Australia – Wet or Dry: technical approaches to water supply in a highly variable climatic and geographic regime

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1. Introduction

This paper argues that the developments in water technology over the last 30 years have been substantial, and that there is much more to come. However, the major issues confronting planners and designers in management, that is, the socio-political and economic domains of water technology, cannot be ignored.

We present some details about the Australian water environment, issues of water shortage, and related technology.

1a. Australia – Wet or Dry?

Australia is a land of geographic and temporal contrasts in its water resources.

- Australia is described as a land of "droughts and flooding rains" in Dorothea Mackellar's poem, "My Country", written in 1918.
- Australia is described as the driest continent outside of Antarctica (Bureau of Meteorology, 2010)
- 1969. Davidson's book "*Australia, wet or dry? : the physical and economic limits to the expansion of irrigation*" was written in a period when the Snowy Mountains Scheme was delivering great benefit to communities in the Murray-Darling Basin, a period of generally good rainfall, with some local drought areas in SE Australia, and a time of a booming agricultural sector.
- 1995-2007. Australia was in an intense period of drought or series of droughts (Bureau of Meteorology, 2010). Every major city in Australia except Darwin was on water restrictions. Some major country towns ran out of water for domestic use.
- 2010. Debate over what constitutes a sustainable population in Australia. The debate was related to climate and sustainability and became a (small?) election issue (Dick Smith, 2010)
- 2010. Release of the Draft Murray-Darling Basin Plan (Murray-Darling Basin Authority, 2010), which proposes cuts of up to 37% or more of water allocation to agriculture. Already there are outcries from the Agricultural community, threatening massive economic damage, significant rises in food prices, and Australia shifting to a net importer of food. The present release is described as a Guide to facilitate discussion before the plan is finalised.

BUT

No place in Australia has an average rainfall below 150mm in a year. Compare this with some cities in Chile and Peru, eg. Arica with average rainfall of 0.76mm and population >190,000).

1b. Is there a water shortage?

In Australia, and elsewhere, we are constantly reminded of a shortage of water and the problems that this creates (Wolf et al, 2003). However, another perspective is that,

- 80% of the planet is covered in water
- More than 90% of Australians live within 100km of the coast
- The major areas of runoff are in Northern Australia, an area of sparse population and climatic extremes (National Water Commission, 2007)

When "water shortages" are discussed it is usually in terms of the quality of water required by the user. However, not all users are equal in their water quality demands.

We are highly reliant on rainfall because:

- It is generally of high quality
- It gets delivered cheaply (sometimes in the form of rivers and groundwater)
- However,
    - We generally have no control on its delivery
    - We have to store it or rely on natural storage systems

1c. Four dimensional water opportunity space

There are four critical issues in the discussion of water resource management and technology, namely:

1. Water quantity
2. Water quality
3. Reliability of supply
4. Delivery to the point of use

These four issues define a four-dimensional space for reviewing the opportunities for technological applications in developing water resources.

Some examples from Australia:

1. Kalgoorlie water supply. The goldfields of Kalgoorlie in the 1870-1890's rapidly depleted local water supplies. In 1896 (completed in 1903) the then longest freshwater water supply pipeline in the world was constructed to bring water from Mundaring Weir on the Darling Scarp 530km to Kalgoorlie, with 8 pumping stations and 2 small holding dams. The pipeline, although upgraded, still supplies over 100,000 people in Kalgoorlie (Evans and West, 2007). In today's value, the Kalgoorlie pipeline was a several billion-dollar project. The criticism of the project drove the chief engineer to suicide. At $1300 per ounce for gold there are few who today would not say that the project was visionary and worthwhile.
2. Serious drought in Australia resulted in the construction of a number of desalination plants in Australian capital cities in the period 2000-2009 (El Saliby et al., 2009). Commissioning of

the Sydney plant in 2009-2010 occurred during a period of substantial rainfall and when water restrictions in Sydney were reduced. The cost of the water from desalination is approximately twice that from the current reservoir based system. There was considerable community protest over the need for the desalination plant. The plant has a capacity of 250,000m^3 per day, will supply 15% of present need, and its power demand is offset by 67 wind turbines, located at Bungendore, some 150km from the desalination plant at Botany Bay. It cost $AUD1.9 billion to build, plus the cost of the wind turbines, which were privately built with a guarantee of the purchase of the power produced. It is interesting to note that, apart from the desalinisation plant, Sydney Water claims that recycling will meet 12% of Sydney's water needs by 2015 and water efficiency will save 24% of water needs by 2015 (NSW Office of the Premier, 2010).

The four water technology issues of quantity, quality, reliability and delivery define a four-dimensional space within which specific water users have domains of opportunity. Technology widens those domains. An obvious example is an urban area near a coast. The technology of desalinisation increases the reliability, quality, quantity and delivery of water for the urban area. However, technology always comes at a cost, not simply economic but also environmental and social. Water is not a free commodity.

The domains of opportunity are determined by water demand, which is subject to technological, social, economic and cultural change. Cattle can tolerate water quality less acceptable to humans, and fish obviously have a completely different water domain to terrestrial animals. Humans can become accustomed to drinking recycled water. Genetic engineering can develop more salt-tolerant crops and animals. Algae, which can thrive in "poor" quality water, are a potential source of biofuels.

1d. Technology

The word "technology" can have many definitions. Technology can be defined as the "usage and knowledge of tools, techniques, crafts, systems, or methods of organization". The Business Dictionary defines technology as "Purposeful application of information in the design, production and utilisation of goods and services, and in the organisation of human activities".

Some examples:

1. It is now mandatory to include water storages (rainwater tanks) in all new urban developments in NSW, and most other states of Australia. Water from tanks is used in toilets, washing machines and other non-potable water use systems (NSW Dept of Environment, Climate Changes and Water, 2010, SA Department of Planning and Local Government, 2010)
2. Despite the "breaking" of the drought in many areas, regulations about water use still apply in many areas. In Sydney there are restrictions on the watering of gardens and industry has water regulations, aimed at efficiency, and some restrictions (Sydney Water, 2010)
3. Water Efficiency Labelling is now mandatory on many products (Chong et al., 2008)
4. Government water saving initiatives (Victorian Govt, 2008, 2009), education programs and other policies (Department of Sustainability, 2010) are aimed to reduce per capita water use.

Management-related regulations are one of the many aspects of technology applied with the objective to improve water use and access water resources..

1e. Water use in Australia

In Australia the average annual per capita consumption of water is approximately 800kL/yr (Australian Bureau of Statistics 2010). Consumption has declined significantly from a peak of approximately 1200kL/yr in 1995. There are significant regional variations (National Water Commission, 2010). The per capita household consumption is approximately 124kL/y. The WHO recommendation is for 10kL/yr (30L/d) to supply basic needs in developing area. Most of the potable water supply in Australia is via freshwater reservoir systems, treatment plants and extensive reticulation networks. In other words, we are highly reliant on rainfall. There is some recycling and reuse, and it is increasing as a percentage of total water supply.

The percentage use of water in different activities, for 2000-01 (Department of Sustainability, Environment, Water, Population and Communities, 2007) is:

Sector	%
Irrigated agriculture	67
Forestry and fishing	<1
Mining	2
Manufacturing	3
Electricity and gas supply	7
Water supply, sewerage, drainage	7
Household	9
Environmental flows	2
Other	3

The following table of water consumption (Pacific Institute, 2009) is largely compiled from the Water Footprint Organisation (2010). Tables like these have problems, essentially because they cannot include all the indirect water costs, such as the water required to support the labour force, nor include the variations arising from the different means and types of production and the inherent unreliability of the basic data.

Item	**Volume of water (L)**
Beverages (per litre)	
• Glass of beer	300
• Glass of water	1
• Bottled water	3
• Milk	1000
• Cup of coffee	1120
• Cup of tea	120
• Glass of wine	960
• Glass of apple juice	950
• Glass of orange juice	850

Goods (per kg)	
• Roasted coffee (to grow)	21000
• Tea (to grow)	9200
• Bread	1300
• Cheese	5000
• Cotton textile	11000
• Sheet paper	125
• Potato chips	925
• Hamburger	16000
• Leather shoes	16600
• Microchip	16000
• Clean wool	170000
• Plastic	200
Crops (per kg)	
• Barley	1300
• Coconut	2500
• Corn	900
• Sugar	1500
• Apple	700
• Potato	500-1500
• Wheat	900-2000
• Alfalfa	900-2000
• sorghum	1100-1800
• Corn/Maize	1000-1800
• Rice	1900-5000
• Soybeans	1100-2000
Animals (per kg of meat) – includes water for feed	
• Sheep	6100
• Goat	4000
• Beef	15000-70000
• Chicken	3500-5700
• Eggs	3300
Industrial products (per kg) – processing water	
• Primary copper	440
• Steel	260
• Prmary aluminium	410
• Phosphatic fertilizer	150
• Nitrogenous fertilizer	120
• Synthetic rubber	460
• Inorganic pigments	410
Manufactured goods	
• Car	150000
• Tyre	2000

This table is enhanced if the unit value of the product is put in terms of the litres of water required to produce one unit value ($) of the item. Such data will of course be subject to variations in prices. An example is given below

Item	**Volume of water (L)**	**Unit cost ($)**	**Litres/$**
Beverages (per liter)			
• Glass of beer	300	20	15
• Bottled water	3	3	1
• Milk	1000	2	500
Goods (per kg)			
• Roasted coffee (to grow)	21000	39	540
• Tea (to grow)	9200	24	383
• Bread	1300	3.5	370
• Sheet paper	125	3	40
• Hamburger	16000	5	3200
• Leather shoes	16600	100	166
Crops (per kg)			
• Barley	1300	0.25	5000
• Sugar	1500	0.6	2800
• Potato	500-1500	4	300
• Wheat	900-2000	0.70	2000
• Corn/Maize	1000-1800	0.5	3000
• Rice	1900-5000	3	1500
Animals (per kg of meat) – includes water for feed			
• Beef	15000-70000	20	3500
• Chicken	3500-5700	6.5	650
• Eggs	3300	6	500
Industrial products (per kg) – processing water			
• Primary copper	440	8.3	50
• Primary aluminium	410	2.3	200
• Gold (total water use)	691,000	40,0000	17
Manufactured goods			
• Car	150000	20,000	7.5
• Tyre	2000	100	20
People (per Annum)	124,000	50.0000 (average income value of a person)	2.5

Information obtained from Macquarie University Living cost (2009) and commodity market data in local papers. It also depends very much on where and how much you buy.

A "rational" economist would tend to focus water resources on those products with the highest value per litre of water. The weakness of this approach is that it ignores both the need to feed and cloth the workforce that produces the goods and services and the social and cultural preferences of the community. For example, there is an economic case for encouraging beer drinking over milk consumption but this might not do our health any good! We leave it to the reader to think on the water value of humans.

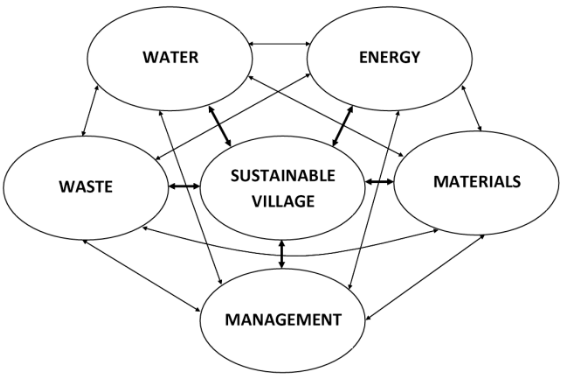
Exported goods are a form of water export. An export-focused economy is effectively exporting its water supplies, termed virtual water trade (Hoff et al, 2010), and involves concepts of "blue" and "green" water.

2. Water Design

2a. Design

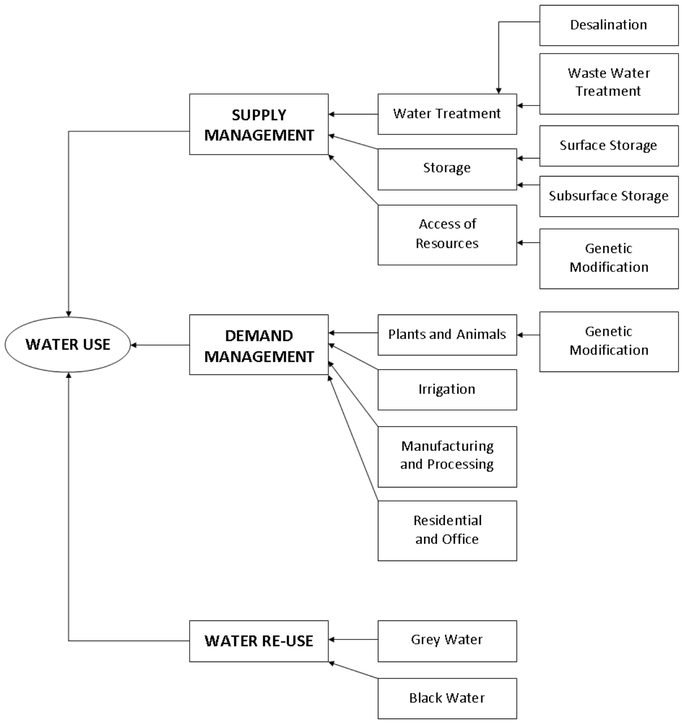
Ultimately, the allocation of water resources is a design issue, meaning, the application of science and technology in the service of humans and their environment.

The allocation of water resources should be part of a "sustainable village" (Riley and Shrestha, 2008) in which the optimisation of all resources and their utilisation is considered. If this interconnectedness of the water cycle is not realised then actions to utilise resources may be suboptimal for sustaining the system as a whole.



Water technologies influence both supply and demand. In recent times focus is on demand management as the surface reservoir-based supply is either limited or too costly to supplement. Demand management is an obvious action if the unit cost of water released by improved demand management is cheaper than the alternative option of supply management.

The following diagram schematically presents a few of the technological options in water management. Ecology is included, as some options in agriculture include genetically modified water-efficient crops and animals.



As noted, a critical issue, and one that may underlie the conflict of urban and rural competition for water, is the ability to pay for the water. Urban areas are generally able to pay a higher unit price for water than rural areas. One would expect that if an urban area can pay a higher price for water it should focus on water sources that it can afford, and free the less costly water resources. However, this is a political decision, not an economic one, as the economic decision would suggest that the water resources should go to those who can pay the higher price. In Australia, we see this happening in the water market, where irrigation allocations for agriculture are being sold to support water supply to urban and environmental needs (Roberts et al., 2006; National Water Commission, 2009; Scott, 2009; Department of Sustainability, Environment, Water, Population and Communities, 2010). Referring back to the table on water usage in Australia, the call on water resources from rural areas to supplement established urban water sources may be considered as minor, but such is not the perception during periods of drought.

Water technology often has to be “visionary” in order to deliver and share the water resource. The development of the Kalgoorlie and Snowy Mountains schemes were, in their day, expensive visionary projects that required substantial political will (and argument). Lateral thinking is always required. The (then) Clarence Colliery in the Upper Blue Mountains, to the west of Sydney, was (in the 1990’s) required to treat mine water to Class A standard before discharging it into the Wollangambe River. Less than 10km further west is the divide between the westward flowing and eastward flowing rivers. It took a drought in Eastern Australia for someone to realise that instead of discharging water down a wild river, and hence changing its hydrologic and geochemical regime, it was more beneficial for the community and the environment to pipe the water over the divide to supply the water-poor communities in the Upper Macquarie River basin. A win-win situation!

However, it is not always easy to convince people and organisations of the merit of lateral thinking. One of us was involved in a consultancy where a mine was pumping water from its pits to the surface, then pumping it approximately 20km away, and either discharging the untreated water via surface irrigation or pumping it back into the ground. The primary recommendation of installing a Reverse Osmosis water treatment plant and selling the water to the nearby urban communities was not accepted. Several years later, and with the problems of well injection and surface evaporation increasing, combined with a severe drought, the treatment and sale option was re-evaluated and actioned. Vision and political and/or management will have to go hand-in-hand.

Not all visions are realistic. There have been suggestions for over a century of diverting water from eastwards flowing rivers in Northern NSW towards the west, that is, a repeat of the Snowy Scheme. Similarly, there are several schemes for diverting the Northern Australia northward flowing rivers to water poor southern Australia. Economics and technological capacity to achieve the objectives are commonly cited reasons for not progressing the proposals (Forest, 2010; Department of Environment, 2010).

3. Key principles of water Management

Within the four-dimensional technology opportunity space of water supply the key issues are sustainability, economics, and the politics of balancing the aspirations of stakeholders.

Over 30 years water in western NSW was allocated to different individuals and groups without careful review of the implications for the future. The allocations were made during a flood-dominated hydrologic regime, when annual rainfalls were above average and dams relatively full (Warner, 2009). The combination of a drought-dominated regime and possible human-induced climate change showed very quickly that water had been over-allocated. In the first decade of the 21st Century there were whole irrigation districts where no water could be allocated to irrigation. Australia went from one of the world's larger exporters of rice to a net importer, with rice production reducing to levels of 40 or more years ago (AFN, 2009). It is easy to play the "blame game", but the reality is that apart from a few people (Davidson, 1969) expectations were widespread in the community that a series of dams built in the 1960's and 1970's had changed the water supply situation with an assurance of reliable and enhanced supply. Hydrologic models based on data from the flood-dominated regime supported this view.

In the background to this story of the over-allocation of water to irrigation in NSW is the problem of a rising water table and salinisation of large areas of prime agricultural land (Department of Sustainability, environment, Water, Population and Communities, 2002).

3a. Sustainability

While the goal of sustainability is widely promoted, the exact nature of this goal is often obscure. Sustainability can have many different definitions. To a farmer sustainability may mean enough water to grow crops and feed stock on the land. It is common to hear farmers talk about the importance of their activity; after all, people have to eat! To an environmental advocate sustainability may mean a healthy river, which is always flowing in its natural hydrologic regime, and in which biodiversity is healthy.

The different definitions or perspectives of sustainability may not be contradictory. Different perspectives often arise when the resource is limited and cannot be shared with abundance in the long term.

Many debates on water focus on the existing available resource. While interested parties may talk about extending the value of the resource through a number of demand-side practices (such as efficient irrigation, recycling) the focus is commonly on maintaining access at existing rates of use. Lateral thinking is not easily done in polarised debates. For example, few people consider salty groundwater in irrigation areas as a resource. It is possible to use the water for high value activities that justify the cost of treatment, or even to use the water with its high salt content in certain processing activities, but that is another story of technology (Australian Museum, 2010; Biopact, 2010) .

3b. Economics and people

In Australia the market approach to water resource management, through water trading, is based on sound economic principles of supply and demand. However, most societies have some form of wealth redistribution for the good of the community and its environment, and Australia is no exception.

It has been stated that if a solely economic approach was taken to the Snowy Mountains scheme it would never have been built, but it was. There were strategic and political decisions for its construction. It was Australia's largest engineering feat, which brought great wealth to the country as well as an influx of migrants. Hydroelectric power from the scheme still contributes significantly to the national grid and saves considerably on greenhouse gas emissions. However, the scheme did not drought-proof the Murray irrigation area as many predicted, and it has contributed to environmental degradation. After many years of debate some of the water has been redistributed back to the eastward flowing Snowy River in an attempt to restore the environment of the river whose waters were largely directed west by the Scheme (Glendining and Pollino, 2009).

There is much written about the sociology of water, and it cannot be ignored in the technology debate on water resource management (Cary, 2001; Stenekes et al., 2008). It doesn't matter how good the science, engineering and design is, the sociological issues can dominate at any time and often in unexpected ways.

4. Some technical approaches

There are a large number of technical approaches to water management, and their relevance to a particular situation depends on the whole range of the water management space.

There is a real sense in which there have been no "quantum leaps" in water technology over the last century. What has happened is that water management is a lot better and more efficient than in the past because of improvements in the way we do things. Technological developments elsewhere, such as in nanotechnology, are applied to improve the efficiency of established water management (technological) strategies. Ultrafiltration is still a form of filtration, which was used in the Middle East some 4,000 years ago. At that time porous rocks and clay pots were the filters, and are still used today. Rainwater tanks were common in households in Australia 100 years ago. Their reintroduction in urban areas is a real sense of *deja vu* for some who had rainwater tank supply in peri-urban areas of Sydney when they were young. Water treatment using chemicals is talked about in the Bible (Elisha put salt into a well with bad water: 2 Kings 2:19-22)

We could provide a long-list of technologies, but these are readily available in reference books and on the web. The role of the water management designer is to review the water-technology opportunity space of quantity, quality, reliability, and delivery, and place this within the socio-economic regime, to develop the optimum technologies. The design of water management systems is an exercise in systems engineering, using all the tools of systems engineers.

Our primary recommendation - look at the whole system to ensure that sub-optimal options are not proposed.

We will present one real world situation from India and two scenarios that may be relevant to Chile.

4a. Odanthurai Panchayat, Tamil Nadu, India

People from a cluster of hamlets in the village of Odanthurai combined to produce an innovative solution to potable water supply and waste water management (Palanitburai et al., 2008). The project was initiated by the women of the community, and partly funded by government It was greatly assisted by a graduate engineer whose family lived in the village.

What they did was:

a. Build a water treatment plant, powered by a pyrolysis unit using wood discards;
b. Pump the water to the five hamlets of the village
c. Collect the waste water from each hamlet and run it through an anaerobic digester, producing methane gas for cooking in the hamlet
d. Used the nutrient rich sludge and effluent to fertilize and water appropriate crops
e. Established a simple solar-powered street lighting system using LED lights
f. Used excess treated water to run a water bottling plant to generate income for the village

The outcomes were:

- Good quality water
- Improved health
- Improved crop production
- Income generation and employment diversity and enhancement

4b. Water supply to an arid town

This is a scenario.

A town located in an arid area requires water. It is located within 200km of the coast. The possible technical solution is:

1. Supply the town from the ocean using desalination

2. Build pipes and pumps to minimise the cost of the supply
3. Construct wind, solar and/or tidal/wave power generation systems to provide power for the system, and possibly also for the town at the same time
4. Implement a stringent water efficiency policy in the town
5. Treat all waste water and any stormwater generated by the town to a standard required for users (agriculture, mining, and other industry) and sell this water and any usable waste by-products (eg sludge) to the users
6. Ensure that local industry does not use potable water from the coast but the treated water from the residential and commercial waste water

The outcomes are:

- Reliability of supply to the community
- Opportunities for industry to expand, develop or simply survive
- No greenhouse gas emissions in the long term
- Job opportunities

You will note that in this scenario we have not attempted to fight the "toilet to the tap" battle with residences. Better to by-pass that cultural conflict as a means of achieving a greater good.

This scenario is given credence by an experience of one of us in Sub-Saharan Africa. When we built a water treatment plant for a small university outside of Kampala we had people lining up to get access to the sludge from the plant for their gardens. The effluent from the treatment plant grew a healthy crop of Eucalyptus trees that were harvested for construction poles (the substitute for scaffolding in the region).

And before you think the distances have to be short, Johannesburg gets some of its water from the Drakensburg Mountains, more than 400km away, and the Feather river aqueduct system, supplying southern California, is over 600km long.

4c. The mine

The scenario is a mine in an arid region. The access to groundwater is limited. The mine creates a large urban water demand, or enhances it at the very least.

Most mining operations are high value, area-local operations. Water is essential in ore processing, washing, dust suppression, fire-fighting, and so forth.

The possible technical solution is:

1. Pipe the water to the mine. If the source is highly saline or not suitable for the mine then treatment (one of the desalination technologies) will be required. However, mine operations often does not require potable water supply, and the limited potable water required by a mine can be produced on-site rather than treating the whole of the water piped to a potable water standard.
2. Local urban water needs can be met from an onsite potable water treatment system
3. The waste water generated from the mine can be treated and reused. Where the contaminants can be removed the waste water can also be used to supply the urban area, after treatment

4. Urban wastewater can be treated and used for irrigation or other uses. The technology has been available for some time to use the methane generated from the treatment of urban waste to power the waste treatment facility, and even return power to the grid.
5. Alternative power systems of wind, solar, hydroelectric and tidal/wave are essential if greenhouse gas emissions are to be minimised.

In one mine site in Queensland, there are discussions about using wastewater from the mine to grow algae, subsequently harvested for biofuels. Algae farming is an option in coal-based power generation systems, using the CO_2 as a means of promoting algae growth and reducing greenhouse gas releases.

4d. The unusual technologies

One cannot leave the technology discussion without talking about some of the unusual or new technologies. Most of these new developments are essentially improvements on the existing technologies. There is no guarantee that these technologies are viable.

1. Whisson windmill – uses the energy from the windmill to drive a compressor to extract water from the air. Similar concept to the Dutch Rainmaker technology, Aeolius Water (Aeolius Tech) has a prototype of a 14m high tower and 8.5m turbine which produces approximately 2000l of water per day
2. Using algae to treat waste water or low quality water and at the same time produce liquid fuels
3. Nano-technology in water treatment, as membranes and to detect pathogens
4. Agent modelling providing the opportunity to test options in a socio-economic regime as well as the bio-physical regime.
5. Smart metering, personalised Wi-Fi control systems, and improved irrigation technology arising from spatial information interfaces through irrigation control systems.

There are other examples of new technologies and concepts in the proving stage.

5. Conclusion

Lewenz (2007), in his book on the sustainable village, has a very simple equation

$$(\text{Matter} + \text{Energy}) * \text{Intelligence} = \text{Wealth}$$

The essential elements of water technology, within the four dimensional opportunity space, are related to the energy we can utilise, the water matter, including the by-products from its access, use and treatment, and the intelligence with which we link together the technical possibilities in the socio-economic regime that we all live in.

Ultimately, good water management leads to wealth in a sustainable system. Poor water management can lead to poverty for generations to come.

6. References

AFN (Australian Food News) 2009. Drought has lingering impact on Australian food production. http://www.ausfoodnews.com.au/2009/05/26/drought-has-lingering-impact-on-australian-food-production.html (Accessed Oct 2010)

Australian Bureau of Statistics. 2010. Water account Australia. http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1370.0~2010~Chapter~Water%20consumption%20per%20person%20(6.3.3) (Accessed Oct 2010)

Australian Museum. Eureka Prize 2010. Inventors harvest award for irrigation lifeline. http://eureka.australianmuseum.net.au/21E4B4C0-5995-11DF-A6AE005056B06558?DISPLAYENTRY=true (Accessed Oct 2010)

Biopact. 2010. Scientists develop plant-powered desalination technology – allows land reclamation. http://news.mongabay.com/bioenergy/2008/09/scientists-develop-plant-powered.html (accessed Oct 2010)

Bureau of Meteorology, Commonwealth of Australia. 2010. Living with drought. http://www.bom.gov.au/climate/drought/livedrought.shtml (accessed Oct 2010)

Bureau of Meteorology, Commonwealth of Australia. 2010. Australia, climate of our continent. http://www.bom.gov.au/lam/climate/levelthree/ausclim/zones.htm#three (Accessed Oct 2010).

Cary,J., Barr,N., Aslin,H., Webb,T., Kelson,S. 2001. Human and social aspects of capacity to change to sustainable management practices. Bureau of Rural sciences, Commonwealth of Australia. 120pp. http://www.anra.gov.au/topics/economics/pubs/national/6-2-2-report.pdf (Accessed Oct 2010)

Chong,J., Kazaglis,A., Hiuco,D. 2008. Cost effectiveness analysis of WELS: the water efficiency labelling and standards scheme. Final Report for Dept of the Environment, Water, Heritage and the Arts, Australian Govt. Institute for Sustainable Futures, UTS. 79pp.

Davidson, B.R. 1969. Australia, wet or dry? : the physical and economic limits to the expansion of irrigation. Melbourne University Press, Clayton, Victoria, 264pp.

Department of the Environment, Water, Heritage and the Arts. 2010. Water the Future. Moving water long distances: Grand schemes or pipe dreams? Australian Govt. 21pp. available at *http://;*www.environment.gov.au/**water**/publications/action/pubs/moving-**water**.rtf (Accessed Oct 2010)

Department of Sustainability, Environment, Water, Population and Communities. Australian Government. 2002. Salinity. http://www.environment.gov.au/soe/2001/publications/fact-sheets/salinity.html (Accessed Oct 2010)

Department of Sustainability, Environment, Water, Population and Communities, Australian Government., 2007. Australia State of the Environment 2006. 7.1 Water availability and use. http://www.environment.gov.au/soe/2006/publications/report/inland-waters-1.html (Accessed Oct 2010)

Department of Sustainability, Environment, Water, Population and Communities. Australian Government. 2010. Australia's water policies and programs. http://www.environment.gov.au/water/policy-programs/

Department of Sustainabiltiy, environment, Water, Population and Communities, Australian Government. 2010. National Water Market System. http://www.environment.gov.au/water/policy-programs/nwms/index.html (Accessed Oct 2010)

El Saliby,I., Okour,Y., Shon,H.K., Kandasamy,J., Kim,S. 2009. Desalination plants in Australia, review and facts. Desalination, 247(1-3), 1-14.

Evans,R. and West,A. 2007. Constructing Australia: A companion to the ABC TV Series. Miegunyah Press, Melbourne 162pp.

Forest, John. MP. 2010. Blog, How do we feed and water Australia's predicted population of 35 million in 2050. http://www.nationals.org.au/News/Speeches/tabid/96/articleType/ArticleView/articleId/4965/categoryId/6/How-do-we-feed-and-water-Australias-predicted-population-of-35-million-in-2050.aspx (Accessed Oct 2010)

Glendining, N.S. and Pollino,C.A. 2009. River restoration using simple decision support tools in the Lower Snowy River. 18th World IMACS/MODSIM Congress, Cairns, Australia 13-17 July 2009 . Copy available at http://mssanz.org.au/modsim09

Hoff,H., Falkenmark,M., Gerten,D., Gordon,L., Karlberg,L., Rockstrom,J. 2010. Greening the global water system. J Hydrology, 384,177-186.

Lewenz,C. 2007. How to build a village. Village Forum Press and Jackson House Publishing Company, Auckland, NZ.245pp.

Mackellar, Dorothea. 1918. My country. In Murdoch, W. (1918) The Oxford book of Australasian Verse. Oxford University Press, London

Murray-Darling Basin Authority. 2010. Murray-darling Basin Plan http://www.mdba.gov.au/basin_plan (Accessed Oct 2010: plan downloadable from the site)

Macquarie University, Macquarie International. 2009. Living costs. http://www.international.mq.edu.au/macquarie/sydney/livingcosts (Accessed Oct 2010)

National Water Commission, Commonwealth of Australia. 2007. Runoff. Australian Water Resources 2005. http://www.water.gov.au/WaterAvailability/Whatisourtotalwaterresource/Runoff/index.aspx?Menu=Level1_3_1_5 (Accessed Oct 2010)

National Water Commission. 2009. Water Markets. http://www.nwc.gov.au/www/html/248-introduction-water-markets.asp (Accessed Oct 2010)

National Water Commission 2010. Capital city water use. http://www.water.gov.au/WaterUse/Capitalcitywateruse/index.aspx?Menu=Level1_4_3 9 Accessed Oct 2010)

NSW Department of Environment, Climate Change, and Water. NSW Government. 2010. NSW rainwater tank rebate. http://www.environment.nsw.gov.au/rebates/ccfrtw.htm (Accessed Oct 2010)

NSW Offfice of the Premier. 2010. Sydney's wind powered desalination plant now online. News Release, Premier of NSW. NSW Government. 28 Jan 2010. http://www.sydneywater.com.au/WhoWeAre/MediaCentre/documents/ministerial/Keneally_switch%20on_280110.pdf (Accessed Oct 2010)

Palanitburai,G., Thirunavukkarasu,M.A., Uma,G. 2008. Change makers at grassroots: Local governance in action. Case studies on panchayati raj system in Tamil Nadu, India. Concept Publishing Company, New Delhi. 310pp.

Riley, S.J. and Shrestha,S. 2008. The sustainable village in a changing world. In Oyawa,W.O. and Kimura,M.(eds) CE2008. *Proceedings of the 2nd International Civil Engineering Conference on Civil Engineering and Sustainable Development. "Modernising our Infrastructure"*. 23-25 Sept 2008. Mombasa, Kenya. p.535-546.

Rivers. 2010. Mudgee District Environment Group Goulburn River – The Drip. http://www.riverssos.com/drip.html (accessed Oct 2010)

Roberts, R., Mitchell,N., Douglas,J. 2006. Water and Australia's future economic growth. Australia Government. Treasury. http://www.treasury.gov.au/documents/1087/PDF/05_Water.pdf

SA Department of Planning and Local government. Government of South Australia. 2010. Rainwater Tanks. http://www.planning.sa.gov.au/go/rainwater-tanks (Accessed Oct 2010)

Scott, S. 2009. An overview of Australia's first water market. Minter Ellison. http://www.minterellison.com/public/connect/Internet/Home/Legal+Insights/Newsletters/Previous+Newsletters/A-ERU2+SEQ+water+market (Accessed 2010)

Stenekes,N., Russell,J., Tucker,C., Mooney, C. 2008. Water for what? Productive and environmental values for water. Understanding social values. Australian Govt, Bureau of Rural Sciences, 140pp. http://adl.brs.gov.au/brsShop/data/water_values_final_report_brs_220708_parts1_2_notracks.pdf (Accessed Oct 2010)

Sydney Water. 2010. Water Wise rules apply. http://www.sydneywater.com.au/Water4Life/WaterWise/ (Accessed Oct 2010)

Smith, Dick, 2010. Population. http://dicksmithpopulation.com/ (Accessed Oct 2010)

The Pacific Institute. 2009. Worlds Water 2009-2009. Table 19. Water content of things. http://www.worldwater.org/data20082009/Table19.pdf (Accessed Oct 2010)

Victorian Government. 2008. Melbourne water saving initiatives. http://www.melbourne.vic.gov.au/Environment/WhatCouncilisDoing/Documents/water_savings_initiatives_map.pdf

Victorian Government. 2009. Water stories. http://www.prov.vic.gov.au/online/water/

Warner,R.F. 2009. Secular regime shifts, global warming and Sydney's water supply. Geographical Research, 47(3)227-241.

Water Footprint Organisation. 2010. Product water footprints. http://www.waterfootprint.org/?page=files/Productwaterfootprint-statistics (Accessed Oct 2010)

Wolf A., Yoffe S., Giordano M 2003. International Waters: Indicators for Identifying basins at risk, PCCP project, UNESCO