DESALINATION PLANT AND DESIGN BUILD OPERATE PACKAGE

I. OVERVIEW OF DESALINATION PLANTS

1. Desalination is a process that extracts minerals from saline water. More generally, desalination refers to the removal of salts and minerals from a target substance, as in soil desalination, which is an issue for agriculture.

2. Saltwater is desalinated to produce water suitable for human consumption or irrigation. One by-product of desalination is salt. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on cost-effective provision of fresh water for human use. Along with recycled wastewater, it is one of the few rainfall-independent water sources.

3. Due to its energy consumption, desalinating sea water is generally more costly than fresh water from rivers or groundwater, water recycling and water conservation. However, these alternatives are not always available and depletion of reserves is a critical problem worldwide. Currently, approximately 1% of the world's population is dependent on desalinated water to meet daily needs, but the United Nations expects that 14% of the world's population will encounter water scarcity by 2025.

4. Desalination is particularly relevant in dry countries such as Australia, which traditionally have relied on collecting rainfall behind dams for water.

5. There are currently185,500 desalination plants in the world producing 87 million cubic meters of water each day and serving 300 million people. These number have been growing each year with the growth rate expected to accelerate as climate change takes effect.

6. Desalination plants are the purvey of private companies and the intellectual property of this technology is well guarded. Nearly all desalination expertise rests in these companies or research institutions such as universities. Desalination plants are normally developed as design build operate or build own operate transfer schemes.

7. Desalination plants are very complex and require sophisticated computer programs and control systems to operate. They are a ‘mobile phone compared to the ‘desktop handset’ of a normal water treatment plant.

II. HOW DOES A DESALINATION PLANT WORKS

8. A desalination plant is not a conventional water treatment plant. It differs in many respects, not the least of which is the process it uses to treat the water. In fact, a desalination plant can be thought of as using a form of conventional water treatment plant to pre-treat water before it gets down to the serious and expensive business of removing salt.

9. A desalination plant creates fresh water from salt water. Water with a salt content higher than about 500 milligrams per litre (mg/l) cannot be sustainably used for irrigation or human consumption (the salt content in a conventional surface-water-fed water supply system is approximately 40 mg/l). Some animals can survive using water with a salt content up to 1,000 mg/l (for example sheep) but this is not common. Artesian water is sometimes described as ‘brackish’, which means is has a salt content that is too high to permit its sustainable use.

Seawater has a salt content of approximately 32,000 mg/l. This number varies across the planet and can range from 30,000 mg/l to 37,000 mg/l.

The term mg/l is used throughout this paper and stands for ‘milligrams per litre’. It is equivalent to ‘parts per million’. A micro-meter, or ‘micron’, is 10^{-6} meters, or 0.000001 meters.

10. A seawater desalination plant has a ‘recovery rate’ of approximately 50% to operate efficiently. This means that for every litre of water taken into a plant about half a litre of fresh water is produced. The remaining half litre is returned to the sea carrying the entire salt load from the full litre taken in. This means that the salt content of the returned water is approximately 64,000 mg/l. Elaborate means are put in place to disperse this highly salty water into the sea as quickly as possible. It also means that if you want to produce 1 litre of water you have to process two litres.

11. A desalination plant has five main components which are shown in the following table. The percentage refers to the percentage of the overall capital cost of a plant. This can vary depending upon the topography (both land and marine), ground conditions, the distance to the coast.

Table 1: Desalination Plant Components

Intake	Pre-treatment	Treatment	Post-Treatment	Waste Disposal
18%	22%	49%	3%	8%
The purpose of the intake system is to get the seawater from the sea to the plant.	The purpose of the pre-treatment system is to prepare the seawater for the next stage of treatment.	The purpose of the treatment system is to produce water ready for post-treatment.	The purpose of the post-treatment system if to prepare water for transfer and consumption.	The purpose of the waste disposal system is to prepare and dispose of the waste material from the treatment processes.
The intake system comprises an intake structure (located offshore), an intake pump station (located at	The pre-treatment system removes all the suspended material in the seawater, effectively converting ‘dirty’	The treatment system removes the salt from the saline water and has two output steams, which are a pure water stream and a	The post-treatment system prepares the pure water from the treatment system ready for its transfer to customers. The	The waste disposal system disposes of the waste produced from the treatment processes. There are two waste

Intake	Pre-treatment	Treatment	Post-Treatment	Waste Disposal
18%	22%	49%	3%	8%
the treatment plant) and an intake pipeline (connecting the two). Nearly all of the intake system is buried.	seawater into 'clean' seawater. The pre-treatment system is really two or more treatment systems all performing specialised functions, with the selection being solely dependent upon the quality of the seawater.	brine stream. There are several available technologies for removing salt from a saline water. By far the most energy efficient is reverse osmosis and this is now very widely used. The reverse osmosis membranes are cleaned each day using concentrated sulphuric acid and biocides. To remove the salt very high pressures are created by pumps, and this uses a lot of energy (electricity). Energy recovery devises to prevent the energy being wasted after the treatment process is has been completed.	water produced from a reverse osmosis system is very pure, and pure water is a very aggressive liquid. If not post-treated it would destroy pipelines and would be harmful to consumers. Chemicals (normally lime which is calcium carbonate) are added to the pure water to make it suitable for transfer and use. Chlorine is also added to ensure the water remains safe from contamination.	streams, namely liquid waste and solid waste. The liquid waste stream comprises the brine solution, chemicals used to keep all the treatment systems clean and any liquid wastes from the pre-treatment system. These are all treated in a tank and then sent back to the ocean though an outfall pipeline and diffuser. The solid waste stream comprises sludges from the pre-treatment process and the spent filter media and membranes. The solid waste is sent to a landfill.

12. The above table shows that successive treatment processes are used to removed smaller and smaller particles from a liquid until the final 'filter' (reverse osmosis) removes particles at the molecular level.

13. There are two other important components associated with a desalination plant. These are:

(i) Providing an adequate supply of electricity to the desalination plant site (desalination plants use a lot of energy to create the high pressures they need to function; and

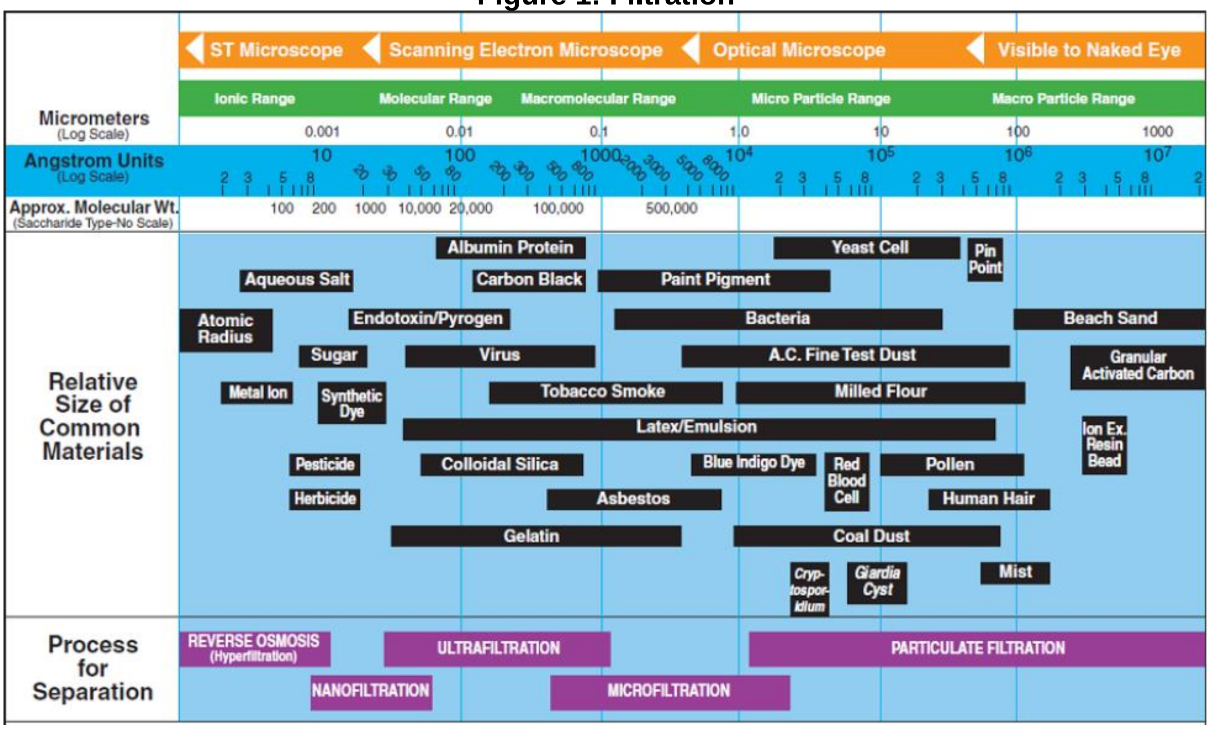
(ii) Transferring the water from the desalination plant to a suitable connection point in the water supply network. Sometimes very long and expensive pipelines and pump stations are needed.

14. Both can add substantially to the cost of a desalination plant.

15. It takes a lot of energy to remove salt from water (regardless of the technology – for example boiling water and capturing the steam as fresh water) and much research has been, and continues to be, put into improving the efficiency of the reverse osmosis process. Unfortunately, the laws of physics place a limit on just how efficient the process can become. Efficiency gains will continue to be made, but these are likely to be only small gains in the future, rather than the large gains that have been achieved historically.

16. The following figure shows the range for different filters and what they remove. Microfiltration and ultrafiltration are sometimes used as a pre-treatment for hyperfiltration (reverse osmosis) in desalination plants. Note that hyperfiltration membranes will remove bacteria, viruses and heavy metals which is a considerable benefit.

Figure 1: Filtration



III. WHEN IS A DESALINTION PLANT THE BEST OPTION

17. Throughout history usable water has been obtained from the ground (wells and bores), the surface (rivers and lakes) and the air (rain and snow). All these sources are suffering from overuse and the encroachment of contamination resulting from man's exploitation of the environment. The severity of this problem is being rapidly exacerbated by climate change. An increasing population together with urbanisation, and a reduction in arable areas due to the loss of surface soil also contribute to the water problem.

18. Fortunately, with affordable desalination now available there is a new and limitless resource in the ocean (the world's oceans hold about 96.5% of the earth's water). That is, at least as long as you live near the sea (most of the world's biggest cities are on or near the coast). Desalination water is expensive water (compared to traditional supplies) but is now being used to

grow crops in the Middle East and Spain. In Australia where the climate is very variable each of the major cities has invested in a large desalination plant as an insurance against reducing rainfalls and long periods of drought.

19. It is this concept of desalination plants providing a guaranteed source of usable water that can tide cities over during droughts that is their strength. Cities now have the option of diverting water more and more water from hinterlands, or leaving that water for food production and producing their own water from the sea. Generally, cities are wealthy compared to rural areas and can afford this technology.

20. Another advantage of desalination, particularly in cities where the users of water pay for the water on a volumetric basis, is that its higher cost encourages both water conservation and water reuse.

21. Finally, as demonstrated in the figure above, the desalination process removes all contaminates from the water including bacteria and viruses resulting in a water that is healthy and fit for sustained human consumption. For example, a desalination plant will remove fluorine preventing skeletal fluorosis. Although these health benefits are not costed into the business cases for desalination plants they are very material.

22. So, when is a desalination plant the best option? The answer is when any of the following apply:

- (i) Where water is scarce and existing sources are either unreliable or becoming contaminated;
- (ii) Where populations and urbanisation is diverting surface water away from important agricultural needs;
- (iii) Where 'future-proofing' is required against climate change; and
- (iv) Where water is needed in arid areas to grow food.

Growing Food in the Desert Using Desalinated Water

IV. WHAT ARE THE PREREQUISITES FOR A DESALINATION PLANT

23. Unfortunately, desalination plants cannot be built just anywhere. Some prerequisites apply:

- (i) The site must be close to the open sea—if the site is in a bay or estuary the brine steam from the plant may not be able to be dispersed resulting in an adverse environmental impact;
- (ii) The site must have access to a reliable and adequate supply of electricity—desalination plants to not take kindly to a sudden loss of power and a large amount of damage can result from an uncontrolled shutdown;
- (iii) The topography of the area (both land and inshore marine environment) must be suitable for the construction of the intake and outfall structures – you won't find a desalination plant on top of a cliff;
- (iv) The marine environment should not be a breeding ground for aquatic animals or contain rare sea grasses;
- (v) The site should be reasonable close to the city it is to supply, and the city must have an adequate water distribution system to transfer the desalinated water to customers (without losing a third of this expensive water along the way); and
- (vi) There needs to sufficient funding available to support the construction of the plant and its ongoing operations and maintenance – unlike conventional treatment plants if a desalination it not careful maintained every day it can cease to function within a few days, the source of water is immediately lost and the repair costs to return it to supply can be very large.

24. If all these boxes can be ticked then it becomes a matter of whether the water resources at the location need augmenting, and whether a desalination plant is the best form of augmentation.

A Desalination Plant Built Next to an Electricity Generating Plant and the Ocean

IV. DESIGN, BUILD AND OPERATE CONTRACTS

25. As mentioned design, build and operate (DBO) or design, build, operate and finance contracts are mostly used for establishing desalination plants. The key difference is how the plant is funded. Private sector funding is usually more expensive than public sector funding (due to higher interest rates), however is has the advantage of shifting the debt off the Government's balance sheet and thereby helping preserve the government's credit rating. Private sector funding has lost favour in recent times due to its high establishment costs and its need for long term contracts (25 years or more).

26. Several procurement methods are used. For very large plants the alliance method of procurement has become popular

27. A DBO, as the name implies, engages a contractor to design build and operate a plant. The minimum desirable operating period is 7 years however periods down to 3 years have been used.

28. The thinking behind a DBO contract is that the builder of an asset must operate the asset, and therefore has an incentive to do a good job in the asset's design and construction. There is some truth in this, but the flaw is that the emphasis then shifts to the maintenance of the asset during the operation period. The contractor only has an incentive to survive the duration of the operation period whereas the employer wants to use the asset for a much longer term. This issue has been addressed in some DBO contracts by offering successive extensions to the operation period based upon the performance of the contractor during the operation period. Regardless, as with any form of contract, the employer must have a competent and technically well informed project management unit to supervise the contractor to ensure it is getting what is has contracted for.

29. There are several key hold points in a DBO contract which enable the Contractor's employer to assure itself that it is getting what it is paying for. These are at the end of design, the end of construction and after the first year of operation. It must be recognised that the employer (providing a service) and the Contractor (financial reward) have different motives and a good DBO contract tries to balance these.

30. With a typical design and construction period of 3 years the duration of the entire contract could be 10 years. In such a circumstance, it is critical that a large amount of care is put into developing the bidding documents and contract, and the appointment of the contractor. It is a 10-year relationship and a relationship that is very difficult and expensive to sever should things sour.

31. The benefits of contracting include the following:

(i) Contracting provide access to expertise an Employer may not have, nor can easily of affordably purchase;
(ii) Contracting permits an employer to focus on its core business and not be distracted by matters best left to others;
(iii) Contracting allows the control of costs and brings certainty to budgeting and forecasting; and
(iv) Contracting can supplement resources during peak work loads.

32. For a desalination plant expertise is needed to both build the plant and operate the plant. If only one to two plants are held amongst many other assets (such as pipeline systems) it is questionable whether the development of in-house and expensive expertise is warranted for such a small part of the business.

33. Looking ahead it is difficult to see any change to the use of DBO or similar contracts to procure and operate desalination plants. There are now several international companies highly skilled in providing this service. DBO contracts themselves will continue to evolve and there are a number of improvements that can be made to cater for increasing level of sophistication of employers, and for local needs.

V. JAFFNA DESALINATION PLANT EXPERIENCE

34. The first stage of the Jaffna desalination plant will produce 24,000 cubic meters per day of desalinated and disinfected water. The plant will be built in conjunction with a downstream water supply network proving a reticulated water supply to 270,000 people in Jaffna. Schematics of the desalination plant site and the downstream pipe network are shown in the next two figures.

35. The contract being used is a DBO contract with a 2.5-year design and construction period and a 7-year operating period.

36. The desalination plant site is located some 42 kilometers to the south east of Jaffna and a part of the project requires the construction of an 8-kilometer pipeline and pump station to connect the plant to the nearest existing water supply transition pipeline. Several planning studies have been undertaken to support the project and social and environmental safeguards have been put in place and monitoring programs have been developed.

37. The project has been advertised internationally, and market interest has been very good.

Figure 2: Schematic of the Jaffna Desalination Plant Site

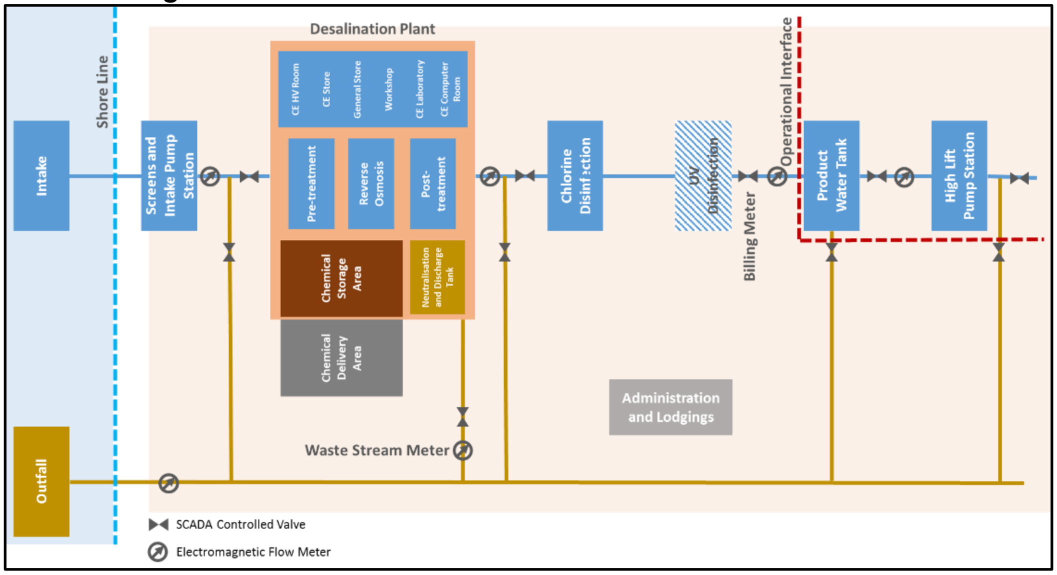
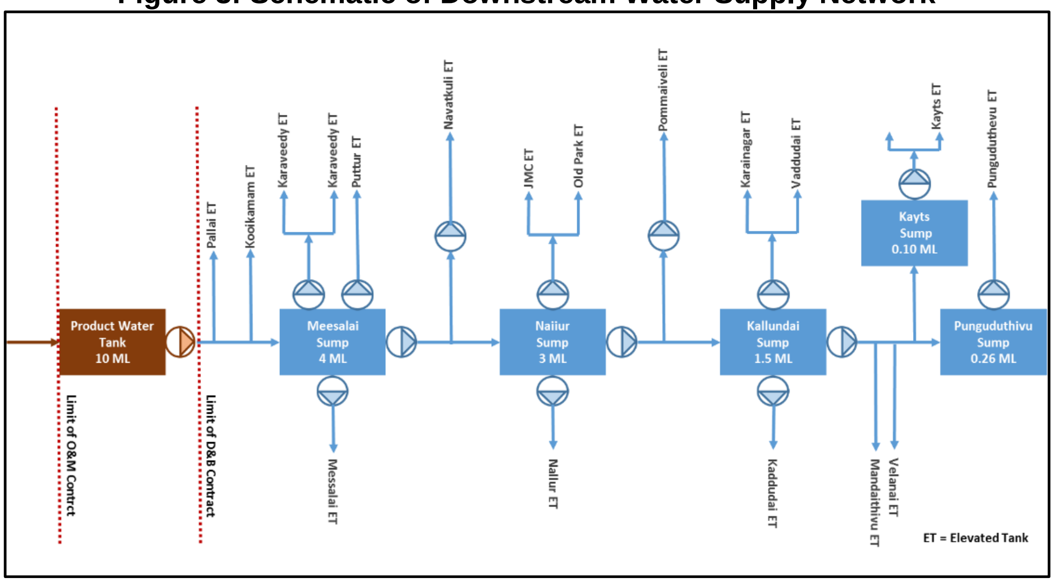


Figure 3: Schematic of Downstream Water Supply Network



38. The Jaffna Desalination Project is currently being tendered, and all the portents are good. Nevertheless, there have been some lessons learned along the way and these may be summarised as follows:

(i) Make sure risks are correctly assigned;
(ii) Make sure the bidding document fosters both competitive tendering;
(iii) Make sure the bidding document utilises the expertise of the market;
(iv) Make sure that the bidding document is clear on the outcomes that are being sought and how these will be measured (a common failing of most contracts); and
(v) Make sure the bidding team has the right mix of skills and experience.

39. Some examples of these lessons are contained in the following table.

Table 2: Lessons Learnt During the Bidding

Risk Assignment	There are things that the contractor can be expected to know and contribute, and things that the employer is best placed to know. An example of the first would be how to combine the different treatment systems to obtain a working plant. An example of the latter is the quality of the raw water. It is useful to produce a table of all the information that is required for a project early in the planning process and assign the items in the table to either the employer or contractor. Where something is not known, it is not always satisfactory to leave it to the contractor to find out, or worse guess. Contractors are conservative and will boost their prices accordingly. Significant events which are clearly outside the control of the employer and contractor should be deemed to be force majeure events and taken by the employer.
Competitive Tendering	There are very good guidelines for determining the qualification criteria for contractors and these should be followed. However, the guidelines should be applied judiciously with the parameters selected to achieve what they are meant to achieve, that is they qualify contractors which have the experience, financial capacity and financial resources to undertake the contract.
Market Expertise	The is a temptation for an employer to get involved in the detailed design of a project, rather than restrict itself to the outcomes required and the boundary conditions that apply (social and environmental safeguards are one form of boundary conditions). In becoming involved an employer limits the contractor using its full expertise in coming up with the most efficient and practical design. As with risk it is best to leave designs decisions with those most qualified to make them. This particularly applies to desalination plants where the technologies continue to rapidly evolve. However, is does require the employer to be quite specific and definition is setting down the outcomes it wants and the boundary conditions that apply.
Project Outcomes	One of the most important items to include in a bidding document is the outcomes the contract is supposed to achieved and the ways in which these outcomes will be measured. If these outcomes are achieved then the contract has met its purpose. An example the high-level project outcomes and the more detailed project outcome for the first two high level project outcomes are shown in the following two tables.
Bidding Team	The bidding team will be a core team which has a range of skill available to it (mostly consultants). The core team must have good project management experience and a knowledge of the technologies it is proposing to employ. For a DBO it is useful if the team also have operational experience.

Table 3: High Level Project Outcomes

No.	Requirement Type	Requirement
1	Functional	Produce Water – Quantity and Quality
2	Functional	Provide for Augmentation
3	Functional	Provide Buildings, Services and Amenities

No.	Requirement Type	Requirement
4	Functional	Hand Back Operations
5	Management	Practise Asset Management
6	Management	Practise Project Management

Table 4: Detailed Project Outcomes – First Two High Level Project Outcomes Only

No.	Criterion	Key Factors	
1	Functional Requirement: Produce Water – Quantity and Quality	1	24 MLD capacity is provided
		2	6/12/18/24 incremental supply is provided - quantity
		3	95.9% quantity reliability is achievable
		4	The specified water quality is provided
		5	6/12/18/24 incremental supply is provided – quality
		6	100% quality reliability is achievable
2	Functional Requirement: Provide for Augmentation	1	Allowance for 24 MLD to 48 MLD capacity is provided
		2	Allowance for a Boron reduction from 2.4 mg/l to 1 mg/l is provided
		3	Allowance for the installation of a DAF system is provided

DAF = dissolved air flotation, mg/l = milligrams per liter, MLD = million liters per day

VII. SUMMARY

40. This paper has covered a range of topics related to desalination, contacting and the Jaffna Desalination Project. As the Jaffna project proceeds more lessons will be learned and the project will provide an excellent case study for possible future desalination plants. Desalination plants are here to stay, and more are likely to be built over the coming years, with financing from multilateral banks.

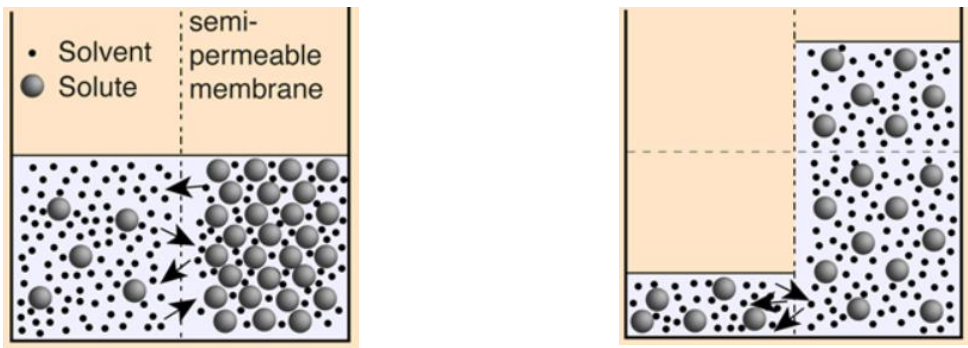
41. The Jaffna project management team has been established and will update this paper as the project proceeds to provide more insights into the procurement of desalination plants.

Inside a Modern Desalination Plant

VI. WHAT ARE OSMOSIS AND OSMOTIC PRESSURE

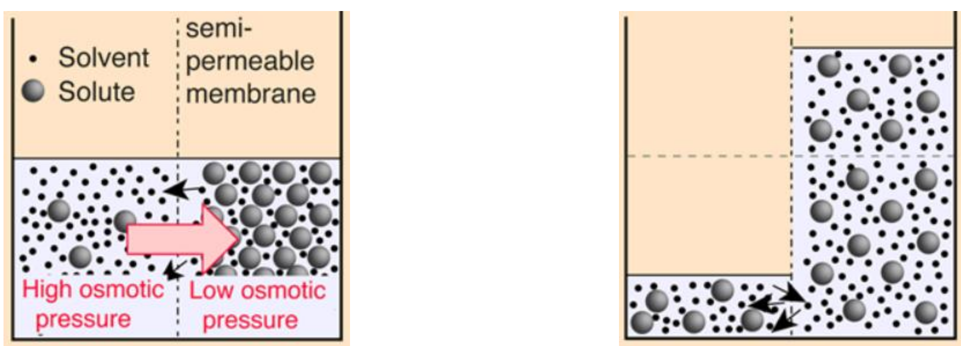
42. Osmosis is a natural process and describes the passage of dissolved ions across a semi-permeable membrane. An example of this project is the passage of chemicals through the wall of a cell in the human body, and is essential for life. The following diagrams describe osmosis and osmotic pressure. The reason this pressure exists is complex and is related to the internal energy of the molecules in question. Suffice to say that is exists and is a major force in nature.

Osmosis



43. If two solutions of different concentration are separated by a semi-permeable membrane which is permeable to the smaller solvent molecules but not to the larger solute molecules, then the solvent will tend to diffuse across the membrane from the less concentrated to the more concentrated solution. This process is called osmosis.

Osmotic Pressure



44. The osmotic pressure is the hydrostatic pressure on the solution is required to prevent the transport of water from a pure source across a semi-permeable membrane into the solution. A positive pressure must be exerted on the solution to prevent osmotic transport.

45. In a desalination plant, we want the salt in seawater to leave the seawater, rather than attract further salt to join it, as would occur in the process described above (that is, change the migration of salt from a low concentration to a high concentration to the other way around). This requires a reversal of the osmotic process. To achieve this reversal, we first need to overcome the naturally occurring osmotic pressure and then add additional pressure to drive the process in the other direction. To create this pressure high pressure pumps are needed and lots is electricity. As the osmotic pressure is a naturally occurring process there is a limit to how efficient desalination plants can become, as described earlier.

46. One final note as this process is not to be confused with diffusion which would see two different solutions mixing to become homogenous.