Desalination Plants:
Potential impacts of brine discharge on marine life

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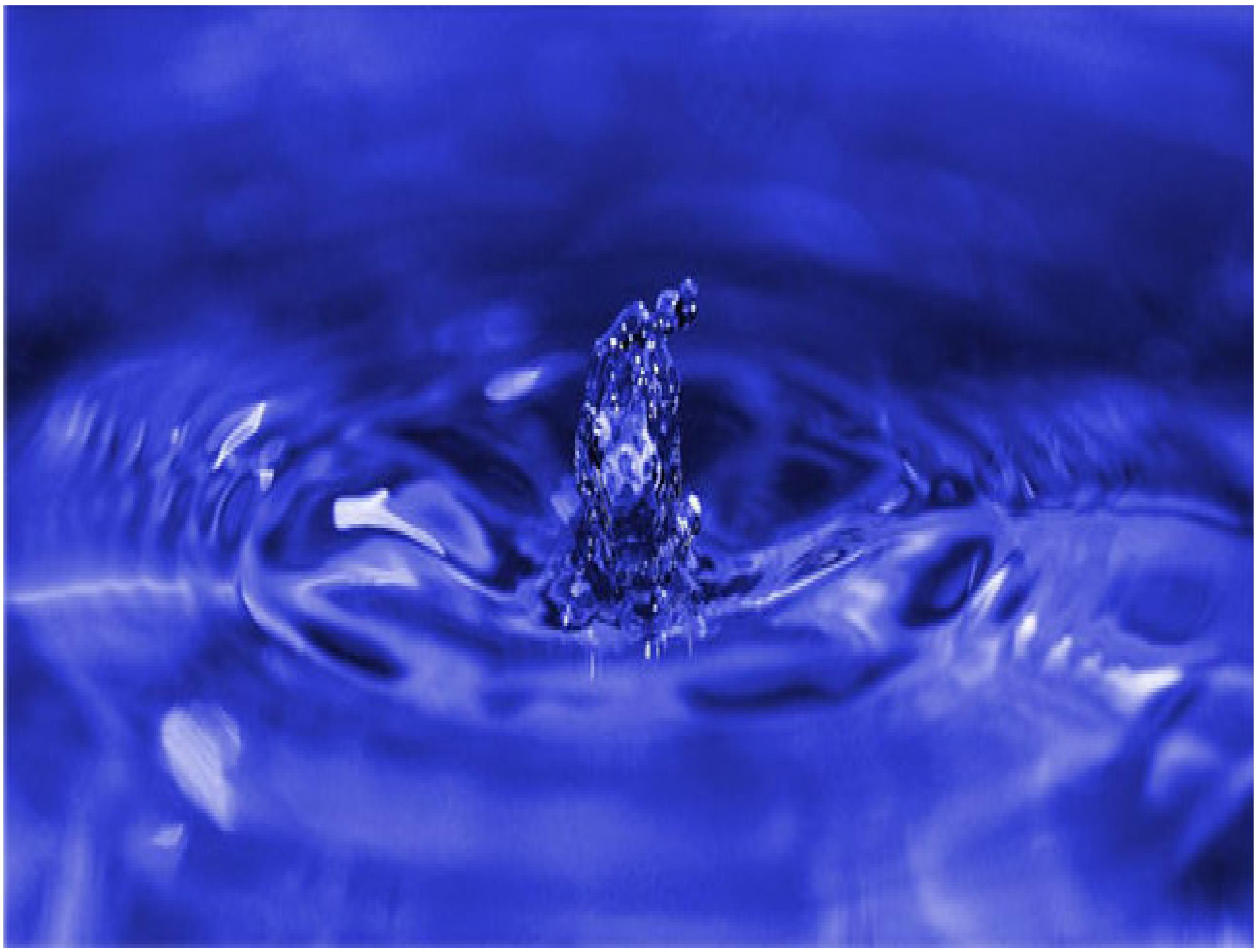
Abstract Water has always been the earth's most valuable natural resource for human beings and ecosystems. Fresh water is an essential natural resource that supports human beings, flora, and fauna habitat. Reductions in water quality and quantity have serious negative impacts on ecosystems. Over the past several decades, a tremendous growth in human populations and industrial activities has resulted in a significant demand for fresh and clean water. To meet these challenges and meet the pressures of demand it is critical to find a new alternative of water resource as the natural water resources have almost vanished. In spite of the high cost of desalinated water, an important quantity is already produced to meet the necessity for fresh water worldwide. Desalination could hold the key for new fresh water resources. Building more dams with significant sizable catchments would be a great solution in regards to supplying Australia with fresh water; however, many regions in Australia are facing a reduction in the rainfall and level of runoff. All the dams around Australia face a vast reduction in the storage level due to the diminishment of the inflow rate and the growth in water usage. Some arguments will be raised against building desalination plants on the grounds of environmental impacts to the surrounding area, especially to marine life due to the high concentrated brine discharge that diffuses back into the ocean. The impacts of the brine discharge are due to the high level of salinity and total alkalinity and alteration to the temperature. These impacts could be considerable in terms of the influence on the marine organisms such as the development of species, survival of larva and breeding and reproductive traits. However this paper provides some evidence that the influence of discharge for desalination plant can be neglected in term of any environmental impact to the aquatic flora and fauna species.



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1. Demand for fresh water

In the last couple of decades, significant growth has occurred in the human population. This increase has resulted in an enormous requirement for extra resources of food, more settlements and discovery of new resources of potable fresh water. The world population growth last century increased from 1.65 billion to 6 billion and it is expected to continue to grow in this century. This rapidly increasing population is placing pressure on the remaining existing water resources. In addition to the development of the industrial and commercial activities around the world that result in the pollution of the available water resources, the waste of natural sources, deforestation and climatic alteration due to global warming can play a significant role in the reduction of average rainfall and runoff (*North et al*, 1995: *World water assessment program*, 2003).

Clean potable water has become a precious commodity because of rising demands from the growing world population and increasing global industrialization. Almost 20% of the world's population is facing lack of access to safe drinking water. Water covers over 75% of the earth surface and saline water makes up 97.5% of this; however just 2.53% is fresh and potable, used for different purposes such as domestic, industrial and agriculture demands. Based on the latest figures from the United Nation's "World Water Development Report" more than 50 percent of the nations in the world will face water crises by 2025, however by 2050 about 75 percent of the world population will have a significant possibility of facing water shortages (*United Nations*, 2003). The answer to these water challenges is to find or create new, alternatives, and inexpensive resources of fresh water. Traditionally dams and artesian wells have been used in order to provide fresh water; however the amount of water that can be produced in these ways is insufficient or unpredictable. Therefore creating a new source of potable water has been a significant issue worldwide and as consequence desalination plants are one of the most vital and valuable alternative resource in many countries around the world. According to the statistic in 1985, there are about 4,600 desalination plants worldwide and these plants are able to produce a total capacity of 2,621 million gallons per day (*AL-Mutaz*, 1991).

Worldwide, the average baseline consumption of fresh water is 300 liters per day per person which equals to around one hundred thousand liters of fresh water per person annually. The demand for fresh water in Saudi Arabia will be over 3,000 millions cubic meters of potable water per year by 2010, which will be required by the increased population. There is an urgent need to discover new alternatives and available sources of fresh water. Desalination techniques have been used since the early stages of life by removing the salt from the seawater to use as drinkable water (*Einav et al*, 2002).

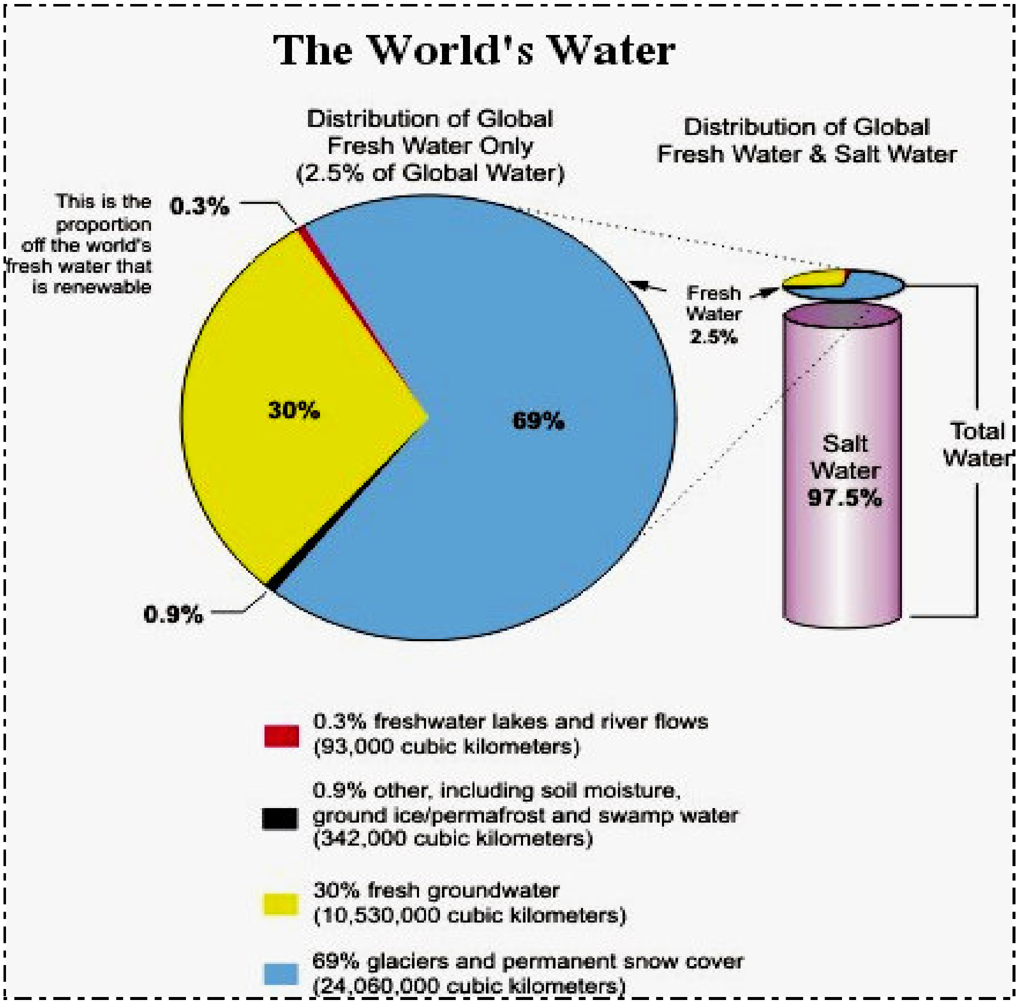


Figure 1.1 demonstrates the disturbance and percentage of fresh and salty water worldwide. Source: Encyclopedia of desalination and water resources.

2. Desalination plant facts

The lack of fresh water or potable water in several countries around the world is a result of the shortage of natural water resources. Therefore, it has been necessary to plan and create new methods such as desalination technology to provide fresh water that is suitable for human and animal consumption and irrigation. The desalination process is one of mankind's earliest designs to separate fresh water from a salt-water solution (*Einav et al*, 2002). Desalination involves several processes to remove the excess salt and other minerals from the water in order to get potable water for human usage. Desalination of sea or ocean water is a widespread technology used in many countries in the world; this sort of technology is very common in the Middle East and North Africa, and is growing fast in United States of America because of water scarcity. Desalination is a two-step process involving both evaporation and condensation by using heat and reverse osmosis technology.

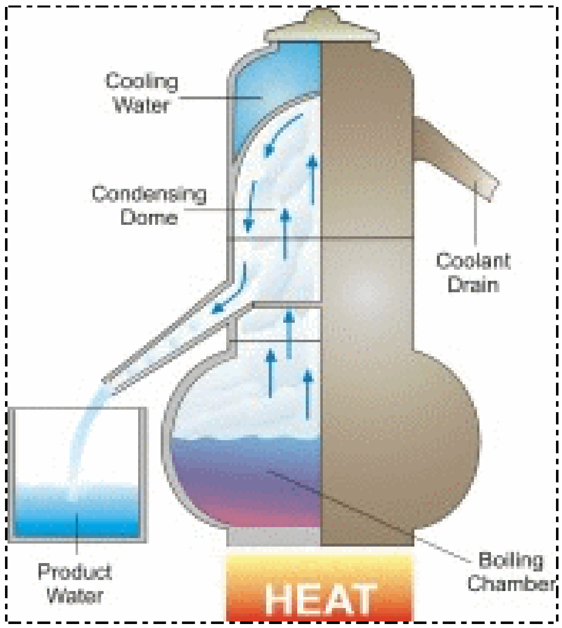


Figure 2.1 shows the process used in desalination plants

Source: United States Geographical Survey

Essentially, a desalination plant is a system to separate saline water into two streams: one with a low concentration of dissolved salt and inorganic materials (the fresh water stream, suitable for consumption by human beings) and the other containing the remaining dissolved salts (the concentrate stream or brine discharge). The amount of flow discharged to waste as a brine discharge varies from 20 to 70 percent of the feed flow, depending on the technology that is used in the plant.

To build a desalination plant, several criteria have to be addressed:

i. Establish the potential location of a desalination plant in an appropriate site where adequate land is available and the land is already zoned for industrial purposes (*Younos*, 2005). A- The site is away from homes and schools so it can not cause noise pollution.

B- Close proximity to the sea or the ocean so the pipeline length is not too long and cost is reduced. C- Good quality seawater and D- to be in close proximity to a power source.

ii. An acceptable plan to deal with the issue of sustainable disposal and potential reuse of brine effluent from the desalination plant to minimise the possible impacts of high salinity and alkalinity from the brine discharge on marine life; and to be environmentally compatible.

iii. Establish a suitable position for the inlet and outlet for feeding water and discharge brine to and from the desalination plant.

The most essential steps in the desalination process are based on using evaporation or membrane technology separation in order to discard the dissolved salt and dissolved minerals from the sea water to obtain fresh and clean water (*Einav et al*, 2002). Recently reverse osmosis technology, which is one of the newest desalinated membrane technologies, has been applied to a wide range of separation processes. The reverse osmosis technology is based on using semi-penetrable membranes to separate into different salt concentrated solutions. Table 2.1 shows the different technologies have been used in desalination plant.

Membrane technologies	Evaporation technologies
Electro dialysis (ED/ EDR) Electronic field is applied on the membrane between two electrodes	**Multi Stage Flash (MSF)** It is passed on an evaporation process by flowing hot water into a low pressure compartment
Reverse Osmosis (RO) The most popular technique worldwide and relies on the external pressure which is higher than osmotic one	**Multi Effect Distillation (MED)** It is based on the cycle of potential heat to generate a steam of fresh water (combination with power station)
	Vapor Compression Distillation (ECD) Basically is a method of using the heat pump of repeated cycles of condensation and evaporation

Table 2.1 demonstrates two different technologies that have been used in desalination plants, in addition to several sorts of machinery for each technology (Einav et al, 2002)

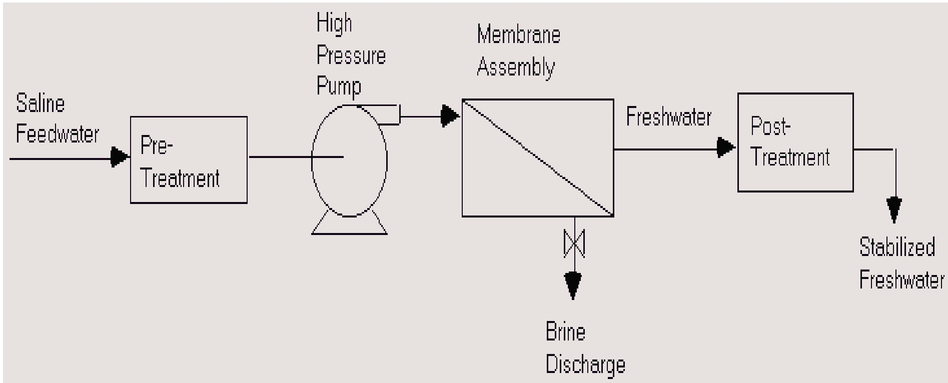


Figure 2.2 shows a simple diagram for a desalination plant from the first step of feeding seawater up to last process of the obtainment of clean water and the brine discharge through a several processes.

3. Desalination plants worldwide

As a consequence due to lack of good quality water, desalination of seawater has been commonly used to solve the problems of water supply for municipal and industrial uses. Currently, approximately 12,300 desalination plants exist in 155 countries worldwide with a combined capacity of over 47 million cubic meters per day (Appendix B presents widely the desalinated water capacity and the number of desalination plants worldwide) (*Global Water Intelligence*, 2006). Appendix A presents a number of satellite images of several desalination plants around the world. About two thirds of which are located in the Middle East with 60% of this worldwide capacity (*Pantell*, 1993), in some of the most arid parts, particularly Gulf States where natural clean potable water is unobtainable or extremely limited. The United States of America, which is the second largest producer of desalinated water after Saudi Arabia, has nearly 800 desalting plants with a combined capacity of about one million cubic meters production which equals to 12% of the world's desalinated water capacity. Encina desalination plant in the United States of America is located on the coast of southern California and produces 50 MG/D that equals 189 ML/D (*Jenkins and Wasyl*, 2005).

Israel (in common with other countries in the Middle East) is in a crisis over water scarcity and the unobtainable fresh water resources, so the first desalination plant was in Ashkelon and has been commissioned in 2000. This plant will provide Israeli consumers with 100 million cubic meters of water a year, which is equivalent of approximately 5-6 percent of the national water, needs and will provide 13% of the country's domestic consumer demands. Ashkelon desalination plant was recognised in 2006 by the international water industry as the world's largest desalination plant facility and the most advanced of its kind worldwide.

3.1 Desalination plants in the Arabian Gulf area

The Middle East in general has been recognised as the biggest producer of desalinated water and the Gulf Area in particular is distinguished as having the highest number of desalination plants existing worldwide. Table B.3 in appendix B presents the number of units and desalinated water production capacity in all states of Arabian Gulf area.

Kuwait was the first country in the Arabian Gulf area to build a desalination plant using seawater in 1953. Kuwait had begun producing 3.1 million cubic meters annually of desalinated seawater in 1957 but the figure increased up to 184 cubic meters per year by 1987 (*Murakami*, 1995). Qatar is another Gulf Arabian state that has adopted desalination plants as a primary source of fresh water for drinking and domestic purposes; Qatar is producing about 150 million cubic meters of desalinated fresh water per year, this amount of clean water is contributing by supplying three-quarters of the total water demand (*Murakami*, 1995).

Saudi Arabia is the world's largest producer of desalinated seawater. The Saline Water Conversion Office (SWCO) had constructed twenty-four desalination plants across the Saudi Arabian coast, including the twelve major plants on the western coast on the Red Sea and another three on the eastern coast on the Arabian Gulf (*Murakami*, 1995). According to SWCO in the beginning of this century (around 2002) twenty-seven plants are providing the Saudi Arabian Kingdom with 814 million cubic meters of water per day to supply the major urban and industrial centers with fresh water. Desalinated seawater meets 70% of the drinking water demand in Saudi Arabia.

The major three desalination plants in Saudi Arabia are Al-Jubail and Al-Khobar plants on the Persian Gulf coast and Shoaiba plant on the Red Sea coast. These three plants provide the major three cities in Saudi Arabia (Riyadh, Dammam and Jeddah) with a total capacity of fresh water of 400 million gallons per day. Table B.4 shows more details about these plants in term of capacity and constructed date.

3.2 Proposed desalination plants in Australia

As in most other countries around the world, Australia is facing a major issue in the demand for clean water. Australia is not only the driest inhabited continent in the world, but also the greatest consumer of water per capita. Australians use more than 980 cubic meters of fresh water annually per person for various purposes. Currently, most major urban cities around Australia are facing new policies and restrictions aimed towards reducing the usage of water by 20 per cent or more over time (*Securing Australia's*, 2007). The last couple of decades in general, and this decade in particular, have shown a significant problem with a water crisis in several regions in Australia. Almost all Australian states have imposed the toughest water restrictions on industry and residents since the 1970s. A considerable reduction in the average rainfall has been observed over the past three decades in Australia in general, and in Western Australia in particular (*Crisp*, 2007). Two major desalination plants are proposed to construct in Australia. One of them, in Perth, and the other will be constructed in New South Wales, in Sydney, a plant has been built already in Western Australia (*Kelson and Grisp*, 2006).

3.2.1 Dams and desalination plants in Australia

Building dams or desalination plants has been an extensive and considerable issue in the last few years around Australia and in Sydney in particular. Building dams with sizeable catchment areas would be a crucial answer to meet the great demands of water provided if there was enough average rainfall and runoff to fill the dams. History has shown in the last 50 years Australia has experienced a widespread drought throughout the country never before seen, more specifically towards the east coast (figure 3.2.1.1). Rainfall across Australia in recent years has begun to have an impact on the dam levels (*Cameron*, 2007). For instance, Sydney's overall dam level has gradually dropped since it was last full in 1980. Since mid 2001 until recent days in 2007, the dam levels have gone from almost 90 percent to about 40 percent (figures 3.2.1.4, 7, and 8). In a similar situation Perth has discovered that this diminishing rainfall and runoff means large reductions in the dam levels (figure 3.2.1.3), leading to a significant decline in available water resources. In Perth, a 20% reduction in rainfall resulted in a 60% decline in supply to its dams. Figure 3.2.1.2 shows that over the past five years inflow rate into dam storages has been reducing at higher rates than the last ten years and those levels have in fact returned to those below the pre 1950s. All states are affected by the changing rain patterns to varying degrees. Figures (3.2.1. 5 and 6) show the changing of total rainfall and the average storage level in different dams in Australia such as Sydney and Perth. Given this history, it is important to start other plans such as building desalination plants. It is therefore time for Australia to change focus from building dams to creating new plans for desalinated ocean water. Therefore, a strong argument will be raised that recently rainwater is limited and the rainfall rate is unpredictable while on the other hand seawater is an unlimited source of water. It is time to accept that desalination is a legitimate option for all coastal cities and there are often better options than building new dams and damaging more coastal rivers.

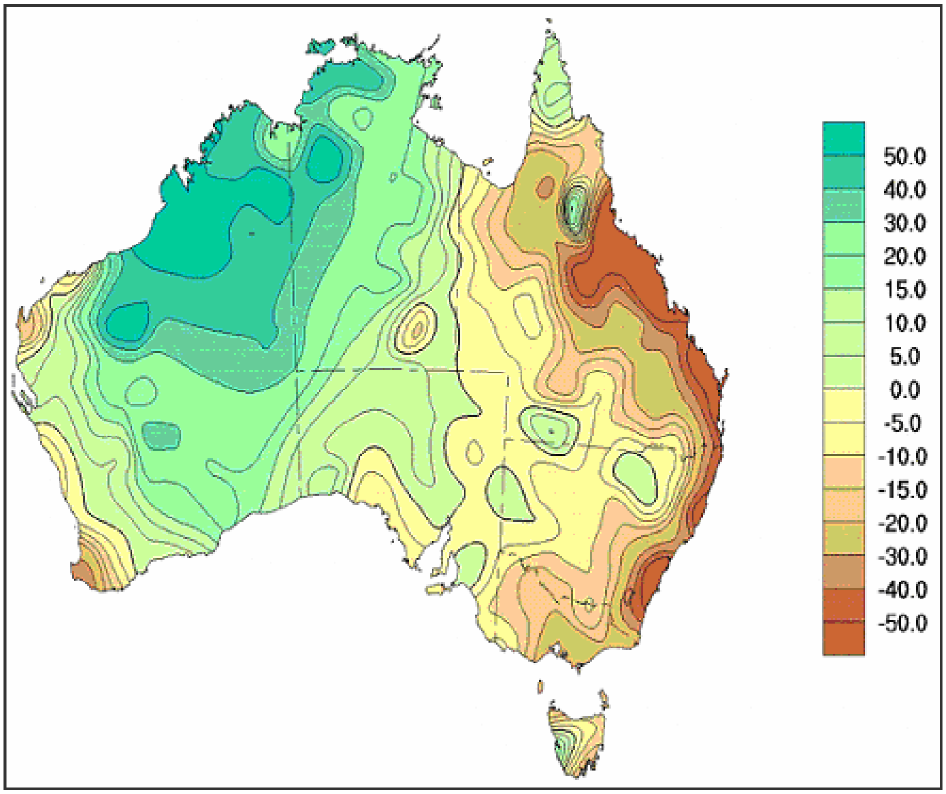


Figure 3.2.1.1 shows the trend in annual total rainfall from 1950-2005 (mm/10years). Source: Modified from Australian Bureau of Meteorology.

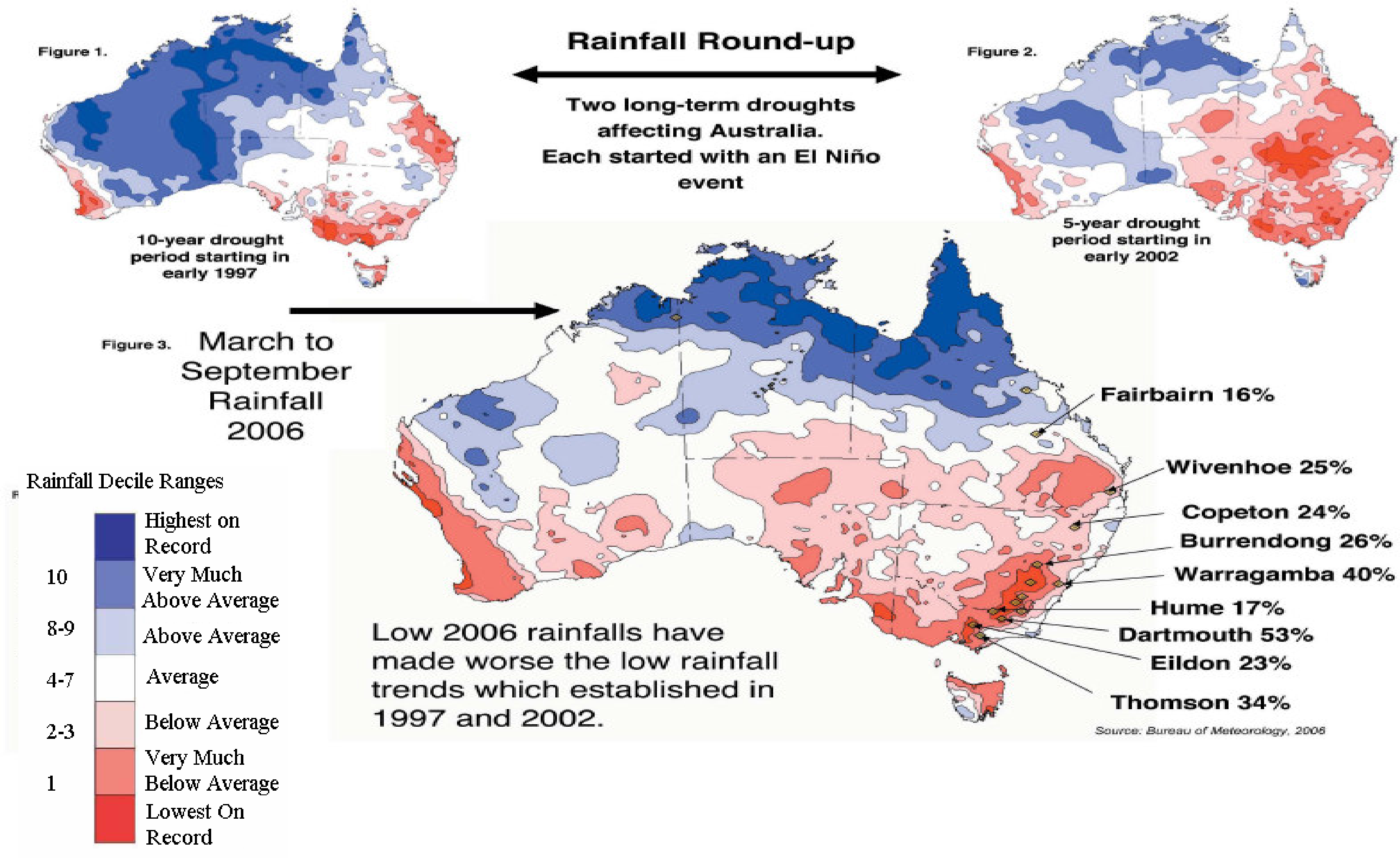


Figure 3.2.1.2 shows the rainfall average in Australia in 2006 with five years drought since 2002 and ten years drought since 1997. Source: Bureau of Meteorology, 2006.

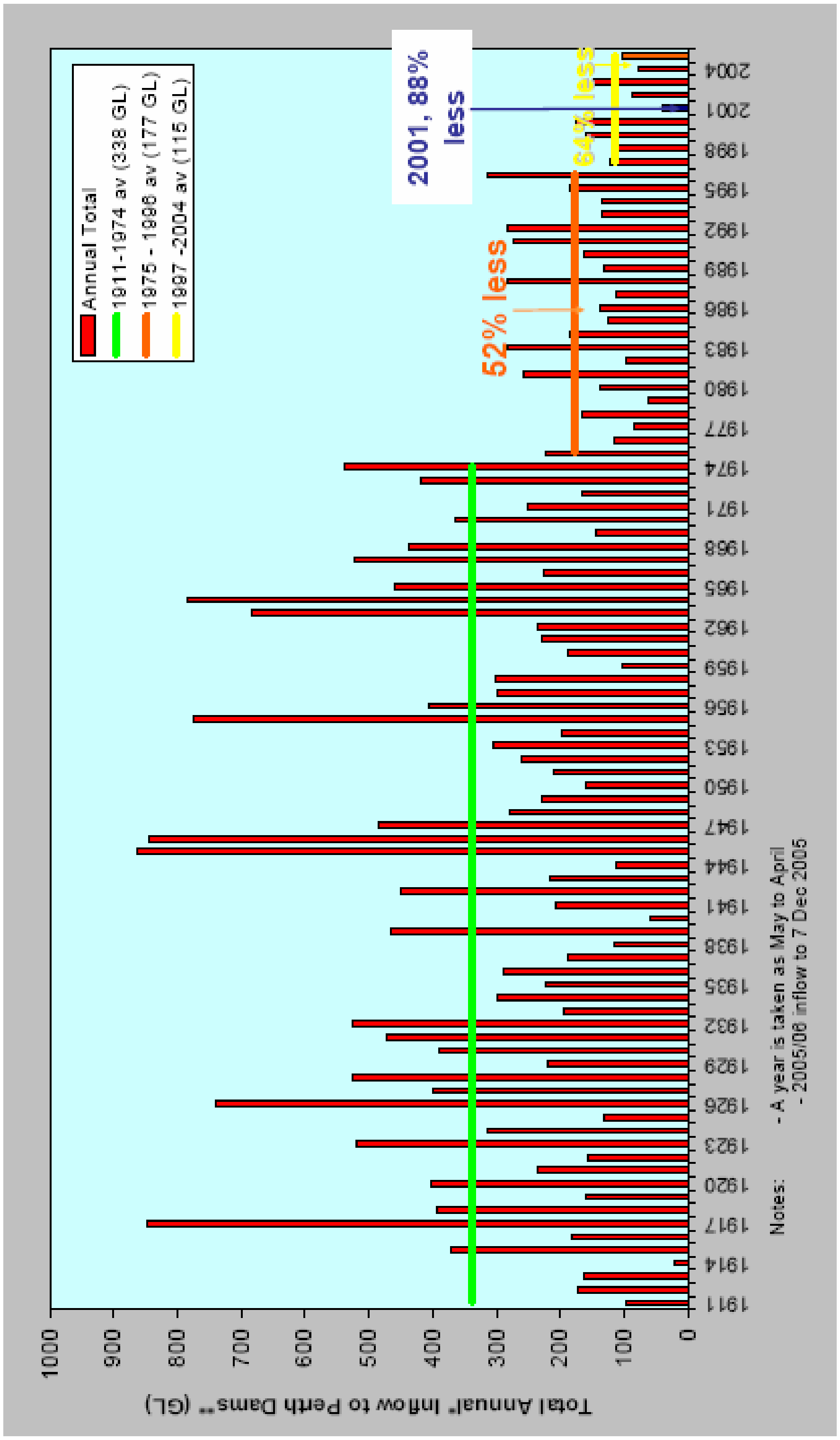


Figure 3.2.1.3 shows the total annual inflow to Perth dams from 1911 through to 2004. Source: Perth Water Corporation Center

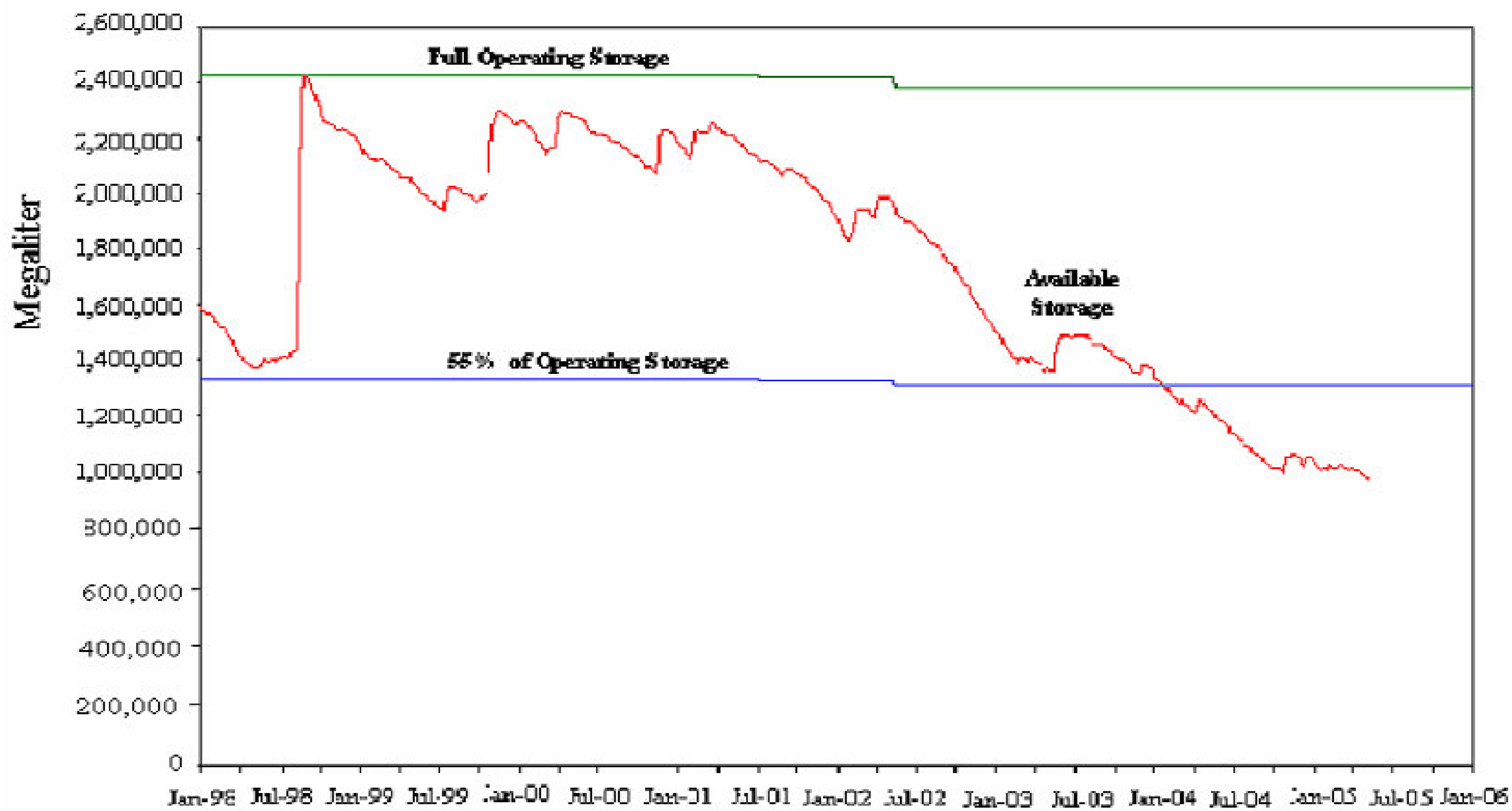


Figure 3.2.1.4 shows the available water storage in Sydney dams in six monthly periods from January 2006. Source: Modified from Sydney Catchment Authority Center

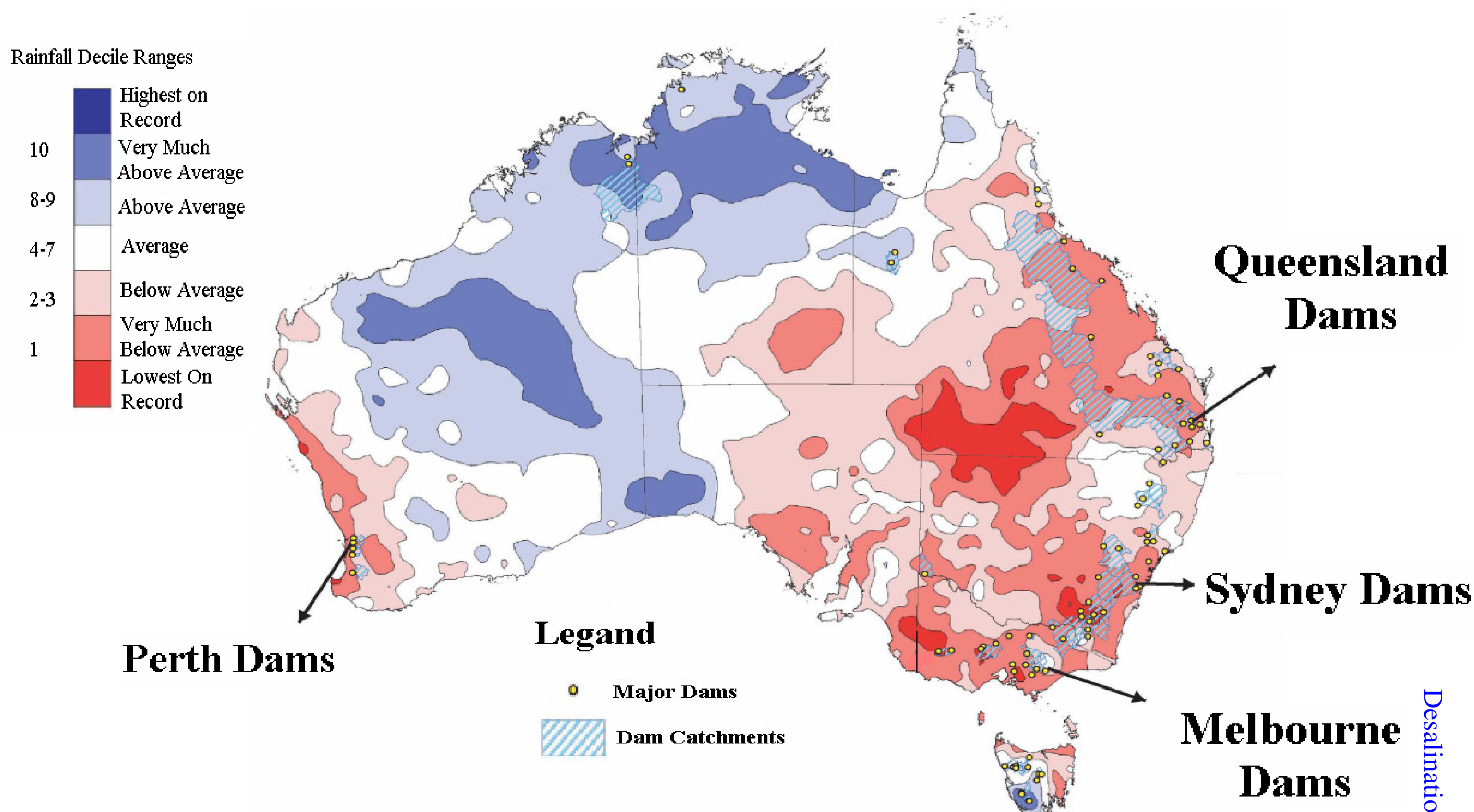
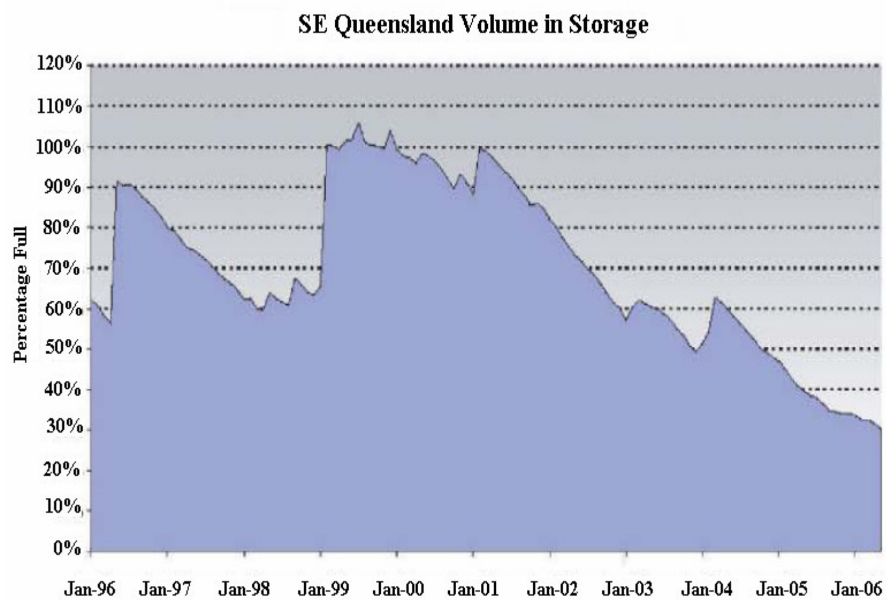
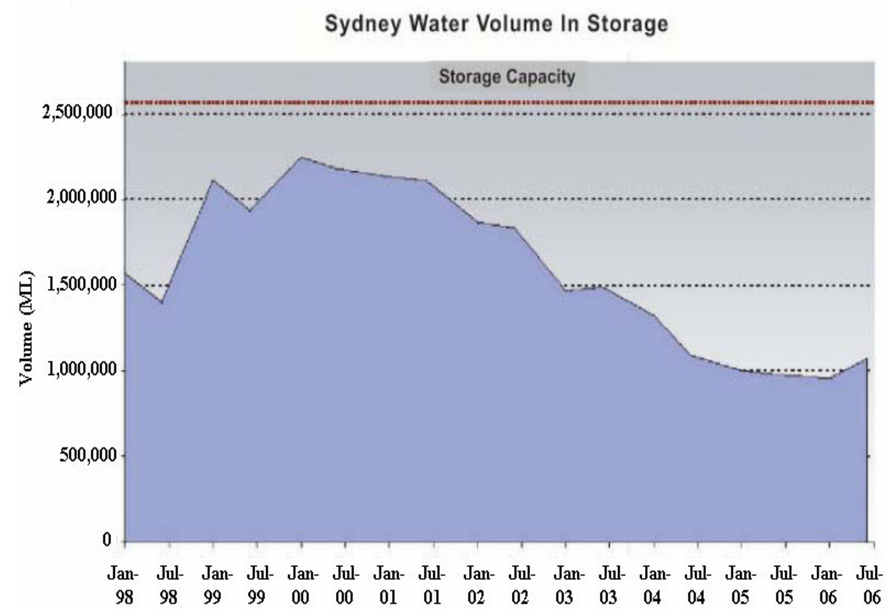
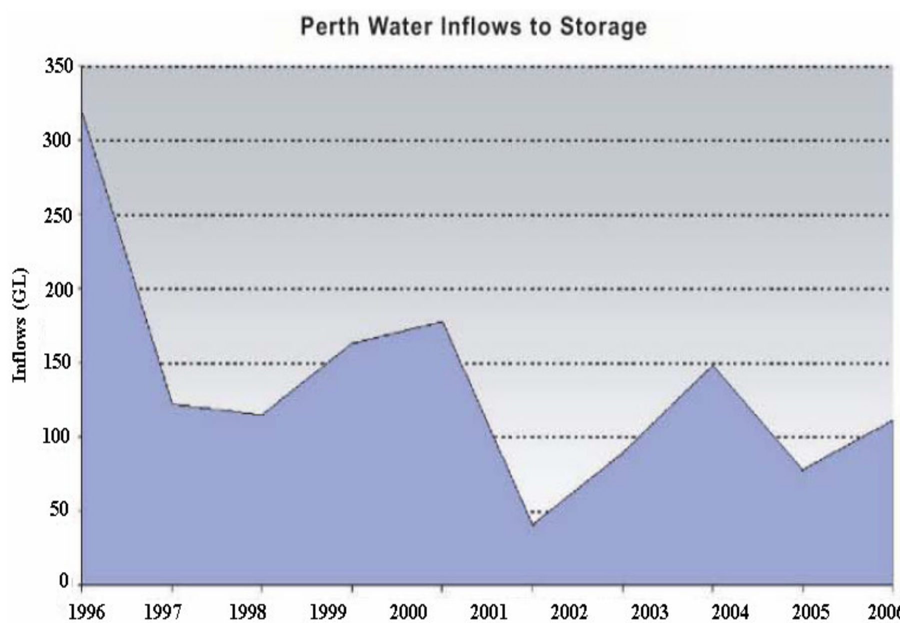


Figure 3.2.1.5 shows Australian Rainfall Deciles from March 2002 till the end of September 2006 with the major dams and dam catchments around Australia. Source Modified from Bureau of Meteorology







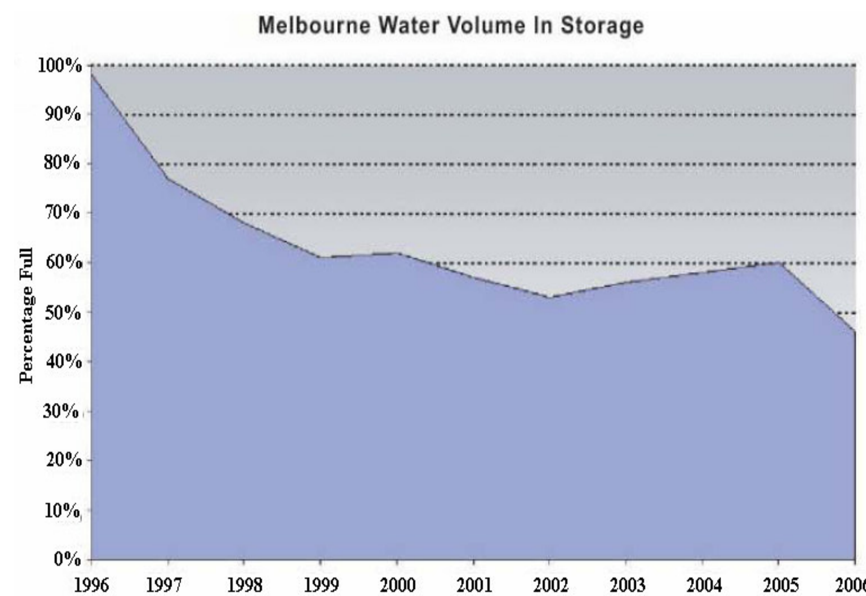


Figure 3.2.1.6 shows the dam storage volumes or inflows in Queensland, Sydney, Melbourne and Perth from 1996-2006. Source: Modified from Bureau of Meteorolog

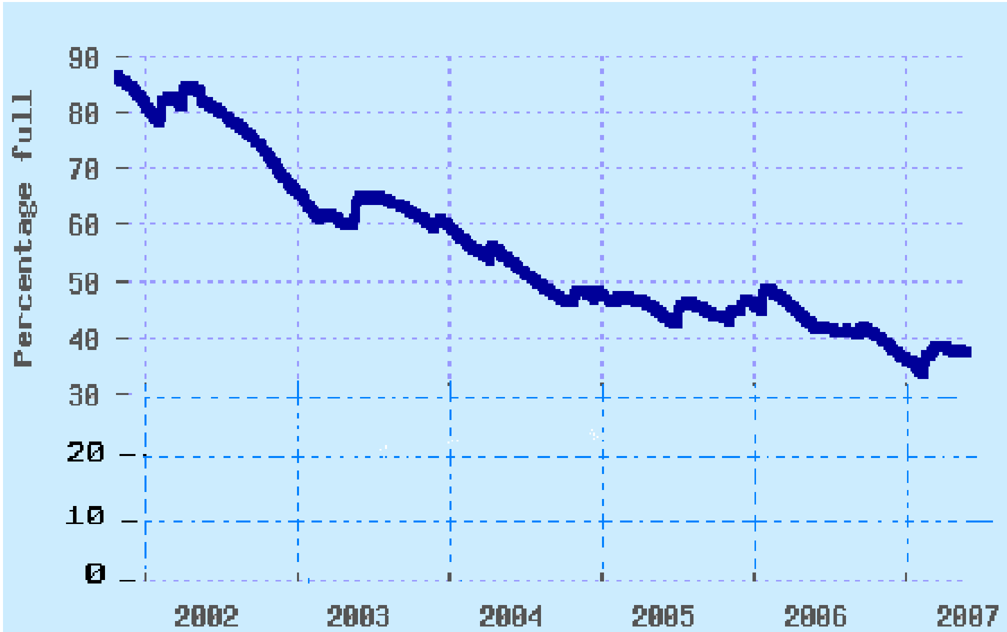


Figure 3.2.1.7 shows a gradual reduction of the percentage of Sydney dam levels from 2002 until the middle of May 2007. Source: Modified from Sydney's dam level.

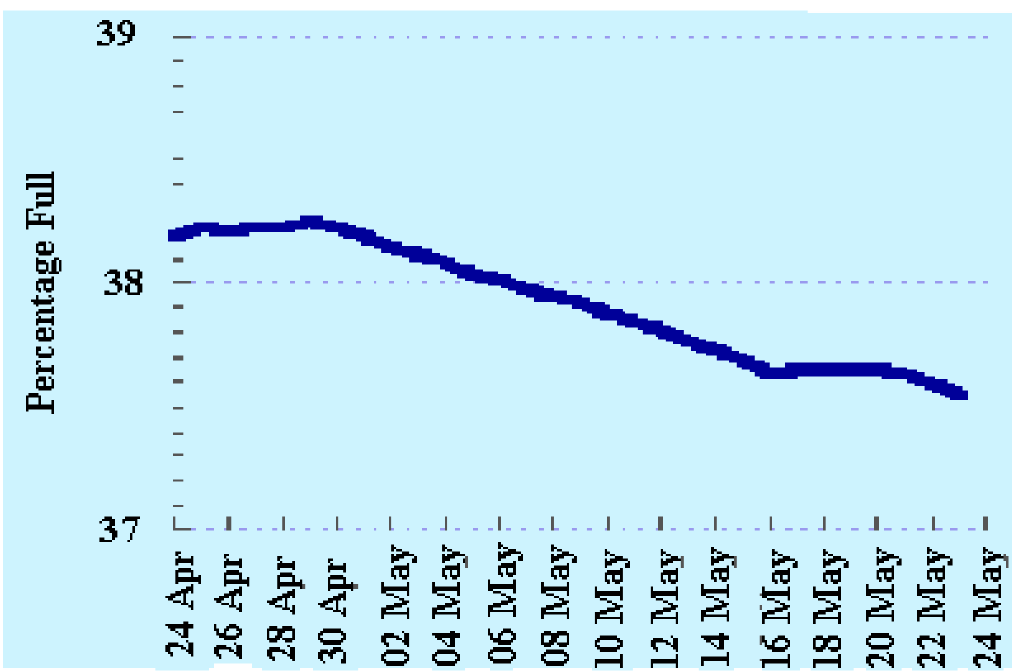


Figure 3.2.1.8 shows the reduction of one of the dam levels in one month from 24 April until 24 May. Source: Sydney's dam level.

A strong direct correlation can be derived between the storage percentage of the dam and both the inflow and the outflow rate. Figure 3.2.1.9 presents the relation between the cumulative inflow and outflow in Sydney's dams in the last five years.

Storage Percentage = Inflow Rate - Outflow rate

Inflow Rate = Rainfall+ Runoff

Outflow Rate = Usage of the dam's water

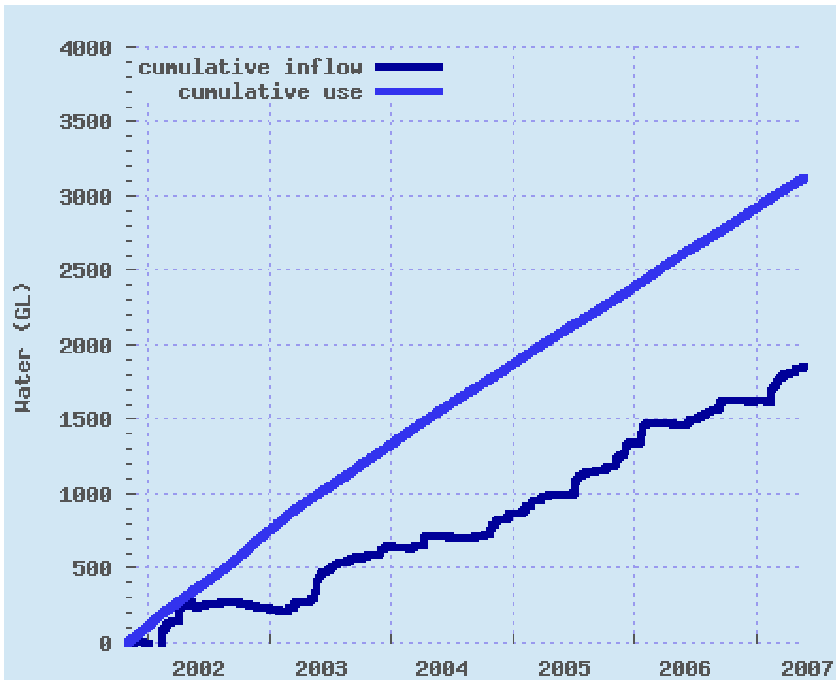


Figure 3.2.1.9 analysis of the relationship between cumulative inflow and outflow rates of Sydney's Dam.

Source: I Live in Sydney.com

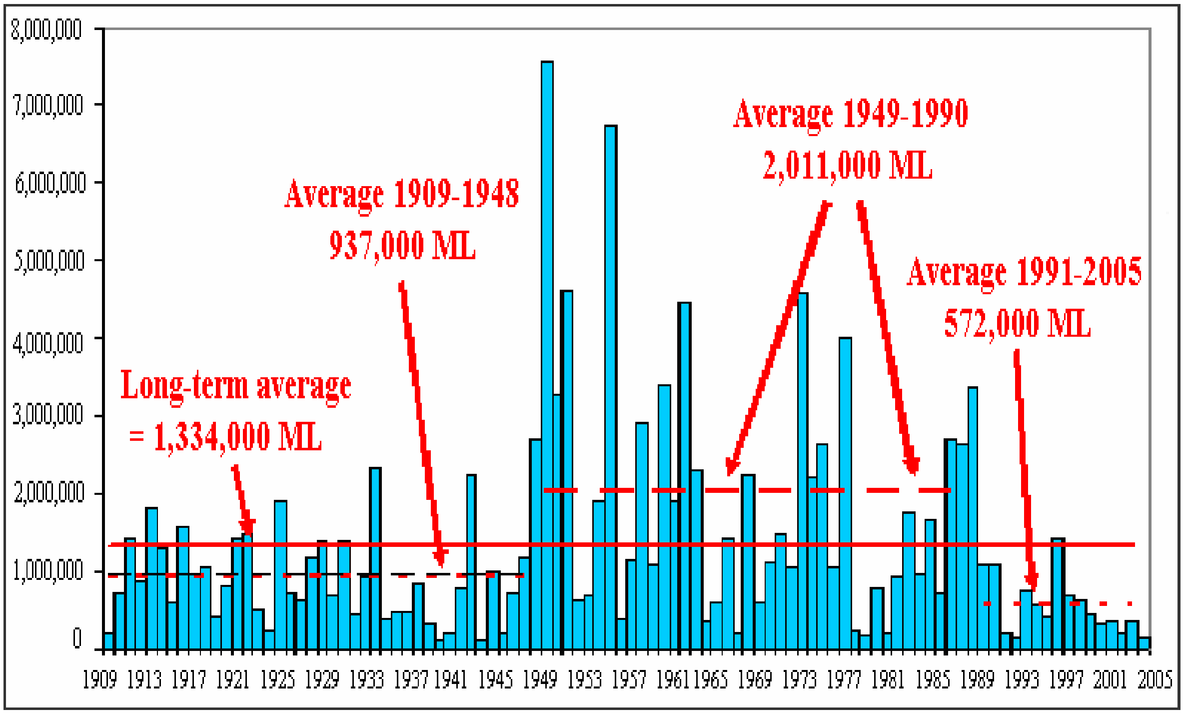


Figure 3.2.1.10 shows the annual inflows for Warragamba and three Nepean dams (Sydney Region) from 1909-2005. Source: Modified from Sydney Catchment Authority Center.

The above figure 3.2.1.10 shows some details of the annual inflows average in Sydney region's dams in about one hundred years. Two other figures (A.13 and A.14) in appendix (A) show more details about the annual inflows for Southwest dams in Western Australia and Wivenhoe Dam in southeast Queensland. All of these figures provide more evidence that rainfall is limited and the inflow rate to the dams around Australia has diminished in the last couple of decades. Therefore the most legitimate, reasonable, and valuable option is building a desalination plant and using this unlimited source of seawater.

3.2.2 Perth desalination plant

Perth Seawater desalination plant has been built at the Kwinana site, 25 km south of Perth. This plant is the largest of its kind in the southern hemisphere and will be able to produce around 45 million cubic meters per year to supply about 17% of Perth's water demands to serve a population of 1.5 million (*Crisp*, 2007;*Cameron*, 2007). Western Australia will be the first state to adopt desalinated water in Australia with an initial daily capacity production of 140,000 cubic meters per day. The total project cost is $AU387 million with annual running costs of less than

$AU20 million and the estimated cost of the water production will be about $AU1.16/kL (*Kelson and Grisp*, 2006; *Cameron*, 2007).

3.2.3 Sydney desalination plant

Although there is a network of eleven dams supplying the Sydney population, the water level of these dams is still low due to the shortage of rainfall as Sydney faces the second worst drought on record. Sydney desalination plant is proposed to build on cleared, industrial zoned land at Kurnell on the south side of Botany Bay. Kurnell is a good site to build this plant for several reasons; a) it is next to the ocean, b) it is an industrial site, and c) long way from residential areas. The New South Wales Government will commit to build this desalination plant by the end of this year if Sydney's water shortage has not improved this year (2007). Kurnell desalination plant is to be constructed in August 2007. The estimated cost of this plant will be $AU2 billion. This plant will be able to provide a third of Sydney's water demand by turning the seawater into half a billion litres of potable water per day.

4. Environmental impacts of desalination plants

A desalination plant is the same as any other industrial activity could have the potential to cause several environmental impacts to the surrounding area and to the atmosphere. A number of environmental impacts can be addressed as a consequence of running desalination plants and can be classified into several aspects such as liquid and solid waste and gas emission etc.

4.1 Chemical materials used in a pretreatment stage of desalinated seawater

Chemical materials are used in a desalination facility in order to treat the seawater from some of the blots (several sorts of substances that are found in seawater and can plug the membrane), and some odd materials that used in the cleaning stage as obtained below (*Younos*, 2005):

- Sodium hypochlorite **$NaOCl$** or free chlorine is used for chlorination to prevent biological growth in the membrane facility.
- Ferric chloride **$FeCl_3$** or aluminum chloride **$AlCl_3$** used as disinfectants for flocculation and removal of suspended matter from the water.
- Sulfuric acid **H_2SO_4** or hydrochloric acid **HCl** to adjust the Ph of the seawater.
- SHMP (sodium hexameta phosphate) **$(NaPO_3)_6$** and similar materials have been used to prevent scale formation on the pipes and on the membrane.
- Sodium bisulphate **$NaHSO_3$** is used in order to neutralise any remains of chlorine in the feed water.
- Crystalline acid EDTA (ethylenediaminetetraacetic acid) **$C_{10}H_{16}N_2O_8$** is used in order to remove the carbonate deposits from the desalination facilities.
- Citric acid **$C_6H_8O_7$**, EDTA and Sodium polyphosphate **$NaPO_3$**, are weak acid detergents used to clean the membrane and this cleaning step is conducted three to four times a year.

4.2 Consideration and criticism

Several environmental impacts could be addressed in terms of running on a desalination facility. It is assumed that using desalination as a water resource would have considerable environmental impacts to the surrounding area including the ecosystems. Significant energy consumption in the desalination process, in order to produce electricity and heat, would lead to greenhouse gas emissions into the atmosphere. The other major issue that can rise in terms of building a desalination plant is the double salt concentration that has been extracted from the seawater and will in most cases be deposited into the ocean as discharge brine. Regardless of the method used in the desalination facility, a number of factors can determine the environmental cost of desalination plants on the surrounding environment. In the reverse osmosis technology, fifty percent of the feed water will be potable water and the other fifty percent will be the discharge brine. It has been estimated that the expected salinity level of the discharge brine is approximately double which equals to 64-70 ppt part per thousands. This is a highly concentrated waste product consisting of everything that was removed from the seawater to produce fresh water. Environmental impacts associated with concentrated discharge have historically been considered as a major environmental concern to marine life with desalination plants.

The environmental impact of desalination plants will vary depending on several factors:

i. The location of desalination plant.
ii. The location of the inlet and outlet.
iii. The method used in the desalination facility and the outlet (water channel and pipeline).

The environmental impact of desalination plants can be classified under several chief aspects: (*Einav et al*, 2002; *Höpner and Windelberg*, 1996):

- ✓ The impact of using the coastal area, building desalination plant will use a significant length of coastal area.
- ✓ Noise pollution as a result of the high-pressure pumps and energy recovery turbines.
- ✓ The impact of the electricity production that is required to power desalination would be responsible for extra greenhouse gas emissions including carbon monoxide CO, nitric oxide NO, nitrogen dioxide NO_2 and sulfur dioxide SO_2 (*Younos*, 2005).
- ✓ Impact of raising the water temperature, the discharge brine has a potential to cause thermal pollution near the outlet, which might pose adverse impacts to marine habitats (*AL-Mutaz*, 1989) (this will be discussed later in this paper).
- ✓ The impacts on marine life are primarily due to almost doubling the salt concentration and the total alkalinity. The heavily concentrated brine solution discharged into the sea from the desalination plant has the potential to kill marine organisms and cause damage to the marine population (this will be addressed widely later in this paper).

5. Impact of discharge brine

5.1 What is brine discharge?

Brine discharge is the fluid waste from a desalination plant, which contains a high percentage of salts and dissolved minerals. It returns back to the sea and spreads according to different aspects. Two different types of the brine discharge are used in the desalination plant, water channel and pipeline.

5.1.1 Brine discharge plume current

The discharge brine might be sent directly into the ocean or sea or combined with other discharge; however, several factors can play a large role in the discharge plume and the diffusion into the seawater. The influencing features are (*Jenkins and wasyl*, 2005):

1. Wind direction and speed. This aspect has a large impact on the diffusion of the discharge brine into the ocean, which can dilute this highly concentrated plume with seawater in a short distance.
2. Wave height and speed. This factor could play a major role in the dispersion of the seawater properties by producing significant effects at higher levels on the ambient environment (*Gill*, 1982).
3. Bathymetry and the tidal mean and average. According to some scientific research; the brine discharge will have a minimum impact on changing the physical properties. Peak Salinity and alkalinity changes will occur during the high tide in a shallow depression (*Swanson et al*, 2006).

Breaking waves induce considerable turbulence and larger waves help create more mixing, tidal currents generate turbulence by fiction of the seafloor, and wind drives surface current which is also turbulent. When any of these elements is large, rapid diffusion will be occurred which means more diffusion and more dilution of the discharge brine into the ocean water. Therefore the zone of risk is reduced but the area of low risk is increased.

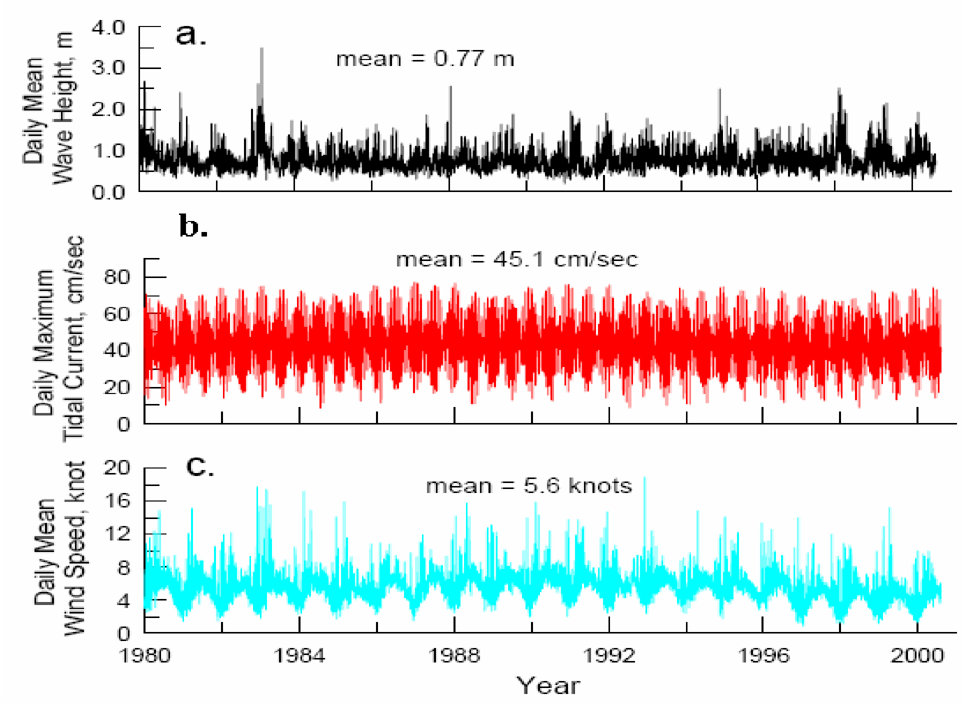


Figure 5.1.2.1 presents the controlling environmental variables brine dilution, of the three factors (Wave, Tide and Wind) at the Scattergood Site of Encina Desalination Plant. Source: Modified from (Jenkins and Wasyl, 2005).

All of these three aspects have an ability to affect the current and the rate of diffusion of the discharge brine into the sea or the ocean. The turbulence level plays a role in the rate of diffusion in the ocean current fluctuation (*Jones and Kenny*, 1971). Therefore these three factors have to be considered as a significant influence on the diffusion and mixing of the brine discharge into the ocean and the faster the dilution the less will be any impacts on the seawater quality. Dilution models for effluent discharges by the *American Environmental Protection Agency* is recommended as a model to experiment and document the diffusion rate of the brine discharge into the seawater (*Frick et al*, 2001).

5.1.2 Environmental and chemical aspects of brine discharge

The largest impact of desalination plant on the surrounding environment is often considered to act on marine life. The discharge brine has the ability to change the salinity, alkalinity and the temperature averages of the seawater and can cause change on marine habitat.

The plume of discharge brine might contain all or some of the following constituents:

A. High salt concentration, chemical used during pretreatment stage.

B. High total alkalinity as a consequence of increasing the calcium carbonate, calcium sulfate and other elements in the seawater to almost double.

C. Higher temperature of the discharge brine due to the high temperature is used in the desalination facility.

D. Toxic metals, which might be produced if the discharge brine has contact with metallic materials used in the plant facilities

In general, the salinity and total alkalinity of the discharge brine is almost double that of average seawater and thermal pollution may occur from the high temperature of the brine discharge. This change in salinity, alkalinity, and temperature could possibly lead to a significant impact on aquatic life.

The seawater average salinity, temperature (*Millero*, 1992) and alkalinity are:

- Salinity of sea and ocean water worldwide varies between 30-37 ppt (part per thousand).
- Temperature of the sea and ocean water surface differs from the two polar areas to the equator between 15-27° C (summer).
- Total alkalinity is approximately 2.32×10^{-3}mol/Kg.

5.1.2.1 Total alkalinity determination and calculation

Specific instruments can measure salinity and temperature but a chemical treatment is needed to determine the total alkalinity.

Total alkalinity is defined as the number of moles of hydrogen ion equivalent obliged to neutralize the excess proton acceptors (*Anderson et al*, 1998). The accurate way of determining the total alkalinity is to calculate the sum of total dissolved inorganic carbon (bicarbonate), organic nitrogen, phosphate, silicate, borate and other bases. This leads to the following definition of alkalinity in seawater:

$$
\begin{aligned}
A_T = {} & [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] + [HPO_4^{2-}] \\
& + 2[PO_4^{3-}] + [SiO(OH)_3^-] + [NH_3] + [HS^-] + \ldots \\
& - [H^+]_F - [HSO_4^-] - [HF] - [H_3PO_4] - \ldots
\end{aligned}
$$

Where the small concentration (usually< 1µmol/kg) from hydroxide, phosphate, silicate and other bases can often be ignored, therefore the following simple equation of total alkalinity can be defined by the determination of the total amount of calcium carbonate in a sample of water.

$$A_T = [HCO_3^-] + 2[CO_3^{2-}]$$

Back titration method is a special technique that has been used in order to determine the total alkalinity. This method has been used due the simplicity of technique and the equipment that is needed. It can be used to determine the total alkalinity in ocean water using hydrochloric acid (**HCl**) and sodium hydroxide (**NaOH**).

Normal seawater sample PH is around 8.2

Density =1.027 Kg/L

Salinity S=36 ppt

Temperature T= 24°C

$$\text{Seawater} + HCl \longrightarrow PH = 3.5$$

$$+ NaOH \longrightarrow PH = 6$$

5.1.2.1.1 Analytical Procedure

Taking 50 ml of seawater and adding the hydrochloric acid to get to the point of pH = 3.5 then the sodium hydroxide is added to obtain a pH = 6, this pH is the end point (equivalence point) of the titration of calcium chloride by sodium hydroxide. The following chemical equation shows the chemical process that happens during the titration of calcium carbonate with hydrochloride acid and then with sodium hydroxide.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2O + CO_2$$

$$CaCl_2 + 2NaOH \longrightarrow Ca(OH)_2 + 2NaCl$$

Equation (5.1.1.1) shows how to calculate the total alkalinity by using the volume and concentration of each of hydrochloric acid (**HCl**) and sodium hydroxide (**NaOH**), which have been used in the chemical experiment, and the density and volume of the seawater (*Anderson et al*, 1999). So this equation presents that total alkalinity can be measured by identifying the difference between the amount of HCl that has been used to acidify the water sample to pH=3.5 and the volume of NaOH which is used to bring the pH back up to 6.

$$A_T = \frac{V_a C_a - V_b C_b}{\rho_o V_o}$$

Equation 5.1.1.1 presents the total alkalinity calculation

A_T: Total Alkalinity

V_a and C_a: volume and concentration of HCl

V_b and C_b: volume and concentration of NaOH

ρ_o: seawater density

V_o: seawater volume

High total alkalinity of seawater has been achieved in the laboratory procedure by inject some carbon dioxide (CO_2) into the seawater to reach pH = 3.5 and then to add few grams of calcium carbonate ($CaCO_3$) to attain pH = 6. Over three times the level of total alkalinity of seawater can be obtained by using this method. Two charts (A.1 and A.2) in Appendix A present the chemical procedures of the amounts of hydrochloric acid and sodium hydroxide to the pH.

5.2 The impact of salinity changes on the marine environment

Changes to salinity can play a significant role in the growth and size of aquatic life and the marine species disturbance. Knowledge of tolerance limits of marine life to different salinity degrees is an important aspect in assessing marine disturbance and population. Changes in the salinity can play two opposite roles on the marine organisms' existence; it can be of benefit for some of these organisms such as shellfish and at the same time can have an adverse impact on other species. The salinity alteration that will be mentioned in this paper ranges between 35 ppt to 70 ppt.

Water salinity changes may influence; (*Neuparath et al*, 2002):

- Development of species and the propagation activity and faster individual growth.
- Survival of larval stages of animals and life expectancy (shorter or longer generation time).
- Population density of organisms (higher or lower population growth rate).
- Breeding of species and reproductive traits.

The salinity around the outlet discharge varies from about 80 ppt to reach the actual seawater salinity 35-36 ppt in balance with the surrounding environment. According to some studies the excess salinity level of seawater from the discharge brine is a direct function of the distance from the desalination charge site. The salinity of seawater might not be remarkably different in profile from the surface to the bottom of the sea; however in the ambient area of the discharge brine outfall it can significantly fluctuate between the surface and ten meters depth for instance (*Abdul-Wahab*, 2007). Figure 5.2.1 shows the seawater salinity profile from surface to eleven meters depth in the surrounding area of Barke desalination plant in Oman. A direct relationship can be clarified between the rates of change of environmental salinity and the effects on marine organisms such as population, size and behavior (*Gunter*, 1961). However, some of the sampling evidences for some fish species indicate that these fish are not very sensitive to the salinity fluctuation (*Perez,* 1969).

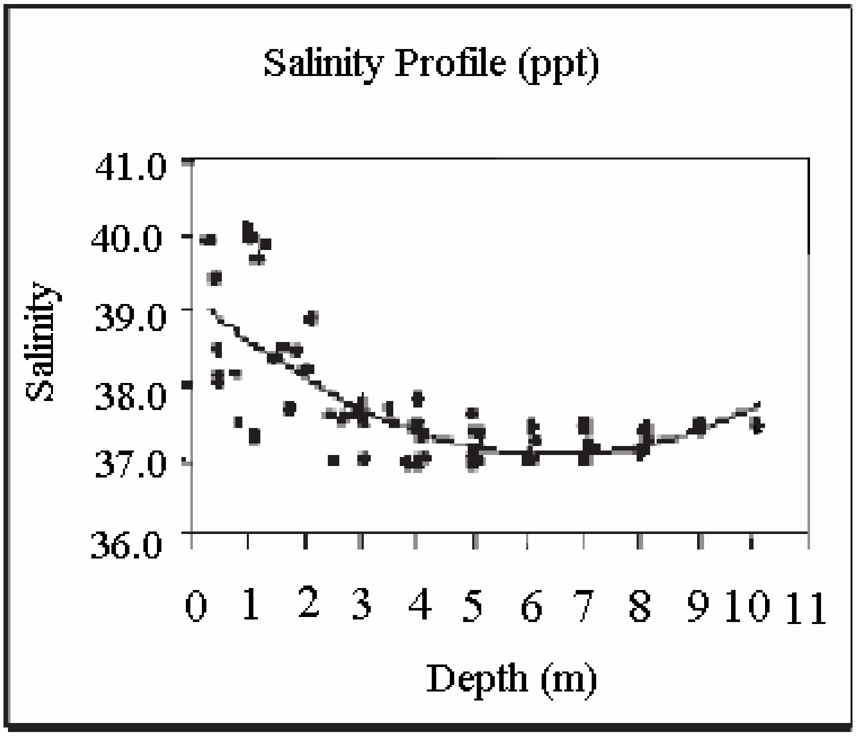


Figure 5.2.1 presents the distribution of the seawater salinity from the surface to 11 meters depth in the ambient of the outfall of Barke desalination plant. Source: modified from (Abdul-Wahab, 2007).

According to some studies about the effects of changes in the salinity of sea water on marine organisms, the primary and apparent changes might occur firstly in mobile species such as plankton and fish, the reaction will be highest in those organisms with a plankton stage in their life history (*Hiscock et al*, 2004). Parry's experiment presents the impact of changing the seawater salinity on some marine species. Salinity alteration plays a significant role on the marine species size, population and behavior; however, these impacts differ between different sorts of organism. It shows that increasing the salinity level up to 50 ppt could possibly have an enormous impact on the size of several types of fish and the survival rate, but the impact on salmon seems to be less than rainbow trout, which on the other hand can survive salinity changes better than the brown trout (*Parry*, 1960). Salinity alteration would probably play a considerable function in the fish distribution, while some of the fish juvenile such as croaker fish offspring are more vulnerable to salinity fluctuation than the spot progeny; however an adult generation of these sorts of fish will have an ability to tolerate a vast range of salinity alteration (*Moser and*

Gerry, 1989). Gunter believes there is a direct negative correlation between the number of marine species and the salinity increment of the seawater (*Gunter*, 1961). There are very limited numbers of documented studies or experiments have been done about the impacts of salinity and temperature fluctuation on the flora species neither sedentary organism.

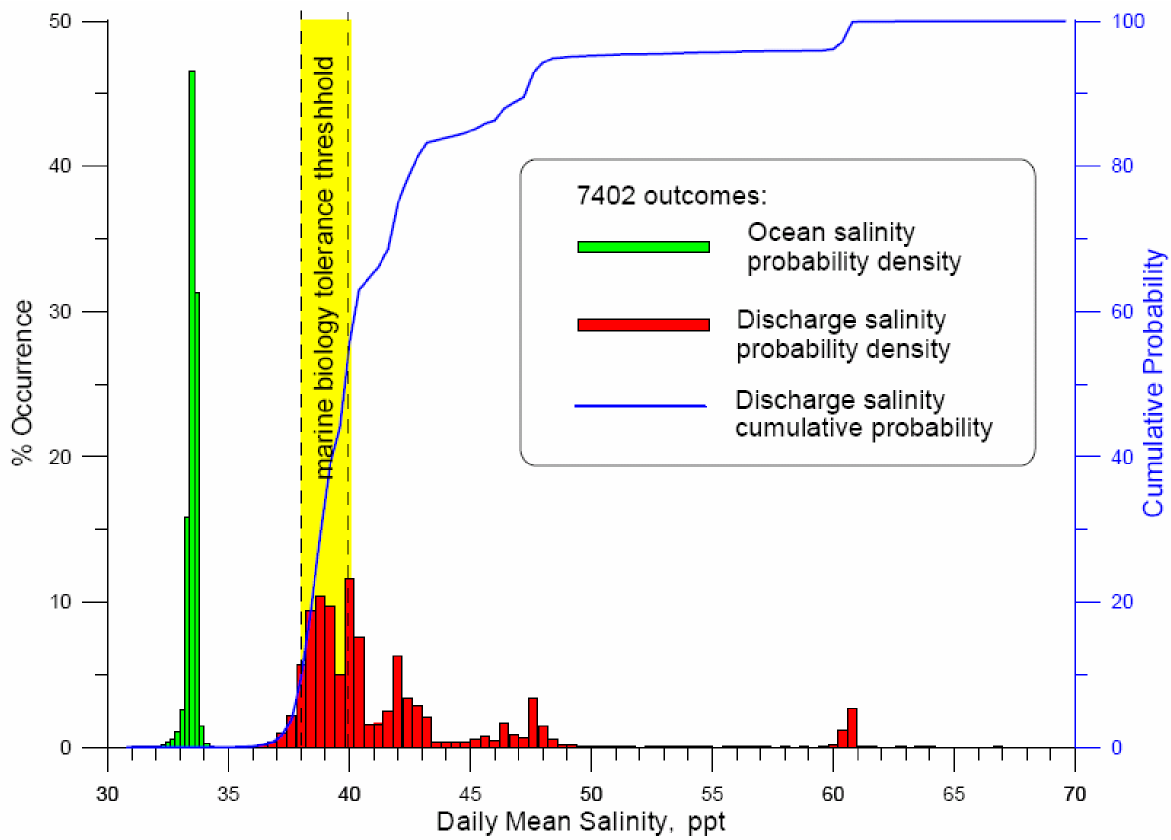


Figure 5.2.2 shows the daily mean ocean and discharge salinity out from the Encina desalination plant for 50 million gallon per day productivity related to the marine biology tolerance and the cumulative probability of the impacts on marine life. Source: (Jenkins and Wasyl, 2005).

5.3 The impact of Temperature alteration on the marine environment

Another impact of the discharge brine is the thermal pollution that can occur by rising the temperature of the seawater. Thermal pollution, which results from cooling water being discharged to the sea or ocean, can be defined as "a major change in the sea temperature". Different consequences can be addressed in order to determine the impact of the temperature alteration on the ambient environment. Generally, the water mass is subdivided vertically by temperature into three main classes.

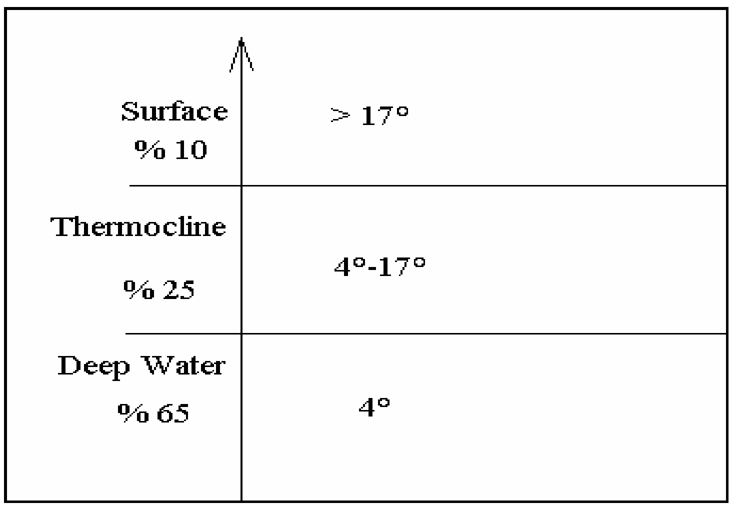


Figure 5.3.1 shows the vertical temperature profile of the ocean or seawater. Source: (Millero et al, 1992).

Several studies have been carried out in order to determine how the distribution and abundance of marine flora and fauna species react to a change in temperature. The temperature of the brine discharge is one of the major concerns for any desalination plant project; this temperature is higher than the ambient ocean water temperature. Marine biologists believe that a significant impact can occur to the natural balance and distribution of the marine life if a temperature alteration applied to the ambient environment (*Buros*, 1994). A direct correlation can be determined between the temperature alteration and the behavior of marine species. Sea temperature is one of the key variables to monitor and can play a great role in the marine flora and fauna's life (*Mann and Lazier*, 2006). The highest temperature value in the surrounding area of the brine discharge has been found to occur very close to the mouth of the outfall diffuser. Abdul-Wahab study presents a direct link between the temperature of the seawater and the distance from the discharge site (*Abdul-Wahab*, 2007). The discharge temperature can spike to as high as 57°C at the mouth of the plume discharge (*Jenkins and Wasyl*, 2005). Figure 5.3.2 presents the difference of temperature changes in the ocean water and on the surrounding area of the discharge brine, it shows more considerable fluctuation can be defined around the discharge brine and varies in significant range from 10 to almost 40°C, while in general ocean environment the temperature varies between 10 to just under 25°C.

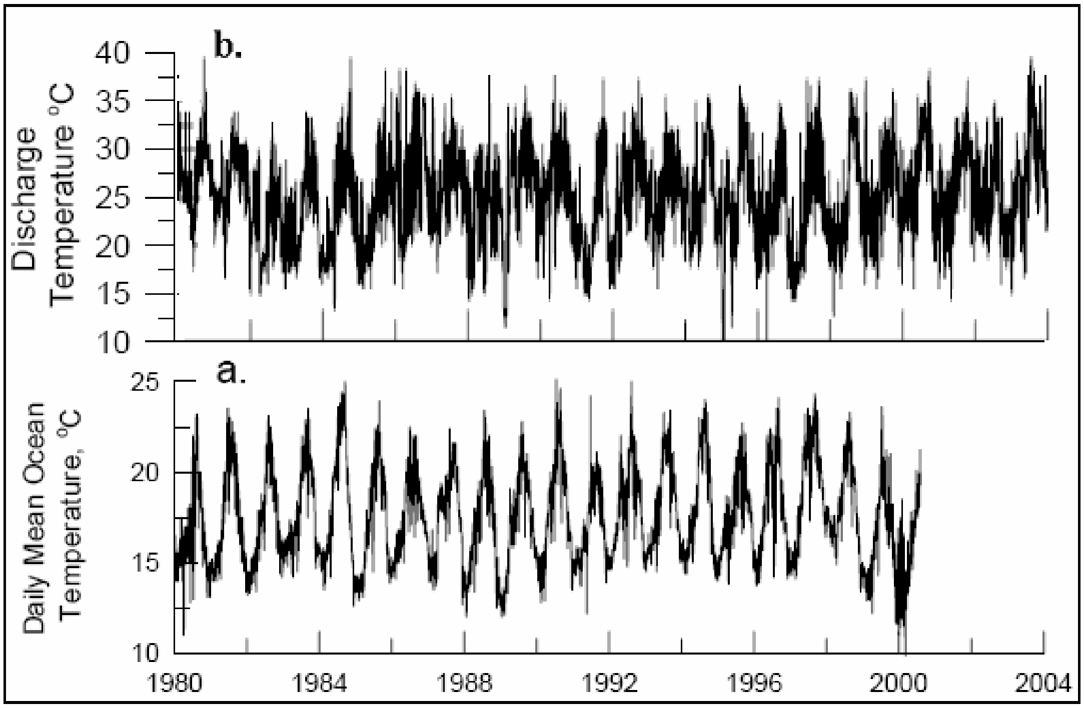


Figure 5.3.2 shows the controlling temperature variables for brine dilution in 24 years for the discharge and the daily mean ocean temperature. Source: Modified from (Jenkins et al, 2005).

Temperature can have an influence on the growth and reproduction of marine species. Mobile species such as plankton and fish are the first most likely sort of marine life to be influenced due to changes in the seawater temperature (*Hiscock et al*, 2004). Changes in the temperature values can have an impact on the marine habitat, a study about the plankton shows that increasing the temperature of the ambient environment will lead to a positive effect on reproduction biology and the growth rate of several species of plankton (*Vijverberg*, 1980). A decrease in the time of the eggs development of several types of fish and increasing the rate of the population growth has occurred due also to an increase in temperature. (*Bottrel*, 1975 and *Armitage et al*, 1973). *He et al*. (1980) studied the effect of temperature on the growth and reproduction rate, and the maturity age of the *Moina Mangolica*, the maturity age reduced from 5.8 days at 20°C to 3.4 days in the 30°C, the reproduction rate has decreased from 4.1 days at 20 °C to once a day at 28°C and the longest life span was 10.8 days at 25°C, but reduced to 4.2 days at 35°C. So temperature can have positive or negative impacts on the marine flora and fauna depending on the species and extent of the change in temperature. A very limited experimental data have been documented about the impact of the temperature changes on several kinds of marine flora and fauna species

5.4 The impact of Total Alkalinity changes on the marine life

An understanding of the oceanic total alkalinity tolerance (positive or negative) of marine species is important in many branches of marine chemistry, ecology and biology. The alkalinity of the seawater is defined as the number of equivalents of calcium carbonate in the seawater (*Brewer and Goldman*, 1976). The total alkalinity tolerance of the marine life and the changes rate of alkalinity that the brine discharge cause to the seawater has not been exactly determined yet due to a very limited number of experiments. As far as marine biologists are aware, this phenomena has not been adequately documented and very limited experimental data exists. There is also limited literature available, which explores the impact of total alkalinity on marine life. Desalination seawater plant has the ability to increase the total alkalinity level of the brine discharge and to the seawater in the area of discharge afterwards. Therefore testing the total alkalinity level out in the diffuser and the ambient environment would be recommended to declare any impact on the marine flora and fauna species.

5.5 Summation

These three factors can have either positive or negative impacts to the environment in the area of desalination and especially to the marine environment species. However according to some experiments in this area, no considerable impacts have been found on the marine flora and fauna species nor a significant change to the seawater quality from the high concentrated discharge out of desalination plant in the area of the outfall (*Sydney's desalination project*, 2005).

6. Conclusion

Over one third of the world's population is already facing problems due to poor water quality, and fresh water being either unavailable or extremely limited. Overgrowth of human population on this planet and the wasteful usage of natural water resources have resulted in increased demand of fresh potable water. The demand for potable water has been a major issue worldwide. Desalination techniques have assisted with the shortage by offering fresh water from sea or ocean water resources. Numerous countries worldwide have commissioned thousands of desalination plants where natural good-quality water is insufficient or is extremely limited. Hence, desalinated seawater technology has been commonly used as a significant alternative source of clean water to supply water for municipal and industrial regions. Australia is one of the countries with a demand for fresh water. Two major desalination plants are proposed to be constructed. The first in Perth has already been commissioned and the second in Sydney is to be constructed in August 2007. Desalinated seawater holds the key for a new fresh water resource in Australia. Seawater is an unlimited source of water and dams are becoming less feasible because of low rainfall and runoff rates. Most of the dams in Australia show a reduction in the inflow rate and the storage level in the past five, ten and fifty years. Desalination plants could have several impacts on the surrounding environment. The major concern of these impacts surrounds the outfall brine discharge because of its physical and chemical features. High salinity, high temperature and high total alkalinity of the discharge brine could have several positive and negative impacts on the surrounding environment. The impact of brine discharge on marine life is low when compared with the high physical and chemical changes to the seawater. It would be desirable to model the plume and to undertake an intensive biological and ecological monitoring program to keep a healthy coastal marine life.

7. Recommendations

Salinity, temperature and total alkalinity fluctuations, as a consequence of the brine discharge of the desalination plant, can play a considerable role in determining the abundance and distribution of flora and fauna's species. This hypothesis needs to be clarified and verified in order to determine the positive and negative impacts on the ambient environment. New data should be generated to determine this. Modeling the plume of the brine discharge will be desirable in order to illustrate the diffusion area. Long term monitoring of the conditions proposed in relation to temperature, salinity and alkalinity at the site of the desalination discharge outlet vicinity during the desalination process is recommended. This would allow the verification of the appropriate distribution of the discharge plume into the seawater and the impact of the above factors on the aquatic organisms could be better understood. A manual water sampling program needs to be undertaken in the area of the desalination outfall discharge. Examination of the water quality of concentrated brine discharge is required with respect to these three factors to determine the possible harm they could cause to the environment. Therefore an intensive study of environmental impacts and seawater quality monitoring needs to be undertaken occasionally, besides further analysis is required to ensure the proposed project in Sydney will not have significant impacts on the coastal environment. Evidence needs to be obtained to prove that desalination plants are not just an incredible source of fresh potable water but, that this process is economical and environmental friendly.

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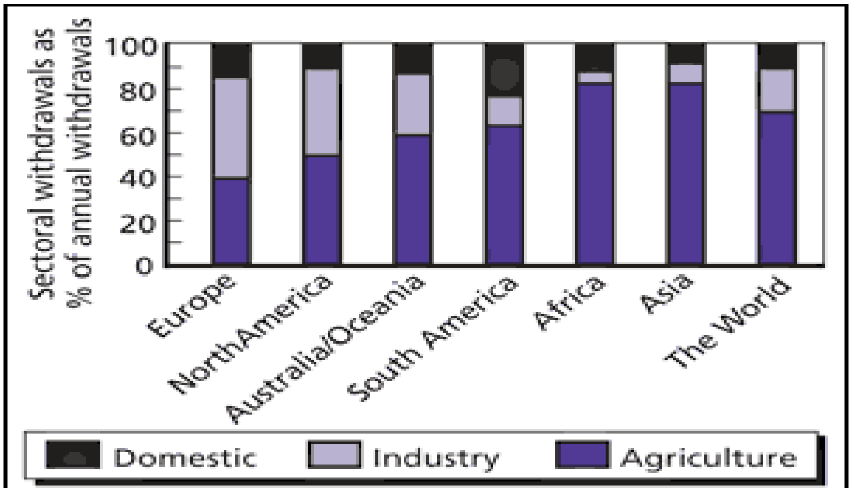
Appendix A:

Information of desalination Plants around the world



SOURCE: United Nations and World Meteorological Organization, *Comprehensive Assessment of Freshwater Resources of the World*, New York: World Meteorological Organization, 1997.

Figure A.1 shows the usage of fresh water in all contents and in the world in three different categories domestically, industrial and agricultural.

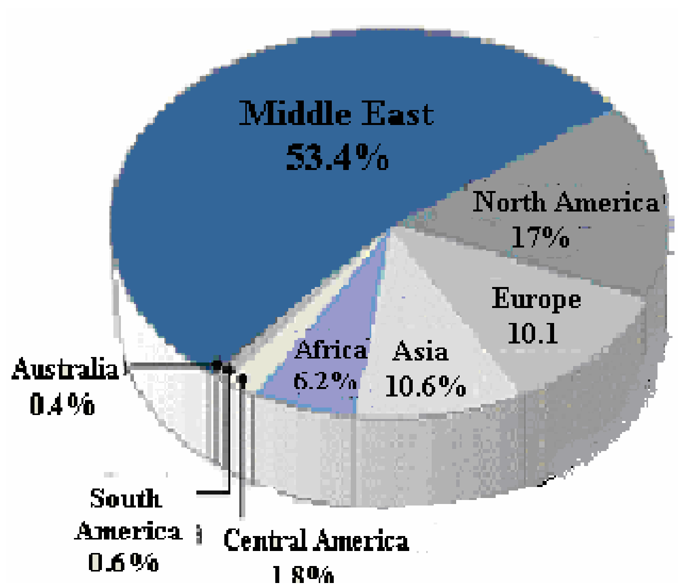


Figure A.2 presents the existing desalination facilities worldwide by region. Source: Modified from International Desalination Association

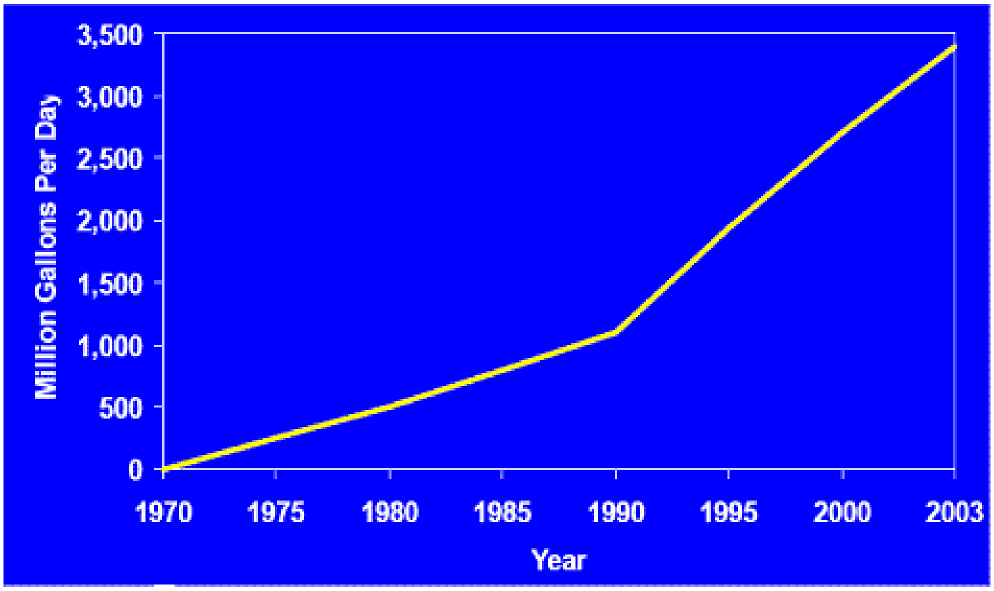


Figure A.3 shows growth worldwide seawater desalination facilities capacity. Source: Modified from International Desalination Association

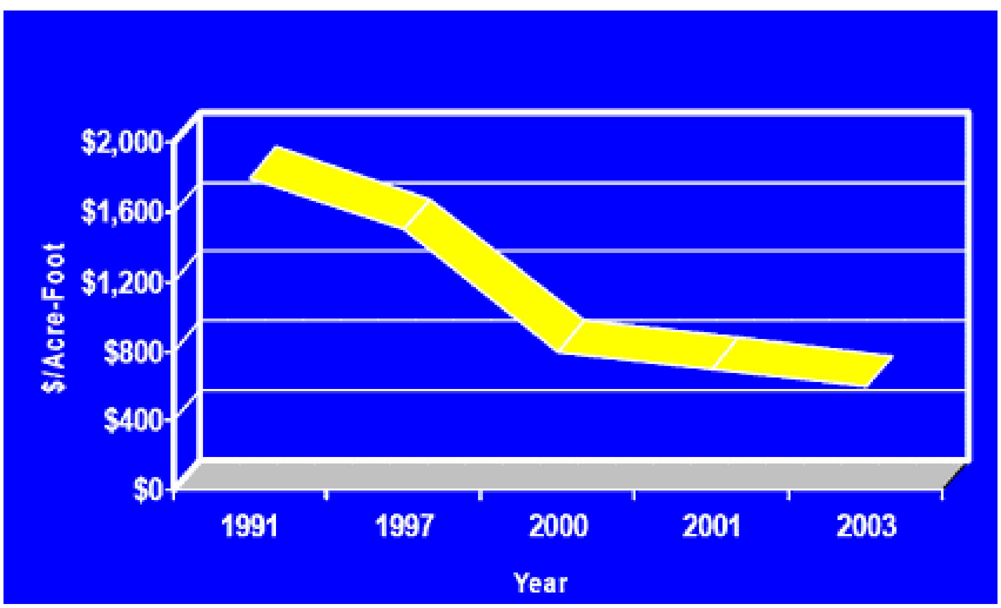


Figure A.4 shows a cost of portable water produced using seawater desalination. Source: Modified from International Desalination Association

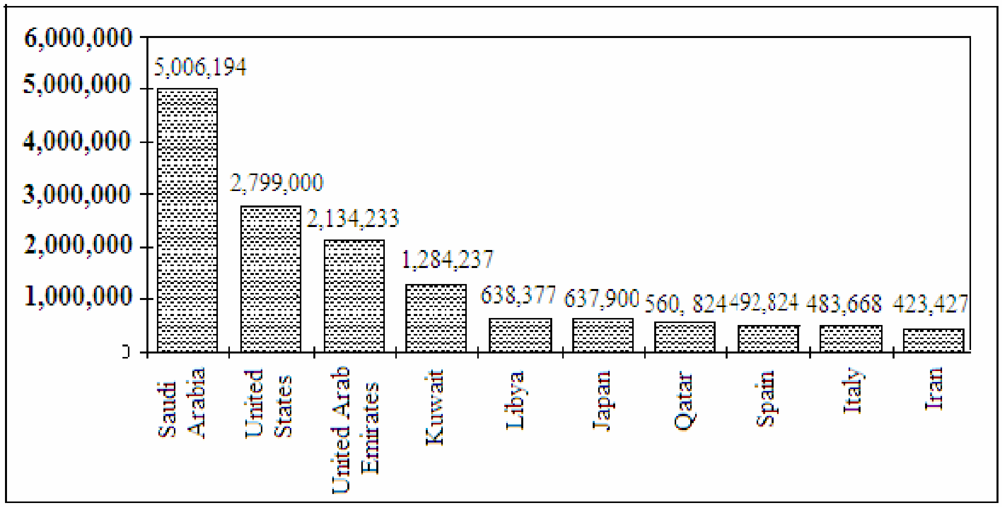


Figure A.5 shows the desalination capacity for the biggest ten countries producer of desalinated water, January 1996. Source: Modified from World Water's

Figure A.6 Shows Encina Desalination plant is located on the site of the Scattergood Generating Station at the southern Coast of California.

Figure A.7 presents a satellite image of Encina Desalination plant on the site of the Scattergood Generating Station and it shows the geographical co-ordinates lat 33.917911º and lon -118.425075º. Source: Google Earth 2007.

Figure A.8 presents a satellite image for Ashkelon desalination plant in Israel; the geographical co-ordinates for this desalination plant are 31º37´40.14˝ N and 34º31´19.53˝ E. Source: Google Earth 2007.

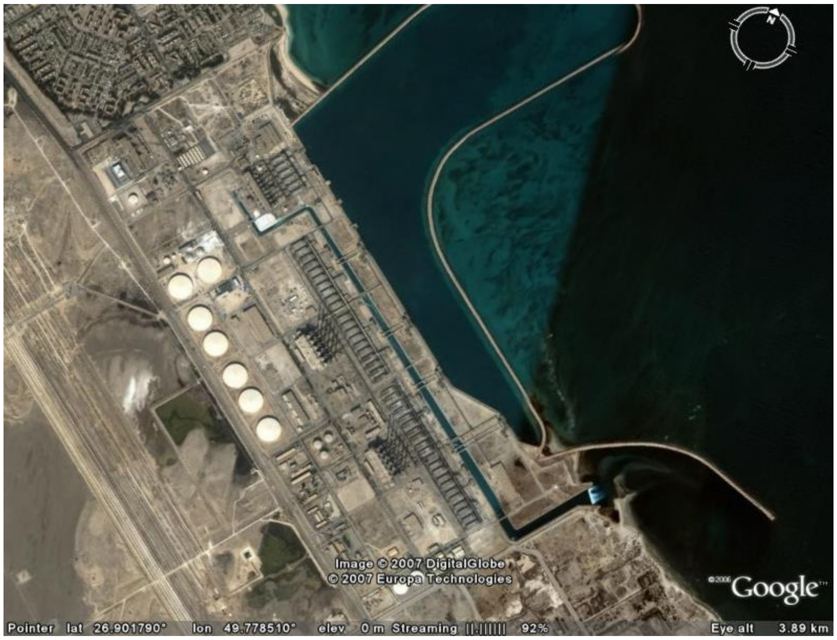


Figure A.9 shows a satellite image of Al-Jubail desalination plant on the eastern coast of Saudi Arabia with a geographical co-ordinate of lat 26.901790 º and lon 49.778510 º. Source: Google Earth 2007.

Figure A.10 shows a satellite image for Shoaiba desalination plant on the western coast of Saudi Arabia with a geographical co-ordinate of lat 20.626805º and lon 39.557861º. Source: Google Earth 2007.

Figure A.11 shows a satellite image for Al-Khobar desalination plant on the eastern coast of Saudi Arabia with a geographical co-ordinate of lat 26.179116º and lon 50.208096º. Source: Google Earth 2007.

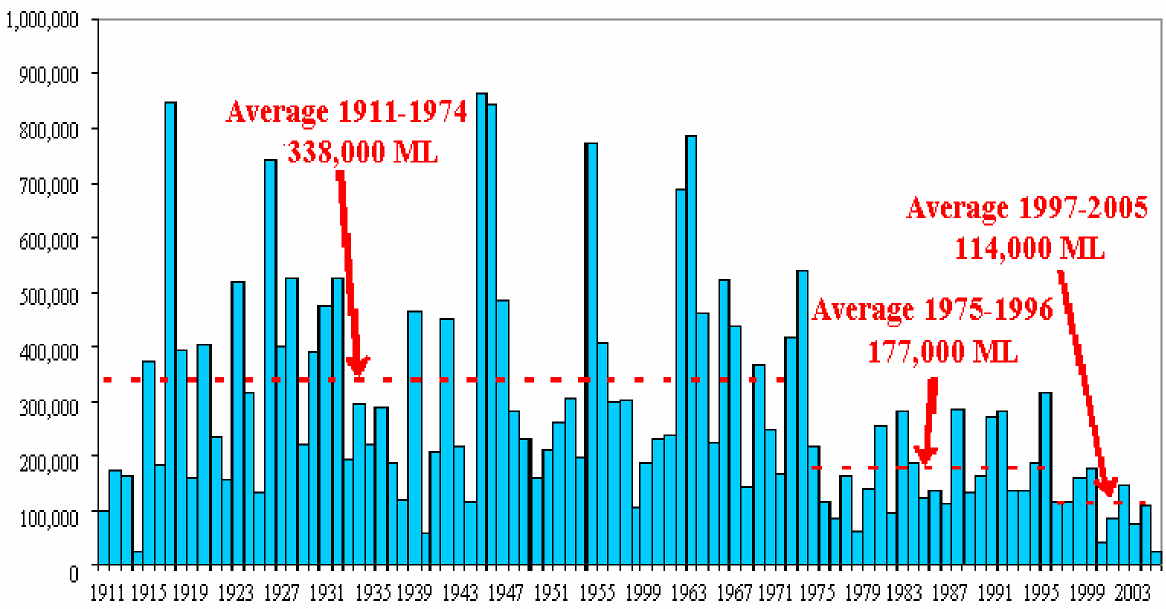


***Figure A.13 shows Annual inflows for South-West Dams (Western Australia) from 1911-2003. Source: Modified from Water Corporation*.**

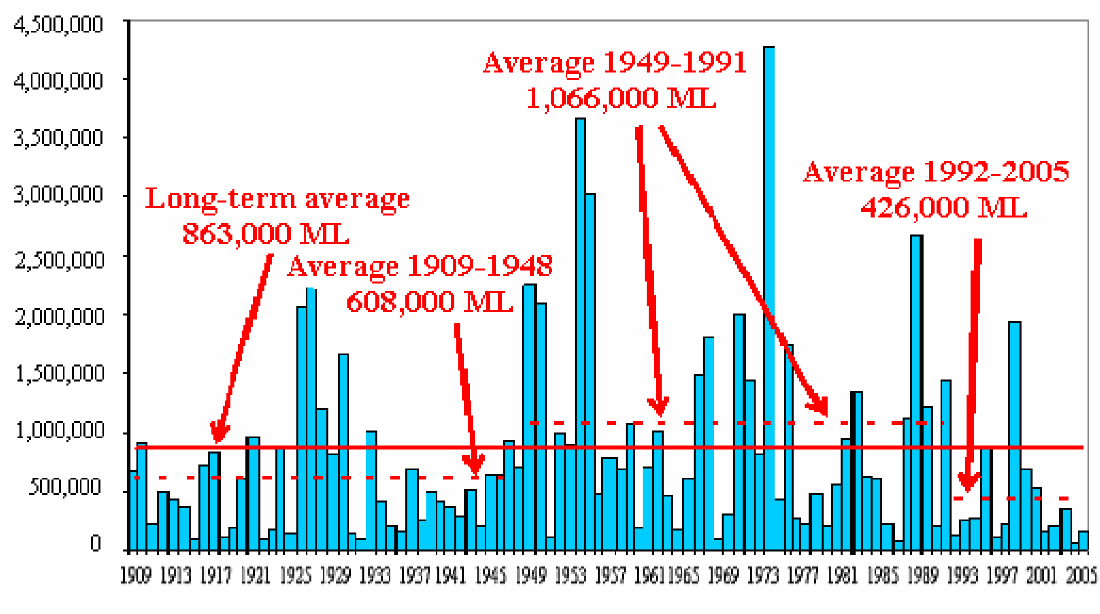


Figure A.14 shows the annual inflows for Wivenhoe dam (south-east Queensland) (Securing Australia's, 2007).

Figure A.15 shows a satellite image of Perth desalination plant; the geographical co-ordinates for this desalination plant are (lat -32.202856º and lon 115.772812º). Source: Google Earth 2007.

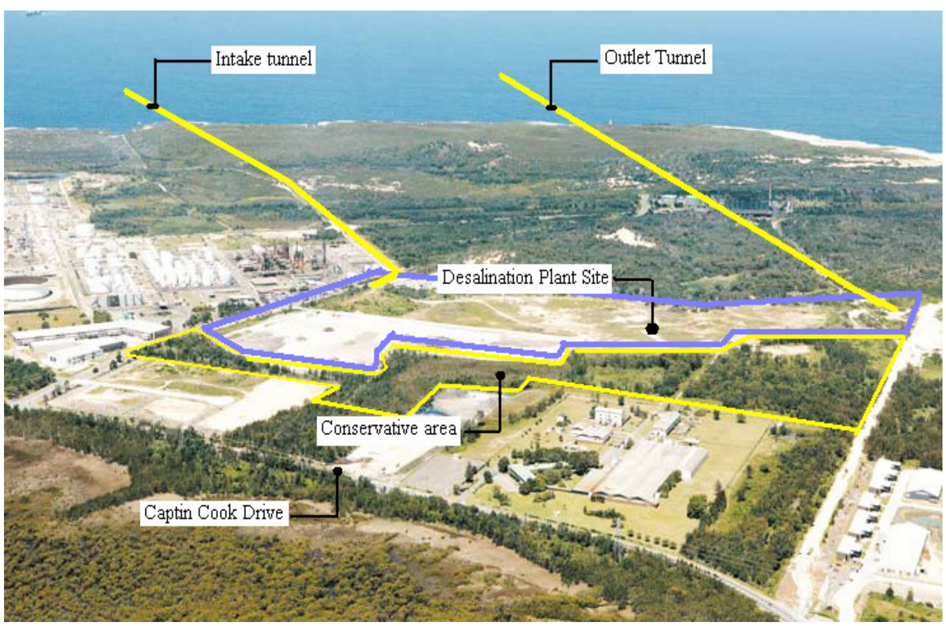


Figure A.16 shows an aerial photo of Kurnell desalination plant site at Botany Bay in Sydney. Source: Sydney Water, 2007.

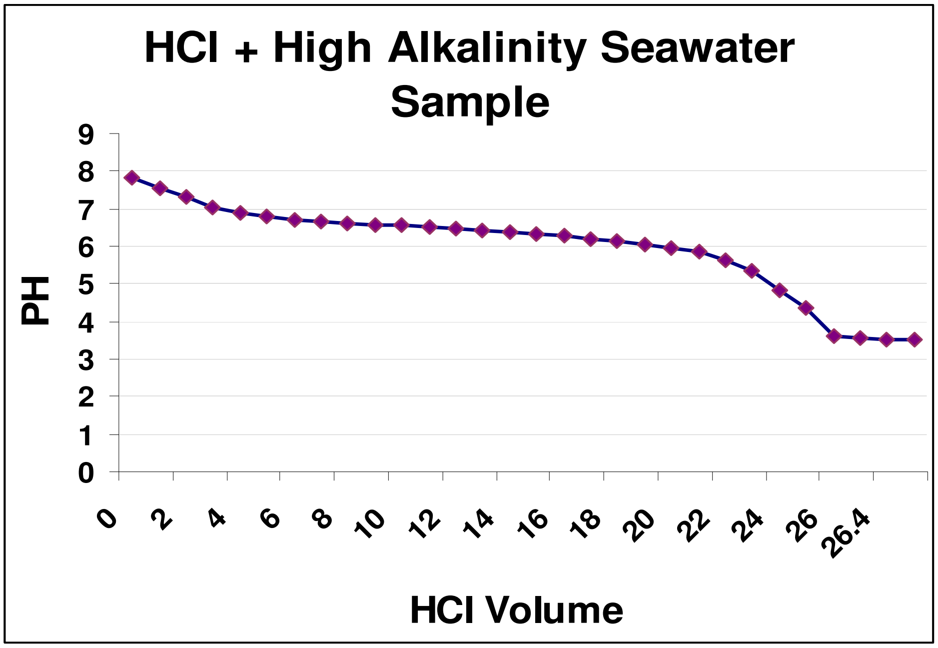


Chart A.1 shows acidified procedure by adding hydrochloric acid to the high alkalinity seawater sample to reach PH = 3.5.

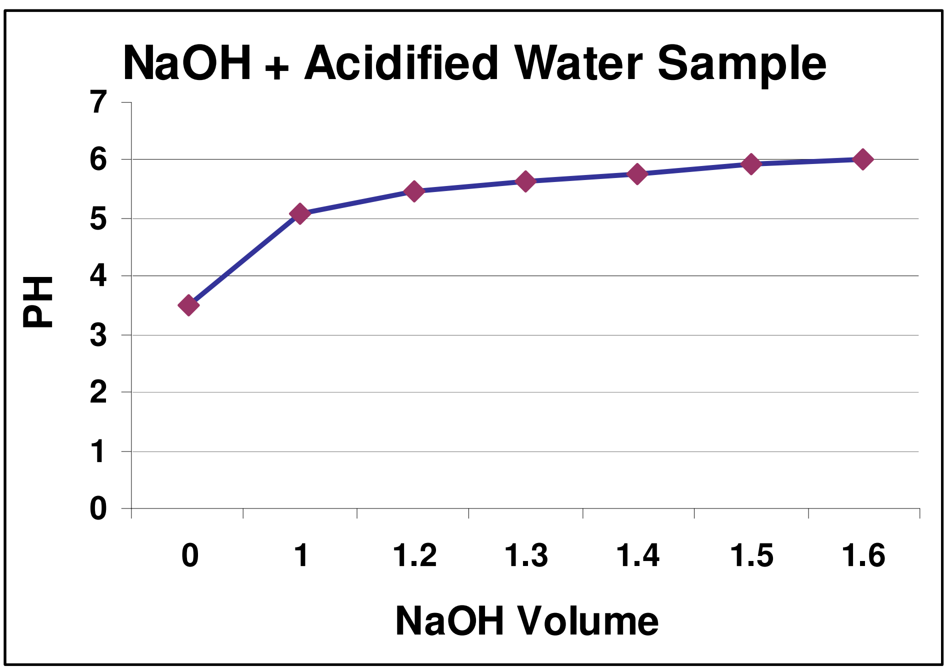


Chart A. 2 shows the procedure of adding sodium hydroxide to the acidified seawater sample to obtain PH = 6.

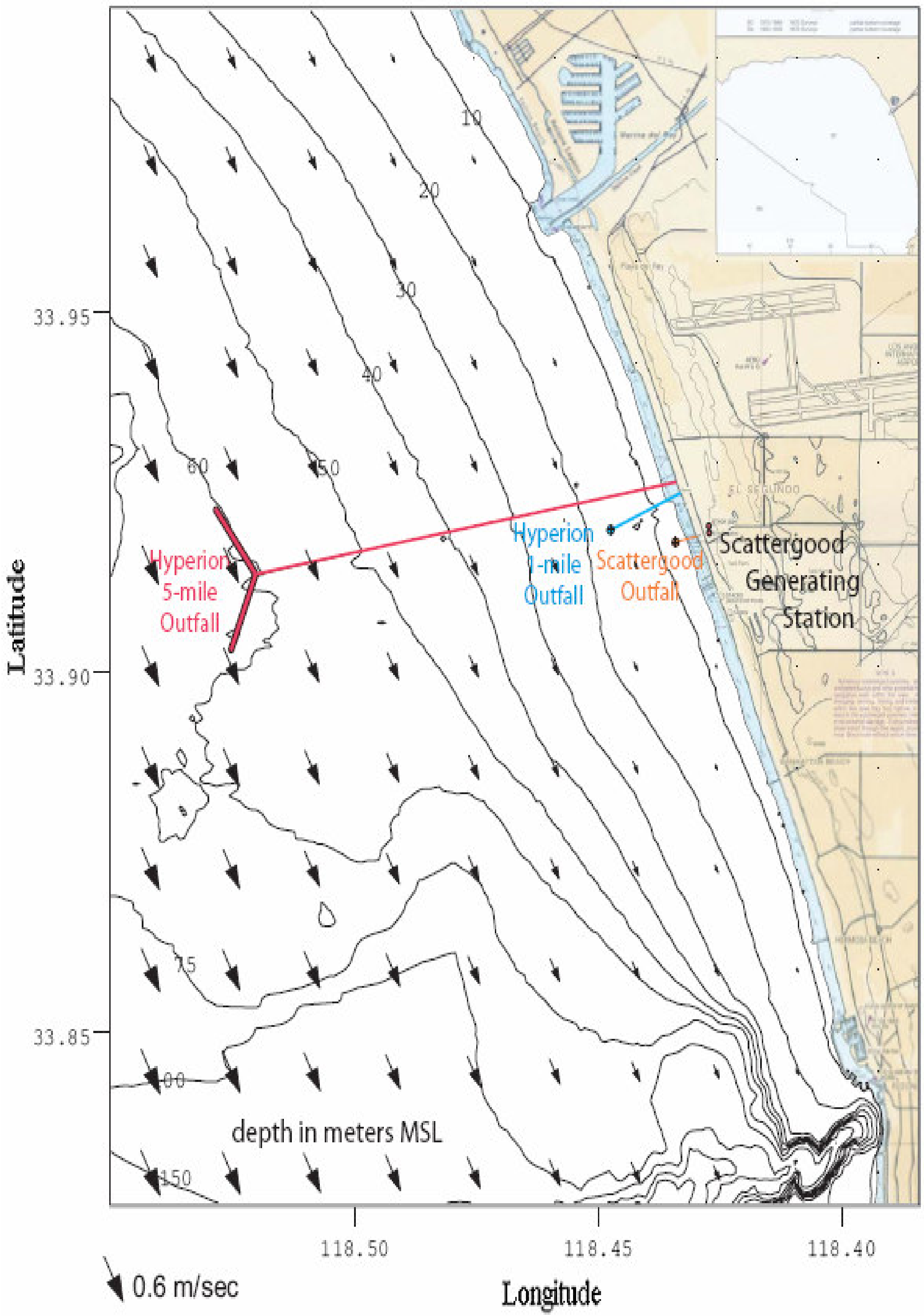


Figure A.17 shows the modeled tide direction around the outfall of the Scattergood generating and desalination plant (Encina desalination plant). Source: (Jenkins et al, 2005)

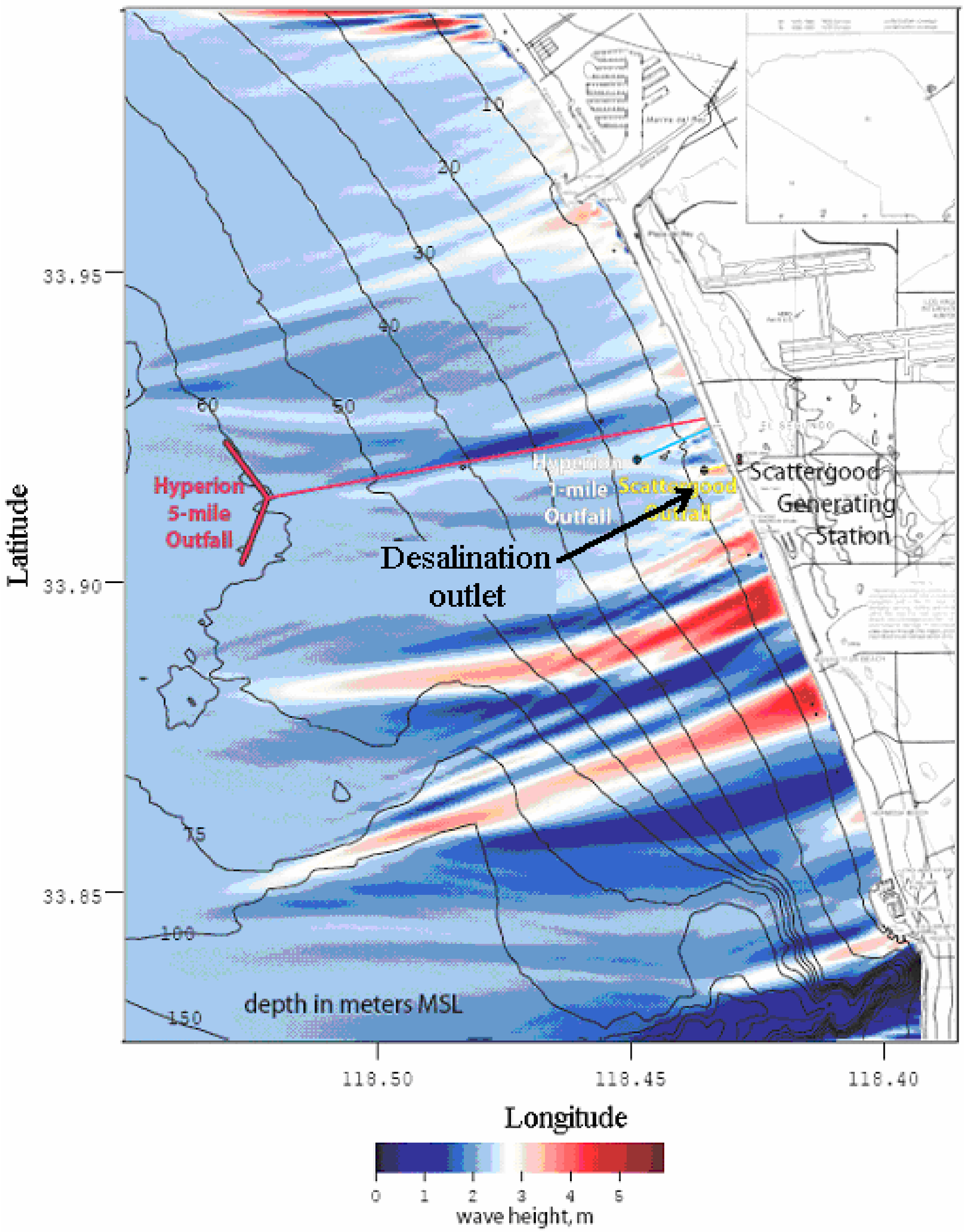


Figure A.18 shows the modeled wave height during the storm of 13 January 1993 with 2.25 m high in the area around the Scattergood generating and desalination plant and how that might affects the current plume discharge brine from the desalination plant. Source: (Jenkins et al, 2005).

Appendix B

Numbers and capacity of desalination plants worldwide

Year	Numbers of Plants	Installed Capacity (m^3/d)
1945	1	326
1946	0	-
1947	5	2,461
1948	1	114
1949	4	2,960
1950	5	3,000
1951	2	446
1952	14	7,295
1953	7	7,096
1954	13	15,879
1955	13	7,113
1956	26	13,310
1957	18	8,232
1958	8	5,758
1959	21	29,315
1960	23	19,742
1961	18	10,055
1962	20	28,314
1963	24	40,282
1964	24	21,761

1965	27	43,842
1966	37	38,842
1967	23	53,760
1968	53	116,887
1969	37	179,499
1970	54	115,358
1971	78	272,358
1972	70	109,729
1973	160	256,816
1974	166	228,701
1975	176	484,941
1976	191	241,856
1977	257	451,860
1978	224	572,873
1979	280	676,744
1980	304	963,998
1981	235	419,997
1982	307	860,906
1983	284	1,636,511
1984	330	815,495
1985	316	1,118,472
1986	341	619,837
1987	295	633,634
1988	304	1,050,311
1989	319	884,050
1990	324	936,610

1991	275	611,609
1992	336	918,189
1993	308	822.755
1994	372	931,244
1995	476	1,580,061
1996	415	1,277,372
1997	384	1, 534,241
1998	400	1,535,182
1999	343	1,290,485
2000	457	1,791,110
2001	409	1,796,573
2002	346	1,644,347
2003	266	2,872,564
2004	176	3,014,296
Total	**10,402**	**35,627,374**

Table B.2 shows the installed desalination capacity by year, number of plants 1945-2004. Source: The World's Water.

Country	Total Capacity (cubic meters/day)
Saudi Arabia	5,006,194
United States	2,799,000
United Arab Emirates	2,134.233
Kuwait	1,284,327
Libya	638,337
Japan	637,900
Qatar	560,764
Spain	492,824
Italy	483,668
Iran	423,427

Iraq	324,476
Bahrain	282,955
Korea	265,957
Netherlands Antilles	210,905
Algeria	190,837
Hong Kong	183,079
Oman	180,621
Kazakhstan	167,379
Malta	145,031
Singapore	133,695
Russia	116,140
India	115,509
Holland	110,438
Mexico	105,146
Indonesia	103,244
Egypt	102,051
Great Britain	101,397
Taiwan	101,180
Israel	90,387
Chile	83,509
Australia	82,129
South Africa	79,531
Virgin Island St. Croix	71,940
Tunisia	47,402
Virgin Islands St. Thomas	46,807
Turkmenistan	43,707
Bahamas	37,474
Yemen	36,996
Canada	35,629
Greece	35,620
Virgin Islands Tortola	31,702
Uzbekistan	31,200
France	29,112
Antigua	28,533
Peru	24,538
Thailand	24,075
Ukraine	21,000
Poland	20,564
Gibraltar	20,079
Morocco	19,700

Venezuela	19,629
Cuba	18,926
Lebanon	17,083
Cayman Islands	16,986
Maldives	16,940
Argentina	15,540
Austria	14,540
Malaysia	13,699
Bermudas	13,171
Azerbaijan	12,680
Belarus	12,640
Czech Republic	11,085
Capo Verde	10,500
French Antigua	10,400
Colombia	7,165
Jordan	7,131
Sahara	7,002
Cyprus	6,275
Jamaica	6,094
Nigeria	6,000
Denmark	5,960
Portugal	5,920
Philippines	5,648
Syria	5,488
Pakistan	4,560
Mauritania	4,440
Ecuador	4,433
Belgium	3,900
Ireland	2,725
Marshall Island	2,650
Switzerland	2,506
Yugoslavia	2,204
Sudan	1,450
Ascension	1,362
Bulgaria	1,320
Sweden	1,300
Norway	1,200
Nauru Pacific	1,136
Dominican Republic	1,135
Namibia	1,090

Brazil	1,079
Paraguay	1,000
Belize	757
Virgin Islands Handsome Bay	681
Virgin Islands Road Town	681
Honduras	651
Turks and Caicos	640
Turkey	600
Virgin Islands St. John	568
Hungary	500
Total Capacity of 100 countries	**16,521,319**

Table B.1 shows the desalination capacity by country from the largest to the least producer, updated 1999. Source: The World's Water.

Arabian Gulf Countries	Number of Units	Capacity (1,000 m3/day)
Saudi Arabia	**874**	**2,980**
Kuwait	**279**	**1,090**
United Arab Emirates	**99**	**1,020**
Bahrain	**143**	**260**
Qatar	**47**	**310**
Oman	**41**	**100**
Total	**1,483**	**5,760**

Table B.3 shows the number of units and the capacity production per thousands cubic meters per day of desalination plants in all states in Arabian Gulf area in 1990 (Murakami, 1995).

Desalination plant	Al-Jubail	Shoaiba	Al-Khobar
Capacity million gallon per day	246.7	107.3	50.7
Constructed date	1988	2001-2003	2002
Geographical position	Eastern Coast	Western Coast	Eastern Coast

Table B.4 presents the three chief desalination plants in Saudi Arabia with the date of construction started, geographical position and the production capacity of fresh water

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