Possible uses for Merredin's salty ground water [1]

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[1] This report aims to discuss ways to reduce the high, salty water table under Merredin whilst creating products of economic and social value to the town.

Contents

Chapter 1

Introduction

Merredin's water table is too high, and salty. This report looks to solve the problem of the town's high, salty, water table using different technologies other than reverse osmosis. It looks at the costs and side benefits of these alternative technologies.

Between 2001 and 2025 the council estimated the annual future maintenance cost in 2025 to be an additional $384,000 per year over costs in 2001 as a result of damage to town infrastructure such as roads, plumbing and buildings, or a total of $4.5 million in 2001 dollars to remediate the problem [3]. The council has enquired whether a suitable mitigation project started now might be able to reduce the total expected cost.

The Rural Towns Liquid Assets project is looking at how the town could convert this potential cost to an asset by using reverse osmosis membrane technology to desalinate the ground water for reuse either within the town or to be sold to other towns via the Goldfields Pipeline.[3, 5]

The prototype use of reverse osmosis discovered a number of significant hurdles to practical implementation and the Council felt it worth investigating alternative technologies. This is sensible because it is common for long running projects to become focused on a single solution and to discount new alternatives as they arise. This does not mean we believe the existing approaches are wrong, rather that other technologies should be reconsidered given the experience gained so far.

Importantly, this report examines the costs and side benefits of alternative solutions to reverse osmosis. Alternatives may initially be more expensive to set up, but may be cheap to run in the long term or may have benefits of significant economic value to the town beyond desalination of groundwater. An economically self-sufficient solution would not need further inputs from Council for ongoing maintenance, and may actually generate money for Council or town. For example, waste heat from a large scale solar thermal electricity plant may be able to perform desalination of groundwater as a side benefit of providing electricity for the town and surrounding areas. If the cost of implementation only for desalination of water was considered, not the value of the electricity generated, the idea would be significantly undervalued. Such a solar electricity plant would be a completely new income generator for Merredin and would decrease its greenhouse gas emissions, and desalinate water as an incidental.

None of the cost estimates in this report are fully costed quotes, but rather the authors' estimates of the relative cost based on limiting factors and their knowledge of the state of the art.

We are going to look at a number of alternative technologies, and we recommend the council adopt a mixed strategy to avoid "putting all the eggs in one basket." For example, rather than building one large evaporation pond, build a number and try different techniques on each. This will also make it easier to handle leaks.

1.0.1 Disclaimer:

Throughout this report the authors have tried to be pessimistic about the costing of all technologies to give the Council a comfort factor. However, being overly pessimistic may rule out some technologies that may actually be ideal. Also, without an engineering design, costings cannot be accurately estimated. Thus, the authors suggest that quotes from reputable engineering, scientific and technical firms be gathered for anything considered for implementation.

The authors also give likelihood estimates for each technology on whether it will achieve Council's goals. A cheap but unproven technology might have lower odds of success than a traditional technology, but have a higher expected payoff should it succeed. The political and economic feasibility of each solution is considered separately.

Chapter 2

Potential technologies

Merredin has a problem with salty water rising under the town. The simplest way to alleviate the problem is to pump the water out and dump it into a salt lake. But is this the most viable and environmentally responsible way? Would it pass DEC (Department of Environment and Conservation) guidelines and legislation?

When considering ways to remove salt water from the ground, we need to consider what our aim is. Do we want to dispose of the water:

- as cheaply as possible?
- in a way that gains economic value from a waste?
- is a side benefit of investing in technologies that have other benefits?

Once we have worked out what we want to do, then we can consider different ways to achieve our aims. Council has indicated it would prefer a mixed strategy, and one that would have economic and social benefits for the town.

In this section, we will describe and summarise various options for Merredin to remove the salty water currently being removed from under the town.

Possible solutions to consider:

- Ways to desalinate water: reverse osmosis, forward osmosis, evaporate/distill and condense, vapour compression condensation, magneto-chemical precipitation
- Disposal of salty water: pipe to salt lake, evaporate, use in other industries, disposal underground
- Use of salty water: algal ponds, greenhouse, irrigation, dust control on roads

Sources of energy for desalination:

- electricity grid
- solar

- wind
- fossil fuels
- bio-fuels
- waste heat

The sources of power for desalination or disposal of salty water will be considered alongside the technologies used to desalinate water as they are closely linked.

Note: Reverse osmosis is already being tested, so is not included in this report.

2.1 Forward osmosis

Forward osmosis works by drawing water across a membrane without the input of electricity or thermal energy — it works in the opposite direction to reverse osmosis. In essence the salty water is contained on one side of the membrane and on the other side of the membrane is something that wants water and will pull water across the membrane. The material to be diluted must be quite concentrated and must exert a strong osmotic pull to drag the water out of the salty solution. Forward osmosis can produce an economically worthwhile product along with concentrated salty water. Forward osmosis is used in kidney dialysis to clean blood.

Some suggested materials for forward osmosis:

- fertiliser
- sugar
- carbon dioxide and ammonia

Examples:

Pivot creates solid fertilisers that need to be turned into liquid fertilisers before use. Forward osmosis could be used to create the liquid fertiliser whilst concentrating the salty water.

Sugar provides a very strong osmotic force. Forward osmosis with sugar would make concentrated salty water and a sugar solution. Yeasts and algae can grow on sugar water, and these may have some economic value depending on the types used.

Carbon dioxide (CO_2) and ammonia (NH_3) in solution can also be used for forward osmosis. The solution could then be used as fertiliser on farms.

Inputs:

Groundwater; solutes to be diluted

Outputs:

Economically useful products; brine.

Advantages:

Creates economic value from a waste product.

Problems:

No particular problems are foreseen with using forward osmosis to concentrate the briny groundwater. This method is unlikely to provide pure water for town use, but does provide a source of water useful in industry and agriculture.

Side benefits:

Does not give off usable energy so is not useful for generating electricity.

2.2 Solar updraft tower

A solar updraft tower uses rising hot air to generate electricity. It is a substantial structure, standing up to one kilometre high and up to seven kilometres across the base. The proposed solar updraft tower in Wentworth Shire, New South Wales, has a hollow tower about 130m across and one kilometre high sitting on top of a very large greenhouse that is five kilometres across. It captures solar energy by heating warm air in the wide, flat greenhouse base and venting it through the tower. The air would be about 35C hotter than air outside the tower. Warm air rises (creating "thermals" which birds and glider pilots use to lift them into the air) and powers turbines in the "chimney." The turbines feed into power generators. The tower should produce 200MW of electricity 24/7 — day and night. This power could be used to desalinate Merredin's ground water. The technology is new but is known to work in a 50kW version built in Spain.

Additionally, the warm conditions in a greenhouse encourage evaporation of water. Open evaporation ponds and stores of saline water could be used as both thermal stores to help maintain air temperature overnight and as ways to concentrate saline water (see problems, below).

The proposed tower in Wentworth Shire has not yet received permission to proceed from the administering council. The Australian and German consortium proposing the solar updraft tower would like to have the first plant up and running by 2008.[2, 4]

Inputs:

Solar heat

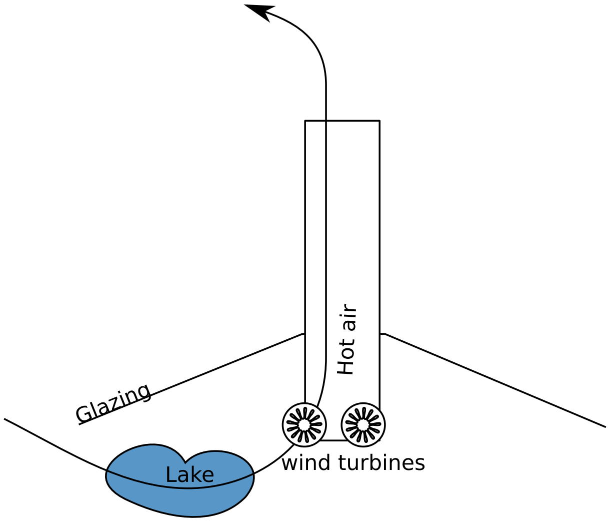

Figure 2.1: A solar updraft tower with evaporation lake.

Outputs:

Electricity.

Advantages:

High energy output providing a constant source of electricity. Large amounts of electricity generated — far in excess of what would be needed to drive desalination. Electricity could be sold back into the grid. Non-polluting — no greenhouse gases are emitted. May provide appropriate environment for solar/evaporation ponds.

Problems:

Solar updraft towers or chimneys require substantial infrastructure and investment. They are very large structures. Private investors would be needed to help build and maintain the solar updraft tower. Since they are so large it may not be economically or politically wise for one council to develop them. Does not solve salt water problem directly and any water evaporated has no benefit for Council.

Side benefits:

Creates electricity that could be used to desalinate water Such structures have would likely draw significant numbers of tourists particularly if it was possible to have a viewing platform and/or restaurant on the tower.

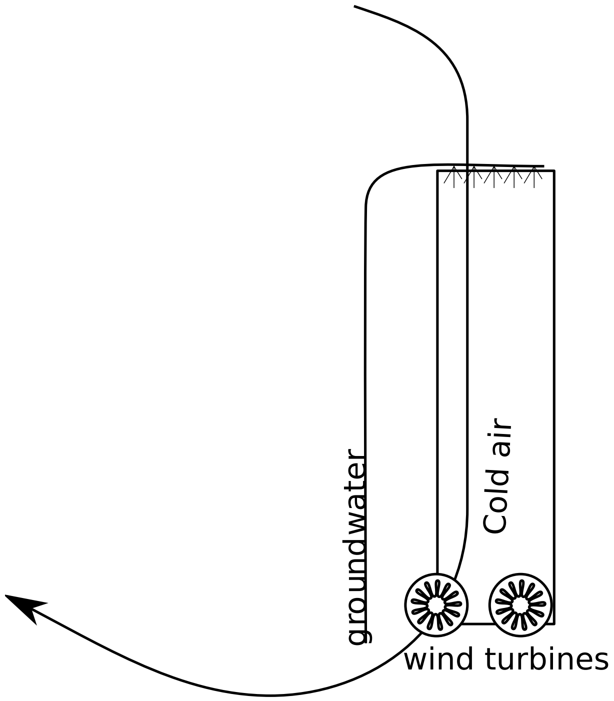

Figure 2.2: An 'energy tower'.

If we have an evaporation basin under the greenhouse the fresh air drawn in will evaporate more water than a static basin. Furthermore, it is possible that the reduced density of humid air (air is 1.6 times more dense than water vapour) will increase the energy extracted by the solar chimney. However, this must be weighed against the energy required to evaporate the water. The whole system should be modeled carefully to determine whether this would be a net win or cost.

2.3 Energy tower, air cooling evaporating tower

An energy tower, or aeroelectric oasis system, would look similar to a solar updraft tower. It has been studied in some detail by Professor Dan Zaslavsky[9]. It could be of similar large size or smaller versions should also work. Instead of collecting heat, water would be pumped to the top of the tower and sprayed/misted. This would evaporate the water and also cool the air in the tower. Cool, humid air would move out the bottom of the tower rather than warm air moving into it. This is the same principle as an evaporative cooler uses.

Let's look at a possible tower for 100kL/day. Saturated air at 16C

> is 1% by volume water. A starting relative humidity of 50% means that each litre of air can absorb 5mL of water vapour. 5mL water vapour at 16C has a mass of $PV = nRT$, $P = 100\text{kPa}$, $V = 5\text{mL}$, $T = 273 + 16(100\text{kPa} \times 5\text{mL}/(273 + 16)\text{K} * R) * (18\text{g/mol}) = 3.75\text{mg}$ of water per litre of air.
>
> Thus, to get rid of 100kL of water (100 tonnes) means we need to evaporate into 27million m^3 of air per day. This sounds a lot, but let us consider a chimney 10m in diameter. This gives a distance of 340km / day or about 4m/s = 14km/hr wind.
>
> Lets say the air cools from 16C to 12C by evaporation. This is a density difference of 1.4%. We can work out the required pressure difference to create this speed of air movement using $P = (\text{density of air}) \times (\text{wind speed})^2 \times (\text{shape factor})$. Thus, we need a pressure difference of $P = (\text{density of air} 1.2\text{kg/m}^3) \times (4\text{m/s})^2 \times (\text{shape factor}) = 20\text{Pa}$.
>
> To create a pressure of 20Pa using two columns of air at 16C and 12C requires $20\text{Pa} = \text{height} \times ((16 + 273\text{K})/(12 + 273\text{K}) - 1) * 12\text{N/m}^2$. 120m high. This is for a very pessimistic mid winter system.
>
> When we consider the performance in summer we find for 30C, 17mg/l, 76km/day, 0.9m/s, 1Pa. 30C cooling to 20C. 2.5m high.
>
> The power available from air movement is $P = \frac{1}{2}\rho\pi D^2 v^3$. where P is in Watts, $\rho = 1.2\text{kg/m}^3$, D is the turbine blade length in m, and v the velocity of air in m/s.

So at midwinter the tower needs to be quite tall to even successfully evaporate that much water. But in summer even a very short tower can drive the evaporation cycle efficiently. This means that Council's preference is to evaporate the majority of the ground water in summer, a short tower could be a very efficient solution.

If we wanted to generate electricity this way, we would aim for about 10m/s air flow. Stepping through the equation at 30C we find that we would need a tower 300m high to produce an air speed of 10m/s and from that, 50kW of power.

So power generation this way is not particularly practical, but as a way of efficiently evaporating water, this method would be very effective. The dry air for evaporation would be drawn in by itself, the outgoing air would be cool and moist and useful for air-conditioning outdoor areas or large sheds.

Council might offer short evaporating towers for workshops in town (such as the hardware shop) that would provide cooling air whilst removing some of the town's excess salt water. The location of the pumps means that any water used in town is less water to pump out of town.

It may be feasible to evaporate large quantities of water to cool the park lands opposite the shops, which would encourage people to stop there in summer for lunch. An air-conditioned parkland could support more lush vegetation and reduce watering requirements for the lawns (in turn reducing the amount of water going into the ground).

Inputs:

Dry warm air; groundwater.

Outputs:

Cool moist air.

Advantages:

For pure evaporation and cooling, this idea is a good one. Many places will already use evaporative cooling with town water. The salt content of the water will require large surface areas for a given cooling capacity but will prevent many airborne pathogens from growing.

Problems:

The problems with Energy towers are similar to those of the solar updraft tower. Due to the way the problem scales with increasing size the most effective systems will be very large.

Evaporative pads would need to be monitored for Legionella bacteria to avoid possible cases of Legionnaire's Disease. Legionella may not be able to grow in the groundwater. This risk is considered small as water is not allowed to stagnate in the system — stagnant water is the best breeding grounds for Legionella species.

Odour in the town groundwater may affect the usefulness of evaporative cooling — the water from one bore is apparently smelly. The smell can probably be removed by letting the water stand in the open for a while, or by oxidation with ozone.

Side benefits:

Energy tower creates electricity that could be used to desalinate water. Such structures have would likely draw significant numbers of tourists particularly if it was possible to have a viewing platform and/or restaurant on the tower.

Air-conditioned parkland may become a significant tourist resource, reduced watering reduces ground water problem.

2.4 Direct solar thermal technologies

If all the energy for one square metre of ground/roof could be collected and turned into electricity, it would provide half the energy needs for a house. Solar technology is not yet very efficient so not all the sun's energy can be collected and used. Normal solar panels are only about 10-15% efficient at turning solar energy into electricity. The Solar Oasis is 3-5 times more efficient at creating electricity from the sun than normal photovoltaic solar panels, making it one of the most efficient converters of solar energy into electricity that we have at present.

Of more economic importance is the cost per peak Watt produced, or alternatively, the average cost per MJ of electricity created. Producing work (electricity) from heat is difficult thermodynamically — that is, you need high temperatures for it to be economical. This means large collector areas.

Solar thermal desalination uses solar power to provide the energy for desalination by a commercial desalination unit. There are a number of different ways to obtain the heat/energy:

Solar pond: Discussed later. Around 90C.

Evacuated tubes: These look like dark, overgrown straight fluorescent tubes. There are two glass tubes, one inside the other, with a vacuum between them. The inner tube is made of dark glass to absorb as much heat as possible, and the outer tube has a reflector to help bounce as much light/heat into the inner tube as possible. The tubes are mass produced in China and cost roughly $33 retail in Melbourne. 10 in Melbourne produce roughly 19MJ/day with back reflectors). They provide low grade heat with no moving or tracking parts that should be sufficient for commercial thermal desalination. They can produce water at around 110C or low grade steam.

Parabolic trough: This is a trough with a curved, reflective inner surface that focuses sunlight onto a solar collecting tube that runs along the centre of the trough. This provides heat that can be used directly to desalinate water or indirectly by producing electricity. The troughs could be manufactured locally. They can produce steam at around 350C.

Parabolic dish: (Solar Oasis approach). Solar concentrating dishes look like radio telescopes with mirrors that reflect the sun to a central point. The amount of energy at that point is very intense and provides high grade heat that can be used to generate electricity. The Solar Oasis dish is currently undergoing trials in Australia. It does not directly desalinate water but does provide either waste heat or electricity, both of which can be used for desalination in commercial units. The waste heat is a byproduct of electricity generation. If the electricity generated does not make the installation economically viable, the additional value of the waste heat may improve its economic viability. They can produce steam at around 550C, or decompose ammonia for long term energy storage.

Co-generation: Another source of heat is waste heat from other industries or machinery. Waste heat can be used for desalination in commercial units. For example, should a diesel generator need to be used for some time, the exhaust could be used to power a thermal desalination process.

The heat produced can be used for different things depending on the quantity and temperature of the produced heat. Steam above 300C is useful for generating electricity. When steam energy is used to make electricity you usually get around 60% of the input energy coming out the exhaust as lower grade heat. The solar oasis system is tuned to produce steam at 550C that drives a turbine and produces waste heat at around 90C.

Various of these collection methods can be joined together — preheating the water with a lower cost technology can be a better use of money. For example, one might heat water to 90C first using a solar pond, then to 350C using parabolic troughs, then finally to 550C using dishes. The downside is a greater variety of machines to understand and maintain.

Low grade (100C) steam can be used with multi-stage and multi-effect distillation processes to produce fresh water. These generally require fairly complex systems to be efficient. For heat below 100C there are a number of techniques for desalination, two noteworthy ones are *multiple-effect humidification* and *vapour-compression condensation*:

TiNOX-watermanagement produces a commercial, self-contained multiple-effect humidification desalination unit. Saline water and heat go into the unit, and it produces fresh water, briny water and waste heat. It has up to 85% recovery of fresh water. One TiNOX unit costs €100,000 and can produce 10kL of fresh water each day [6]. The contact for this system said he was quite interested in some kind of linkage project with WA and could result in the systems being built in Merredin much more cheaply.

Vapour-compression condensation approaches can use quite low temperature waste heat, although the efficiency tails off exponentially with decreasing temperature (as the fraction of the air that is water halves with every 12C or so, we need to move more and more air for each litre of water). Operating temperatures of 50C and above are considered practical. We will look at this approach in more detail.

Energy storage

The solar oasis group have demonstrated a way to store heat produced in good weather. They decompose ammonia gas into hydrogen and nitrogen gases and store these products in a large pressure vessel. When power is desired the two gases are 'burnt' together using the same approach as is used to produce ammonia commercially. The burning gases produce ammonia and lots of heat, which is used to power a turbine[1]. Both the ammonia and the hydrogen/nitrogen mixture can be stored in the same tank because the ammonia becomes a liquid which can be drawn from the bottom of the tank. This technique has been demonstrated as a prototype and is a very significant step forwards.

The problem with most wind and solar technologies is that they are unpredictable in their power availability. This storage system means that Merredin would be able to produce power on demand rather than only when the sun shines. This means that Merredin could provide electricity for peak demand, which is worth

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[1] In the future the turbine could be replaced with a fuel cell for higher efficiency.

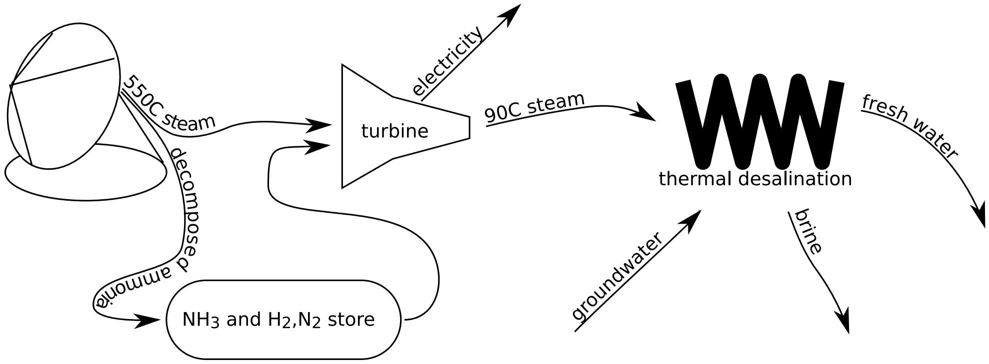

Figure 2.3: A possible system using Solar Oasis dishes, chemical storage and desalination.

a lot more money than at low demand times.

Another technique demonstrated in the US is to store the heat as molten salt in insulated tanks. This approach is simpler to understand and implement, but the heat is harder to maintain compared to the chemical approach.

Inputs:

Sunlight — solar thermal, solar electricity; groundwater.

Outputs:

Electricity on demand Clean water Concentrated brine Waste heat

Advantages:

Solar thermal has distinct advantages in sunny areas such as Merredin. There are many sunny hours each year in Merredin and an average of 20 MJ/m^2 falls upon Merredin each day over the entire year. Solar electricity is renewable and does not generate greenhouse gases - It can provide heat, energy and carbon credits. High grade heat can be stored, and used efficiently for multiple products.

Problems:

Small systems tend to perform poorly due to high surface to volume ratios. Thus a trial plant will tend to be expensive.

2.5 Greenhouse evaporation

Greenhouse evaporation takes place in a double walled greenhouse. The principles involved are similar to an evaporative cooler. A simple heat exchange across the

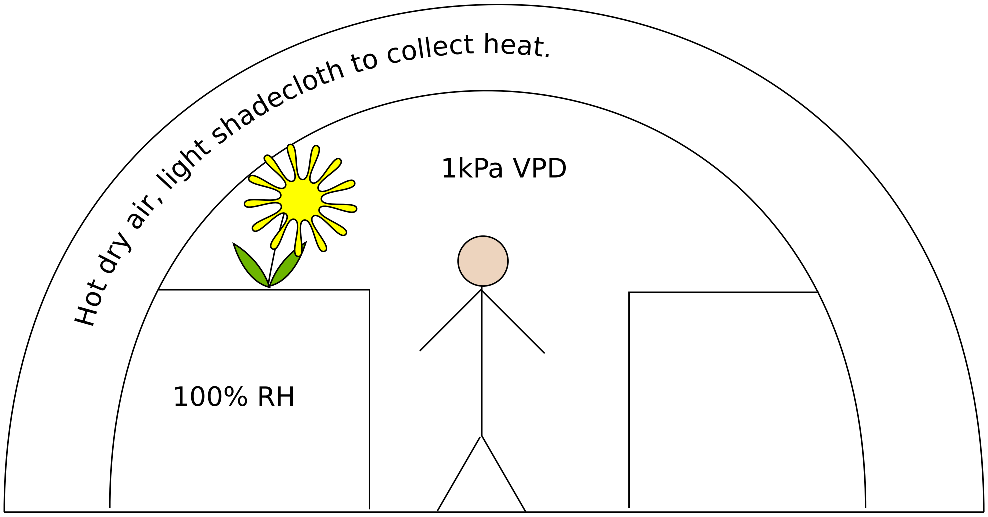

Figure 2.4: A cross section through a greenhouse aeroponic system

inner shell of the greenhouse also provides further warmth to the greenhouse.

Dry air is pulled in through the gap between the inner and outer shells of the greenhouse. During the day, it gains energy from the sun and heats up as it moves along the outer layer greenhouse. Some of this heat is transferred through the inner shell of the greenhouse, warming it up. Fans blow the air through large evaporative pads[2] into the inner area of the greenhouse. The pads are fed saline water to evaporate in pads such as those used in household or industrial evaporative coolers.

The air, now full of moisture, provides an environment suitable plants to grow. If the air can be maintained at 100% humidity around plant roots, plants will grow without soil. This is known as aeroponics or airponics. Misters can be used to deliver nutrients directly to the plants' roots. The temperature can be maintained by changing the rate of evaporation and shading the greenhouse as necessary.

The limiting factor in greenhouses in Merredin is most likely the amount of CO_2 available for plants. The natural concentration of CO_2 in the atmosphere is around 0.4% (and going up, apparently), but in a greenhouse with lots of sun and water commercial growers often have to inject CO_2 because the plants absorb it quickly from the air.

To increase the CO_2 levels in the greenhouse we could instead bring in fresh air. But fresh air is dry (especially in Merredin). Bringing in fresh air requires more water, which drives the use of Merredin's salty groundwater.

subtropical crops: tomatoes; basil; sweet potato/kumera.

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[2] such as CelDeck

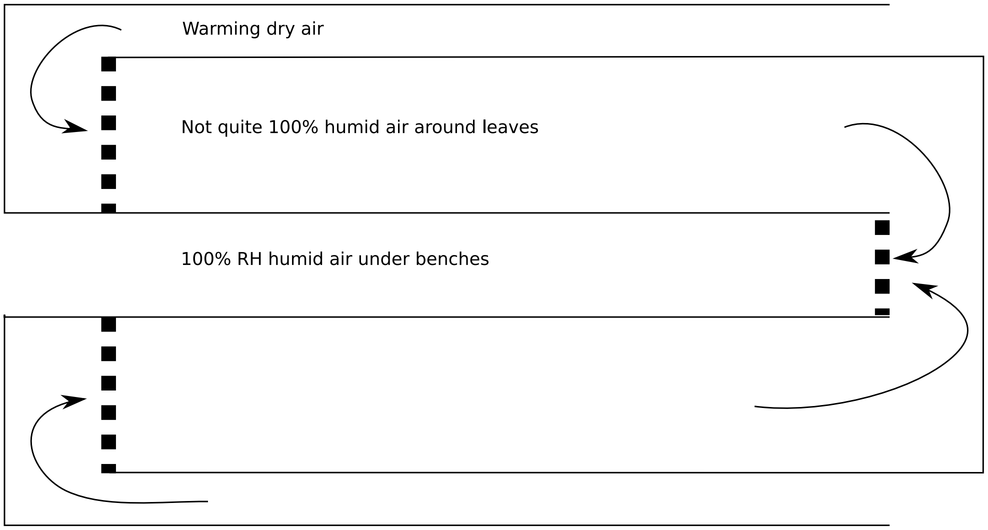

Figure 2.5: A top view of a rough design for a regenerative greenhouse

tropical crops: bananas; ginger; turmeric.

A double walled U-bend greenhouse is preferred as it would be more useful in winter. The double wall acts as a simple heat exchanger and provides extra insulation. A single walled greenhouse is likely to lose too much heat on Merredin's occasional frosty night.

Inputs:

Sunlight; groundwater.

Outputs:

Some water; crops/food.

Advantages:

Uses saline water to grow valuable crops. Very cheap to test.

Problems:

Has not been tested in this format.

2.5.1 Side Benefits:

The condensate on walls can be collected with suitable plastic welded gutters along walls.

The out-going humid air might be a useful input to vapour compression condensation water recovery, or multiple effect humidification (such as that used in commercial units).

Evaporative greenhouse space could be provided to interested parties as allotments for growing fruit and vegetables. Greenhouses could also be used by council to grow revegetation plants. A large scale evaporative greenhouse over an amphitheatre, stadium or park could be used to provide a cool environment in summer.

2.6 Wind and wind power

The wind brings several things to Merredin most relevant are kinetic energy and dry, warm, fresh air.

Kinetic or motion energy is the force that air can push on turbine blade. This is used to turn wind pumps (wind mills) that pump water out of the ground. It might be feasible to use wind pumps to push water out to a suitable salt lake.

Although not directly in the scope of this report, at the council meeting we discussed using wind and solar pumps to extract salt water under crop land and pipe through polypipe as a replacement for deep drain works. This has the advantage of reducing the impact on crop lands over deep drains, and that salt water can be drawn out from below the freshwater layer all year round, working to replace the salt water table with a fresh water one.

The authors are unaware of any technologies that can direct desalinate water using the kinetic energy of wind. The most likely method would be to use wind power to generate electric power which can then be used to drive a reverse osmosis system. Wind is too unpredictable to directly pump the water for reverse osmosis in large scale, but it is worth considering designing a simple reverse osmosis unit farmers could fit to a conventional wind pump. With large scale manufacture and user replaceable membranes this could help mitigate drought on remote farms.

Wind power could be used to store energy (see subsection energy storage in Solar thermal, above).

Inputs:

Wind; groundwater.

Outputs:

(with desal plant) Water; brine.

Advantages:

Wind technology is old, but reliable and often available.

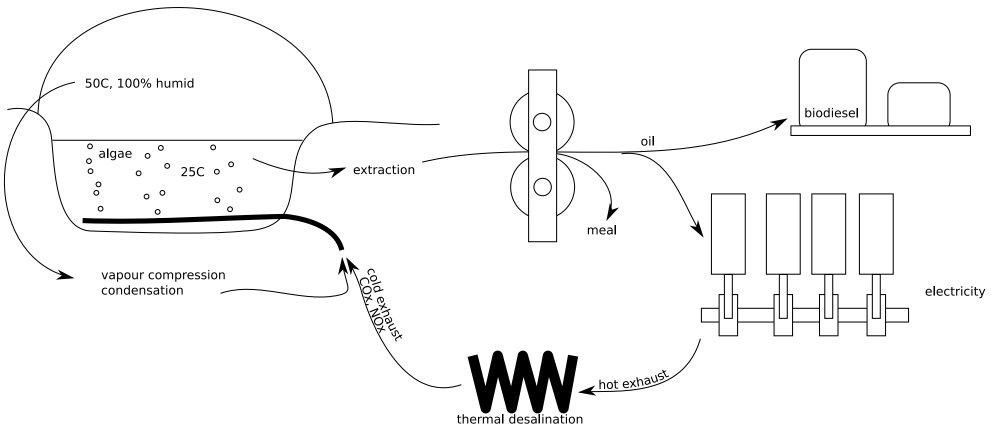

Figure 2.6: A possible system using algae to collect the sun's energy.

Problems:

Wind itself is often unreliable and many desalination plant technologies require a constant supply of energy.

2.7 Algaculture

Growing algae may provide any of the following:

- Chemical energy
- Fertilizer
- Protein rich stock feed
- Human food

Algae are best known from their ability to create toxic blooms in stagnant water or to create unsightly green swimming pools. Algae can be as big as bull kelp — all seaweeds (macroalgae) are algae — or as small as single microorganisms (microalgae). The algae considered here are single celled microorganisms that cause various sorts of algal blooms in water. They are also at the bottom of the food chain — many other aquatic organisms rely on algae for their food. Just like land-based plants, algae require carbon dioxide and sunlight to grow, along with various nutrients.

Over the last 15 or so years, a number of groups have been investigating the use of algae to create biodiesel. Some forms of algae have very high oil levels (up to 40% of the wet weight of algae is oil). Some of these algae also grow in salty water, such as that produced from the Merredin bores.

Algae are found in almost all water (unless it has been treated to kill algae, such as when chlorine is used). Algae will grow in a pond, particularly if suitable fertilizers (nitrates, iron chelates, sulphur and phosphates, storm water runoff, fertiliser runoff, or town sewage) are present. They prefer the same sorts of temperatures that humans do — between about 15 to 35 degrees C, and temperatures around 25 degrees provide best growth.

One of the best species of alga for oil production is *Botryococcus braunii.* A number of laboratories have used this alga in non-commercial biodiesel/algodiesel research. It grows in briny water (such as that under Merredin) and up to 85% of its dry weight is hydrocarbons (fats or oils). Algae require sulphur to grow, so the sulphur in Merredin's water should not provide a problem.

Algae can be skimmed or filtered or centrifuged out of water, dried and then crushed in a press to access 70-75% of the oils. Further processing can access up to 99% of the oil in the algae. The algae and/or oil produced can be burnt directly in some engines, or can be turned into biodiesel. Any meal left over from the extraction of oil is rich in protein and can be used as animal feed (assuming there are no contaminants in the water), fertiliser or burnt for power generation. If the meal was burned, the resulting carbon dioxide gas could be bubbled through the algal ponds and used to grow more algae. Depending on the algae grown, there may be pharmaceuticals/vitamins or dyes that can be extracted.

Inputs:

Groundwater; fertilisers; sunlight.

Outputs:

Algae.

Advantages:

Simple. Relatively low cost with good economic benefits.

Good use of space — the amount of oil harvested each year from one hectare of algae is claimed to be around 90,000L compared to about 1,000L from one hectare under canola each year [8].

Covered algal ponds should be relatively cheap to set up — council has some ponds already and access to greenhouses.

The town already has a private biodiesel production plant. There is great potential for offsetting fuel costs for council owned diesel trucks and provision of biodiesel for local use.

A number of expert groups are looking into "algodiesel" within Australia [7] Also, Prof Steve Halls may be interested [7].

Problems:

Algodiesel is an emerging technology at this stage. It is not yet proven commercially and no fully implemented commercial plants exist. As it is still in the experimental stage, there may be research funding available (a plus, not a minus).

We query how much water would be evaporated from the ponds as they would be under greenhouses. This may be avoided simply by ensuring a consistent airflow through the greenhouses. Alternatively, we can combine solar ponds, algal ponds and vapour compression condensation together to supplement each technologies' shortcomings.

Temperature — algae are very likely to die in the warmest water that is pumped from under Merredin. This could be avoided by mixing colder bore water with the warmer water.

Since algae grow so quickly in ideal conditions, they can use up all the available oxygen in the water, causing them to die off and also create immense stenches as the algae break down. This can easily be avoided by: a) keeping the water aerated and moving — most algal ponds are joined together in a "raceway" and use water wheels such as those used in irrigation to keep water churned up and moving between ponds b) harvesting the algae when they reach optimum levels before they die.

All sorts of algae are found "in the wild." Wild algae can contaminate those that produce more oil. To reduce contamination of the algae that produce the most oil, most facilities use greenhouses. Greenhouses also keep the algal farm at a more optimum temperature for fastest growth.

Side benefits:

Possible way to reduce sewage and storm water outfall, and reduce fertilisers in local waterways. May combine with biodiesel fueled generator — CO_2 and NOx gases from exhaust will help grow more algae. May also provide stock feed, fertiliser, pharmaceuticals, dyes.

Ideally the whole system would be mostly closed, burning some mixture of algodiesel, straight algo-oil and ground up alga in a diesel engine, the exhaust gasses would be bubbled back through the ponds to encourage algal growth and the extra biomass, now with added nitrogen, could be sold as a fertiliser or stock-feed. The heat from the exhaust might be used for desalination, or just to heat the water with the algae. By closing the loop we can claim the system is carbon sequestering and may be a new way to solve the greenhouse/climate change problem.

2.8 Magneto-Chemical precipitation

This is a new technique whereby suitably coated magnetic particles react with solutes such as salts and heavy metals. The magnetic particles flocculate and fall out of the solution or can be gathered using magnets, and are treated chemically for reuse. The technique is not yet widely used but has a wide range of possible

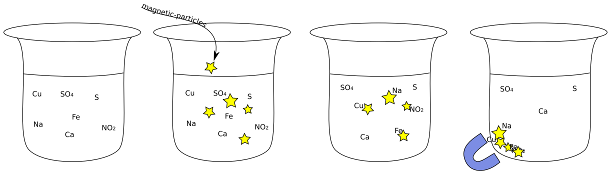

Figure 2.7: Extracting selected ions by magneto-chemical precipitation.

applications including waste water clean up and desalination. The available technologies appear to be commercial systems undergoing trials. The magnetic particles can be tuned to extract a specific set of ions, perhaps as a cheap preprocessing step to osmosis, or to adjust the salt balance for fish culture. It may even be practical for direct desalination.

Inputs:

Groundwater.

Outputs:

Clean water; Solutes.

Advantages:

Provides clean water.

Problems:

very experimental, can find no information demonstrating use to desalinate water at this stage.

Further reading: `http://www.woodardcurran.com/Newsletters/DAID/31/SA_ID/`

2.9 Evaporation ponds

An open evaporation pond is probably the cheapest option, but requires large areas, can cause ground water pollution unless carefully designed and is rather unpredictable in the amount of water evaporated. Depending on the temperatures and air conditions, it can take some time (months to years) to completely dry out an evaporation pond.

One concern with the existing evaporation basin results is the fact that the leakage was measured at 3mm/day. 3mm over 1 hectare is 30kL — comparable to the amount being dumped.

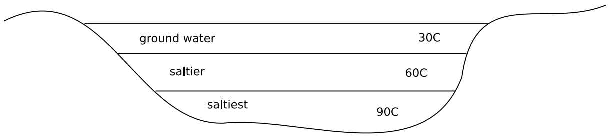

Figure 2.8: A solar pond showing the layers.

Inputs:

Groundwater; Sunlight.

Outputs:

Dirty salt.

Advantages:

Cheap; Can grow algae[3].

Problems:

No economic advantage to evaporating water this way. Does not "seem to be doing anything" to alleviate problem — you can't see water evaporating. Must be constructed properly so that water does not seep into subsoil under pond. Possible slow evaporation rate. Large areas of shallow ponds required.

Enhancements:

Cover with a wind speed increaser (possibly a giant airfoil) which could also divert rain. Line dam with polyliner to reduce loss of salty water into ground if correct soil not used for construction. Increase evaporation by increasing surface area using agitation, spraying or aeration (could be ornamental in effect).

2.10 Solar ponds

The groundwater could be used to make solar ponds. Solar ponds are a simple and effective way to capture the sun's heat and store in water. Very salty water is dense and sits at the bottom of the pond. Because it is dense it doesn't rise when it is hotter than the fresher water above, stopping convection. Because of this, it is able to trap a lot of heat. The change in amount of salt results from an inversion layer where dense hot salty water is trapped under less hot, less salty water.

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[3] note that the Merredin desal project brochure pictures shows algal growth.

A well designed solar pond is about 90C at the bottom and 30C at the top. The heat in the pond drives evaporation and the concentration of the water. The pond can be topped up with bore water.

The hot water at the bottom is very salty, but with a suitable heat exchanger (perhaps some black ag-pipe laid on the bottom) this heat can be used to power any of the thermal desalination processes.

One possible configuration would float the incoming groundwater on the surface of the pond. Some water would evaporated. Other water would be thermally desalinated, perhaps using a TiNOX-like system, or vapour-compression using the heat extracted from the bottom layer. The more concentrated salt solution would then be inserted into the next layer where it would heat up again. This layer would be then further desalinated and the final concentrated brine would be either inserted at the base of the solar pond, or flushed to an evaporation pond/salt lake, or inserted under the groundwater.

Inputs:

Groundwater. Sunlight.

Outputs:

Possible heat for use with other technologies. Concentrated brine.

Advantages:

Should be more effective at evaporating water than evaporation ponds. Cheap source of medium grade heat — the cheapest collection technique per m^2. Potentially very low cost desalination process.

Disadvantages:

No economic benefit unless heat can be used for driving other desalination processes or electricity production. The pond can't be used for algae or fish at the same time.

Side benefits:

Heat can be used to provide low grade heat for electricity production.

Enhancements:

As for evaporation ponds.

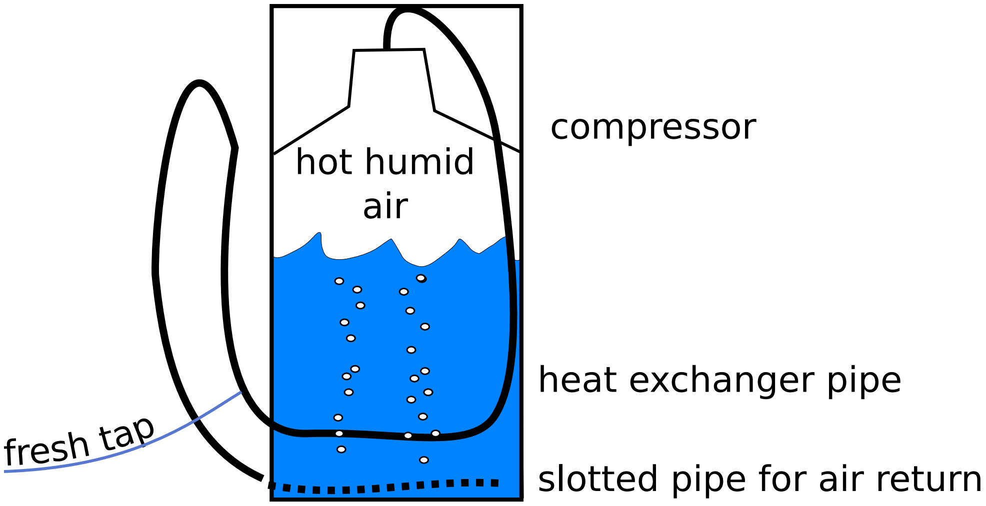

Figure 2.9: The basic structure of vapour compression. The water could be in a large evaporating pond with greenhouse or a small metal tank.

2.11 Vapour compression condensation

Vapour compression condensation is in effect a form of distillation[1]. At any given temperature, air can only hold so much water vapour[4]. For example at around 25C, air can only hold 2% water (this means the air is fully saturated, it is very humid and it is very probably raining). When air is compressed ("vapour compression") at 25C, it is not able to hold as much water. Any excess water stops being a gas and becomes liquid water again — it condenses out. A side benefit is when water condenses, it gives off heat (see Chapter B.5). Also when air is compressed, it heats up (as you may have noticed if you use a hand pump to pump up your bike tyres — the pump gets hot).

The compression required is modest (say 25kPa) and can be achieved with a basic blower, perhaps one used in grain handling. Salt water can be heated up by a solar pond or other low grade energy such as within a greenhouse. Higher temperatures mean more water evaporates per cubic metre of air reducing the amount of air moved. The warm, humid air can be drawn into a compressor and pumped under pressure into a heat exchanger. The warm moist air under pressure gives up some of its water, now distilled, and also releases heat.

The heat exchanger might be an array of 10cm diameter unslotted ag pipe under the solar pool or an adjacent algal pool, then perhaps finally being wrapped around the cooler incoming salty water. This would give up its heat to the incoming water, helping to keep energy within the system. The compressor

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[4] technically, for a given temperature the water vapour partial pressure is constant, any excess is more stable as a liquid

can be driven by the mains or by solar power.

Once we have cooled the air down and extracted the water vapour we can re-inject the air into the heating pond, perhaps using another array of (this time) slotted ag pipe. By blowing bubbles through the water we increase the surface area dramatically and recover almost all the heat from the air.

The energy comes from both the sun heating the water, and also from energy powering the compressor. This approach works under a wide range of operating conditions and is very simple to make.

Inputs:

Groundwater; Solar or mains power.

Outputs:

Water; Brine.

Advantages:

Provides environment that can be combined with other systems for economic advantage. Relatively self-contained. Simple design, simple to understand. This warm, agitated environment would be good for growing algae, and if the system is covered, we can inject exhaust from a diesel generator. This system can thus be combined well with the algodiesel system, and also could take air from the evaporative greenhouse project.

Disadvantages:

Requires power to run. Takes more space than other approaches — less efficient use of the sun's light. Needs to be built from scratch — no known commercial units available (but may provide economic benefit for town industry)

2.12 Reduce groundwater recharge

In discussions with Council, little interest was displayed in this option (perhaps due to the perception that it would 'not appear to be doing something').

A number of options for reducing groundwater recharge are listed here in case any do appeal to Council:

- smarter pricing on town water — value town water at a more realistic economic price, helps conserve water
- encourage wide-scale rainwater collection, including storm water (which will reduce recharge into groundwater)

- surface water and subsurface water reduction by restoring indigenous species particularly along waterways (reduce recharge, also may be tourist attraction, some trees such as the indigenous Merrit tree pump about 600L of water a day into the atmosphere so 100 mature trees would help reduce groundwater levels).
- irrigation of suitable trees with town subsurface water. Such trees could be used for wood production, etc.
- sell salty water — are there materials of economic value in the water, particularly if concentrated?
- appropriate use of water restrictions (e.g. no watering in winter, when Merredin gets most of its rain = groundwater recharging)
- contour drains put in to recharge areas to catch surface run-off. The downslope side of the drain could be planted out with economically useful plants producing oil, wood or flowers such as oil eucalypti or scarlet banksias (David Morley has a great deal of knowledge about this). Also helps remediate salt scalding in paddocks.

2.13 Dilute

Merredin has a consistent source of fresh water. Salt water can be diluted with processed waste water and town water to level suitable for salt tolerant crops such as barley, warragul greens, salt bush, samphire, cotula or used to water parkland in summer (as is already occurring).

Inputs:

Groundwater; Potable water

Outputs:

Irrigation water.

Advantages:

Cheap.

Disadvantages:

May help increase groundwater recharge. Politically does not appear to be doing much with the water: Is this a wise use of a limited freshwater resource? Tends to move salt to the surface.

2.14 Disposal of brine

Any desalination technology outputs concentrated brine. What can be done with the brine?

The chemical components of the brine may be of use to industry, depending on the concentrations present. However under the current economic conditions, it is unlikely that the brine could be sold.

Can the brine be piped out to a salt lake? Will it disturb the ecology of the lake or contravene legislation? This would be a fairly cheap option but is possibly not environmentally friendly.

Solar heat above 120C is adequate to dry the brine to pure salt, which is easier to transport or sell.

A possible place to put the salty brine is in fact back under the town (or at least back under the evaporation/solar ponds). This is not as silly as it sounds as that is where the salt came from in the first place. The idea is to put the salt back down in concentrated form as low in the ground as possible. Because the salt water is more dense it will sit below the less salty water. Determining the chance of remixing should be done by a hydrologist, but because of the reduced volume and different density, this salt layer should be quite stable. It is unlikely to contaminate the groundwater as this is at a much higher level in the soil. This is likely to be the cheapest way to dispose of concentrate, but could be a contravention of legislation or best practice disposal.

2.15 Is there a problem?

Finally, we must ask how confident we are that there is a problem. The cheapest solution today is to do nothing. Can we accurately measure the future cost of repair to town infrastructure? Will there be better technologies that desalinate water more cheaply in 10 years?

Technology	Cost	Works?	Politically feasible	Economically feasible	Economic outputs	Description and notes
Evaporation ponds	\$/\$\$	Y	N	N		No outputs, no economic or political advantage
Solar Updraft Tower	\$\$\$\$	Y	N	?	E	Large amount of land needed, high cost, creates large amounts of electricity
Energy tower	\$\$\$\$	?Y	N	?	O	Untried technology, similar feasibility problems to solar updraft tower
Solar thermal — multiple versions, practicality and viability depend on type used and form of desalinisation preferred						
Solar ponds	\$	Y	Y	Y	H	A source of medium grade heat. Cheapest per m^2
Evacuated tubes	\$/\$\$	Y	Y	?	H	low grade steam produced, not useful for generating electricity
Parabolic trough	\$\$	Y	Y	Y	H	medium grade steam produced, could preheat steam for electricity generation
Solar oasis (dish)	\$\$\$	Y	Y	Y	H	High grade heat useful for electricity production, tourist potential
Co-generation	\$	Y	Y	Y	H	Use of waste heat from solar thermal for heating of greenhouse
Solar/thermal energy storage	\$\$\$	Y	Y	Y?	O	Commercially available, high set up cost. Stores energy as nitrogen and hydrogen
Greenhouse approaches						
Greenhouse specific	\$/\$\$	?	Y	Y	O	Grow economically useful crops (e.g. tomatoes, bananas, basil). Query on how much water can be evaporated.
Greenhouse condensate	\$	?	Y	Y	W	Collect condensed water using gutters on walls. “Freebie.” Dependant on greenhouse
Regeneration	\$\$	?	Y	Y	O	Greenhouse in greenhouse with heat exchanger to conserve heat
Desalination technologies						
Forward Osmosis	\$\$	Y	Y	Y	O	No external energy input necessary, useful for industry/agriculture
TiNOX desalination	\$\$\$	Y	Y	Y?	WH	Low temperature commercial desalinator, query on economic viability due to high setup cost
Vapour compression condensation	\$	Y	Y	Y	W	Can be combined with other technologies to enhanced effect
Magneto-chemical precipitation	\$\$\$	?	Y	Y	W	Unproven on the large scale. Can be combined with other technologies to enhanced effect
Aquaculture						
Algal culture	\$/\$\$	Y	Y	?Y	O	Algae could reduce pollution and be a source of oil for diesel, fertiliser and food/pharmaceuticals depending on the type of algae grown
Fish culture	\$/\$\$	Y	Y	?Y	O	Fish can be fed algae to produce saleable product
Dilute saline water	\$\$	Y	N	?		For irrigation. Greater use of potable water, not politically sound strategy
Air cooling and evaporation tower	\$	?Y	Y	Y	O	Provides cheap cooling power in summer whilst removing ground water. May be affected by ground water odour.
Pipeline to Bandee Lakes	\$\$/\$\$\$	?Y	?N	N		Likely to be politically unwise. Would this clear environmental hurdles?
Layer under town	\$	Y	?	Y		Brine sits below freshwater. Bore hole puts concentrated salty water on bedrock.
Is there a problem?	0	?	X	?		Will technology in 10 years use salty water more effectively?

Cost for pilot	\$: <\$10,000	\$\$: \$10,000 — <\$100,000	\$\$\$: \$100,000 — <\$1,000,000	\$\$\$\$: >\$1,000,000

?: questionable	N: no	Y: yes/good/OK	W: water	E: electricity	H: heat	O: other

Chapter 3

Recommendations

There are a range of activities that Council may wish to put in place to test some of the alternatives offered in this report.

Recommended strategies are:

3.1 Determine where the water is coming from.

We are not convinced that the true source of the water has been correctly identified. Glen Riethmuller at the Department of Agriculture is interested in looking at the winter vs summer infiltration rate of lawn and garden irrigation.

David Morley is concerned about water sitting in the Cohn drain. One suggestion was to run a 100mm dia low pressure pipe from the weir at the top of the drain to a point over the subterranian dyke.

David Morley also has demonstrated restoration of salt affected crop lands by using gently sloping contour drains that divert the water away from scalds. This approach could be combined with oil mallees or local species behind the swale for an extra cash crop.

The council lake is in one of the highest water table areas, and the lawn is suffering from too much salt. Determine whether the lawns are being over irrigated (Especially in winter). Check whether the lake has become too salty (killing the trees on the island), consider lining the lake. Extraction border under lake.

3.2 Develop solar thermal technology

The cheapest solar thermal technology is the solar pond, which can be tested with equipment already available in town — use one of the evaporation basins as a solar pond. Use an old CBH tarp as a liner (a few holes aren't a big deal). Fill the bottom layer using the brine from the road works desalination unit.

Then carefully add groundwater over the top. Record the temperature over a month. Trial using ag pipe to extract the heat.

Open dialogue with TiNOX and determine whether ground water would be suitable for their unit.

If plausible, order a mini-sal TiNOX desalination unit (€14109 + shipping) and trial with solar pond.

Open dialogue with Wizard Power (Artur Zawadski). Give him solar data from Dept. of Ag(19.4)MJ/m^2) and BOM(20.1MJ/m^2).

If plausible, order a 'solar oasis' dish, set up a trial plant in the north end of the council park — desalinate bore water for lake and sell electricity. Put up signs explaining process, lots of meters showing solar rate; electricity generation rate, total, council energy usage; water desalination rate, total water desalinated.

This option is perhaps the most sensitive to the state, federal and worldwide political climate and with the recent rapid changes in federal government position on climate change, and the potential to introduce carbon credit trading, this technology may be the best long term investment.

3.3 Develop algae culture experience

We don't know what sorts of algae are best grown in town water. Set up a trial of algae to see what will grow locally in Merredin's bore water. Arrange for high school students to experiment with half barrels to see what can be grown and how. Vary the ground water, fertilizers, minerals, exhaust solubility and effects. Prototype extraction processes to get local knowledge about algae.

Look at co-generation using biodiesel, canola oil and eventually pressed algal oil with the high school mechanics students.

3.4 Combine technologies

Many technologies work well together. Algae production can provide a way to clean co-generation exhaust, produce stock feed and could be used in conjunction with vapour compression condensation and solar ponds.

Once we know how two technologies work separately, consider the problems with each and look at coupling them. This is how complex biological systems work, and these are generally far more efficient and cheaper than mechanical processes.

3.5 Trial aeroponics

There is rumoured to be a shed with 40 sets of frames and films for tunnel-style greenhouses. Set up a trial system somewhere convenient. Determine how much water can be evaporated, which crops can grow, how salty the waste can be. There would be no need to install a pipeline for this — to start with just truck the ground water to the site.

Find locals interested in greenhouse allotments.

Consider employing horticulturist to develop efficient propagation of local species for commercial development, offer them for sale to tourists, provide local plants for revegetation of waterways, rehabilitation of council land, offer all residents 5 free plants, etc.

3.6 Economy

Look at creating a salt water economic — sell the water to interested parties at negative cost (determined based on the cost of disposal). There may be small scale entrepreneurs who have uses for small quantities (say 1kL/day). Enough of these and you no longer have a problem.

Offer Master's or PhD scholarships to look at the efficiency/effectiveness of each project. Steve Halls at Murdock university is interested in algae for fuel and may be interested in supervising and directing research work in town.

3.7 Other paths

Consider using forward osmosis with Pivot for solid to liquid fertilizer production.

Plant more trees?

Appendix A

Groundwater recharge

In the simplest terms, Merredin's groundwater is rising because more water is entering the ground than is leaving it. The water is salty because the ground has salt in it and the rising groundwater dissolves the salt. There are not enough large trees, shrubs, grasses and other deep rooted plants in open areas to stop rainwater recharging the groundwater. Since the township of Merredin is in the bottom of a large basin and water flows downhill, the groundwater flows to the bottom of the bowl and starts filling it up.

The most obvious way to reduce the problem in the long term is to reduce groundwater recharge. Identifying the sources of groundwater recharge and remediating these should reduce the problem but may not alleviate the problem entirely. Is the groundwater recharge happening in agricultural land around the town? Is it happening within the town itself, from townspeople over-watering gardens or over-irrigation of council facilities, or is it infiltrating from Cohn Creek, which tends to accumulate water and may well not be watertight?

However this may not be politically expedient as it requires changes to the way water is managed in Merredin and also may not actually work. Council would prefer to take the water that is there and use it for economic and social advantage.

Appendix B

The science of moving water and desalination

B.1 Energy and Power

Energy and power are often confused, in part because the terms are used interchangeably in everyday life. We talk about using a lot of power to heat the house, and describe vivacious people as full of energy.

Energy is a quantity of work. Lifting a bag of groceries onto the bench requires the same amount of energy whether we lift it quickly or slowly. Energy gets used up.

Power is the rate of use of energy. Lifting your groceries quickly requires more power than if you did it slowly. Power doesn't get used up.

A reasonable way to think about energy and power is by comparison to travelling. If you think of the distance from Merredin to Perth as like energy, then the speed you drive is like power. Driving faster will get you to Perth quicker, but no matter how fast or slow you drive, it's always 250km.

B.2 Moving water

Water is fairly convenient to handle, being non-toxic. Many people are familiar with pumping and moving water and widely in an agricultural setting. However, moving water is costly. We can work out how much energy is required to move water with some simple physics:

We will assume that one litre of water has a mass of one kilogram. This is only a rough estimate, but is good enough in practice.

If we stuck a pipe in a dam and tried to pump the water out from the top we would find that if the tube rose more than 10m vertically, no water would be drawn out, no matter how powerful the pump. This is because the water is not 'sucked up', but rather, the water is pushed up the pipe by the earth's air pushing down on the dam. A column of water 10 meters high corresponds to a pressure of 1 atmosphere. Lifting a kilogram of water one metre requires 10J of energy. Lifting 600tonnes of water 50m takes 300MJ or 3.5kW continuously for day.

Pushing water through a pipe creates a back pressure due to friction with the pipe. Large diameter pipes have less friction for a given flow rate. Because water at a height always corresponds to a pressure, we call this height *'head'*. We can work out how much head is required to push water through a pipe using a formula such as presented on this website: `http://www.efunda.com/formulae/fluids/calc_pipe_friction.cfm`

From that we can find that for a 10cm diameter polypipe lying on flat, level ground and we want to push water through at 1m/s over a km we need to put in as much power as lifting the water 9m at 1m/s. Similarly, pushing water through 500km of 760mm steel pipe up 340m of elevation, as in the Golden Pipeline, might take 735m of total head.

B.3 Osmotic pressure

In the same way that pushing water through a pipe can be considered the same as lifting it up a given height, salt dissolved in water creates a pressure compared to fresh water. We don't normally notice this pressure, but it is very important biologically. We call this pressure the "osmotic pressure" of the fluid and we can measure it by putting the salty water on one side of a membrane and the fresh water on the other side and measuring the pressure differential between the two. The formula for osmotic pressure is very simple: MRT, where

M is the concentration of the salt, R is a special fixed number, and T is the temperature in kelvin (degrees C above absolute zero where) degrees C is 273 Kelvins).

The Merredin bore water has an M of approximately $0.55 mol/L$ and T is between $280K$ and $330K$ (7 to 57 degrees C). R is always 8.31. This gives an osmotic pressure of between $1.3MPa$ and $1.5MPa$. This is equivalent to pumping a column of water up 130 to 150m.

This gives us a lower bound on the amount of energy we must use to remove the salt from water. To remove half the water from the salt solution we would double the amount of salt in the remaining portion requiring an equivalent amount of energy to pumping that water up 150m. This is 900MJ/day for our estimate of 600kL a day, or equivalent to 10kW continuous. This is a lower physical bound — we can't beat this but in practice we will need considerably more energy to overcome friction in the membrane and other losses.

The 2004 report[5] gave an energy cost (upper bound) of 2.8kW continuous to desalinate 10kL/day or an energy efficiency of $170W/2.8kW = 6\%$. This is comparable to the current state of the art of reverse osmosis technology. The pressure required to drive the water through the membrane was in fact 4.2MPa (or enough power to pump water up 420m).

B.4 Forward osmosis

It is tempting to ask whether we could avoid this huge energy cost by putting an even more concentrated solution on the 'fresh' side of the membrane. This might seem counter productive, but if the stronger salt were harmless for our needs, or if we could separate it out easily afterwards this might work. This is called forward osmosis.

It turns out that this idea has been tested in both ways - self-hydrating water packs have been used by the military for producing fresh water from potentially contaminated water. The pack contains a sugar and a membrane. The water flows in to form a sweet drink.

The second idea is to use a highly soluble gas (carbon dioxide and ammonia gas in a mixture) which can be separated out by heating the water. Unlike solids, gas become less soluble as the liquid is heated. This heat might be provided by direct solar power or the heat collected by evacuated tubes, as it is fairly dilute.

B.5 Distillation

An old technique for desalinating water is the still. In this process the osmotic pressure is overcome by heating the water to increase the vapour pressure.

Every substance forms a natural equilibrium between the substance in solid, liquid and gas forms. At 0C water at atmospheric pressure tends to favour the solid form (ice), at 100C the gas form. Between 0 and 100C at normal atmospheric pressure, water tends to be found in its liquid form. Adding salt to the water means that it freezes at a lower temperature. Boil a pot at 4000m and suddenly your hot cup of tea is not so hot.

When we add salt we move this balance just like with a membrane (and because there ain't no such things as a free lunch, we cannot do any better or worse theoretically). If we put fresh water and salty water in an air tight box and left them for a long time some of the water will move from the fresh water to the salty water, diluting it. This is the reason that sugar you spilt on the floor yesterday is sticky today — sugar pulls water from the atmosphere and it has turned from sugar into sugar syrup on the floor by drying out your air.

Theoretically, we cannot do any better energy-wise removing salt by distillation than via reverse osmosis. However, reverse osmosis is not very efficient, as we have seen. Nor is distillation, but there is a lot of room for improvement in both technologies and which you use depends very much on things like how much energy costs, what forms of energy are available and how important you think it is to avoid burning fossils.

Distillation has another significant catch — heat. Water is an amazing substance and can store a tremendous amount of heat. To heat 250g (a cup) of water 1 degree takes about 1kJ. To heat that cup of water from 15C tap temperature to 99C boiling water takes 87kJ, equivalent to lifting that water 35 km into the air! This is called the specific heat or heat capacity.

But that is not the really energy intensive bit! The bad bit is that to boil water takes 500 times as much energy as heating it 1 degree. This explains why it takes a little longer for a kettle to boil dry that it does to almost boil. If it takes a minute to heat the water from 15C to 99C, it will take 6.5 minutes more to boil dry. This heat is called the latent heat of evaporation.

Luckily, when the water condenses again it gives back that heat. This is how the cafe heats the milk for your cappuccino: the machine heats the water to around 150C. If the water stayed liquid, adding 15mL of hot water would heat the 100mL of 4C milk to 23C (room temperature). But because the water is turned to steam inside the machine, and condenses back in the milk, giving off all the energy needed to turn water into steam, the milk gets heated to 90C.

If we could recover all the latent heat, and all the specific heat we would only need to provide the osmotic pressure energy to desalinate the water. This means we would only need to find 900MJ of heat to add to the process (refer to section B.3).

B.6 The sun

The sun is a giant nuclear reactor giving us vast amounts of energy. If you go out into the sun in January you'll probably get around 1kW of light per square meter. That means an average person lying in the sun is getting the equivalent of a 1 bar heater pointing directly at their skin.

Of course in winter there is less sun and at night there isn't any sun at all. We can correct for this by working out the average energy available each day over the whole year. For Merredin this works out to be $20MJ/m^2day$.

So if we had a perfect distillation plant that required 900MJ / day to desalinate half the town salt water we would need only $90m^2$ collection area — about the area of a 3 car garage. In practice we can't do this. Instead the efficiency of solar thermal desalination plants is measured in the number of (re)uses of latent heat required to boil the water. In other words, the efficiency of solar thermal desalination is measured by how many times we can reuse the latent heat in the steam to boil more water, and what losses of heat we would expect.

Say a solar thermal desal plant that simply boiled the water away, and condensed it again, without recovering any of the heat. Not recovering any heat mean the plant uses 15MW continuous over a day and has a heat loss of 100%. It would be given a reuse rating of 1 (100% loss of energy).

In New Mexico and Southern California various solar desalination plants have been built and the general conclusion was that a practical value for reuse was around about 8 (ie 1/8th of the heat is lost every time you reuse it, or that you can reuse the heat 8 times before you lose all of it). This means that a direct solar thermal desalination plant using 'multiple effect flash distillation' would require around about 2MW continuous, or 1.7 hectares of solar collectors given Merredin's solar energy budget.

Note that this would only extract half the water from the ground water. If we wanted to recover 75% we can work out how much energy is required to extract half the water from salty half. This would involve doubling the osmotic pressure change from our earlier example, but at the same time halve the amount of water — we would need another 2MW to extract 75% of the water. Similarly another 2MW would get us another 12.5% for a total of 87.5% recovery. You can see that we rapidly get diminishing returns for our effort.

This is why salt lakes often still have a pool of water in the middle - it takes so much energy to suck that last bit of water out that even in a desert it rains often enough to keep things topped up.

Appendix C

Further Reading:

C.1 Biodiesel

http://www.unh.edu/p2/biodiesel/article_alge.html http://www.onlineopinion.com.au/view.asp?article=3896 http://www.castoroil.in/reference/plant_oils/uses/fuel/sources/algae/biodiesel_algae.html http://wwwscieng.murdoch.edu.au/centres/algae/BEAM-Net/BEAM-Appl0.htm https://tele.engr.usu.edu/biophotonics_Spring_2006/Modules/Presentations/Edwards_final_Paper.doc http://en.wikipedia.org/wiki/Algaculture http://forums.biodieselnow.com/forum.asp?FORUM_ID=71 http://en.wikipedia.org/wiki/Biodiesel http://www.unh.edu/p2/biodiesel/article_alge.html http://www.biodiesel.co.uk/levington.htm

C.2 Magneto-Chemical precipitation

http://www.woodardcurran.com/Newsletters/DAID/31/SA_ID/

Appendix D

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