Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

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Abstract

The ready and secure supply of potable water is a pre-requisite for the economic development of Western Australia. This supply has to be well managed such that the development options of future generations are preserved. The Perth metropolitan area, City of Mandurah, the Goldfields and Agricultural Water Supply are being serviced by an integrated combination of surface and groundwater resource distribution system. It has been proven that seawater desalination is able to deliver significant quantities of potable water, independent of climate. The government of Western Australia has decided that the next major water source will be a 45GL/year seawater Reverse Osmosis (RO) desalination plant to be built at Kwinana. Another source of water supply is development of the South West Yarragadee aquifer. It will consist of a well field, a filtration-based treatment plant and storage tank, transfer main pipelines from the head works to the Stirling Trunk Main at Harvey, pumping stations at Ravenswood and an adaptive approach to tone down any risk where necessary.

In order to attempt to measure the functionality at which these two systems are functioning, five system perspectives and their respective functions are defined and then appropriate indicators are used to measure these function. In this project, the functionality of the two systems involved will be measured using relative values. This means that the value of the indicators will be compare relative to a benchmarked value. Eventually, these relative indicator values are added up, and compared. The system with the higher value will be the one performing at a higher functionality.
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1. Introduction

The economic advancement of Western Australia requires the availability of easily accessible water supplies which must be used in a manner so as to preserve the development options of future generations.

1.1 Water Supply System in Perth

The Perth metropolitan area, City of Mandurah, the Goldfields and Agricultural Water Supply are being serviced by an integrated combination of surface and groundwater resource distribution system. This whole set up is called the Integrated Water Supply System (IWSS) which can be seen in figure 1 below. The Water Corporation has the responsibility to supply water to the regions within the IWSS under its operating license granted by the Economic Regulation Authority. While the Water and Rivers Commission within the Department of Environment allocates water to users, inclusive of the Water Corporation, the latter is liable to plan and provide sufficient allowance for future growth in the IWSS (Strategen 2005).
1.2 Water Strategy

According to Water Corporation’s Source Plan (2005), the most recent revision to the Source Development Plan for the IWSS was in 2001. At that point in time, all assessment done on source yields was based on the recorded streamflow sequence recording from 1975. There is a seemingly downward trend of rainfall over the last few years. In the winter of 2001, the least inflow to dams in the Perth urban regions
since 1914 was noted. This made the inflows of the 2001 and 2002 winters the nastiest biannual drought on record. For eight consecutive years (1997-2004), the annual inflow had been around the 115 gigalitres mark, which is appreciably lower than post-1974 annual mean of 161 gigalitres (Govt. of WA 2003).

It is not realistic to predict with absolute sureness, how the climate will be like in the next couple of decades, but it is necessary that the Water Corporation be adequately prepared for future low-rainfall events. The eight year (as mentioned above) climate and streamflow pattern has been used by the Corporation as a template for its Source Development plan (Swan Catchment Council 2004; Govt of WA 2003). The annual per-capita demand is fixed at 155kL till a water source that is able to meet the demands of the IWSS has been found. It is absolutely necessary for the Water Corporation to have long term planning to ensure the water supply for Perth remains secure and sustainable for future generations. There are three basic assumptions made by the Water Corporation as part of its planning process for the IWSS. There are namely:

- The rate of increase of water demand extrapolated into the future based on current trends;
- Average amount of water supplied by current and potential resources; and
- The level of dependability of water supply expected by the people within the IWSS.

The above assumptions are reviewed by the Water Corporation frequently, and an analysis of the existing situations revolving around the water demand is done, before any concrete decision is made to carry on with any construction of a new water source. A risk assessment tactic is engaged to aid decision making, and basically, a few conditions are well thought-out during the process, specifically:

- Groundwater availability and accessibility;
- Conclusion drawn from population and per-capita demand; and
- The possibility of enforcing water rations should there be lack of water source expansion.
At large, the approximate annual yield of present water sources to the IWSS is around 256 gigalitres, split between groundwater sources (120 gigalitres) and surface water sources (136 gigalitres). On paper, the rough annual water demand for the IWSS for 2004 through 2005 is 289 gigalitres. To be able to meet this demand consistently, an annual source yield of 318 gigalitres is necessary, which is about 60 gigalitres more than current source availability. Currently, this deficit is made up by abstracting from the Gnangara groundwater source. It is recognized that in order to meet future demands of water by the IWSS through 2015, on top of efficient water management and recycling schemes by the Corporation, a further 90 gigalitres is required balance out the water demand of the IWSS (Water Corporation’s Source Plan 2005).

Fig 2: Graph showing the annual surface stream flows in Perth’s Water Supply System (Water Corp 2005).

1.3 **Need for Alternative Water Source**

Perth’s climate is becoming drier and its rainfall decreasing notably in the south-west region of Western Australia since the middle of 1970s. Concurrently, the population of residential areas in the Swan Coastal Plain also increased, which naturally leads to water demand rising. The period from 1985 to 2000, water usage in Western Australia nearly doubled to around 1800 gigalitres (GL) per annum. Within the same time frame, groundwater use saw a three fold rise (Water and Rivers Commission 2000).
Studies like the Western Australia Water Assessment (2000) also forecasted that the usage of water will repeat its doubling trend over the coming two decades. For the looks of things, there will be mounting pressure being placed on current available water resources. This problem is more pronounced in regions where water use is on the verge of reaching their sustainable threshold (EPA 2005).

To provide a stable and secure water supply is a deep-seated facet of the Water Corporation’s responsibility, since this level of security has great influences on its customers: individual consumers, businesses and the community within the IWSS. For the past decade or so, the Water Corporation has successfully responded emerging change in climate, governments and people’s expectation for a secure water supply and the drive for more efficient use and recycling of water. All these have been achieved amidst the rising demand for water due to growing population and development in economy. $665m has been invested by the Corporation in a record program to develop technologies and water resource management so as to double the supply capacity of the IWSS over the last ten years. The ongoing uncertainty in the change of climate, whether or not the spate of drier weather and reduced rainfall since 1997 is an accurate indicator of the future, presents considerable difficulties in the development of a secure and sustainable water supply to match the growth of its demand (Strategen 2005).

1.4 Feasible Alternative Water Resources

There is a growing need for Western Australia to have new water sources to meet the increasing demand within the IWSS and the fast developing South West region. At the moment, the Water Corporation is looking into a several novel supply of water. Firstly, it’s the 45 gigalitres per annum desalination plant (targeted to complete by October 2006), then it’s the 17 gigalitres per annum water trade with Harvey Water (complete by October 2007) and lastly annual 45 gigalitres abstraction of the South West Yarragadee aquifer (complete by December 2009) (Water and Rivers Commission 2003).
This augmented demand in water is owed to population and economic growth. Although efficient water-use management strategies like wastewater recycling are in place, it is still not able to fully meet the growth demand. The study into the proposed has already enabled a decision to start the 45 gigalitres per annum desalination facility at Kwinana. The desalination plant in the Kwinana region is to have an expected lifespan of 20 years and will be operated at full load, round the clock, the whole year round. Similarly, the Water Corporation is also in the phase of investigating the feasibility of using the groundwater source at the South West Yarragadee Aquifer. In juxtaposition to the South West Yarragadee Water Supply proposal, the Corporation will also carry out complementary water efficiency scheme. Some of which are:

- Recycling of water;
- Trading of water;
- Management of water catchments;
- Development of groundwater sources (Gingin, Yanchep and Eglinton);
- Development of surface water sources (Wellington); and
2. Literature Review

2.1 Desalination Background

Desalination is a process that removes dissolved minerals from seawater, brackish water and treated wastewater, so as to reduce the salinity of the feed water from a high level of total dissolved solids (TDS) of about 35000 parts per million (ppm) to an satisfactory level of around 500 ppm (Dore 2004; Joseph Saravanan and Renganarayanan 2004). To date, there are numerous kinds of technologies being developed for desalination (Dore 2004).

The continuous rise in world population coupled with the global growth in industrial facilities has caused increasing stress on the fresh water supply from natural occurring sources like rivers, lakes and aquifers. Governments and organizations around the world have recognized the urgent need for new sources of potable water to offset the fast increasing demand. More than 70% of the Earth’s surface is covered with saline water. This is ample catalyst for countries to focus on research and development of the desalination technology. Today, there are more than 11000 desalination plants worldwide and about two thirds of which are found in the Middle East (Mielke 1999). Considering the declining availability of naturally occurring water sources and the fast growing international demand for water, the seawater desalination market quickly grows could increase to more than $70b for the two decades to come. At the moment, RO desalination technology is progressing at an incredible pace, although MSF distillation still takes the lion’s share of the pie where total installed desalination capacity is concerned (Abdel-Jawad et.al. 2001).

The desalination process can be split into two categories, namely, thermal methods (involve boiling of water to generate water vapor) and membrane processes (utilization of a membrane to create two zones of varying concentrations so as to turn out fresh water) (Dore 2004). The various methods to remove salt from water to yield potable water include Multi-stage flash distillation (MSF), Electro-dialysis (ED) and Reverse osmosis (RO). The latter will be the focused on more in this report. It is reported by Wangnick (2000) that MSF distillation represents about 70% of the
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seawater desalination market whereas RO took roughly 17% of the market share with 3250000 m³ per day contracted. Due to the straightforwardness of the RO process, it is fast catching up with MSF distillation. For starters, there is no need for temperature increase, which largely reduces corrosion issues. There is no phase change required, which greatly reduces the amount of energy requires as well. There has also been worldwide conformity that the unit cost of desalinated water using the RO process is cheaper than by using MSF distillation (Ebrahim et.al. 2001). Even in oil producing countries, like the Middle East, where energy is cheap, facilities using RO is up-and-coming as an integrated process in dual-purpose hybrid plants (combination of power station and an MSF/RO plant for potable water production). The only major shortcoming of the RO is the membranes susceptibility to fouling. Especially in direct seawater intake systems, pre-treatment is definitely essential upstream the RO process (Brehant Bonnellye and Perez 2002).

2.2 Desalination Processes

Since its introduction, desalination facilities have been implemented worldwide for more than 5 decades, and it is a reliable means of water supply in many countries like the Middle East, USA and Israel etc. As more enhanced and cost-effective technologies are introduced, cost of desalination has been rapidly decreasing in the last decade or so (UNEP 1996).

There are many methods of desalination today. All of them work towards the common aim of producing a stable supply of potable water. As mentioned before, desalination processes can be divided into thermal and membrane processes. The thermal processes include MSF distillation, multiple effect distillation (MED) and vapor compression distillation (VCD) whereas the membrane process consists of electrodialysis (ED) and reverse osmosis (RO). These are some of the major methods of desalination used around the world (UN 1985).

Each of the mentioned method will be talked about briefly in this section, while the reverse osmosis process is described in more detail as it is the main focus of this report. A case study of a RO desalination plant built by the Water Corporation in
Kwinana, Perth, will be used to illustrate the actual workings of the entire reverse osmosis process in a real life application.

2.3 Thermal Processes

The basic process involved is to heat the water to boiling point so as to produce the maximum amount of water vapor, and then condensing the water vapor to form fresh water. The economically viable way to do this in a large-scale desalination facility is to alter the saturation pressure of the water being boiled. This lowers the boiling point of the water and affects 2 major practices in the desalination process:

- Multiple boiling; and
- Scale control.

For water to boil the correct temperature in relation to its surrounding pressure must be obtained and there must be sufficient energy for it to vaporize. When the water is boiling, and the supply of heat is removed, it will not continue boiling for a long time. The boiling process can be restarted by either continuing the supply of heat, or decreasing the surround pressure above the water. This will cause the water to be at a temperature above its boiling point and will continue to boil with the extra heat from the higher temperature to provide the vaporization energy required. As this heat of vaporization is supplied, the temperature will drop to the new boiling point. Multiple boiling is practiced in consecutive vessels (each having a lower temperature and pressure) to appreciably decrease the amount of energy required for vaporization (Jones et. al. 1982).

Scale control is another important process in seawater desalination. As the feed seawater moves through the consecutive vessels, it reduces in temperature and become more concentrated. When this occurs, those salts that are not so soluble may start to precipitate (Hobbs 1980). The cause of large-scale scaling, calcium sulphate (CaSO₄) begins precipitation at around 95°C. It forms a tough scale around tubes and vessels which causes operational problems and is hard to remove. As such, to prevent this problem from occurring, it is crucial to maintain the temperature and boiling point of the seawater below that temperature (Saravanan & Renganarayanan 2004).
2.3.1 Multi-stage Flash Distillation

Basically, multi-stage flash (MSF) distillation involves the evaporating seawater and getting back pure water by condensation. The heated salt solution is enters the chamber under lower pressure. When this happens, some of the water evaporates immediately and condenses on tubes that are cooled by sea water that is flowing back to the steam heated heat input section (UKAEA 1970). The flow diagram below shows the stages of a MSF distillation system.

MSF facilities normally operate at maximum seawater temperature between 90-120ºC. Although by operating the plant at the upper temperature limit increases efficiency in desalination, it also increases the likelihood for damaging scale development and accelerated corrosion of metal surfaces (UKAEA 1970).

![Flow diagram showing the MSF distillation process](image-url)

Fig 3: Schematic diagram showing the MSF distillation process (Ammerlaan 1982).

2.3.2 Multiple Effect Distillation

This is a similar process to the MSF distillation. It takes place in a series of chambers (effects) and uses the theory of decreasing ambient pressure in the various chambers. This enables the seawater to undergo multiple boiling without additional energy being supplied. In a MED facility, the feed seawater goes into the first chamber or effect
and is heated to boiling point by being preheated in tubes. After that, it is sprayed or circulated onto the surface of evaporator tubes in a thin film so as to aid boiling and evaporation. The tubes are heated up by utilizing steam from a boiler which then condenses on the opposite sides of the tubes. The condensed water is then directed back to the boiler for recycling.

Not all the seawater sprayed to the tubes in the first effect is evaporated. Whatever remain moves on to the second effect where it is sprayed onto another system of tubes. The tubes in the second effect are heated by the vapors created in the first effect. The vapor then condenses to give fresh water while supply heat energy to evaporate some of the remaining seawater in the next effect. This process is continued for up to 16 effects found in a typical large facility. More often than not, the leftover seawater in each effect is pumped to the next effect, so that it can be applied in the next system of tubes. More condensation occurs in each effect on tubes that bring the feed water from the sea to the first effect. This process pre-warms the seawater before its being evaporated in the first effect (Mielke 1999).

2.3.3 Vapor Compression Distillation

This process is commonly utilized by small to medium sized desalination facilities. Basically, the heat energy used for evaporating the water comes from compression of the water vapor stream. At the moment, there are 2 kinds of compressors available. Firstly it’s the Thermo-vapor Compression Distillation (compresses and reuses vapor in the system by using an external steam source as the energy input to the system), then it’s the Mechanical Vapor Compression (compresses and recycles internal vapor in the system but uses an electric mechanical compressor as energy source).

VC systems have different types of configurations to support heat exchange to aid seawater evaporation. For the thermo-vapor compression distillation unit, a venture office at the steam jet forms and extracts water vapor from the main chamber, thus creating a lower ambient temperature in the main chamber. This jet of steam compresses the extracted water vapor. The mixture of water vapor condenses on the
walls of the tube, supplying the heat required to evaporate the seawater being applied on the other side of the tube wall in that chamber (UNEP 1996).

As for mechanical vapor compression type systems, the compressor reuses and compresses a portion of the vapor formed inside of the chamber by evaporation. Seawater is also sprayed on the outside of the heated tube bundle, which causes it to partially evaporate and form more fresh water (UNEP 1996).

Fig 4: Schematic diagram showing the workings of a Vapor Compression Distillation System (Ammerlaan 1982).

2.4 Membrane Processes

Membrane processes makes use of the ability of semi-permeable membranes to separate and selectively isolate salts and water. There are two commercially viable techniques of desalination, electro-dialysis and reverse Osmosis, each of which has rather different processes of removing salt from water (UN 1985).
2.4.1 Electro-dialysis

Electro-dialysis works on the principle of electrostatic attraction of cations and anions to oppositely charged electrodes in the saline solution. The dissolved ions in a salt solution are spread out, neutralizing their individual charges. When the electrodes with an external current source is placed in the salt solution, a current flows through the solution, causing the ions to migrate to the electrode with the opposite charge. In order to utilize this process for desalination, membrane that selectively allows either cations or anions through, have to be used. These membranes are then arranged alternately with an anion-selective membrane and cation-selective membrane. A spacer sheet that allows water to flow along the surface of the membrane is placed between pair of cation/anion selective membrane.

The spacer sheet will provide a channel that carries feed/product water, while the following one carries the salt solution. When current flows from the electrodes, the salty feed water flows along the product water spacer sheet at right angles to the electrodes. This way, the anions in the solution is attracted to the anode. As a result, the solution in the product water channel becomes lower in salt content. The anions pass through the anion-selective membrane and stops there as it cannot pass further than the cation selective membrane. This traps the anions in the salt solution. The same goes for the cations, they get attracted to the cathode, move in the opposite direction through the cation-selective membrane to the concentrate channel on the other side. The cations are trapped there since they cannot pass further then the adjacent anion-selective membrane (van Hoof et. al. 1999).

As a result, alternate arrangements of concentrated and diluted solutions are formed in the spaces between the alternative membranes. These spaces are called cells. Each cell pair consist of one cell with the diluted product water and the other with the concentrated salty feed water.

Pre-treatment of the raw feed water is required to prevent fouling of the membranes and the post-treatment for the product water may include gas removal and pH adjustments (William & Edyvean 1998).
2.4.2 Reverse Osmosis

RO is fairly young technology as compared to distillation and ED. Its successful commercialization started in the early 1970s. In recent years, seawater RO systems have undergone an astonishing revolution, which greatly increased the capacity in
which desalination facilities can handle. The capital and operating costs has also decreased (Wilf and Bartels 2004). This makes RO is one of the more economical method used to desalinate seawater. It has the advantage of low energy requirements over other desalination processes (Moreno and Pinilla 2004).

The way RO works is an easy concept. Basically, when pure water and a salt solution in a container are separated by a semi-permeable membrane, pure water diffuses through the pores of the membrane and dilutes the salt solution by the process of osmosis. It is interesting to note that the semi-permeable membrane does not always exist in a physical form (Merten 1966). Eventually, the concentration on both sides of the membrane becomes the same and osmosis is halted. Pure water is able to move through the semi-permeable membrane as though there is a driving force, due to the presence of a concentration gradient across the membrane. This driving force is called the osmotic pressure. Temperature of the water and salt concentration of the solution will cause the required force to drive water across the membrane to vary. By applying a pressure on the salt solution, the osmosis process can be reversed. Ultimately, when this pressure on the salt solution is greater than the osmotic pressure, pure water then moves from the salt solution into the pure water compartment, against the conventional osmotic flow (U.S. Department of the Interior 1977).

Fig 7: Simple diagram showing how osmosis works.

Fig 8: Simplified diagram showing how RO works.
Fig 9: Schematic diagram of a RO plant (Wade and Callister 1997).

2.5 Pre-Treatment

The basic function of having a pre-treatment system is the do away with substances that will block or shorten the life-span of the membrane (Moreno and Pinilla 2004). High-quality pre-treatment, is the key factor for thriving, long-standing operation of RO desalination plant (Brehant Bonnelye and Perez 2002).

“Seawater is a complex conglomeration of micro-organisms, organic and mineral matter widely dispersed within a saline water matrix” (van Hoof Hashim and Kordes 1999). Many of the compounds that are found within the saline matrix of seawater tend to foul membranes easily. They are specifically:

- Dissolved organic matter;
- Organic and inorganic suspended solids;
- Sand;
- Oil;
- Clays; and
- Bacteria.

The process of membrane fouling could be further aggravated when flow conditions caused micro-organisms to be crushed and their cellular constituents released or when
chlorination is not sufficient to prevent the development of biofilms with the emission of extra-cellular polymers (William and Edyvean 1998).

## 2.6 Cost of Desalination

In addition to the initial capital and operating costs, the eventual cost of producing water is one of the most imperative factors relating to the selection of desalination as a water treatment process. The table below shows a breakdown of the costs of the various types of desalination being looked into in this dissertation.

<table>
<thead>
<tr>
<th>Process</th>
<th>Capital investment (AUD/kL/day)</th>
<th>Unit cost of water (AUD/kL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSF</td>
<td>1550-3100</td>
<td>1.5-4.2</td>
</tr>
<tr>
<td>SWRO</td>
<td>1240-2480</td>
<td>1.1-3.8</td>
</tr>
<tr>
<td>MED</td>
<td>1400-2800</td>
<td>1.3-3.3</td>
</tr>
<tr>
<td>METC</td>
<td>1380-2780</td>
<td>1.2-3.1</td>
</tr>
<tr>
<td>MVC</td>
<td>1390-3880</td>
<td>1.8-5.9</td>
</tr>
</tbody>
</table>

Table 1: Shows the relative costs to produce a kiloliter of water for the different methods of desalination (Water Corp 2003).

The three factors that have the largest effect on the cost of desalination per unit of fresh water produced are the feed water salinity level, cost of energy and size of desalination facility, which exhibits economies of scale. When the salt concentration of the feed water increases, operating costs increases as well due to longer operation time and usage of extra equipment. The cost of desalting seawater is three to four times the cost of desalting brackish water, with RO being the cheapest process for this application. Up till 1999, in certain parts of the US, the cost of desalting brackish water became less than transferring large amounts of conventionally treated water over long distances in pipes (Buros 2000). The energy required for desalination can represent 50-75% of operating costs, with RO having the lowest energy demand. Actually, the distillation processes benefit most from economies of scale, whereas for RO plants, such economies of scale will lead to a fall in unit costs at a slower rate. RO has a lower unit water costs because of its lower energy demands, making it the most economical of all the desalination methods mentioned here (Azpitarte Mesa and
Gomez 1996). Also, although RO have higher initial capital costs, the unit cost of the desalted water is determined by membrane life and energy costs (Ammerlaan 1982). In the table below, there is the approximate cost breakdown of the various stages of building an RO desalination facility.

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage of total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction/site works</td>
<td>10-20%</td>
</tr>
<tr>
<td>Buildings</td>
<td>15-25%</td>
</tr>
<tr>
<td>Raw water supply</td>
<td>15%</td>
</tr>
<tr>
<td>Pre-treatment</td>
<td>5-20%</td>
</tr>
<tr>
<td>Desalination process</td>
<td>40-55%</td>
</tr>
<tr>
<td>Post-treatment</td>
<td>5-15%</td>
</tr>
<tr>
<td>Concentrate Disposal</td>
<td>10-40%</td>
</tr>
</tbody>
</table>

Table 2: The approximate break down in percentage of the investment capital required (Water Corp 2003).
3. **Alternative Water Source: Desalination Plant**

In order to meet the rising in-house water and industrial needs of the Integrated Water Supply System (IWSS), the Water Corporation has come up with a Drought Emergency Response Plan. This plan states:

- Water demand to be restricted to about 200GL/yr through a comprehensive prohibition on water use outside of dwellings, thus ensuring adequate supply for in-house and industrial needs;
- Surface water storages drawdown has to be effectively empty by June 2004;
- Minimum abstraction of up to 165, 170, 150 and 150 GL/year of groundwater from existing assets from 2002/2003 to 2005/2006 respectively under all emergency supply options; and
- In 2002, the cabinet decided on a base case groundwater supply and one of the following options to supply an additional 30GL/year of water from October 2004 to be able to carry on supplying water at stage 7 level of restrictions (180GL/year) in 2004/2005 and 2005/2006 if the drought continues and existing sources of water are depleted:
  1. Abstract up to additional 30GL/year of groundwater using existing groundwater assets.
  2. Abstract and invest in 15GL/year for new Yarragadee assets. This option would need to be supported with an additional 15GL/year from existing groundwater assets to meet the 30GL/year supply target.

Basically, these emergency measures are proposed to target the worst case scenario of a very low inflow into metropolitan dams during the upcoming two winters. In actual fact, the probability of implementing these measures is low. An emergency response will be triggered when inflow to dams in the IWSS through the winter of 2002 is not enough to avoid the possibility of such low levels through the following summer (Govt. of WA 2003).
3.1 Factors affecting Desalination Selection

Other than the quality and the kind of source water and quality of product water required, lots of factors affect the selection of the optimum desalination process to use. For example, if the facility is remotely sited, the technology of choice should be robust and as independent of support from outside of the region as possible, both in respect of spare parts and chemicals as well as operating knowledge. This shows that the selection process is not entirely subjected to energy usage. Membrane processes usually have lesser energy consumption but may involve more chemicals and expertise in their operation. In the table below, there is a list of the selection parameters that forms the foundation when deciding on the best type of desalination process to utilize (Water Corporation 2005a).

<table>
<thead>
<tr>
<th>Selection Parameters for the type of Desalination</th>
<th>8. Plant reliability and lifespan</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quality of feed water</td>
<td>9. Finance costs</td>
</tr>
<tr>
<td>2. Availability of infrastructure</td>
<td>10. Operation and maintenance</td>
</tr>
<tr>
<td>3. Requirements of infrastructure</td>
<td>11. Environmental factors</td>
</tr>
<tr>
<td>5. Process design and type</td>
<td>13. Product water quality</td>
</tr>
<tr>
<td>6. Plant size</td>
<td></td>
</tr>
<tr>
<td>7. Precise site conditions</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Factors that affects the kind of desalination chosen (Welker Environmental Agency 2002).

When there are a few alternative desalination schemes that are applicable for a specific case, the final decision relating to the more leading combination should be based on criteria like:

- commercial maturity of technology;
- Simplicity of operation and maintenance of the system; and
- Availability of local support.

The most likely processes that are suitable for implementation are Multiple Effect Thermo Compression Distillation (METC), Mechanical Vapour Compression (MVC) and Reverse Osmosis (RO) (Water Corporation 2004).
Other alternative saline options have been considered by the Water Corporation and their feasibility closely studied. Some of the options include:

- Desalinating brackish surface water from the wheatbelt;
- Pumping and desalinating brackish water from the Yarragadee aquifer; and
- Desalinating brackish groundwater from the wheatbelt.

Seawater desalination at coastal regions was proved to be the most cost-effective choice for desalination due to much more addition costs that will be incurred from transporting water from the wheatbelt or pumping it from the deep Yarragadee aquifer. Before deciding on RO, there were a few alternatives being considered for the desalination process and plant design. They are namely desalination by a thermal process (MED), desalination by RO and hybrid configurations (combination of MED and RO). Basically the selection criteria included total capital and operational costs, energy availability and consumption, timeframe and lastly, environmental constraints. RO was found to be the most cost effective option, considering the time required to finish the projects (Wilf & Bartels 2004).

### 3.2 Seawater Desalination Plant

It has been proven that seawater desalination is able to deliver significant quantities of potable water, independent of climate. Seawater desalination will continue to be a benchmark, used to compare with other water source alternatives (Buros 2000). Although many alternate water sources seem to be cheaper alternative for than current desalination costs, with the uncertainty of future climate and streamflow, seawater desalination does provide a robust water source option for the IWSS into the future.

The government of Western Australia has decided that the next major water source will be a 45GL/year seawater desalination plant to be built at Kwinana. This desalination facility has been incorporated into the Water Corporation’s source development timetable for the IWSS and is a step forward in ensuring scheme reliability. This seawater desalination plant in the Kwinana region of Western Australia has an expected lifespan of 20 years and the desalination facility will be operated continuously at full capacity, 24 hours a day all the year round (Water Corp 2005).
3.3 Perth Metropolitan Desalination Plant

This desalination plant will be providing 45GL/year of potable water to the IWSS and the approximate seawater intake will be about 300ML/day to produce to more than 150ML of potable water which requires up to 24.1MW of power. The desalination facility will discharge an average of 180ML/day of concentrated seawater of the order 65000 mg/L or TDS (total dissolved solids) at 1 to 2°C above ambient seawater temperature. The figure below shows the location of where the desalination plant will be constructed and also the associated pipeline routes to be built. There is a possibility of combining the intake seawater with cooling water discharged from Western Power’s Kwinana (Govt. of WA 2003).

The desalination process is based on RO. Essentially, the workings of the desalination plant involves drawing seawater from Cockburn Sound, and possible pre-treatment to remove solids and suspended particles, and then pressurizing the seawater over a membrane so that freshwater is driven through the membrane and concentrated.
seawater is left behind. This concentrated seawater and backwash arising from pretreatment, will be discharged altogether back into Cockburn Sound. The maintenance of the pretreatment system, membranes and seawater intake and outlet pipes requires the use of several or a combination of biocides and anti-scalants. The pretreatment process involves the addition of flocculants, liquid chlorine (Cl₂), sulphuric acid (H₂SO₄), iron chloride (FeCl₃) and anti-scalant (Crisp 2003).

3.3.1 Desalination Facility

The desalination facility at Kwinana and its associated infrastructure will consist of the following components:

- Seawater pump station;
- Pre-treatment including flocculation and filters;
- Lime silos;
- Reverse osmosis membrane racks;
- Chlorination, fluoridation and carbonation facility;
- Product water pumping station;
- Switch gear building;
- Spare part store (mechanical and electrical workshop);
- Gate house/administration; and
- Car park and access roads (Crisp 2003).
Prior to actual commencement of the desalination project, relevant environmental factors will have to be considered. In section 46(6) of the Environmental Protection Act 1986 requires the Environmental Protection Agency to report to the Minister for Environment on whether or not the proposed changes to the surrounding environment caused by the construction of the desalination facility (Water Corp 2005).

The proposed 45GL/year production capacity for the desalination plant will have approximately 300ML/day of seawater will be provided for the desalination plant and 180ML/day of concentrated seawater will be returned together with the backwash
Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

from pre-treatment to the sea as discharge. This is calculated based on a recovery of 45% (Water Corp 2005).

Fig 12: Perth Metropolitan Desalination Plant layout at Kwinana (Water Corp 2004).

### 3.3.2 Desalination Process

The RO system within the desalination plant will consist of the following basic components:

- Filter system, backwash tank and chemical dosing (pre-treatment);
- Maintenance of RO membranes;
- High pressure pumps;
- RO-modules; and
- Product treatment.

The figure below illustrates a flow diagram which is similar to the process that is used in the proposed desalination plant at Kwinana (Crisp 2003).
3.3.3 Pre-Treatment Stage

Proper pre-treatment is the most crucial factor for successful long-term performance of reverse osmosis seawater desalination plant. Since seawater is a mixture and solution of many microorganisms, organic and inorganic matter, it is able to foul the
RO membranes easily. This is the reason why pre-treating the feed water is very important. The conventional pre-treatment disinfection/flocculation/coagulation/multimedia filtration is used commonly for seawater RO plants to lower silt density index (SDI) and remove excessive turbidity and suspended solids. This however, is not a complete barrier to colloids and suspended particles and produces unsteady feed water quality and quantity.

Pre-treatment of feed water is essential to allow potable water to pass through very narrow passages within the RO membranes. For this case, the pre-treatment of feed water involves the following processes:

- Disinfection;
- Coagulation;
- pH adjustment; and
- Removal of suspended solids.

The filtration system needs backwashing every 15-20 minutes with 12% solution of sodium hypochlorite, some kind of biocide. The backwash from the pre-treatment system will then be mixed with the seawater return and discharged into Cockburn Sound (Water Corp 2005).

### 3.3.4 Feed water

After pre-treating the feed seawater for suspended solids, phosphonocarboxlic acid (anti-scalant) is sometimes added to the feed water to the RO facility at concentrations of around 4-6 mg/L so as to prevent scale precipitation on the RO membranes. This amount can vary according to the quality of feed water and this anti-scalant will be eventually discharged together with the concentrated seawater return into Cockburn Sound. High pressure pumps provide the necessary driving force to enable the feed seawater to pass through the membranes, leaving the salts behind. A pressure of in the region of 70 bars is required for each membrane to desalt standard seawater (Welker Environmental Agency 2002).
3.3.5 Product Potable Water

The water produced from RO process has a low pH from the initial acidification of the feed seawater and absorption of carbon dioxide in the process. In order to neutralize the acidity, the product water is treated with appropriate doses of lime to provide potable water in agreement with the requirements of the Australian Drinking Water Guidelines 1996 (Welker Environmental Agency 2002).

In addition, adequate pumping facilities will be installed within the desalination plant so that the product potable water can be pumped into Tamsworth Hill or Thompson Lake storage reservoirs. From there, it will be supplied to the IWSS.

3.3.6 Membrane Maintenance

It is essential to do maintenance of the RO membranes periodically. The process of cleaning includes using an acidic detergent (sulphamic acid or citric acid) which can chemically clean both the filtration and RO membranes. This cleaning routine is done about 2-4 times a year depending on the degree of fouling of membranes.
The table below shows the break down of the estimated composition of membrane maintenance discharge into Cockburn Sound. In addition, micro-organism growth is kept in control by adding 2, 2 dibromo-3-nitrilopropionamide (biocide) periodically in the filtration and RO systems within the facility.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Volume (m³)</td>
<td>300</td>
</tr>
<tr>
<td>Temperature (ºC)</td>
<td>22-26</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>~45000</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>pH</td>
<td>6-9</td>
</tr>
<tr>
<td>Type of chemical detergent</td>
<td>As recommended by membrane manufacturer</td>
</tr>
</tbody>
</table>

Table 4: Shows the approximate composition of the wastewater discharge from the desalination plant (Water Corp 2003).

### 3.3.7 Brine Discharge

One disadvantage of using RO to desalt seawater is the concentrated seawater return that needs to be returned to the marine environment. Basically, the discharge from the desalination facility comprises of concentrated seawater return from the RO process and backwashes from the pre-treatment and cleaning processes. Any free chlorine present will be neutralized with sodium metasulphite before being discharged into Cockburn Sound.

It has been estimated that the expected salinity of the effluent stream prior to discharge is approximately 65000 mg/L. Also, the estimated temperature increase of the water will be in the range of 1-2ºC higher than ambient temperature. This is caused mainly by the energy transferred from the pumps. Additionally, backwash from the pre-treatment of feed seawater will also be mixed into the return water before release into the marine environment (Welker Environmental Agency 2002).
### 3.3.8 Method of Disposal of Seawater Return

In order to minimize the effects of the concentrated seawater into Cockburn Sound, the seawater return that is discharged by a pipeline being built to the sea has a specially designed diffuser as can be seen in the schematic below. The seawater return is released at an average rate of about 1.8 m$^3$/s, at a minimum depth of around 8 m via a subsurface pipeline through a diffuser array. The diffuser is designed to be about 160m in length with around 16 risers at 10m interval spacing, terminating in ports of about 200 mm wide, so as to be able to obtain a 1:37 dilution. As a precaution against exposure and impact, the pipeline will be buried below the surface, with the risers terminating about 1 m above the seabed (Welker Environmental Agency 2002).

![Perth Seawater Desalination Project Brine Discharge System](image)

Fig 16: Schematic of the brine discharge system (Water Corp 2004).

### 3.3.9 Chemical Storage

There is a list of chemicals that will be used at the desalination facility. They include:
- Chlorine (disinfection);
- Sulphuric acid (pH adjustment);
Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

- Ferric chloride (coagulant);
- 2,2 dibromo-3-nitrilopropionamide (biocide);
- Sulphamic acid (chemical agent to clean filtration and RO membranes);
- Sodium metasulphite (remove oxidizing agents and chloramines);
- Fluorosilicic acid (fluoridation of product water);
- Carbon dioxide (pH adjustment of product water); and
- Hydrated lime (buffering of product water).

There will be a chlorination system that will use liquefied chlorine that will be stored in 920kg drums. These drums will then be configured in a sequenced vacuum draw-off arrangement. The drums will also be stored in a specifically designed building with modern containment facilities. It is estimated to have 10 such drums on site at any one time.

As for the sulphuric acid, ferric chloride and fluorsilicic acid, there will be tank to store them outdoors. These tanks are very large, around 20000L in capacity. The tanks will be bunded and designed closely with the guidelines of AS3780 and the Dangerous Goods Regulations.

Carbon dioxide will be also stored in liquid form in a 25 tonne storage bullet outdoors, and also following guidelines set by the Dangerous Goods Regulations. Finally, the hydrated lime will be stored in two 50 tonne silos. Since hydrated lime is not listed as “dangerous goods”, its storage facilities will be designed according to best engineering practice (Welker Environmental Agency 2002).

### 3.3.10 Pipelines

As mentioned earlier, there will be construction pipelines in association with the desalination plant. Three major pipelines will be built to take in feed seawater, discharge seawater return into the Cockburn Sound and transporting product water to storage reservoirs. The table below shows the estimated length of pipelines that is needed for each kind of usage.
Table 5: Shows the estimated dimensions of the pipelines required (Water Corp 2003).

<table>
<thead>
<tr>
<th>Pipeline use</th>
<th>Diameter/m</th>
<th>No. of pipes</th>
<th>Estimated Length/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seawater supply/intake</td>
<td>1.4</td>
<td>1</td>
<td>~1.5</td>
</tr>
<tr>
<td>Seawater discharge/outfall</td>
<td>1.2</td>
<td>1</td>
<td>~1.5</td>
</tr>
<tr>
<td>Product water transport to reservoir</td>
<td>0.9</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
4. South West Yarragadee

From 2003 to 2004, the Water Corporation did detailed investigations to determine if the large scale abstraction of groundwater from the South West Yarragadee Formation will bring about drawdown impacts on the region’s water table, wetlands and surrounding ecosystems.

At the end of the 19th century, the first development started to make it a water supply source when the wells for the Bunbury water supply were built. The South West Yarragadee aquifer has the potential to be a chief regional water source (Bestow 1973). In recent times, the South West Yarragadee aquifer once again has been acknowledged as a long-term resource in a very strategic locality, by the Perth’s Water Future study. Nevertheless, more investigations still need to be carried out (Water Authority 1995). The Perth’s Water Future longer term vision statement said “By 2050, a major proportion of the water supply for Perth and Mandurah will come from the resources of the Yarragadee Formation in the Southern Perth Basin, south of Bunbury” (Water Authority 1995a).

Fig 17: Location of the proposed SW Yarragadee borefield (Strategen 2005).
4.1 Climate of the South West

The south west region of Western Australia experiences a climate similar to that of the Mediterranean. The winters are mild and wet, with hot dry summers. The average rainfall ranges from around 1200mm in the south to about 800mm in the north. The average annual potential evapo-transpiration is slightly less than 1200mm. The average actual evapo-transpiration varies from 700-800 mm/year. This value increases from north-east to the south-west (Bureau of Meteorology 2001).

4.2 Scott Coastal Plain

Fig 18: Map showing the hydrogeological make up of the South West region (Strategen 2005).
The surface geology of the Scott Coastal Plain consists of superficial formations. This formation ranges from 20 to 30 metres in thickness throughout the plain other than coastal dune areas, where they can go up to 200 metres in thickness. In the eastern and western regions, these superficial formations overlie the Leederville Formation, whereas in the central region of the eastern Scott Coastal Plain, it overlies the Yarragadee Formation. In addition, the Bunbury Basalt too occurs beneath some parts of the region, and eventually outcrops at Black Point, few places along the Donnelly River (Strategen 2005).

The South Perth basin is the name given to the deep sedimentary hydrogeological basin located between the Darling and Dunsborough Faults. The Southern Perth Basin lies between the Darling Scarp and the Leeuwin-Naturaliste Ridge. The geological position the South west Yarragadee aquifer is then within the confines of the Southern Perth Basin, south west of Perth. It’s been long documented that the Southern Perth Basin is a major groundwater source. The basin extends to depths beyond 12,000 metres, with the upper 1000 to 2000 metres containing fresh water (Strategen 2005).

The Blackwood Plateau is predominantly lateritic. It has deep surface drainage features like the Blackwood River in the South. Margaret River runs through the Blackwood Plateau, and across the Leeuwin-Naturaliste Ridge. There are also quite a few northward flowing rivers draining transversely through the Swan Coastal Plain into Geographe Bay.

The elevation of the Blackwood Plateau actually varies from 40 to 180 mAHD. There are permanent water pools found at areas of gentle gradient. Such areas include Margaret River and on St John Brook (Davidson 1995). Usually, coastal plains are made up of thin sand and clays with thicker sandy regions related to coastal dunes systems. Generally, the coastal plains reach elevations of 40 mAHD and slope gradually towards the coast.

Outcrops of basalt around Bunbury form a marked promontory. A similar outcrop of the basalt forms Black Point on the south coast. The western part of the Scott Coastal Plain is drained by the Scott and Blackwood Rivers, both of which flows into the
Hardy Inlet. The Scott River catchment mainly comprises thin superficial formations overlying the Leederville Formation or Bunbury Basalt. The central part of the Scott Coastal Plain is poorly drained, and is characterized by swamps and perennial freshwater lakes, including Lake Jasper which covers an area of about 4.5 km². This area mostly overlies the Yarragadee Formation. Barlee Brook and the Donnelly River drain the eastern part of the Scott Coastal Plain, originating on the Darling Plateau and running across the superficial formations overlying the Leederville Formation (Strategen 2005).

4.2 Groundwater Background

Groundwater resources of this region have been developed for more than a century, following drilling of the first production wells in the Yarragadee Aquifer for Bunbury water supply around 1898. Systematic investigation began in the late 1960s, with an exploratory drilling program continuing until 1992. The work provided a good understanding of the Yarragadee and Leederville aquifers as well as the coastal plains.

About 800,000 gigalitres (GL) of fresh water is being stored in the various formations of the Southern Perth Basin, which means it is equivalent to about 2300 times the annual recharge, and this provides substantial buffering capacity to even out the effects of annual variations in rainfall. Of the average 5740 GL/year of rainfall over the area, an estimated 350 GL/year recharges the groundwater system, a significant part of it going to the Yarragadee Formation. The formation is recharged by direct infiltration of rainfall in areas where it outcrops at the surface, and by leakage from overlying formations. It is predominantly sand, with some gravel and with layers of interbedded shales and siltstones.

Aquifers are underground areas of water- bearing permeable rock, earth, gravel, sand, silt or clay. They are an vital source of drinking water in Perth. Many studies have proven that a lot of natural water bodies like wetlands, lakes, estuarine and marine ecosystems are more or less reliant on groundwater (Ingebritsen 1998).
Groundwater may be loosely defined as the sub-surface water in fully saturated rocks which are known as aquifers. It is the largest accessible store of freshwater on the Earth. Approximately half of this water is held in aquifers within 800m of the ground surface. Most of the Earth’s groundwater stems from meteoric water (precipitated atmospheric moisture) percolating downwards by gravity, through unsaturated aeration zones. Other than this meteoric water, varying volumes of connate water (water that were trapped during the deposition of the rock or soil) may be present (ed. Watts and Halliwell 1996).

Groundwater is a highly valuable and abundant resource, however in places with low rainfall, it is not able to renew itself as quickly as it is being abstracted by humans. If groundwater is extracted intensively from water wells, as for irrigation or municipal use to supply water to cities, it may not recover to its pre-development state. The groundwater sources in Perth, basically come from three key aquifers. They are actually located under the Perth urban region, namely the Superficial, Leederville and Yarragadee aquifer. Yarragadee is an unconfined aquifer. It is composed of inter-bedded lenses of siltstone, sandstone and shale. The South Perth Shale beds within the Parmelia Formation or Cockleshell Formation Gulley confine Yarragadee above it. It is connected hydraulically to the Leederville aquifer where the Parmelia Formation or South Perth Shale beds are absent. The groundwater that is found in the Yarragadee aquifer is generally more than 36000 years old. The age ranges however, from around 600 years in the recharge area to more than 37700 years at other parts of the aquifer (Thorp and Davidson 1991).

Although the Commission of the Perth’s Water Future proposal’s has been accepted as the foundation for the Water Corporation’s source development program for the IWSS, the recent dry spells have been reasons for re-evaluation of the yields from present and proposed sources. The result of this re-evaluation enforce the fact it is important to be adequately geared up for accelerated source development strategies so that future needs are able to be met with minimum severe water restrictions imposed. A vetting process in 2002 to choose likely possibilities for the accelerated development scheme gave the green light to carry on with the assessment of the South West Yarragadee water supply development proposal rather than groundwater from
Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

the Gingin region or surface water development from the Brunswick River. For Yarragadee, there is an availability of large reserves of groundwater, and there is very little competition for the short term period, as such any environmental concerns would be deemed controllable. Furthermore, the development of south west region can be aided through this new water source development. The State Water Strategy also states that, with the development of the South West Yarragadee resource, it is “for the benefit of communities in the South West and those serviced by the Integrated Water Supply Scheme” (Govt. of Western Australia 2003a).

As a rule of thumb, the various different water resource options should not be considered as competing alternatives, where the choice of one option means that the others are not up to par. In this dissertation, the pros and cons between using a Desalination Plant at Kwinana and South West Yarragadee as the next major water supply will be discussed and their sustainably functionality compared.

Fig 19: Schematic showing the water balance of the aquifer (Strategen 2005a).
4.4 South West Yarragadee Project

At the moment, the 45 gigalitres per year desalination plant has already received environmental approval by the Government of Western Australia (2003). The next significant source for consideration would have to be the South West Yarragadee Water Supply Development proposal. The proposed water supply development at South West Yarragadee aquifer to supply 45 gigalitres per annum of water to the IWSS is planned to be made up of a well field, a filtration-based treatment plant and storage tank, transfer main pipelines from the head works to the Stirling Trunk Main at Harvey, pumping stations at Ravenswood and an adaptive approach to tone down any risk where necessary.

It had been proposed that the development of the South West Yarragadee aquifer and the subsequent operation of a water supply scheme to supply 45GL/year to the IWSS. This project can be broken down into the following components:

- Wellfield/borefield;
- Filtration based treatment plant and storage facility;
- Transfer mains from the headworks to the Stirling Trunk Main at Harvey and pumping stations at Ravenswood to boost through existing trunk main to Tamworth; and
- Using an adaptive management approach to mitigate risks as deemed fit.

Basically, the project aims to develop a water supply source from the Blackwood Plateau area of the South West, so that it is able to supply 45GL/year to the IWSS. This project will most likely include a wellfield/borefield to abstract groundwater from the SW Yarragadee aquifer on the Blackwood Plateau. The area for the proposed borefield is probably north of the Blackwood River, west of Nannup and south of Busselton (Strategen 2005).

There will be a filtration based treatment plant to be constructed and be located to the north of the aquifer and transfer mains to take water from the headworks to the existing Stirling Trunk Main at Harvey. The water abstracted will then be transferred through the trunk main which will be improved by a new piping station at Ravenswood.
In addition, there will be a monitoring program, stakeholder involvement and a range of management and mitigation actions being put into place, so as to be able to provide for the accomplishment of social, environmental and economic benefits, through implementation of this South West Yarragadee project. At the moment, Bunbury and Busselton-Capel are recognized as two of the fastest growing areas in Western Australia. Since this project is location in the 2 regions favor, it is able to meet their long-term water supply demands. The table below shows the primary characteristic of the South West Yarragadee project (Mulholland 2005).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project life</td>
<td>Years</td>
<td>30 years</td>
</tr>
<tr>
<td>Abstraction of groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source</td>
<td>-</td>
<td>Yarragadee aquifer</td>
</tr>
<tr>
<td>Amount abstracted</td>
<td>GL/year</td>
<td>45GL/year</td>
</tr>
<tr>
<td>Water Supply Trunk Mains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>Kilometers</td>
<td>About 130km</td>
</tr>
<tr>
<td>Diameter</td>
<td>Millimeter</td>
<td>1400mm</td>
</tr>
<tr>
<td>Treatment Plant</td>
<td>Facilities</td>
<td>Filtration, chlorination, pH adjustment, sludge drying beds.</td>
</tr>
</tbody>
</table>

Fig 6: Shows the summary of the South West Yarragadee Project.

South West Yarragadee has been identified as a substantial fresh water source by the Water and Rivers Commission, following an in-depth study of the hydrogeological, environmental, social and economic aspects of the Yarragadee aquifer from 2002 through to 2003 to gauge the practicability of the groundwater source. According to this study, it is quite conclusive that there is a vast amount of excellent quality groundwater contained within the Yarragadee aquifer in the South West region. The Commission believes that there is about 600000 GL of good quality water within the aquifer.

Groundwater use in the region at the moment is about 72GL/year. This makes up about 62% of the total licensed allocations of 116GL/year. The Economics Consulting
Services (ECS 2003) had stated that groundwater use in the area is expected to rise to about 175GL/year by 2030, so as to meet regional growth demand.

A study was done by URS in 2004 on the groundwater dependent ecosystems around the region and has projected the initial ecological water requirements of these ecosystems that will be potentially affected by groundwater abstraction from the Yarragadee aquifer. The result of this study is widely considered to be very conservative and is intended to identify those groundwater dependent ecosystems that are at risk from potential drawdown effects. However, more detailed information is required to make it more conclusive.

4.5 Potential Impacts of Groundwater Abstraction

From 2003 to 2004, the Water Corporation went about investigating if groundwater abstraction from the Yarragadee Formation will cause drawdown effects on the region’s water table, wetlands and associated ecosystems. The investigation program consists predominantly of hydrogeological data review, pump testing of test wells and numerical modeling of groundwater leakage.

To be more precise, in order to examine the relationship between the water table, wetlands and the groundwater system around the Yarragadee formation, the following studies were carried out:

- Reviewing available hydrogeological data to identify likely effects on the water table that could be caused from draw downs of water levels in the Yarragadee formation;
- Pump testing of specific investigation wells so as to determine the hydraulic characteristics of various geologic formations.
- Modeling of groundwater leakage so as to quantitatively examine the potential for changes in the water table in response to changes in aquifer pressures below the surface (Davidson 1995).
The effects of water table draw downs in the Yarragadee formation were modeled so as to study the effects on vertical leakage and on groundwater levels in the superficial formations in the eastern Scott Coastal Plain. Though this study, it is known that the average recharge to the superficial formations is about 13% of rainfall. If there were changes to water pressures in the Yarragadee Formation, like if it was to decrease by 1m, the water table will be lowered by 0.74m over a 10 year period if the recharge remains constant. However, to offset this effect to make the winter water table constant, the recharge will need to be increased to about 19% of the rainfall. This is required to counterbalance the 2m drawdown effect within the Yarragadee Formation.

Since the shallow groundwater system is more or less full, a significant quantity of recharge will be rejected. As such, if there is any lowering of the water table, its will be reflected as an increase in recharge through a lower rate of rejection. This lowering of the water table will in turn cause reduced evapotranspiration losses, allowing for further increases in recharge. An increase in recharge between 13% and 19% is well within recharge values that are expected in a high rainfall-low evaporation environment such as this. In areas with comparable surface geology and worst rainfall-evaporation conditions, up to 30% of rainfall recharge rates have been recorded. Since recharge takes place during the winter months, there is bound to have drawdown of the water table occurring during summer, even though pumping is totally balanced off by the induced increase in recharge that would occur through the winter months (Yu Davidson & Milligan 2002).

Due to the unpredictable surface and underlying geology and topography, the result of the numerical model showed different results over the area being studied. In places with silty and clayey superficial layers, it would require drawdowns much more than 2m within the Yarragadee Formation to have any significant effect on the water table. This fact was backed by results from examining the response in groundwater levels in the region to local pumping
from the Yarragadee Formation for agricultural purposes. In addition, Yarragadee Formation levels have decreased about half meter from 1998 to 2003. Though there is not visible upward or downward trend in the overlying superficial formations monitoring well. Likewise, at the point where the Bunbury Basalt occurs between the superficial and the Yarragadee Formation, there is small occurrence of drawdowns but is highly unlikely that it will be transmitted to the water table. On top of this, in places where there is thick Bunbury Basalt, it is equally unlikely that large drawdowns in the Yarragadee Formation would be transmitted through as well (Strategen 2005).

![Fig 20: Map of areas that are susceptible to the draw down impacts of groundwater abstraction (Strategen 2005).](image)
The water table within the Yarragadee Formation has been reflecting a lowering pattern, probably due to reduced recharge in recent lower rainfall years. Other factors like groundwater pumping for dairy farms and horticulture on the eastern Scott Coastal Plain also adds to the lowering effect. The water table is lowered by about 0.5 metres over a 5 year period. More in-depth studies have to be done in order to estimate how much pumping and climate change has contributed to this decrease exactly. A point to note is that, although the minimum levels registered in the last few years were lower than preceding year’s records, no change was seen in winter water levels. This clearly shows that there is adequate recharge to fully “fill up” the groundwater levels every year. Since the groundwater levels has decreased in the last few year, the recharge has actually increased, due to the fact that more “empty volume” is required to be filled up (Mulholland 2005).

4.6 Groundwater modelling

It is known that groundwater systems are intricate natural systems with considerable variability in their physical characteristics in all directions. As such, Application of the fundamental theory of groundwater hydraulics to aquifer systems with complex three dimensional geometry, interactions with surface water and changing inputs, e.g. climate and recharge, and outputs, e.g. abstractions and drainage, requires significant computing capability. Computer-based groundwater flow modelling techniques have been developed to allow these complex systems to be simulated and various management possibilities tested. This allows estimates to be made of how water levels and pressures in aquifers vary over time in response to any likely recharge and abstraction scenarios (Yu Davidson & Milligan 2002).
5. Methods

This study involves using part of the methodology to create the Index for Sustainable Functionality to measure the functionality of the two systems. Firstly, the systems to be studied are defined. There are two systems (Desalination plant and South West Yarragadde) to be looked at in this project. After this is done, the functions of each system-perspective will then have to be defined. There are five perspectives (Perth community, South West community, Water Corporation, Environmental and Economic) being defined for this project.

A function is the process that a system is providing from a particular perspective. Indicators are quantitative measures of the functionality of a system-perspective. In this chapter, the indicators will be developed and quantified for each function that the two systems involved provides to each perspective.

In this project, the functionality of the two systems involved will be measured using relative values. This means that the value of the indicators will be compare relative to a benchmarked value. There will be an upper bound (functional) and lower bound (dysfunctional). The upper bound will have a value of 1 and the lower bound will have a value of 0. These values will then be put together in a matrix format.

5.1 Selection of Indicators

Indicators can be said to be representation of a trend. Indicators trend measurable change in some social, economic or environmental system over time. Usually, indicators focus on a small, manageable and telling piece of a certain system, so as to give people a clearer understanding of the bigger picture.

Indicators are commonly used, across a range of disciplines, to measure the functionality of systems that are being studied. While economic indicators have been commonly used for a long time, the importance of using indicators in applications of sustainable development has only recently been recognized (Azar Holmberg & Lindgren 1996).
Several factors must be considered when selecting indicators. The Selection Criteria for the indicators are:

- Indicators must represent the desired aspect of the function;
- Indicators must be scientifically valid;
- Indicators must be available over time, and be able to improve and decline over the same timeframe; and
- Indicator data have to be comparable to acceptable thresholds or targets.

5.2 Indicators

This chapter aims to come out with a set of indicators that can be used to effectively and comprehensively measure the functional sustainability of the two system domain, namely the Kwinana Desalination plant and the South West Yarragadee project. Very often, indicators have been used in many areas of study, attempting to measure important elements of complex systems (Department of the Environment and Heritage 2005). Examples include economic indicators like the GDP (Gross Domestic Product) have been most frequently linked to indicators in the past. It is not until the last ten years that decision makers have recognized the potential importance that indicators can play in sustainable development. Indicators of sustainability can allow measurement and calibration of set sustainability goals, provide early warning signs to change, and can act as an effective tool to bring across the values and ideas behind sustainability (DiSano 2005).

The indicators outlined in this chapter will start to quantify the level of functionality of the Desalination and Yarragadee systems. Basically, there is one function associated with Each perspective and it is to these functions that the indicators will be applied.
5.3 Perth Community Perspective

5.3.1 Function: Provision of alternative affordable and secure potable water.

Basically, water is the most fundamental requirement for human survival and also economic development. It is of paramount importance to have a secure and sustainable supply of potable water, delivered at the lowest possible price. This is crucial, so as to ensure future economic and industrial development within Western Australia. In responding to meet Perth’s short term water requirements, several actions have taken place. These include development of new bores and dams, saving water through rebates on water-saving appliances and also large-scale recycling of industrial water (Water Corp 2005).

It is not foolproof to rely totally on our dams and bores for the medium and long term water needs of Western Australia in a drying climate. As such, in order to add a reliable, rainfall-independent component to the water supply system the largest and most technological advanced desalination plant is being built at Kwinana. In addition to this, plans are underway to develop South West Yarragadee as another 45GL/year water supply supplement to the existing system.

Indicators that are picked to measure this function are:
1. Overall cost of water produced per kiloliter.
2. Potential to meet supply which is targeted to be 600GL/year.
3. Provide emergency provision: Years of emergency supply.

Indicator 1: Overall cost of water produced per kiloliter.
This indicator measures the function of having a secure and affordable source of potable for the residents of the IWSS. Many factors contribute to the capital and subsequent operating costs of producing the product water, in the absence of a conventional water source. For smaller scale desalination plants or groundwater abstraction facilities, capital costs can be considerably higher. By making the plant larger scale results in reduced costs, due to economies of scale.
For desalination, it is $1.16/kL of water and $0.85/kL of water for the South West Yarragadee project. Clearly, it can be seen that it is costlier initially for using the desalination option to supply water than abstracting groundwater from the Yarragadee aquifer. In this case, desalination will be used as the benchmark to be compared against, therefore desalination will have a value of 1 ($1.16/$1.16 = 1) and South West Yarragadee will have a value of 0.73 ($0.85/$1.16 = 0.73).

**Indicator 2: Potential to meet supply which is targeted to be 373GL/year.**

In order for the alternate source of water to be functional, it must be able to reliably supply enough water for the area that it serves. This indicator will be able to reflect the function by showing if the system is able to sustainably provide water to meet projected demands.

It has been forecasted that a supply of about 373GL/year of water is required by the IWSS (Perth water balance 2003). Therefore, in order to show the potential to meet projected water supply, the amount that each system is able to supply is divided by the projected supply needed to be met. Since both systems provide 45GL/year of potable water, they will have a same value of 0.12 (45/373).

**Indicator 3: Provide emergency provision: Years of emergency supply.**

This indicator states the years in which the systems is able to efficiently provide a source of potable water should other conventional source of water to the IWSS fail. This will be determined from the effective lifespan of each system being studied.

The expected lifespan of the desalination facility is about 25 years, whereas the South West Yarragadee project is expected to last 30 years. By using desalination as a benchmark again, desalination will get a value of 1 (25/25 years = 1) and South West Yarragadee will get a fully functional value taken to be 1 (30/25 = 1.2).
5.4 South West Community Perspective

5.4.1 Function: Provision of affordable and reliable potable water.

There is a need to develop new and alternative sources of water to meet the increasing long term demand of water in the IWSS and the rapidly growing South West region. The increasing need for more water is fueled by the following factors:

- Predicted growth in demand for water within the areas served by the IWSS and the South West.
- Decreasing rainfall in recent years and the projection of a drying climate causing a decrease in water available from existing sources supplying the South West.

Due to increasing population and economy fueling the increased demand in water, there is a need for the proposed South West Yarragadee project to proceed with complementary initiatives like desalination (Water Corp 2004).

The indicators chosen for this function are:

1. Potential to meet supply in 2030 (targeted to be 1400GL/year).
2. Allocation of water supply (as a percentage).

**Indicator 1: Potential to meet supply in 2030 (targeted to be 1400GL/year).**

This indicator will be able to measure the functionality by showing if the source of water supply from each system is able to adequately meet supply demand projection. It will be a good indication to show if the system is functioning or is dysfunctional.

Likewise, to get the relative indicator value for this indicator, the amount of water each system is supplying is divided by the targeted water demand. Both systems will have the same value of 0.032 (45/1400 GL).

**Indicator 2: Allocation of water supply (as a percentage).**

As from the South West community perspective, it will be indicator of functionality of the system if the use of the water source is used efficiently. Development should only occur if there is a net public benefit from development. This would mean that
water from the system should be used within the IWSS for it to be functioning in accordance with this system perspective.

For this indicator, the water from South West Yarragadee will be taken to be used mostly by the local community and the nearby regions since the study done by Strategen in 2005 showed that the people in the region would prefer the water from Yarragadee be used in the area instead of being transported elsewhere. As such, the relative indicator value will be taken to be 0.5. As for desalination, the water produced will most probably be pumped into a storage facility where it will be distributed throughout the IWSS. This will give the desalination system a value of 1 as it fulfills the cause of its construction, which is to provide a secure and reliable source of water to the IWSS.

5.5 Water Corporation Perspective

5.5.1 Function: Provision of a secure and reliable water source for Perth.

The Water Corporation is obligated to provide a secure and affordable supply of water to the area within the IWSS, under its operating licence issued by the Economic Regulation Authority. This is inclusive of planning for future growth in that area.

The indicators for this function are listed below:

1. Capital cost per kiloliter of water produced.
2. Power consumed per kiloliter of water produced.
3. Potential for future expansion of facility.
4. Risk of failure of supply for consumers.

**Indicator 1: Capital cost per kiloliter of water produced.**

This indicator shows the costs involved in the development of the source of water in each scenario. Since the initial capital investment determines the ultimate cost of production of the product water, this will be able to effectively measure this given function.
The relative indicator value for this is obtained by dividing the initial capital costs for construction by the total production capacity of the plant and then using the cost per gigaliter for desalination as the benchmark (it will have a value of 1) and dividing the cost per gigaliter of water from South West Yarragadee by the capital cost per gigaliter for desalination. The desalination system will have a value of $8.36/kL ($376m/45 GL = $7.69/kL) and South West Yarragadee will have a value of $8.51/kL ($383m/45 GL = $8.51/GL). Finally to get the relative indicator value, desalination will have a value of 1 and South West Yarragadee will have a value of 1 ($8.51/$8.36 = 1.02).

Indicator 2: Power consumed per kiloliter of water produced.
High energy or power requirement would mean higher production of greenhouse gases and thus higher cost involved in water production. This will in turn cause the water to be more expensive. By measuring the amount of power consumed per kiloliter of water produced, we are able to measure this function.

The power consumed for the South West Yarragadee project will be considered to be negligible in comparison to the Kwinana desalination facility. The power consumed for desalination is 4.5kWhr/kL (Water Corp 2005). The relative indicator value for desalination will then be 0 and South West Yarragadee will have a value of 1.

Indicator 3: Potential for future expansion of facility.
This indicator shows if there is sufficient resource for the facility to be able to increase production capacity in the future, so as to meet increasing demand for water fueled by projected increases in population within the IWSS. If there is potential for future expansion, in terms of the Water Corporation perspective,

The Water Corporation thinks of the desalination option to have unlimited expansion potential. Based on the study into the feasibility of developing South West Yarragadee as a water source, there is considerable potential for future expansion in abstraction capacity (Welker Environmental Agency 2002). Therefore, both systems will have a relative indicator value of 1 (high functionality).
Indicator 4: Risk of failure of supply for consumers.
The above indicator basically gauges the possibility of the water supply failing to meet the demand of residents within the IWSS. Since the function from the Water Corporation’s perspective is to provide a secure and reliable source of potable water, this would be a valuable indicator measuring the function (Welker Environmental Agency 2002).

Since desalination is independent of climate and South West Yarragadee has sufficient buffering capacity for any variation in rainfall, the risk of failure of the two systems can be said to be negligible. This will give both systems equal value of 1.

5.6 Environmental Perspective

5.6.1 Function: Provision of sustainable water supply with minimal environmental impacts.

In parallel development of a more diverse and sustainable source of water for the IWSS and the South West, it is also important to have minimum adverse impacts on the environment. Since water is primarily obtained from the natural environment, it is important to keep it as unpolluted as possible.

Indicators to quantify this function are as follows:

1. Amount of greenhouse gas emitted per kiloliter of water produced.
2. Impacts on other water resources.
3. Waste discharged per kiloliter of water produced.
4. Risk of failure of supply for consumer.

Indicator 1: Amount of greenhouse gas emitted per kiloliter of water produced.
Greenhouse gases have long been recognized as the main “culprit” for global warming and many other environmental problems. This is a primary environmental consideration associated with the use of desalination technology. Measuring the amount of greenhouse gas emitted per kiloliter of water produced, can be used as a good indicator of whether the system is putting any pressure on the environment.
Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

Since the desalination system is the only system that produces greenhouse emission (231000 tonne/year or 0.005 tonne/kL), and the South West Yarragadee produces negligible greenhouse emissions, the latter will be having a relative indicator value of 1 and the desalination system, value of 0.

**Indicator 2: Impacts on other water resources.**
To provide a sustainable source of water with minimal impact to the environment would mean not having any negative impacts on other sources of water. With regards to this indicator, both systems have negative impacts on their surrounding water resources. The desalination plant at Kwinana discharges concentrated brine into Cockburn Sound while the groundwater abstraction at South West Yarragadee causes drawn down effects on neighboring water resources.

**Indicator 3: Waste discharged per kiloliter of water produced.**
This indicator really just measures the amount of waste discharge that is produced by each system. Since waste discharge that is released into the environment will caused detrimental effects over time, the value of this indicator can then accurately measure the function for both systems from the environmental perspective.

The disposal of the wastewater from the desalination facility in an environmentally appropriate manner is crucial to the operation of the plant. Disposing the waste into the sea is not a problem provided the influence of temperature and salinity of the returning brine is contained in the immediate vicinity of the outfall. However, modelling of the possible scenarios will be done to ensure that the proposal meets environmental requirements. At the same time, care must be taken relative to possible problems from added components like biocides, ferrous chloride, dissolved oxygen and water temperature (Welker Environmental Agency 2002).

Since the South West Yarragadee produces no discharge, it will have a relative indicator value of 1. The desalination plant discharges 0.004L/kL (180ML/45GL = 0.004L/kL), thus it will have a relative indicator value of 0, since it produces waste which makes it less functional.
5.7 Economic Perspective

5.7.1 Function: Provision of income to the WA economy.

The economic aspect of the development of the two water sources would be how much of the capital spent is going into the local economy and the proportion that is flowing out of the state to overseas economies.

Indicators chosen to assess this are:

1. Percentage of capital going into local economy.
2. Percentage of capital going into foreign economy.

**Indicator 1: Percentage of capital going into local economy.**

This indicator measures the amount of capital that is flowing into the West Australian economy. This will have a boosting effect on the economy since the capital invested to develop the supply of water stays within Perth.

The desalination plant at Kwinana is being developed as a joint venture with a French company and the capital invested would be a 50-50 share split. The South West Yarragadee project has not been finalized but it is likely to be a local development. As such, the relative indicator value for the desalination system is 0.5 and 1 for the South West Yarragadee system.

**Indicator 2: Percentage of capital going into foreign economy.**

This indicator measures the amount of investment capital that is going out of the local economy. Since the desalination plant is a joint venture, it will have a 0.5 relative indicator value while the South West Yarragadee have a value of 0.

5.8 Matrix

In the matrix found in table 7, absolute values of the various indicators for the 5 different perspectives are shown. For the cause of normalizing the indicator values in this dissertation, the values from the desalination plant at Kwinana will be used at a benchmark to compare with those in the South West Yarragadee system. The absolute
values are obtained, and then they are divided by the values from the indicators from the desalination system.

In cases where there is not specific data available, depending on the indicator measuring the function, a value of 1 (functional) or 0 (dysfunctional) is given to the respective indicator. In the matrix in table 8, the values of the indicators are given in relative indicator values. When these values are added up for the respective systems, it is able to give a gauge of the functionality of each system.

<table>
<thead>
<tr>
<th>Perspectives</th>
<th>Functions</th>
<th>Indicators</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Desalination</td>
</tr>
<tr>
<td>Perth</td>
<td>Provision of affordable and sustainable drinking water.</td>
<td>1. Overall cost of water produced per kL.</td>
<td>$1.16</td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td>2. Potential to meet supply in 2030, targeted to be 600 GL/year.</td>
<td>45/373</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Provide emergency provision: Years of emergency supply GL.</td>
<td>20</td>
</tr>
<tr>
<td>South West</td>
<td>Provision of affordable irrigation and potable water supply.</td>
<td>1. Potential to meet supply in 2030, targeted to be 1400GL/year.</td>
<td>0.032</td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td>2. Allocation of water supply.</td>
<td>1</td>
</tr>
<tr>
<td>Water</td>
<td>Provision of a secure and sustainable water source for Perth.</td>
<td>1. Capital cost per kL of water produced.</td>
<td>$346m/45000</td>
</tr>
<tr>
<td>Corporation</td>
<td></td>
<td>2. Power consumed per kL of water produced.</td>
<td>24.1 MW/45000</td>
</tr>
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<td></td>
<td></td>
<td>3. Cost of plant operation per kL.</td>
<td>$0.44/kL</td>
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<td></td>
<td></td>
<td>4. Potential for future expansion of facility.</td>
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<td></td>
<td></td>
<td>5. Risk of failure of supply for consumers.</td>
<td>-</td>
</tr>
<tr>
<td>Environment</td>
<td>Provision of sustainable water supply with minimal environmental impacts.</td>
<td>1. Greenhouse emissions. Tonnes per kL of water produced.</td>
<td>0.005tpa</td>
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<tr>
<td></td>
<td></td>
<td>2. Impacts on other water resources.</td>
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<tr>
<td></td>
<td></td>
<td>3. Waste discharge per kL of water produced.</td>
<td>0.004L/kL</td>
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<td></td>
<td></td>
<td>4. Area of vegetation needed to be cleared for facility.</td>
<td>3 Ha</td>
</tr>
<tr>
<td>Economy</td>
<td>Boosting the WA economy.</td>
<td>1. Percentage of capital going into local economy.</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Percentage of capital going into foreign economy.</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 7: Shows the matrix with the absolute values of the indicators.
### Perspectives

<table>
<thead>
<tr>
<th>Functions</th>
<th>Indicators</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perth Community</td>
<td>Provisions of affordable and sustainable drinking water.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Overall cost of water produced per kL.</td>
<td>Desalination 0.73</td>
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<td></td>
<td>Yarragadee 1.0</td>
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<td></td>
<td>2. Potential to meet supply in 2030, targeted to be 600 GL/year.</td>
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<tr>
<td></td>
<td></td>
<td>Desalination 0.12</td>
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<tr>
<td></td>
<td></td>
<td>Yarragadee 0.12</td>
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<td></td>
<td>3. Provide emergency provision: Years of emergency supply GL.</td>
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<td></td>
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<td>Desalination 1.0</td>
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<td></td>
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<td>Yarragadee 1.0</td>
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<td>South West Community</td>
<td>Provisions of affordable irrigation and potable water supply.</td>
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<td></td>
<td>1. Potential to meet supply in 2030, targeted to be 1400GL/year.</td>
<td>Desalination 0.032</td>
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<td>Yarragadee 0.032</td>
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<td>2. Allocation of water supply.</td>
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<td></td>
<td>Desalination 0.5</td>
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<td></td>
<td></td>
<td>Yarragadee 0.5</td>
</tr>
<tr>
<td>Water Corporation</td>
<td>Provisions of a secure and sustainable water source for Perth.</td>
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<tr>
<td></td>
<td>1. Capital cost per kL of water produced.</td>
<td>Desalination 1.0</td>
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<td></td>
<td></td>
<td>Yarragadee 1.0</td>
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<td></td>
<td>2. Power consumed per kL of water produced.</td>
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<td></td>
<td></td>
<td>Desalination 0.0</td>
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<td></td>
<td>Yarragadee 0.0</td>
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<tr>
<td></td>
<td>3. Cost of plant operation per kL.</td>
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<td>Desalination 0.0</td>
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<td>Yarragadee 0.0</td>
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<td>4. Potential for future expansion of facility.</td>
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<td>Desalination 1.0</td>
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<tr>
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<td></td>
<td>Yarragadee 1.0</td>
</tr>
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<td></td>
<td>5. Risk of failure of supply for consumers.</td>
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<td></td>
<td></td>
<td>Desalination 1.0</td>
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<tr>
<td></td>
<td></td>
<td>Yarragadee 1.0</td>
</tr>
<tr>
<td>Environment</td>
<td>Provisions of sustainable water supply with minimal environmental impacts.</td>
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</tr>
<tr>
<td></td>
<td>1. Greenhouse emissions. (Tonne per kL of water produced)</td>
<td>Desalination 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yarragadee 1.0</td>
</tr>
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<td></td>
<td>2. Impacts on other water resources.</td>
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<td>Desalination 1.0</td>
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<td></td>
<td>Yarragadee 1.0</td>
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<td></td>
<td>3. Waste discharge per kL of water produced.</td>
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<td></td>
<td></td>
<td>Desalination 0.0</td>
</tr>
<tr>
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<td></td>
<td>Yarragadee 0.0</td>
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<td></td>
<td>4. Area of vegetation needed to be cleared for facility.</td>
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<td>Desalination 1.0</td>
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<td></td>
<td>1. Percentage of capital going into local economy.</td>
<td>Desalination 0.5</td>
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<td>Yarragadee 1.0</td>
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<td></td>
<td></td>
<td>Desalination 0.5</td>
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<tr>
<td></td>
<td></td>
<td>Yarragadee 0.0</td>
</tr>
</tbody>
</table>

Table 8: Shows the matrix with the relative values of the indicators.
6. **Discussion**

6.1 **South West Community**

The evaluation of the functionality of from the South West community’s perspective can be more in depth with more indicators to measure its function. Firstly, from the aboriginal heritage point of view, there will be effects on specific area of interests, should the construction of pipeline, well field and treatment facility commence. There could be potential for problems arising from effects this project on the neighboring water resources. Since rivers, streams and pools have been used by aboriginals in that area for fishing in the past and present, such development would have negative impacts on these water bodies have thus affecting their way of life. In addition, any impacts on the ecological system or biodiversity will inevitably affect the cultural heritage values of the aboriginals, as their cultural heritage relates closely to environmental values (ARCWIS 2003).

It is recommended by the Water and Rivers Commission to conduct an in-depth investigation into the potential effects the South West Yarragadee development will have on the aboriginal cultural heritage before the commence of any plans to go ahead with construction.

6.2 **Potential impacts of Desalination Plant discharge**

The discharge of concentrated seawater back into Cockburn Sound through a custom built brine diffuser has potential to cause detrimental environmental impacts that requires serious consideration. Since the diffuser will cause the dilution of the concentrated seawater discharge, the diluted discharge (less than 0.5kg/m³) still the tendency to flow to the bottom of the Cockburn Sound. There is then the potential for this to result in stratification and reduced oxygen levels in the deep waters of Cockburn Sound (Water Corp 2003).

There are numerous aquatic ecosystems and habitats throughout the Southern Perth Basin. There are estuarine systems that provide habitat for saltwater fish and other vertebrate species and macro algae growth, riverine and riparian habitats and a wide
range of wetlands within the project vicinity supports a large array of diverse, locally significant plants species and fauna communities that are both regionally and nationally significant (Water and Rivers Commission 2001).

5.5 Discussion

The systems being looked at in this dissertation are multidimensional and strongly reflect the diverse realities that are indicative of complex interactions and networks. In the past, system domains have been assessed traditionally using indicators that mask their true complexity by treating the economy, society and the environment as distinct or only weakly related.

Increasingly, the limitations of using traditional indicators in system functionality assessments are becoming apparent. For instance, the amount of waste that is discharged into the environment says very little about how much harm it does to the natural system, unless vigorous study and modelling is done to assess the impact. As such, it will be right to say that indicators for measuring the functionality of a system domain have to reflect what is happening in the larger system, or the "big picture," through observation of a smaller part of the system. Indicators to assess progress towards system sustainability and functionality must therefore be as creative and multidimensional as the domains they are intended to serve.

Indicators should be able to measure functionality in a quantitative manner. However, Ferrer-Balas, Bruno, de Mingo & Sans (2004) suggested a qualitative approach might be more desirable. This is probably due to the fact that the concept of whether a system is functioning sustainably is abstract to a certain degree. The method of measuring of functionality used in this project allows comparison of between domains. However, it is essential to recognize the fact that some of the qualitative aspects could be neglected with this method.

There are many different types of activities in the world today that is dysfunctional. As such, in order to attempt at measuring the functionality of a system, indicators are chosen, adhering to a set of standard guidelines, to help determine whether or not a
Comparing the Functionality of the Kwinana Desalination Plant with the South West Yarragadee Groundwater Development.

sustainability criterion is being met (Azar, Holmberg & Lindgren 1996). However, they acknowledge that there are no exact limits defining the functionality but rather the boundaries between what is functional and what is dysfunctional and also to establish reference values for a functional or dysfunctional system is not straightforward.

Another limitation to indicator selection is that one set of indicators cannot fully reflect the complexities of what functionality means in time or space, let alone quantify them without error (Venetoulis 2001). Although it is required for indicators to be scientifically valid and accurately represent the desired aspect of the function, this again is very much a subjective task. Indicator data may not exist for a particular function, or might not be easily accessible. Proxies dilute the validity of measuring functional performance, but in cases where ideal indicators are unavailable, their use is necessary.

Although indicators do not always provide a timely reflection on the ability of a system to perform its functions and there may be time-lags between an action and the corresponding impact on indicator data. Thus, indicators may only offer insight into past sustainability rather than providing information on the current state of a system (Azar, Holmberg & Lindgren 1996). Again, the careful choice of indicators is imperative in order to minimize inaccuracy. It is quite difficult to define and verify thresholds since the upper limits and lower limits of an indicator are most certainly subjective to the individual interpreting the indicator or are relative within a specified domain or system. An example will be how much brine discharged produced by the desalination is considered acceptable within a broader domain of the Perth Metropolitan Area? On the other hand, is it totally true that a fully functional system is one that produces minimal discharge or is there a tolerable threshold under which the indicator is fully functional?

Since South West Yarragadee have been proposed as a potable water supply source for the IWSS, the main challenge is to develop a water supply source for the IWSS in such a way that it will be benefiting the South West and the IWSS but with minimal effects on the regional flora, fauna and water sources. The South West Yarragadee
Water Supply Development must meet environmental objectives to be a “net benefit” proposal and should conform to the requirements of the Water and Rivers Commission in obtaining a licence under the Rights in Water and Irrigation Act 1914. It should also be understood that all reasonable regional requirements should be met from this project development. The most acceptable outcome would have to be the successful implementation of the South West Yarragadee Water Supply development in the “most functional and sustainable” manner.

Throughout the course of the indicator selection process, there are indicators which were discarded despite their high capacity to accurately indicate functionality. The majority of such exclusions occurred on the basis of lack of data in a scientific manner. Several other indicators were discarded due to their lack of cohesion with the function. They simply either covered aspects of other system perspectives or did not represent the function to an acceptable degree. The indicators that emerged from the selection process are believed to strongly reflect the functions defined for their respective system perspectives, whilst having adequate data to effectively indicate functionality both the desalination and South West Yarragadee systems.
7. Conclusion and Recommendations

After the analysis of the indicators that have been set up to measure the respective functions of the 5 specified perspectives, the South West Yarragadee groundwater development was deemed to be performing at a higher functionality to the Perth Metropolitan Desalination project. With the indicators that were chosen, they reflect the sustainable functionality of the two system domain involved.

It is good to fully analyze all the potential social, economic and environmental aspects of both systems fully, Perth Metropolitan Desalination Plant and South West Yarragadee before commencing their advancement. The idea of the “most sustainable” way that can be used to implement the projects is good and should be based on the objectives and principles that were set up for their evaluation.

It is paramount after identifying the system that is being studied, and the specified goals and objectives should be laid out properly. The parties involved, like in this case, Water Corporation, should liaise with relevant governing bodies like the Water and Rivers Commission and discuss the linkage between the identified issues of concern. An example would be the extent of groundwater abstraction in relation to the unfavorable effects of draw downs.

To conclude, there is a need to evaluate how the indicator would be incorporated in the selected perspectives to measure its respective functions. To measure wholly the actually functionality is very complex. Numerous in-depth studying and evaluation is needed from public, private and civic sectors. In order to determine if the system performs at an acceptable level of functionality, it is good to have greater collaboration between Water Corporation, government and members of the community, and through this making the diverse sectors of the community more involved in the efforts for more sustainable and functional management.
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