting equipment and inspection of its status
▪ Collection of environmental deviations and ensure identification, implementation of corrective actions
▪ Plan HSE emergency drills, review reports and update procedures
▪ Ensure continuous control on identified risks
▪ Monitor collection, storage and disposal of wastes
▪ Ensure the availability of medical facilities and medicines in the ambulance
▪ Monitor the validity of certification of equipment and operator license
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Degree in Occupational Safety & Health or related disciplines
▪ Valid registration as a Workplace Safety and Health Officer
▪ Minimum of X years of experience in a similar position
▪ Certification with SCDF as a Fire Safety Manager is an advantage
Required skills-set: ▪ Awareness of Quality, Occupational Health & Safety and Environment Management system principles ▪ Knowledge of applicable legal requirements ▪ Hazard Risk assessment ▪ Aspect Impact assessment ▪ Interpersonal and supervisory skills. ▪ Computer literate ▪ Communications skills **Desired certifications and skills:** Work under pressure (i.e., handling significant problems and tasks which come up simultaneously and/or unexpectedly). Perform training activities. Write reports and statistical data analysis.
Work Location: Plant or Supervising Organization

Job Description
Job Title: Laboratory Manager
Situation in Organization
Reports to plant general manager
Job Dimensions

- Value of operated production: XXX
- Number of subordinates: XXX
- XXX

Activities

Supervise, control and ensure that all chemical plant maintenance and laboratory activities are accomplished in accordance with authorized plans, procedures, schedules, cost budgeted and quality standards.

Responsibilities

As Laboratory Manager, the responsibilities would include, but are not limited to the following:

- Maintain an up-to-date knowledge of the plant running condition and chemical dosing. Maintain appropriate record of chemical plant activities.
- To observe and guide the implementation of work safety procedure and practice.
- Direct the implementation of established maintenance schedules and procedures to ensure effective chemical plant operation. Establish and initiate the annual and preventive maintenance of chemical plant.
- Review and recommend new plans, procedures and schedule for chemical plants, acid cleaning, boil out and laboratory etc.
- Prepare reports and appropriate recommendation to superior, to help evaluate progress and take appropriate action.
- Supervise, direct and co-ordinate the activities of all Engineers and other personnel assigned to Chemical Section.
- To ensure availability of bulk chemicals, fine chemicals, glasswares and other consumables and to raise Purchase Requisitions as and when required.
- Ensure availability of MSDS for chemicals
- Ensure calibration of identified critical equipment in the lab.
- Conduct frequent measurement of water quality in the lab and report deviations, if identified.
- Monitor and report stack emission
- Ensure availability of suitable PPE, eyewash facility, first aid measures in the chemical handling area
- Ensure proper waste disposal measures
- Perform other duties as assigned.

Profile /Qualifications /Experience Required

- Post-graduation in Chemistry, or
- Post-graduation in Chemistry with environmental and safety qualification.
- X years in Power/Desalination plant.

Required skills-set:

1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles
2. Knowledge of applicable legal requirements
3. Hazard Risk assessment
4. Aspect Impact assessment
5. Knowledge of environmental and health impact of chemicals being used in the plant
6. Should be well conversed with Power/Desalination Operational activities in Chemical Lab.
7. Decision making.
8. Analytical.
9. Teamwork.

Desired certifications and skills:

SAP working knowledge is preferred. ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred.

Work Location: Plant or Supervising Organization

Job Description
Job Title: Engineering Manager
Situation in Organization
Reports to plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Develops and applies an engineering support and technical service for the facility. His/her team is responsible to resolve operational difficulties/troubleshooting, evaluate material performance, review plant/equipment designs/specifications, coordinate in developing projects, suggest proactive actions to enhance plant performance, minimize O&M cost, achieve targeted plant availability, maximize sustainability of the production and the facility, suggest measures to extend plant life, etc. Responsible for planning, design, and construction phase services.
Responsibilities
As Engineering Manager, the responsibilities would include, but are not limited to the following:
▪ Provides guidance and direction on department design guides, standards, systems, applicable engineering codes
▪ Carrying out diligent verification of basic data, design specifications, systems standards of major plant equipment installed by the EPC contractors & desalination projects or to be installed in new Projects.
▪ develop the “Scope of Work” defining the functional requirements/equipment specifications, in case any system/equipment requires modification to be performed by outsourced agency.
▪ Responsible for responding to the queries and/or clarifications concerning technical specifications asked by the Contractors.
▪ Assures that plant O&M crews can analyze critical system upsets/operating problems and recommend measures to avoid recurrences.
▪ Responsible for the performance of Residual Life Assessment (RLA) studies for the major plant equipment and recommend corrective actions for extending the lifespan and/or for better and economic utilization of the equipment, wherever necessary.
▪ Assure all major areas of engineering support and technical consultancy offered by the ▪ Engineering & Technical Support Management team.
▪ Assists with performance management process, mentoring, recognition, and any corrective actions required.
▪ May participate in career planning and learning and development.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ M.S. (Chemical Science or Engineering) + X years of similar job experience
▪ X years with M.S. in O&M in Senior Position or X years with Ph.D. in O&M in Senior Position both having sound chemical, biological and metallurgical backgrounds.
Required skills-set: ▪ 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles

- 2. Extensive practical exposure to process, mainly Desalination (SWRO or SWRO) Plants, capable of reviewing Plant designs, technical evaluation of projects, versed with engineering calculations, material and energy balance, design and rating of RO systems, hydraulic calculations, process and control and system/protection analyses, international codes, practices, regulations and standards. material performance and corrosion, Risk- Based Inspection and inspection techniques, determination of Plant aging, Residual Life Assessment on fixed equipment (Pumps, pressure piping system, RO system, Energy Recovery Devices, Water Transmission pipelines, pressure vessels, columns, etc.), schematic diagrams, specification assessment, working knowledge to use RO-process related latest software, analytical ability to handle troubleshooting, process/equipment failures, carryout investigations/ Root Cause Analysis, suggest plant modifications/process improvement, analyze the impact of chemical imbalances, know potential water/environmental pollutants, their maximum permissible limits and hazards, carryout feasibility studies, experience of Report writing and technical editing.
- 3. Familiarization with Value Engineering, predictive/ preventive/ corrective maintenance, Analysis of Process Data Sheets, etc., will be additional advantage.

Desired certifications and skills:
Basic computer skills, such as MS Word, MS Excel, MS Power Point, and MS project, etc., are must. Similarly, the candidate should have proficient English communication, reporting and presentation skills.

Work Location: Plant or Supervising Organization

Job Description
Job Title: Maintenance Manager
Situation in Organization
Reports to plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
The Maintenance Manager is responsible for the efficient and reliable maintenance of the plant ensuring all safety regulation, maintenance procedures and plant polices are followed.
Responsibilities
As Maintenance Manager, the responsibilities would include, but are not limited to the following:
▪ Supervises and assigns work to engineers & supervisors and ensures that all tasks are carried out timely. Responsibilities include training employees planning, assigning and directing work, appraising performance, rewarding and disciplining employees addressing complaints and resolving problems.
▪ To implement preventive maintenance plans and to arrange corrective maintenance activities as per requirement.
▪ The Maintenance Manager is directly responsible to ensure operation of the station's Computerized Maintenance System through the implemented software for all maintenance activity, (if available).
▪ To ensure the effective utilization of all material and human resources keeping in view the implementation of all safety regulations and maintenance procedures.

	▪ To conduct co-ordination meetings with different sections of maintenance department to analyze maintenance activities and to ensure trouble free running of the plant.
	▪ Recommend for the department annual maintenance and capital budget for approval of plant manager.
	▪ To reviews purchase requisitions for spare parts and consumables ensuring budgetary constraints and arrange strategic spares availability to cope up with the maintenance requirements.
	▪ To analyze and resolve work problems or supervise workers in solving work problems. Initiates plans to motivate workers to achieve work goals. Coordinate with other department Managers to investigate & find out root causes of chronic & intermittent problems as per requirement.
	▪ Ensure Environmental Aspect-Impact and Hazard Risk Assessment are carried out, controlled and updated.
	▪ Identify, establish and monitor IMS (Integrated Management System) objectives, targets and programs.
	▪ Provide necessary resources for effective implementation and sustenance of IMS.
	▪ Report IMS performance to the management periodically.
	▪ Ensure Legal compliance with respect to their scope of activities.
	▪ Ensure identification of root cause for the identified non-conformances/ deviations and to implement corrective actions/Preventive actions.
	▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
	▪ Carry out annual performance evaluation of reporting employees9. Responsible for waste management.
	▪ Ensure the provision of PPE (Personal Protective Equipment) and other safety equipment to the working personnel in the plant.
	▪ Monitor and control contractors' & subcontractors' activities within the premises with respect to IMS.
	▪ Ensure achievement of IMS objectives and targets.
	▪ Ensure PTW Permit To Work) procedure is implemented effectively.
	▪ Ensure identified on the job training are provided systematically.
	▪ Coordinate and participate in the mock emergency drills.
	▪ Identify, calibrate, and maintain measuring instruments.
	▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required	
	▪ Bachelor's engineering degree (B.E) in Mechanical / Electrical / Electronic field from four-year College or university.
	▪ Minimum of X years related experience and training or equivalent combination of education and experience.
Required skills-set:	
	1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of applicable legal requirements 3. Hazard Risk assessment 4. Aspect Impact assessment 5. Investigating skills 6. Knowledge of spillage containment 7. Knowledge of managing HSE emergencies 8. Knowledge of identification, classification and disposal of waste 9. Leadership and communication skills 10. Computer literate. Able to use MS Outlook for correspondence.

11. Be able to use SAP as end user.
12. Be able to lead and manage the maintenance team.

Work Location: Plant or Supervising Organization

Job Description
Job Title: Mechanical Technician
Situation in Organization
Reports to Mechanical Supervisor
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Works under the direction of Mechanical Supervisor/ Foreman to execute all preventive and corrective maintenance, monthly /annual outage, and overhauling work activities on plant equipment
Responsibilities
As Mechanical Technician, the responsibilities would include, but are not limited to the following:
▪ To performs routine, corrective and preventive maintenance of plant equipment, repair, lubrication and cleaning of machines and tools, mechanical, electrical and hydraulic systems as per the direction of Maintenance Supervisor/ Foreman.
▪ To use precision measuring devices such as dial indicator, feeler gauges, height gauges, micrometers, venire calipers and dial indicators to verify conformances of machine alignment & other installations.
▪ To operate bench grinder, drill machine and cutter as and when required. Also, to operate Fork Lift truck if required and performs small welding and fabrication jobs.
▪ To apply mechanical craft, techniques, processes and principles and be responsible for all necessary preparation required to carry out mechanical maintenance to equipment/area assigned to him.
▪ Co-ordinate with other technicians all assigned maintenance and repair works, and ensures that al equipment is kept in good operating condition after repair.
▪ To report to his Forman for spare parts and consumables in his area to update spares availability to cope up with the maintenance requirements.
▪ To confirm all safety and proper isolation is carried out to repair the equipment under maintenance with coordination with his Forman and local operator.
▪ To apply knowledge of properties and uses of various metals such as aluminum, brass, steel, cast iron, and stainless steel as per requirement of maintenance task.
▪ Follow standard procedures.
▪ Use proper PPEs and implement prescribed risk controls.
▪ Report deviations in Quality, Health and safety management system.
▪ Report emergencies and near misses.
▪ Ensure proper waste disposal measures.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Diploma in Mechanics.
▪ Minimum of X years of general experience, X years related experience and training or equivalent combination of education and experience.

Required skills-set:

1. Generic awareness of Quality, Occupational Health & Safety and Environment Management system principles
2. Knowledge of identification, classification and disposal of waste
3. Knowledge of Emission Monitoring
4. Knowledge of environmental and health impact of chemicals being used in the plant
5. Knowledge of firefighting equipment
6. Knowledge of PPE and safety equipment
7. Knowledge of First aid measures
8. Be able to execute the maintenance activities with high performance.
9. Hazard Risk assessment
10. Aspect Impact assessment

Desired certifications and skills:
ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred

Work Location: Plant

Job Description
Job Title: Operations Manager
Situation in Organization
Reports to plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Ensure effective management and control of plant operating functions/all desalination plant operation & maintenance and laboratory activities in accordance with established and contractual requirements, schedules, quality cost and time objectives.
Responsibilities
As Operations Manager, the responsibilities would include, but are not limited to the following:
▪ Responsible for the overall administration and supervision of operation staff and operating activities including planned shut down and starting of the plant in accordance with established work plans schedules and ensuring safety of all personnel and environment.
▪ Participate in and concur all decisions regarding new design criteria, technical specifications and operating methods related to the plant.
▪ Preparing the plant operating budget and cost control system.
▪ Conduct regular meetings to discuss work progress, schedules, problems, interferences, priorities etc.
▪ Responsible for efficiency and progress of work in accordance with production schedules and established standards.
▪ Responsible for initiating changes in methods, schedules and procedures needed to meet specific exigencies of the plant operations after suitable approval from the Plant Manager.

	▪ Maintain reporting system which provides sufficient data to ensure that operations are being accomplished within the specified limits, schedules and technical parameters.
	▪ Ensure and advise on proper and effective allocation and development of human resources to ensure maximum efficiency. Submit periodic reports to his supervisor and keep him informed on all technical problems, if any, as well as on new changes or modifications on existing work plant or schedule.
	▪ Ensure Environmental Aspect-Impact and Hazard Risk Assessment are carried out, controlled and updated.
	▪ Identify, establish and monitor IMS (Integrated Management System) objectives, Targets and programs.
	▪ Provide necessary resources for effective implementation and sustenance of IMS.
	▪ Report IMS performance to the management periodically.
	▪ Ensure Legal compliance with respect to their scope of activities.
	▪ Ensure identification of root cause for the identified non-conformances/ deviations and to implement corrective actions/Preventive actions.
	▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
	▪ Carry out annual performance evaluation of reporting employees. Responsible for waste management.
	▪ Ensure the provision of PPE and other safety equipment to the working personnel in the plant.
	▪ Monitor and control contractors' & subcontractors' activities within the premises with respect to IMS.
	▪ Ensure achievement of IMS objectives and targets.
	▪ Ensure PTW procedure is implemented effectively.
	▪ Ensure identified on the job training are provided systematically.
	▪ Coordinate and participate in the emergency mock drills.
	▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required	
	▪ Minimum: Bachelor of Engineering is a must, preferred post-graduation in engineering with power plant engineering specialization.
	▪ X years in desalination, minimum X years in RO desalination plant.
Required skills-set: 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of applicable legal requirements 3. Hazard Risk assessment 4. Aspect Impact assessment 5. Investigating skills 6. Knowledge of spillage containment 7. Knowledge of managing HSE emergencies 8. Knowledge of identification, classification, and disposal of waste 9. Should be well conversed with Desalination/RO Operational activities. 10. Leadership and communication skills 11. Decision making and analytical skills. 12. Teamwork and problem-solving skills. **Desired certifications and skills:** SAP working knowledge is preferred, if SAP system available). ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred.	
Work Location: Plant	

Job Description
Job Title: Shift Engineer
Situation in Organization
Reports to Operations Manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Supervise, control and co-ordinate all plant operations activities to ensure timely and effective plant production in accordance with established schedules, quality, cost and time objectives. Responsible for safe startup/shut down of the plant as per the Standard Operating Procedures.
Responsibilities
As Shift Engineer, the responsibilities would include, but are not limited to the following:
▪ Organize the plant in such a way that work is carried out to the required standard with minimum risk to men, machine and materials, comply with safety and environmental standards.
▪ Coordinate with all other departments all activities that are related to plant operations during the shift and comply with safety rules and regulations. Have a complete understanding of the permit to work system applied to the plant. Issue and cancel permits to work per authorization. Coordinate activities involving plant chemistry with the Chemist.
▪ Follow preset operational schedules to fulfill the planned production targets safely and efficiently. Coordinate all activities or changes in plant status with operations manager.
▪ Make quick, on the spot decisions to correct abnormalities or disturbances. Take corrective actions during a state of emergency. Supervise the interlock checks on startups, protection tests, non-routine activities like preservation, acid cleaning etc.
▪ Monitor the overall status of the plant and summarize activities in the logbook. Fill daily plant status reports and relay all activities that occurred during his shift.
▪ Maintain staff evaluation records, vacation schedules etc. prepare evaluation forms for personnel requirement.
▪ Prepare incident / accident reports and other reports required by the departments. Keep accurate records and prepare daily and monthly reports. Assist in the training and familiarization of new personnel in the shift. Study and suggest for any modifications which can improve the plant efficiency.
▪ Ensure Environmental Aspect-Impact and Hazard Risk Assessment are carried out, controlled and updated.
▪ Implement, monitor and report IMS (Integrated Management System) objectives, Targets and programs.
▪ Provide necessary resources for effective implementation and sustenance of IMS.
▪ Report IMS performance to the management periodically.
▪ Ensure Legal compliance with respect to their scope of activities.
▪ Ensure identification of root cause for the identified non-conformances/ deviations and to implement corrective actions/Preventive actions.
▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
▪ Carry out annual performance evaluation of reporting employees.

▪ Responsible to ensure the compliance to legal requirements, contractual and organizational requirements.
▪ Provide on-the-job training to new employees and evaluate their OJT Performance.
▪ Identification, documentation and control of hazards in assigned work area.
▪ Ensure aspects identified are monitored and operational controls are followed.
▪ Report deviations in Integrated Management System, identify root cause and implement corrective and preventive actions.
▪ Reporting of emergencies and incidents and near misses.
▪ Effective resource utilisation.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Minimum: Bachelor of Engineering, preferred post-graduation in engineering with power plant engineering specialization.
▪ Minimum X years in Desalination/RO plant.
Required skills-set: 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of applicable legal requirements 3. Hazard Risk assessment 4. Aspect Impact assessment 5. Investigating skills 6. Knowledge of spillage containment 7. Knowledge of managing HSE emergencies 8. Knowledge of identification, classification, and disposal of waste 9. Knowledge of Emission Monitoring 10. Should be well conversed with Desalination/RO Operational activities. 11. Decision making and analytical skills. 12. Teamwork and problem-solving skills. **Desired certifications and skills:** SAP working knowledge is preferred if SAP available. ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred.
Work Location: Plant

Job Description
Job Title: Local Operator
Situation in Organization
Reports to Shift Supervisor
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Carry out all electrical operations of breakers, isolators, Master Control Boards, etc. Perform unit synchronization and assist electrical maintenance in trouble shooting to carry out all electrical isolation for PTW (Permit To Work). Monitor the electrical status of the plant in round the clock shift.
Responsibilities

As Local Operator, the responsibilities would include, but are not limited to the following:
▪ Comply with safety rules and regulations. Be familiar with the fire equipment in his area.
▪ Follow the instructions of the Shift Charge Engineer and Shift Supervisor. Coordinate with the Shift Supervisor, Desalination Operators and with other Operators regarding all activities that affect them.
▪ Monitor the electrical status of the plant, enter periodic readings on log sheets, and summarize all activities and events that took place during his shift into the logbook.
▪ Perform all electrical isolations for equipment to be out for maintenance as per the Permit To Work. Normalize the equipment after cancellation when instructed to do so.
▪ Be alert and take quick actions to overcome sudden changes in operating status. Understand the logic of the operation and understand and follow control logic.
▪ Carry out all electrical protection tests according to set schedules. Raise work requests or defect notes for any faulty equipment.
▪ Assist in the training and familiarization of new operators.
▪ Follow standard procedures.
▪ Use proper PPEs and implement prescribed risk controls.
▪ Report deviations in Quality, Health and safety management system.
▪ Report emergencies and near misses.
▪ Ensure proper waste disposal measures.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Minimum: Diploma in Electrical Engineering, a specialization in electrical safety is a plus.
▪ Minimum X years in Desalination/RO plant.
Required skills-set: 1. Generic awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of identification, classification and disposal of waste 3. Knowledge of Emission Monitoring 4. Knowledge of environmental and health impact of chemicals being used in the plant 5. Knowledge of firefighting equipment 6. Knowledge of PPE and safety equipment 7. Knowledge of First aid measure 8. Should be well conversed with Switch Board Operational activities. 9. Interpersonal and analytical skills. **Desired certifications and skills:** ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred. Electrical safety.
Work Location: Plant

Job Description
Job Title: Section Head – Electrical
Situation in Organization
Reports to Maintenance Manager
Job Dimensions

▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Works under the direction of Maintenance Manager to plan all type maintenance, monthly /annual outage and overhauling work activities on plant equipment and keeping the record.
Responsibilities
As Section Head - Electrical, the responsibilities would include, but are not limited to the following:
▪ To prepare purchase requisitions for spare parts and consumables ensuring budgetary constraints and arrange strategic spares availability to cope up with the maintenance requirements.
▪ Acquires considerable knowledge of the process and the relevant systems throughout the plant and applies the same to trouble shoot problems and leads the maintenance team in resolving the issues.
▪ Executes work order through CMMS (Computerized Maintenance Management System)(SAP, if available) and co-ordinates with maintenance engineer for job completion and technical matters.
▪ To apply technical craft, techniques, processes and principles and be responsible for all necessary preparation required to carry out mechanical maintenance to equipment/area assigned to him.
▪ To report to Maintenance Manager for daily activities spare parts and consumables in the department to update spares availability to cope up with the maintenance requirements.
▪ To performs routine, corrective and preventive maintenance of plant equipment, cleaning of machines related to I&C section.
▪ Ensure Environmental Aspect-Impact and Hazard Risk Assessment are carried out, controlled and updated.
▪ Implement, monitor and report IMS objectives, Targets and programs.
▪ Provide necessary resources for effective implementation and sustenance of IMS.
▪ Report IMS performance to the management periodically.
▪ Ensure Legal compliance with respect to their scope of activities.
▪ Ensure identification of root cause for the identified non-conformances/ deviations and to implement corrective actions/Preventive actions.
▪ Identify the competency gap for their subordinate personnel and implement necessary actions.
▪ Carry out annual performance evaluation of reporting employees.
▪ Responsible to ensure the compliance to legal requirements, contractual and organizational requirements.
▪ Provide on-the-job training to new employees and evaluate their OJT (On the Job Training) Performance.
▪ Identification, documentation and control of hazards in assigned work area.
▪ Ensure aspects identified are monitored and operational controls are followed.
▪ Report deviations in Integrated Management System & identify root cause and implement corrective and preventive actions.
▪ Reporting of emergencies and incidents and near misses.
▪ Effective resource utilization.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Bachelor’s engineering degree (B.E) in electronic field from four-year College or university, Master’s degree preferred
▪ Minimum of X years related experience and training or equivalent combination of education and experience.

Required skills-set: 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of applicable legal requirements 3. Hazard Risk assessment 4. Aspect Impact assessment 5. Investigating skills 6. Knowledge of spillage containment 7. Knowledge of managing HSE emergencies 8. Knowledge of identification, classification and disposal of waste 9. Leadership and communication skills 10. Computer literate. Able to use MS Outlook for correspondence. 11. Be able to use SAP as end user.
Work Location: Plant

Job Description
Job Title: Skilled Labor
Situation in Organization
Maintenance / Operations
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Works under the direction of Maintenance Technician/Supervisor/ Foreman to assist in execution of all preventive and corrective maintenance, monthly /annual outage and overhauling work activities on plant equipment.
Responsibilities
As skilled worker, the responsibilities would include, but are not limited to the following:
▪ Performs routine maintenance of plant equipment, repair, lubrication and cleaning of machines and tools, mechanical, electrical, and hydraulic systems as per the direction of Maintenance Supervisor/ Foreman.
▪ To use common measuring devices such as vernier calipers, micrometers, and dial indicators to perform maintenance tasks.
▪ To operate bench grinder, drill machine and cutter as and when required. Also, to operate Fork Lift truck if required and performs small welding and fabrication jobs.
▪ To be responsible for all necessary preparation required to carry out maintenance to equipment/area assigned to him.
▪ Co-ordinate with other technicians and ensure that all equipment is kept in good operating condition after repair.
▪ To report to his Forman for spare parts and consumables in his area to update spares availability to cope up with the maintenance requirements.
▪ To confirm all safety and proper isolation is carried out to repair the equipment under maintenance with coordination with his Forman and local operator.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ High school leaving certificate, technical certificate courses are a plus.

▪ Minimum X years related experience and training or equivalent combination of education and experience.
Required skills-set: 1. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Be able to assist in execution of maintenance activities. 3. Be able to perform small jobs independently.
Work Location: Plant

Job Description
Job Title: I&C Technician
Situation in Organization
Reports to Maintenance Supervisor
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Works under the direction of Maintenance Supervisor/ Foreman to execute all preventive and corrective maintenance, monthly /annual outage and overhauling work activities on plant equipment.
Responsibilities
As I&C Technician, the responsibilities would include, but are not limited to the following:
▪ To performs routine, corrective and preventive maintenance of plant equipment, repair, lubrication and cleaning of machines and tools, mechanical, electrical and hydraulic systems as per the direction of Maintenance Supervisor/ Foreman.
▪ To use precision measuring devices such as dial indicator, feeler gauges, height gauges, micrometers, venire calipers and dial indicators to verify conformances of machine alignment & other installations.
▪ To operate bench grinder, drill machine and cutter as and when required. Also, to operate Fork Lift truck if required and performs small welding and fabrication jobs.
▪ To apply mechanical craft, techniques, processes, and principles and be responsible for all necessary preparation required to carry out mechanical maintenance to equipment/area assigned to him.
▪ Co-ordinate with other technicians all assigned maintenance and repair works, and ensures that all equipment is kept in good operating condition after repair
▪ To report to his Forman for spare parts and consumables in his area to update spares availability to cope up with the maintenance requirements.
▪ Follow standard procedures.
▪ Use proper PPEs and implement prescribed risk controls.
▪ Report deviations in quality, health and safety management system.
▪ Report emergencies and near misses.
▪ Ensure proper waste disposal measures.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Associate's Diploma in Mechanics or equivalent

▪ Minimum of X years related experience and training or equivalent combination of education and experience.
Required skills-set: 1. Generic awareness of Quality, Occupational Health & Safety and Environment Management system principles 2. Knowledge of identification, classification, and disposal of waste 3. Knowledge of Emission Monitoring 4. Knowledge of environmental and health impact of chemicals being used in the plant 5. Knowledge of firefighting equipment 6. Knowledge of PPE and safety equipment 7. Knowledge of First aid measures 8. Be able to execute the maintenance activities with high performance.
Work Location: Plant

Job Description
Job Title: Operations Manager (Employer)
Situation in Organization
Reports to employer
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Ensure effective management and control of plant operating functions/all desalination plant operation & maintenance and laboratory activities in accordance with established and contractual requirements, schedules, quality cost and time objectives given to the contractor.
Responsibilities
As Operations Manager, the responsibilities would include, but are not limited to the following:
▪ Supervision, monitoring and control of the overall plant operations according to the contractual requirements.
▪ Participate in and concur all decisions regarding new design criteria, technical specifications and operating methods related to the plant and according to the contractual requirements.
▪ Supervise the plant operating budget and cost control system.
▪ Conduct regular follow-up meetings to discuss work progress, schedules, problems, interferences, priorities etc.
▪ Responsible for the approval of changes in methods, schedules and procedures needed to meet specific exigencies of the plant operations.
▪ Maintain reporting system which provides sufficient data to ensure that operations are being accomplished within the specified limits, schedules and technical parameters.
▪ Supervise and control proper and effective allocation and development of human resources to ensure maximum efficiency.
▪ Control Environmental Aspect-Impact and Hazard Risk Assessments.
▪ Follow-up on IMS performance.
▪ Control legal compliance with respect to their scope of activities.
▪ Control and approve root cause for the identified non-conformances/ deviations and the implementation of corrective actions/Preventive actions.

▪ Monitor and control contractors' & subcontractors' activities within the premises with respect to IMS.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Minimum: Bachelor of Engineering is a must, preferred post-graduation in engineering with power plant engineering specialization.
▪ 10 years in desalination, minimum 7 years in RO desalination plant.
Required skills-set: 13. Awareness of Quality, Occupational Health & Safety and Environment Management system principles 14. Knowledge of applicable legal requirements 15. Hazard Risk assessment 16. Aspect Impact assessment 17. Investigating skills 18. Knowledge of spillage containment 19. Knowledge of managing HSE emergencies 20. Knowledge of identification, classification, and disposal of waste 21. Should be well conversed with Desalination/RO Operational activities. 22. Leadership and communication skills 23. Decision making and analytical skills. 24. Teamwork and problem-solving skills. **Desired certifications and skills:** SAP working knowledge is preferred, if SAP system available). ISO9001, 14001, OHSAS 18001 awareness/working knowledge is preferred.
Work Location: Employer

Job Description
Job Title: Quality Manager
Situation in Organization
Reports to plant general manager
Job Dimensions
▪ Value of operated production: XXX ▪ Number of subordinates: XXX ▪ XXX
Activities
Supports the Top Management in all quality aspects and assures and controls the quality of the water production and plant operations. He /she is responsible for the compliance with the employer's requirements and puts in place and supervises the quality policy regulations and standards.
Responsibilities
As Quality Manager, the responsibilities would include, but are not limited to the following:
▪ Manage and actively participating in plant activities while maintaining focus to overall company objectives and consistency through quality management
▪ Ensures, in accordance with the management guidelines, the implementation, updating, review and auditing of the plant quality systems

▪ Establishes and maintains quality policy, processes, procedures, and related documents. Provides education to all field employees and contractors
▪ Reviews Quality Manuals, documents, and implementation procedures to verify compliance with industry codes and standards, regulations and regulatory commitments.
▪ Monitors the effective implementation of appropriate quality system procedures and provide for their updating in line with changes in Legislation and Company Directives
▪ Provides for motivation and familiarization of all plant personnel respecting the importance of complying with the quality system procedures.
▪ Assists the Engineering and Operations Department in all issues concerned with quality procedures and standards at work.
▪ Conducts quality audits both internal and external
▪ Carries out analysis to optimize and limits costs for inspections versus quality requirements.
▪ Provides technical support to Senior Management on any quality related subjects
▪ Preparation of quality assurance and control documentation and reports and briefs management.
▪ Reviews from a quality perspective (and approves if required) documents prepared by internal or external organizations such as quality manuals and procedures, technical deliverables, test plans and procedures, purchase orders, and subcontracts.
▪ Promotes safety awareness including adhering to safety rules and requirements. Participates, as needed, in safety field audits and assessments.
▪ Perform other duties as assigned.
Profile /Qualifications /Experience Required
▪ Bachelor Degree in Civil or Mechanical or related disciplines, preferred Master Degree
▪ Further qualifications as Lead Auditor
▪ Minimum of 7 years of experience in a similar position, 5 years of experience on supervision level
▪ Certification as a Fire Safety Manager is an advantage
Required skills-set: ▪ Knowledge on Quality, Occupational Health & Safety and Environment Management system principles ▪ Knowledge of applicable legal requirements and ISO standards (i.e. ISO 9001-2015) ▪ Excellent technical writing skills ▪ Interpersonal and supervisory skills. ▪ Computer literate ▪ Communications skills **Desired certifications and skills:** Perform a broad range of supervisory responsibilities over others. Work under pressure (i.e., handling significant problems and tasks which come up simultaneously and/or unexpectedly). Write reports and statistical data analysis.
Work Location: Plant

7.3 Permit-to-Work Form (example)

Permit to Work Form

Permit to Work/Work Order Number :

This Permit To Work is the formal way of tracking the authorisation and communication of all specified high-risk tasks involved with a work activity.

Section 1: General Details	
Work Activity Title: (As per Work Activity Risk Assessment)	
Location of Work Site:	
Company/Entity doing the work:	
Estimated Duration of Work:	From / / to / / (Max 3 weeks)
Specified High-Risk Work Tasks Covered by this Permit To Work:	Tick appropriate boxes and attach a copy of the required Form/s ☐ Hot Work ☐ Excavation ☐ Confined Space ☐ Plant Isolation ☐ Work at Heights ☐ Live Electrical Maintenance Work ☐ HV Switching Sheet and associated Access and Test Permits

Section 2: Permit Request *(On-Site Supervisor of the contractor/workers who have been engaged to perform the work):*

This acknowledgement signifies a formal request to commence a work activity involving one or more specified high-risk tasks. As the person requesting this permit, I hereby certify that:

- ☐ I have developed and/or reviewed the Risk Assessment and required Control Form/s relevant to this work activity.
- ☐ I have consulted with relevant people to ensure that controls are adequate.
- ☐ I am competent to coordinate this work activity in accordance with the attached Risk Assessment and Control Form/s.
- ☐ I shall undertake to implement all planned and necessary controls to ensure the health and safety of those completing or impacted by the activity.
- ☐ I shall ensure that the persons required to carry out the work are advised of and understand the requirements of the Risk Assessment and Control Form/s, and the Permit To Work / Access Instructions in Section 4 below.
- ☐ I shall monitor hazards and control methods throughout the work activity.
- ☐ I am requesting this Permit to be reviewed, registered and numbered by the PBPL Permit to Work Authorised Person.

Name:		**Signature:**		**Date:**		**Time:**	

Section 3: PBPL Person Engaging Contractor /Worker Review:

This sign off is to signify that the PBPL person who engaged the contractor/worker has reviewed all documentation and provided comments.

- ☐ I have reviewed the content of all related documents including the Risk Assessment and required Control Form/s and provided feedback to the contractor/workers.
- ☐ I confirm as the PBPL person who engaged the contractor/worker, I will monitor the methods of work and the implementation of the proposed controls to ensure that PBPL standards for health and safety are being achieved throughout the works.
- ☐ I have informed the relevant person/s for the area that the work is being performed in, the full scope of works to be completed by the contractor/workers and the processes developed for supervising and enforcing the works.

Name:		**Signature:**		**Date:**		**Time:**	

Section 4: PBPL Authorisation *(Completed by PBPL Permit to Work Authorised Person)*

This PBPL Authorisation signifies that the planning component of the work activity has been completed and that the work is authorised to commence in accordance with the Risk Assessment and required Control Form/s. As the PBPL Permit to Work Authorised person, I hereby certify that:

- ☐ I have reviewed the content of all related documents including the Risk Assessment and required Control Form/s.
- ☐ I have registered this Permit in the PBPL Permit To Work Register, allocated it a number and have written the number on all associated documents.

Name:		**Signature:**		**Date:**		**Time:**	
Constraints:	This Authorisation is valid until the following occurs, or the date and time shown below:						
				Date:		**Time:**	

☐ **Has an Extension of time been requested for the Permit to Work?** (Max 7 days from original close out date) **please refer to Section 8.**

Section 5: Permit To Work / Access Instructions

Note: **If you are entering a confined space as part of this work activity, you will need to sign onto and off the Confined Space Entry Record Only.** *(A person required to work under this Permit To Work must comply with each of these listed instructions).*

1.	Ensure you understand the scope of the activity and your role / tasks.
2.	Ensure you have read, and/or have had explained and understand, the Risk Assessment and Control Form/s. Ask questions if you are unsure. Report any pre-work concerns you may have.
3.	At the start of each shift contact the On-Site Supervisor, obtain any Permit To Work / Access instructions and obtain permission to commence work.

Permit to Work/Work Order Number :	

Section 5: Permit To Work / Access Instructions (cont'd)	
4.	Sign on at the commencement of each shift and sign off at the end of each shift.
5.	Notify other relevant Work Party Members and the On-Site Supervisor of the contractor/workers who have been engaged to perform the work immediately if you become aware of a new hazard while completing the work.

Section 6: Contractor Supervision *(if applicable)*				
Pre-start meeting held with the following contractor(s):				
Inspection/hold points to be when:				
Final Inspection on completion:	**Time:**		**Date:**	
Variations (if applicable):				

Section 7: Work Party Sign On / Off *(except for those entering Confined Spaces)*						
SIGN ON				SIGN OFF		
Print name (First & Last)	**Date**	**Time**	**Signature**	**Date**	**Time**	**Signature**

Section 8: Permit Extension (*Completed by ORIGINAL PBPL Authorised Person*)

This PBPL Authorisation signifies that the planning component of the work activity has been reviewed and the work is authorised to continue in accordance with the Risk Assessment and required Control Form/s. As the **ORIGINAL** PBPL Permit to Work Authorised person, I hereby certify that:

☐ I have reviewed the content of all related documents including the Risk Assessment and required Control Form/s.

☐ I have amended this Permit in the PBPL Permit To Work Register. The extension can only be given once and for a maximum of 7 days from the original close out date.

Permit Extended: From / / to / / (Max 7 Days)

Name:		**Signature:**		**Date:**		**Time:**	

Section 9: Permit Withdrawal (*On-Site Supervisor of the contractor/workers who have been engaged to perform the work*)

The work activity is complete, all persons are accounted for and the work site has been left in a safe manner. This Permit To Work, the Risk Assessment and Control Form/s must be returned to the PBPL Permit to Work Authorised Person.

Name:		**Signature:**		**Date:**		**Time:**	

Section 10: PBPL Person Engaging Contractor /Worker Close-Out

The work activity is complete, all persons are accounted for and the work site has been left in a safe manner. This Permit To Work, the Risk Assessment and Control Form/s must be returned to the PBPL Permit to Work Authorised Person by the on-site supervisor of the contractor/workers who have been engaged to perform the work.

Name:		**Signature:**		**Date:**		**Time:**	

Section 11: Permit Close-Out *(Completed by PBPL Permit to Work Authorised Person)*

All work associated with this Permit To Work has been completed and the documentation returned to me. I have closed-out the Permit in the PBPL Permit To Work Register and submitted the associated documents for scanning and filing.

Name:		**Signature:**		**Date:**		**Time:**	

7.4 Tool for calculating the water production cost

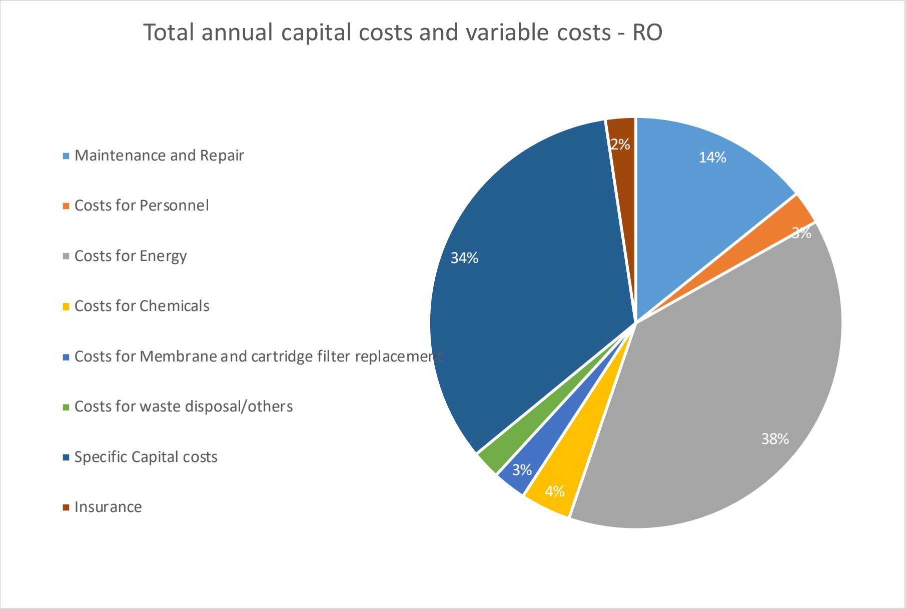
WPC - Calculation Tool for Seawater Water Desalination plants

Plant Location:	SW Plant - XXX									
Product water (Permeate)	12016.3	m³/h			=	288,392 m³/d	=	100,000,000 m³/a		
yield	0.45									
salt content feed	42,000	ppm			=	4.2 w%				
max. salt content permeat	300	ppm			=	0.03 w%				
feed	26703.0	m³/h			=	640,872 m³/d	=	222,222,222 m³/a		
brine	14686.6	m³/h			=	352,479 m³/d	=	122,222,222 m³/a		
operating hours	8,322	h/a	0.95	availability						
Energy Mix Renewable/Grid	25.0%									
Total Capital Costs										
Specific Total Investment Costs	1250	$/(m³/d)								360490267 $
Annual fixed costs from Investment										
From direct & indirect capital costs										25,577,670.26 $/a
Funding Period [a]:	25		Total interest rate and repayment rate [%]:	5		r [-]: 0.071				
total capital costs										**25,577,670.26** $/a
specific capital costs of the investment (product water)										**0.256 $/m³**
Annual fixed & variable costs from Operation & Maintenance										
maintenance & repair									21.39%	10,814,708.00 $/a
	3	% of investment								0.11 $/m³
Insurance									3.56%	1,802,451.33 $/a
	0.5	of capital costs [%]:								0.02 $/m³
staff									3.96%	2,000,000.00 $/a
costs [$/person/a]:	20000		staff [person]	100						0.02 $/m³
chemicals and additives									5.93%	3,000,000.00 $/a
	0.030	$/m³ product water								0.03 $/m³
replacement of membranes and cartridge filters									3.96%	2,000,000.00 $/a
	0.020	$/m³ product water								0.02 $/m³

Variable costs from Energy Mix						
[electr. energy] kWh/m³	3		total consumption [kW]: 36049			
Greenhouse Gas Emissions for electricity production from Grid						
	0.400	kgCO2/kWh	90000 tCO2/a			
energy (electrical) from Renewable Energy				4.45%	2,250,000.00	$/a
spec. costs [$/kWh]:	0.030		consumption [kW]: 9012		0.02	$/m³
energy (electrical) from Grid				53.39%	27,000,000.00	$/a
spec. costs [$/kWh]:	0.120		consumption [kW]: 27037		0.27	$/m³
waste disposal/others				3.36%	1,700,000.00	$/a
	0.017	$/m³ product water			0.02	$/m³
total fixed & variable costs				100%	**50,567,159.34**	**$/a**
specific variable costs (product water)					**0.506**	**$/m³**
annual capital costs and variable costs					**76,144,829.60**	**$/a**
specific costs (product water)					**0.761**	**$/m³**
specific carbon dioxide emissions (product water)					0.90	kg CO2/m³

Box for data entry	(yellow)
Results	(green)

Annual Fixed and Variable Costs	$/a	
Maintenance and Repair	10,814,708.00	14%
Costs for Personnel	2,000,000.00	3%
Costs for Energy	29,250,000.00	38%
Costs for Chemicals	3,000,000.00	4%
Costs for Membrane and cartridge filter replacement	2,000,000.00	3%
Costs for waste disposal/others	1,700,000.00	2%
Specific Capital costs	25,577,670.26	34%
Insurance	1,802,451.33	2%
Total annual capital costs and variable costs	76,144,829.60	100%



7.5 High-risk components of SWRO plants and recommended protective measures

Table 7-1 High-risk components of SWRO plants and protective measures [47]

Components	Recommendations
Pipelines	▪ The implementations of an accidental spill prevention plan for preventing and controlling accidental spills or discharges (especially concentrate discharges). ▪ Damaged or leaking containers will be isolated, when possible, in a containment area or repackaged to prevent loss, exposure or hazards. ▪ Leak detection of water pipeline. ▪ Periodic inspection of the water pipeline systems (routine maintenance of piping system). ▪ The replacement of old pipes with new pipelines. ▪ Prevention of corrosion. ▪ Preventive and corrective maintenance of the fiberglass reinforced polyester seawater collector (estimate the lifetime of collectors and change them periodically)
Transformer (oil-cooled)	▪ Transformer status check/control. ▪ Preventive maintenance of the various safety and protection devices of the transformer (relays, fuses, circuit breakers, powder, and carbon dioxide extinguishers). ▪ Dielectric oil transformer quality control (transformer oil aging) and replacement. ▪ Compliance with safety instructions. ▪ Design to the appropriate electrical standards. ▪ Periodically temperature oil checks. ▪ Gas emission control and periodic oil analysis.
High-pressure pumps	▪ Preventive and corrective maintenances are recommended. ▪ Install flow indicators. ▪ Increase pressure indication and alarms. ▪ Preventive and corrective maintenance can reduce the physical hazard of noise. ▪ Recommend anti-vibration pump core.
Compressors	▪ Installing a pressure sensor. ▪ Carbon dioxide extinguishers. ▪ Fire-fighting equipment, procedures, and alarms for emergency response. ▪ Use of Personal protective equipment (PPE)
Pressure vessels	▪ Periodic pressure vessels inspection. ▪ Operating service pressure respect. ▪ Respect of the safety distance (explosion prevention). ▪ Pressure control instrument.

[47] M. Bouamri, H. Bouabdesselam (2018). Risk analysis in seawater desalination sector: a case study of Beni Saf Water Company

Components	Recommendations
ERD (Energy recovery devices) – if existing	▪ Periodic verification is recommended. ▪ Leak and seal detectors. ▪ Ensure the ERD is well supported. ▪ Never exceed permitted flow limits. ▪ ERD cavitation prevention (most recognized problem for ERD).

7.6 Material Safety Data Sheet for hydrochloric acid (example)

Sigma-Aldrich.

www.sigmaaldrich.com

SAFETY DATA SHEET
according to Regulation (EC) No. 1907/2006

Version 8.2
Revision Date 07.06.2021
Print Date 05.02.2022
GENERIC EU MSDS - NO COUNTRY SPECIFIC DATA - NO OEL DATA

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifiers

Product name	:	Hydrochloric acid
Product Number	:	H1758
Brand	:	Sigma
Index-No.	:	017-002-01-X
REACH No.	:	01-2119484862-27-XXXX
CAS-No.	:	7647-01-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Manufacture of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich Chemie GmbH Eschenstrasse 5 D-82024 TAUFKIRCHEN
Telephone	:	+49 (0)89 6513-1130
Fax	:	+49 (0)89 6513-1161
E-mail address	:	technischerservice@merckgroup.com

1.4 Emergency telephone

Emergency Phone #	:	0800 181 7059 (CHEMTREC Deutschland) +49 (0)696 43508409 (CHEMTREC weltweit)

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification according to Regulation (EC) No 1272/2008
Corrosive to Metals (Category 1), H290
Skin corrosion (Sub-category 1B), H314
Serious eye damage (Category 1), H318
Specific target organ toxicity - single exposure (Category 3), Respiratory system, H335

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 Label elements

Labelling according Regulation (EC) No 1272/2008

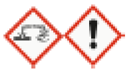
Sigma- H1758

Page 1 of 10

The life science business of Merck operates as MilliporeSigma in the US and Canada

Figure 7-1: MSDS for hydrochloric acid[48]

[48] https://www.sigmaaldrich.com/DE/en/sds/SIGMA/H1758

Pictogram	
Signal word	Danger
Hazard statement(s)	
H290	May be corrosive to metals.
H314	Causes severe skin burns and eye damage.
H335	May cause respiratory irritation.
Precautionary statement(s)	
P234	Keep only in original packaging.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapors/ spray.
P271	Use only outdoors or in a well-ventilated area.
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Supplemental Hazard Statements	none

Reduced Labeling (<= 125 ml)

Pictogram	
Signal word	Danger
Hazard statement(s)	
H314	Causes severe skin burns and eye damage.
Precautionary statement(s)	
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection/ hearing protection.
P303 + P361 + P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Supplemental Hazard Statements	none

2.3 Other hazards

This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

SECTION 3: Composition/information on ingredients

3.2 Mixtures

Component		Classification	Concentration
Hydrochloric Acid			
CAS-No.	7647-01-0	Met. Corr. 1; Skin Corr.	>= 30 - < 50

EC-No. Index-No. Registration number	231-595-7 017-002-01-X 01-2119484862-27-XXXX	1B; Eye Dam. 1; STOT SE 3; H290, H314, H318, H335 Concentration limits: >= 0,1 %: Met. Corr. 1, H290; >= 25 %: Skin Corr. 1B, H314; 10 - < 25 %: Skin Irrit. 2, H315; 10 - < 25 %: Eye Irrit. 2, H319; >= 10 %: STOT SE 3, H335;	%

For the full text of the H-Statements mentioned in this Section, see Section 16.

SECTION 4: First aid measures

4.1 Description of first-aid measures

General advice
First aiders need to protect themselves. Show this material safety data sheet to the doctor in attendance.

If inhaled
After inhalation: fresh air. Call in physician.

In case of skin contact
In case of skin contact: Take off immediately all contaminated clothing. Rinse skin with water/ shower. Call a physician immediately.

In case of eye contact
After eye contact: rinse out with plenty of water. Immediately call in ophthalmologist. Remove contact lenses.

If swallowed
After swallowing: make victim drink water (two glasses at most), avoid vomiting (risk of perforation). Call a physician immediately. Do not attempt to neutralise.

4.2 Most important symptoms and effects, both acute and delayed
The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed
No data available

SECTION 5: Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media
Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

Unsuitable extinguishing media
For this substance/mixture no limitations of extinguishing agents are given.

5.2 Special hazards arising from the substance or mixture
Hydrogen chloride gas
Hydrogen chloride gas
Not combustible.
Ambient fire may liberate hazardous vapours.

5.3 Advice for firefighters
Stay in danger area only with self-contained breathing apparatus. Prevent skin contact by keeping a safe distance or by wearing suitable protective clothing.

5.4 Further information
Suppress (knock down) gases/vapors/mists with a water spray jet. Prevent fire extinguishing water from contaminating surface water or the ground water system.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures
Advice for non-emergency personnel: Do not breathe vapors, aerosols. Avoid substance contact. Ensure adequate ventilation. Evacuate the danger area, observe emergency procedures, consult an expert.
For personal protection see section 8.

6.2 Environmental precautions
Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up
Cover drains. Collect, bind, and pump off spills. Observe possible material restrictions (see sections 7 and 10). Take up with liquid-absorbent and neutralising material (e.g. Chemizorb® H^+, Merck Art. No. 101595). Dispose of properly. Clean up affected area.

6.4 Reference to other sections
For disposal see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Storage conditions
No metal containers.
Tightly closed.

7.3 Specific end use(s)
Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Ingredients with workplace control parameters

8.2 Exposure controls

Personal protective equipment

Eye/face protection
Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU). Tightly fitting safety goggles

Skin protection
This recommendation applies only to the product stated in the safety data sheet, supplied by us and for the designated use. When dissolving in or mixing with other substances and under conditions deviating from those stated in EN374 please contact the supplier of CE-approved gloves (e.g. KCL GmbH, D-36124 Eichenzell, Internet: www.kcl.de).
Full contact
Material: Nitrile rubber
Minimum layer thickness: 0,11 mm
Break through time: 480 min
Material tested:KCL 741 Dermatril® L

This recommendation applies only to the product stated in the safety data sheet, supplied by us and for the designated use. When dissolving in or mixing with other substances and under conditions deviating from those stated in EN374 please contact the supplier of CE-approved gloves (e.g. KCL GmbH, D-36124 Eichenzell, Internet: www.kcl.de).
Splash contact
Material: Latex gloves
Minimum layer thickness: 0,6 mm
Break through time: 120 min
Material tested:Lapren® (KCL 706 / Aldrich Z677558, Size M)

Body Protection
Acid-resistant protective clothing

Respiratory protection
required when vapours/aerosols are generated.
Our recommendations on filtering respiratory protection are based on the following standards: DIN EN 143, DIN 14387 and other accompanying standards relating to the used respiratory protection system.
Recommended Filter type: Filter type ABEK

The entrepeneur has to ensure that maintenance, cleaning and testing of respiratory protective devices are carried out according to the instructions of the producer. These measures have to be properly documented.

Control of environmental exposure
Do not let product enter drains.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Color: light yellow
b)	Odor	pungent
c)	Odor Threshold	No data available
d)	pH	< 1 at 20 °C
e)	Melting point/freezing point	-30 °C
f)	Initial boiling point and boiling range	> 100 °C - lit.
g)	Flash point	Not applicable
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapor pressure	227 hPa at 21,1 °C 547 hPa at 37,7 °C
l)	Vapor density	No data available
m)	Relative density	No data available
n)	Water solubility	soluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Autoignition temperature	Not applicable
q)	Decomposition temperature	No data available
r)	Viscosity	Viscosity, kinematic: No data available Viscosity, dynamic: 2,3 mPa.s at 15 °C
s)	Explosive properties	No data available
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

SECTION 10: Stability and reactivity

10.1 Reactivity
No data available

10.2 Chemical stability
The product is chemically stable under standard ambient conditions (room temperature) .

10.3 Possibility of hazardous reactions
No data available

10.4 Conditions to avoid
no information available

10.5 Incompatible materials
Bases, Amines, Alkali metals, Metals, permanganates, for example potassium permanganate, Fluorine, metal acetylides, hexalithium disilicideMetals

10.6 Hazardous decomposition products
In the event of fire: see section 5

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Mixture

Acute toxicity
Symptoms: If ingested, severe burns of the mouth and throat, as well as a danger of perforation of the esophagus and the stomach.
Symptoms: mucosal irritations, Cough, Shortness of breath, Possible damages:, damage of respiratory tract
Dermal: No data available

Skin corrosion/irritation
Mixture causes burns.

Serious eye damage/eye irritation
Mixture causes serious eye damage. Risk of blindness!

Respiratory or skin sensitization
No data available

Germ cell mutagenicity
No data available

Carcinogenicity
No data available

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
Mixture may cause respiratory irritation.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

11.2 Additional Information

RTECS: MW4025000
Other dangerous properties can not be excluded.

Handle in accordance with good industrial hygiene and safety practice.

Components

Hydrochloric Acid

Acute toxicity
Oral: No data available
Inhalation: Cough Difficulty in breathing
Inhalation: absorption
Symptoms: mucosal irritations, Cough, Shortness of breath, Inhalation may lead to the formation of oedemas in the respiratory tract., Possible damages:, damage of respiratory tract, tissue damage
Dermal: No data available

Skin corrosion/irritation
Skin - reconstructed human epidermis (RhE)
Result: Corrosive
(OECD Test Guideline 431)

Serious eye damage/eye irritation
Eyes - Bovine cornea
Result: Corrosive
(OECD Test Guideline 437)

Respiratory or skin sensitization
Maximization Test - Guinea pig
Result: negative
(OECD Test Guideline 406)

Germ cell mutagenicity
Test Type: Chromosome aberration test in vitro
Test system: Chinese hamster ovary cells
Result: Conflicting results have been seen in different studies.

Carcinogenicity
Carcinogenicity - Did not show carcinogenic effects in animal experiments. (IUCLID)

Reproductive toxicity
No data available

Specific target organ toxicity - single exposure
May cause respiratory irritation.
The substance or mixture is classified as specific target organ toxicant, single exposure, category 3 with respiratory tract irritation.
Acute inhalation toxicity - mucosal irritations, Cough, Shortness of breath, Inhalation may lead to the formation of oedemas in the respiratory tract., Possible damages:, damage of respiratory tract, tissue damage

Specific target organ toxicity - repeated exposure
The substance or mixture is not classified as specific target organ toxicant, repeated exposure.**Aspiration hazard**
No aspiration toxicity classification

SECTION 12: Ecological information

12.1 Toxicity

Mixture
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
This substance/mixture contains no components considered to be either persistent, bioaccumulative and toxic (PBT), or very persistent and very bioaccumulative (vPvB) at levels of 0.1% or higher.

12.6 Other adverse effects
No data available

Components

Hydrochloric Acid
No data available

Toxicity to fish	LC50 - Gambusia affinis (Mosquito fish) - 282 mg/l - 96 h Remarks: (IUCLID)

SECTION 13: Disposal considerations

13.1 Waste treatment methods

Product
See www.retrologistik.com for processes regarding the return of chemicals and containers, or contact us there if you have further questions.

SECTION 14: Transport information

14.1 UN number

ADR/RID: 1789	IMDG: 1789	IATA: 1789

14.2 UN proper shipping name
ADR/RID: HYDROCHLORIC ACID
IMDG: HYDROCHLORIC ACID
IATA: Hydrochloric acid

14.3 Transport hazard class(es)

ADR/RID: 8	IMDG: 8	IATA: 8

14.4 Packaging group

ADR/RID: II	IMDG: II	IATA: II

14.5 Environmental hazards

ADR/RID: no	IMDG Marine pollutant: no	IATA: no

14.6 Special precautions for user
No data available

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

This material safety data sheet complies with the requirements of Regulation (EC) No. 1907/2006.

Other regulations

Take note of Dir 94/33/EC on the protection of young people at work.

15.2 Chemical Safety Assessment

For this product a chemical safety assessment was not carried out

SECTION 16: Other information

Full text of H-Statements referred to under sections 2 and 3.

H290	May be corrosive to metals.
H314	Causes severe skin burns and eye damage.
H315	Causes skin irritation.
H318	Causes serious eye damage.
H319	Causes serious eye irritation.
H335	May cause respiratory irritation.

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.

The branding on the header and/or footer of this document may temporarily not visually match the product purchased as we transition our branding. However, all of the information in the document regarding the product remains unchanged and matches the product ordered. For further information please contact mlsbranding@sial.com.

7.7 Parameters for water analysis

Table 7-2: Parameters for raw water analysis

Raw Water Analysis			
Parameter	**Hourly/ Daily**	**Weekly**	**Monthly**
Temperature	X		
Turbidity	X		
Silt Density Index (SDI)	X		
Oxidation Reduction Potential	X		
pH	X		
Total Suspended Solids (TSS)		X	
Total Dissolved Solids (TDS) and/or Conductivity		X	
Chlorophyll a			X
Total Organic Carbon (TOC)			X
Total Hydrocarbons			X
NO_3 / Phosphates			X
Volatile Organic Compounds			X
Total Coliforms			X
E. Coli			X

Table 7-3: Parameters for drinking water analysis (I)

Drinking Water Analysis I			
Parameter	**Hourly/ Daily**	**Weekly**	**Monthly**
1. Physical Requirements			
Colour	**X**		
Odour	**X**		
Taste	**X**		
Turbidity (NTU)	**X**		
Conductivity	**X**		
pH	**X**		
2. Chemical Requirements			
Free Residual Chlorine (as Cl)	**X**		
Total Organic Carbon (TOC)		**X**	
Total Dissolved Solids		**X**	
Chloride (as Cl)			**X**
Alkalinity (Total as $CaCO_3$)			**X**
Free Ammonia			**X**
Albuminoid Ammonia			**X**
Nitrate (as NO_3)			**X**
Nitirite (as NO_2^-)			**X**
Fluoride (as F^-)			**X**
Total Phosphate (as PO_4)			**X**
Total Hardness (as $CaCO_3$)			**X**
Total Iron (as Fe)			**X**

Table 7-4: Parameters for drinking water analysis (II)

Drinking Water Analysis II			
Parameter	**Hourly/ Daily**	**Weekly**	**Monthly**
Sulphate (as SO_4)			**X**
Oil and Grease			**X**
Calcium (as Ca)			**X**
Magnesium (as Mg)			**X**
Sodium (as Na)			**X**
Manganese (as Mn)			**X**
Aluminum (as Al)			**X**
Potassium (as K)			**X**
Barium (as Ba)			**X**
Bicarbonate (as HCO^-_3)			**X**
Strontium (as Sr)			**X**
Boron (as B)			**X**
3. Other Parameters			
E. Coli and Cryptosporidium	**X**		
Langelier Saturation Index (LSI)			**X**
Total Recoverable Hydrocarbons			**X**
Heavy metals (Cd, Cr, Pb, Hg, Cu, As, etc.)			**X**
Radioactive metals (Ra,U)			**X**

Table 7-5: Parameters for concentrate water analysis

Concentrate Water Analysis			
Parameter	Hourly/ Daily	Weekly	Monthly
Temperature at the measurement point	X		
pH at ambient temperature	X		
Total Residual Chlorine (as OCl^-)	X		
Total Suspended Solids		X	
Total Dissolved Solids		X	
Chemical Oxygen Demand (COD)		X	
Faecal Coliform Level		X	
Biochemical oxygen demand (BOD5 in five days at 20°C)			X
Oil and Grease			X
Dissolved Phosphates			X
Ammonia Nitrogen (as N)			X
Fluorides (as F)			X
Cadmium (as Cd)			X
Chromium, total (as Cr)			X
Copper (as Cu)			X
Lead (as Pb)			X
Mercury (as Hg)			X
Nickel (as Ni)			X

7.8 Basic preventive maintenance schedule

Table 7-6: Basic preventive maintenance schedule for SWRO plants[49].

Preventive Maintenance Schedule			
Equipment	**Maintenance Description**	**Frequency**	**Comments**
Source water intakes			
Inlet	Examine the accumulation of deposits on the coarse sieves (for on-shore intakes)	Daily	
	Observe entry velocity of water into landside inlet chute, if entry velocity is too high: open additional inlet gates (for on-shore intakes)	Daily	
	Clean debris from the coarse screens (for on-shore intakes)	Quarterly	
	Clean debris from the coarse screens (for off-shore intakes)	Every 12-18 months	
	Check structural integrity of the inlet	Every 12-18 months	
Intake conduit	Manual cleaning	Every 12-18 months	
Intake screens	Inspect debris accumulation on the fine screens (on-shore)	Daily	
	Check the function of the screening´s cleaning, conveyance, disposal systems and floatbales that could cause damage	Daily	
	Clean screens with fresh water	Weekly	
	Lubricate screen bearings	Quarterly	
	Exercise screen crane and gates	Anually	
Source water pretreatment			
Dissolved air flotation (DAF) clarifiers	Shut down and bypass DAF	If turbidity is <5 NTU	Otherwise risk of overdosing of coagulant/flocculant
	Check air compressors and pumps (flow, pressure, noise, vibration, leaks, oil/bearing condition)	Daily	
	Clean clarifier influent/effluent weirs	Monthly	
	Lubricate sludge collection equipment	Quarterly	If applicable
	Remove sludge from bottom of DAF tanks	Annually	
Granular media filter	Inspection of the filter media condition	Every 6-12 months	
	Evaluation of loss of filter material	Anually	2-4 cm annual loss of filter material is normal. Top off when media is reduced by ~10cm below design level.
	1-day soaking of the granular media pretreatment filters	When necessary	With citric/sulphuric acid (against calcite deposits) or sodium hydroyide solution (against organic residuals)
	Inspection of the rubber lining or epoxy coat on the internal walls of pressure filters	Every 5 years	

[49] Based on recommendations from N. Voutchkov (2014). Desalination Engineering – Operation and Maintenance.

Preventive Maintenance Schedule

Equipment	Maintenance Description	Frequency	Comments
Source water pretreatment			
Membrane pretreatment filter (MF, UF)	Chemical enhanced backwash (CEB)	Daily	Twice during algal bloom
	Clean-in-place chemically recovery cleaning (CIP)	Every 15-30 days	Dependending on development of differential pressure
Cartridge filter	Replace filter element	Differential pressure 0.7-1.0 bar	Wear gloves when installing new filters to avoid biofouling
Reverse Osmosis System Operation			
RO membrane element	<u>Membrane cleaning with CIP system, if…</u> - 10-15% increase in the pressure difference between feed and concentrate - 10-15% decrease in permeate flow or increase in permeat TDS concentration - Before and after long-term RO train shutdown - Utilization period of 4-6 months is exceeded	-	Depending on feed water quality and pretreament efficiency
	<u>Membrane rotation, if...</u> - Weight of the two front elements (closest to inlet) increases over 30% in comparison to the new membranes - Recovery of RO train less then 20% - Differential pressure reduced by less than 10% after last two CIP events - Utilization period of 6-12 months is exceeded	-	Depends on fouling. Labour intensive Preferably use CIP and perform rotation during other maintenance at RO train.
	<u>Replacement of membrane element, if ...</u> - Permeate conductivity constantly >2000 µS/cm - Permanent loss of normalized flow of 15% - Differential pressure permanently increased with more than 15% - Differential pressure reduced only to 3.5 bars after CIP	-	
Energy recovery system	Flush PX units with clean water/RO permeate	When RO system operation is discontinued	To avoid particle deposition which may prevent restart
	Replace seals, alignment pins, O-rings (when excess kubrication flow occurs)	When necessary	
Post-Treatment			
Lime System	Check and exercise lime dosing valves	Weekly	To prevent deposits
	Flushing of lime conveyance lines	Every 1-2 weeks	
	Clean lime saturation channels	Monthly	
	Cleaning lime mixing system	Every 6-12 months	
Calcite system	Replacing the contact bed of the calcite media	Every 5-10 years	

Preventive Maintenance Schedule

Equipment	Maintenance Description	Frequency	Comments
Desalination Plant Discharge Management			
Pretreatment backwash & sludge system	Cleaning sensors for the measurement of the sludge banket depth	Weekly	
	Inspection of the sludge feed pumps	Weekly	
	Remove accumulated solids out of the backwash water retention tank	Monthly	
	Inspect and clean discharge water quality monitoring and sample collecting equipment. Calibrate sensors according to manufacturer's instructions	Monthly	
Off-shore outfall with diffuser	Inspect for excessive growth of aquatic life, clean manually.	Annually	Performed by professional divers
	Check for structural integrity	During annual inspection	
Chemical Feed Systems			
Chemical storage tanks	Check for any inexplicable changes. Check if the chemical level is suitable for next scheduled delivery (when necessary).	Daily	
	Check for leaks around the tank	Daily	
	Check composition of chemical compared to specifications. Do not accept inadequate concentration.	At delivery of chemical	
	Clean and calibrate liquid level sensors	Every 6 months	
	Empty, wash and clean tank + check for leaks	Every 6 months	
Equipment			
Pumps	Adjust pressure switches, clean and check valves	As needed	
	Check pumps for flow, pressure, noise, leaks	Daily	
	Check oil, bearing condition and control signs	Daily	
	Check electrical connections, switches for operation, calibrate insturments	Monthly	
	Check current readings at pump startup & normal operational conditions	Monthly	
	Lubricate pump drive bearings, replace mechanical seal, calibrate flow meters	Anually	
	Inspect pump internals, if maximum flow decreases more than 10% -> exchange of parts	Every 5 years	
Air blowers	Check blowers for air flow, pressure, noise, leaks	Daily	

Preventive Maintenance Schedule

Equipment	Maintenance Description	Frequency	Comments
Equipment			
Motors	Check motor input voltage and current frequency	At least monthly	
	Change filters	Every 500 run hours or quaterly	
	Change motor oil	Every 2000 run hours or anually	
Bearings	Check bearing temperature and status of grease and oil (no moisture/contamination)	At least monthly	
	Alignment of shafts (pumps, other large equipment with bearings)	Semianually	
Valves	Check tightness of flanges	Every 3 months	Butterfly Valves
	Check valves full range of operation	Monthly	
	Lubricate valves	Semianually	Plug-, Ball- valves
	Check tightness of flanges	Monthly	Plug-, Ball- valves
	Seat inspection	Anually	Check valves
Mechanical seals	Check springs and gaskets for external leaks around the shaft	Weekly	
Mechanical drives	Check belts and pulleys for wear, alignment, tension. Clean.	Monthly	
	Inspect chain alignment and slack	Quarterly	
	Lubricate chains that have no continous lubrication system	Every 3 months	

7.9 Standardized written safety instructions

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

DESIGNATION

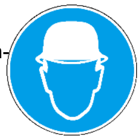
Loading and unloading vehicles

DANGERS TO HUMANS AND THE ENVIRONMENT

- Slipping, tipping or falling load.
- Injuries caused by the tail lift swinging back.
- Drive-up ramps kicking back.

PROTECTIVE MEASURES AND RULES OF CONDUCT






- Loading and unloading activities may only be carried out by instructed persons.
- Wear suitable personal protective equipment, such as safety shoes, hard hat, gloves and high-visibility and high-visibility waistcoat.
- Adequately secure loading and unloading points in public traffic areas.
- Use suitable load handling equipment such as grabs, tongs, pallet forks, load hooks.
- Only use faultless, undamaged lifting gear (chains, ropes).
- Loading equipment such as cranes, excavators, loaders, fork-lift trucks may only be used by instructed persons in accordance with the manufacturer's instructions.
- Persons must never stand under the suspended load.
- The driver's cab of the transport vehicle must be left during the loading process.
- Loading rails must be secured against slipping and must not exceed a gradient of 17°.
- When driving on loading rails or ramps, use a guide or signaler if necessary.
- Carefully open the tail lifts, standing to the side of the tail lift.
- Ensure that the load is adequately secured.
- Keep the load's centre of gravity as low as possible.
- Unauthorised persons are not allowed in the danger zone of the loading point.

WHAT TO DO IN THE CASE OF MALFUNCTIONS

- Close off the accident site.
- Secure the scene of the accident in the area of public road traffic.
- Instruct people to leave the danger area.

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

First aider: Mr/Mrs ....   Emergency call: ………….

- Take immediate action at the scene of the accident.
- Call ambulance/doctor.
- Inform employer/supervisor.

MAINTENANCE

- For maintenance and servicing, the manufacturer's operating instructions must be observed.
- Loading rails and slings must be checked for perfect condition before use.

Figure 7-2: Safety instructions for loading and unloading vehicles

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

DESIGNATION

Personal protective equipment against falls from heights

DANGERS TO HUMANS AND THE ENVIRNOMENT

- Danger of falling or falling out (e.g. personnel lifting equipment).
- Collision with solid objects.

PROTECTIVE MEASURES AND RULES OF CONDUCT

- Read and observe the manufacturer's instructions for use.
- Only the provided protection system may be used. Modifications or additions are not permitted.
- Before use, check the personal protective equipment for apparent defects.
- The connecting element of the lanyard may only be attached to the specified catching or retaining eyelet of the harness.
- Prevent slack rope.
- Only the anchor point specified by the supervisor (minimum load capacity **7.5 kN**) may be used. Unintentional detachment of the connector from the anchor point must be precluded.
- The equipment may only be used to secure persons, but not for other purposes, e.g. as a sling for loads.

WHAT TO DO IN THE CASE OF MALFUNCTIONS

- Any defect in the personal protective equipment must be reported to the supervisor.
- Do not use fall protection equipment and withdraw it from further use if
  - there is any damage.
  - its functioning is impaired.
  - it has been stressed by a fall.
- Leave the danger zone (fall zone) immediately.
- Do not use fall protection equipment again until an expert has approved its further use.

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

- To rescue a worker caught by the personal protective equipment after a fall, connect the rescue lifting device provided to the lanyard and to the anchor point. The worker must then be pulled up.
- The rescue must be carried out immediately. Do not let person hang in the harness for longer than **20 minutes**.
- The accident must be reported. A first responder should be called in to administer first aid.

EMERGENCY CALL: .... First aider: ....

Keep calm and respond to queries.

MAINTENANCE

- The personal protective equipment against falls from a height may only be transported in the associated container (metal case).
- The personal protective equipment must not be exposed to influences that may affect its safe condition. Such influences are e.g.
  - effects of aggressive substances such as acids, alkalis, solvents, oils, cleaning agents,
  - flying sparks, higher temperatures with textile fiber materials above 60° C),
  - lower temperatures for plastic parts (below -10° C).
- In storage, personal protective equipment against falls from a height may only be stored freely suspended without exposure to UV radiation (sunlight).

Figure 7-3: Safety instructions for fall protection

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

DESIGNATION

Ladder

DANGERS TO HUMANS AND THE ENVIRNOMENT

- Falling over or off the ladder
- Slipping of the ladder or the user
- Falling of objects
- Contact with live parts or wires

PROTECTIVE MEASURES AND RULES OF CONDUCT

- Observe the pictograms on the ladder rail.
- Check ladders for obvious defects before each use (visual inspection).
- Do not provisionally repair or extend ladders.
- Remove defective ladders from further use (by appropriate means).
- Use the ladder for its intended purpose. (Do not use stepladders as lean-to ladders, do not climb from stepladders to higher areas).
- Do not climb the top two rungs of a stepladder.
- Do not climb the top four rungs of a single ladder.
- A lean-to ladder has to be at least one metre higher than the height to be climbed.
- Wear clean, non-slip footwear when climbing a ladder.
- Do not place ladders behind closed doors.
- Keep a safe distance when working near power lines.
- Secure the ladder with an anti-spreading device to prevent it from sliding apart or folding up unintentionally.
- Keep ascent and descent surfaces free of objects (for example tools).
- Climb up and down facing the ladder. Maintain three-point contact.
- When working from the ladder, do not lean out to the side and avoid working overhead.
- Set up the ladder in a stable position. For lean-to ladders, observe the angle of attack (65° to 75°, elbow test).
- Secure the ladder head against falling over or slipping away (tie it down) or attach ladder safety hooks or have a second person hold on to it.
- When setting up a ladder on soft ground, use aids such as ladder spikes or similar.
- When setting up a ladder on uneven ground, use traverses.
- Ladders are only to be used for small-scale work. The ladder is not a permanent workplace.

WHAT TO DO IN THE CASE OF MALFUNCTIONS

- Check the ladder and its installation.
- Remove any defects found or withdraw the ladder from further use.
- Wooden ladders must not have a covering coat of paint.
- Inform superiors

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

- Provide first aid.
- Make an emergency call.
- Secure the scene of the accident.
- Inform employer/supervisor

First aider: .... Emergency call: ……………………………………………….

MAINTENANCE

- Ladders are only to be repaired with original spare parts.
- Repairs, maintenance work & inspections may only be carried out by persons authorized to do so.
- Storage of ladders: protected against mechanical damage, moisture, drying out and bending.

Figure 7-4: Safety instructions for working on a ladder.

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

DESIGNATION

Forklift truck

DANGERS TO HUMANS AND THE ENVIRNOMENT

- Danger due to falling load!
- Danger due to overturning!
- Danger due to noise and vibrations!
- Danger from exhaust gases on machines with combustion engines!
- Danger due to restricted visibility from the load!
- Danger from slipping when mounting and dismounting!

PROTECTIVE MEASURES AND RULES OF CONDUCT

Hearing protection: Wear ear protection when working at noise levels above 80dB(A)!
Foot protection: Wear safety shoes!

Conduct:

- Machines may only be operated by instructed persons with a valid driving license!
- The accident prevention regulations and the manufacturer's operating instructions must be observed!
- Riding on the machine or working equipment is prohibited!
- Jumping on and off while driving is prohibited!
- Only drive with the driver restraint system (seat belt)!
- Stay in the driver's seat if there is a risk of falling over!
- Drive at an appropriate speed on approved roads!
- Always pick up the load as close as possible to the back of the forks and drive in the lowest position.
- Do not exceed the maximum permissible load!
- In case of limited visibility: drive backwards or be instructed!
- When using work baskets, these must be secured. Driving with persons in the work basket is prohibited!
- Only use machines with combustion engines in adequately ventilated rooms!
- Secure parked vehicles against rolling away and unauthorized use, lower the load suspension!
- Check function and visual inspection as well as traffic safety before driving!
- Do not smoke when refueling! Carry a fire extinguisher (min. 2kg)!

WHAT TO DO IN THE CASE OF MALFUNCTIONS

Fire:
- Fight smaller fires with a fire extinguisher - call the fire brigade!

Fault:
- In case of danger, stop the engine immediately!
- During maintenance, cleaning and repair work: Remove the ignition key and wait until the engine has come to a standstill, lower the load suspension!
- Do not continue work until the fault has been rectified by an expert!

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

- Carry out emergency measures at the scene of the accident!
- Call an ambulance/doctor!
- Inform supervisors and the occupational insurance association!
  First responder: ....

MAINTENANCE

- Always check the function and safety devices of the machine before putting it into operation!
- Observe the manufacturer's instructions regarding maintenance and care!
- Repairs may only be carried out by qualified personnel!

CONSEQUENCES OF NON-COMPLIANCE

- Health consequences: injuries and illness!
- Consequences under industrial law: warning, reprimand!

Figure 7-5: Safety instructions for forklift truck

Company:	**Safety Instructions**	**Date:**
Working area:	**Activity:**	**Signature:**

DESIGNATION

Working in containers and confined spaces

DANGERS TO HUMANS AND THE ENVIRNOMENT

- Danger from oxygen deficiency
- Danger due to installations
- Risk of injury from unsecured drives
- Danger of falling when working on ladders or other higher workplaces.
- Limited freedom of movement, which can lead to burns during e.g., welding work.
- Danger due to hazardous concentration of gases and steams.
- Danger from operationally live electrical equipment.

PROTECTIVE MEASURES AND RULES OF CONDUCT

- Work only with special written approval and after special protective measures have been taken.
- Work may only be carried out after the supervisor has established that the measures laid down in writing have been complied with.
- Before starting work, the insured persons shall be instructed about the hazards arising during their activities as well as about protective measures and what to do in the event of a hazard.
- Containers and confined spaces must be emptied and free of substances or mixtures before work begins (this does not apply if no hazards emanate from the contents or if the hazards emanating from the contents cannot be eliminated for operational reasons and protective measures are taken).
- Before work is carried out, it must be ensured that inlets and outlets from or through which substances or mixtures in hazardous concentrations or quantities or at hazardous temperatures or pressures can enter containers and confined spaces are effectively interrupted.
- Before work is carried out and during work, ventilation must be provided to ensure that no gases, vapours, mists or dusts in concentrations harmful to health, no dangerous explosive atmospheres or oxygen deficiency can occur in containers and confined spaces (otherwise respiratory protection).
- If harmful substances in hazardous concentrations or a hazardous explosive atmosphere are likely to be present in the exhaust air, the exhaust air must be discharged in such a way that persons are not endangered.
- Monitor the effectiveness of the ventilation.
- Stop work immediately if the ventilation becomes ineffective. Check the effectiveness of the ventilation before resuming work.
- If ventilation measures are not possible - or not sufficiently effective - so that harmful concentrations of gases, vapours, mists or dusts may occur, personal protective equipment must be used.
- If the formation of hazardous explosive atmospheres is possible, additional explosion protection measures are required.
- Work in containers and confined spaces must not begin until dangerous movements caused by moving parts or installations not used for the performance of work have stopped, unauthorised, erroneous or unexpected starting has been safely prevented and the start of dangerous movements due to stored energy has been safely prevented. Radiation sources shall be removed, effectively shielded or switched off and secured against being switched on before work begins in containers and confined spaces.
- Heating and cooling equipment as well as refrigeration systems shall be put out of operation and secured against starting up before work begins if their surface temperatures could endanger insured persons. Work may only be carried out in containers and confined spaces when there is no longer any risk from excessively high or low temperatures. (If it is necessary to deviate from this for operational reasons, work may be carried out in containers and confined spaces if the insured persons are protected in some other way).
- It is not permitted to carry compressed gas containers (except respiratory protection).
- When using portable electrical equipment, protective measures must be taken against increased electrical hazards.
- Special explosion protection measures are required if hazardous explosive atmospheres are present or may form because ventilation cannot be carried out effectively enough or at all.
- Preventive occupational health examinations are necessary if the limit values are exceeded.

WHAT TO DO IN THE CASE OF MALFUNCTIONS

- Inform your responsible supervisor.
- In case of lighting failure, stop work immediately.
- In the event of a particularly dangerous situation, stop work and inform the supervisor.
- Warn other employees.
- Secure the work area sufficiently.

WHAT TO DO IN THE CASE OF ACCIDENTS – FIRST-AID – EMERGENCY TEL. NO. 911

- Keep calm.
- Switch off the machines.
- Rescue the injured person.
- Carry out immediate measures at the scene of the accident (call in first aiders). (Stop bleeding, immobilize injured body parts, calm the injured person).
- Consult an accident insurance doctor if incapacity for work is to be expected.
- Inform the supervisor or his representative immediately.
- First aid must be recorded in the first aid book according to the instructions.

First aider: ....
Emergency call: ………………………………………………….

MAINTENANCE

- The supervisor shall monitor the observance of the established protective measures.

CONSEQUENCES OF NON-COMPLIANCE

- Failure to comply with these operating instructions may result in considerable damage to health and property.
- The consequences of non-compliance with these operating instructions under labor law may be a warning or dismissal.

Figure 7-6: Safety instructions for working in confined spaces

7.10 Template for risk assessments

Table 7-7: Template for risk assessment

Risk Assessment

Assessed by: **Date:**

Task No.	Acitvity	Hazard Involved	Persons at Risk	Risk Rating			Risk Control Measures	Residual Risk			Signature of Responsible Person
				Likeli-hood	Severity	Risk Value		Likeli-hood	Severity	Risk Value	
1.											
2.											
3.											
4.											
5.											
6.											
7.											
8.											
9.											
10.											

Guidelines

Planning and Management of Brackish Water Reverse Osmosis Desalination Plants in Jordan