POTABLE REUSE – WHAT ARE WE AFRAID OF ?

Ian B Law

IBL Solutions
iblaw@bigpond.com

"A Nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of shortsightedness. The hard lessons of history are clear, written on the deserted sands and ruins of once proud civilisations" **Lyndon B. Johnson, 36th President of the USA**

1. INTRODUCTION

Advanced reuse, and the subsequent use of the reclaimed water to supplement a community's water supplies, is a topic that often elicits debate between professionals and lay-people alike; and this has been the case ever since the first such facility was commissioned in the 1960s.

The 'precautionary principle', a term described by some as being a reason for doing nothing, is certainly applied to this form of water supply augmentation. This is despite the fact that such schemes always incorporate more 'treatment barriers' than are provided in many conventional water treatment systems that draw from raw water supplies of dubious quality.

Nevertheless, there has been much achieved in the field of Advanced Reuse and this paper provides an overview of developments since the world's first direct potable reuse plant was commissioned in Windhoek, Namibia in 1968. It notes that the improvement in the technologies applied has generally been driven by the increase in analytical capability and that, in line with this, membrane systems are finding increasing application in the reclamation plants; as highlighted by the recent NEWater plants in Singapore.

There is now an increasing interest in Australia in Advanced Reuse as a means of meeting our increasing demands for a safe and sustainable supply of water into the future – Goulburn in NSW and Toowoomba in Queensland being prime examples. However, there is still a reticence in some quarters of our fair land to even discuss it, let alone consider it.

The paper concludes with a look into the future – what should be done and what is likely to be achieved in this important area of Advanced Reuse – and suggests that it should receive serious consideration as a reliable and cost effective of the means of diversifying our water supplies.

2. ADVANCED REUSE MILESTONES

"*Water streams through history as a very shining and challenging ingredient in the making of people"* **Shimon Peres, Founder of the Peres Centre for Peace**

Much has happened since the Windhoek Plant was commissioned in 1968:

Salient milestones are:

- The world's first Direct Potable Reuse plant was started up in Windhoek, Namibia in 1968 using technology that was available at that time. This plant has undergone many technological changes since then.

- Reverse Osmosis (RO) was first applied in 1976 at Orange County Water District's (OCWD's) Water Factory 21.

- The world's first Planned Indirect Potable Reuse scheme, involving the return of reclaimed water to a surface water reservoir, was commisioned in 1978 at UOSA.

- Ozone coupled with activated carbon was first trialled in a water reclamation context in 1978 at the 5,000m^3/day Stander Plant in Pretoria, South Africa

- The first use of long term health effects testing was commenced in 1983 at the Denver Pilot Plant using both rats and mice.

- Microfiltration (MF) was first applied as a pretreatment stage to RO in 1993 at OCWD's Water Factory 21.

- On-line monitoring techniques for MF and RO systems were developed and trialled in 1996 as part San Diego's Aqua 2000 research programme.

- A Membrane Bioreactor (MBR) was first applied as a pretreatment stage to RO in 1997 at the McAllen Plant in Texas, US.

- Singapore's NEWater 10,000m^3/day Demonstration Plant, incorporating the MF/RO/UV treatment train was commissioned in 2000.

- A 2 year health effects testing programme, using both fish and mice for the first time, was started in 2000 in Singapore.

- The MF/RO/UV treatment train is adopted in Singapore, with two full-scale plants operational in 2002.

A summary of these and some other Advanced Reuse milestones is presented in Figure 1.

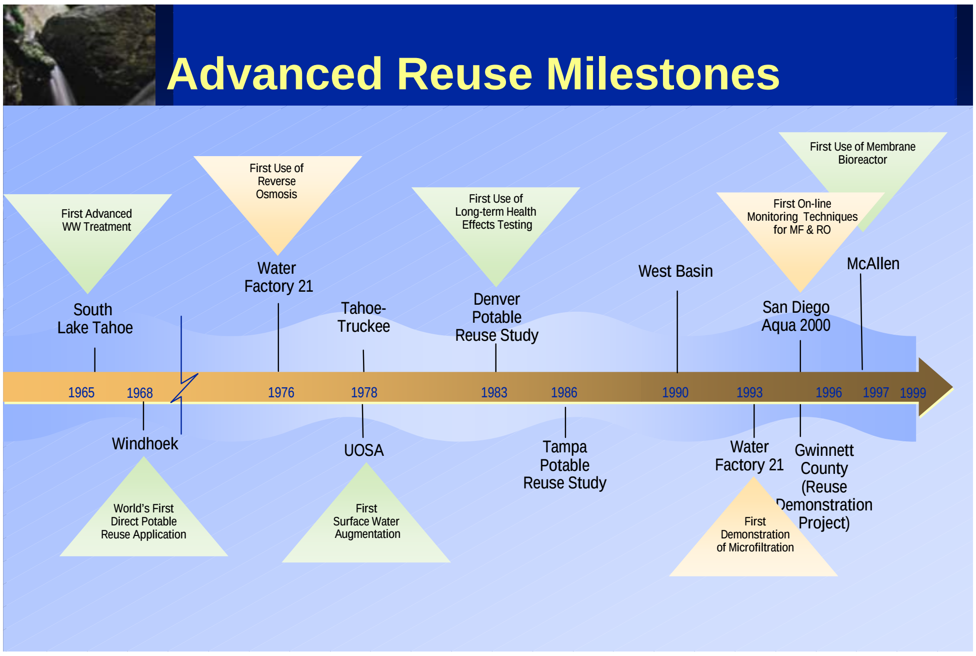

Figure 1: Salient Milestones in Advanced Reuse Applications

There has been an exponential growth in membrane usage since 1995, best exemplified by the following:

1994 – there were two MF/UF manufacturers with installations greater than 2,000 m^3/d
1994 – the largest municipal MF/UF plant had a capacity of 20,000 m^3/d
2002 – there were eleven MF/UF manufacturers active in the municipal market
2002 – the largest municipal plant was 100,000 m^3/d
2004 - a 300,000 m^3/d facility will be on-line

One advantage of this exponential growth in membrane applications is that the unit cost of the facilities has been decreasing, with the result that the unit cost of reclaimed water produced from such plants is also decreasing and, in many locations, is now competitive with other sources of water.

3. PROJECT DRIVERS AND TECHNOLOGIES APPLIED

"Water should be judged not by its history but by its quality" **Dr Lucas Van Vuuren, pioneer of water reclamation research in South Africa in the 1960s.**

Why did these advanced reuse projects proceed and what technologies did they use ? This Section addresses these questions.

Project Drivers

The drivers for four notable advanced reuse projects – Windhoek, UOSA, OWCD's Groundwater Replenishment System (GWRS) and Singapore's NEWater initiative – are summarised in Table 1. It will be noted that Windhoek and OCWD's GWRS have similar drivers, with perhaps the most important being that additional water had to be found to meet futue demand and water reclamation was deemed the most appropriate way to go. UOSA was driven more by a receiving water quality requirement and Singapore by a need to secure its water supplies into the future.

Table 1: Project Drivers

Windhoek: • Low rainfall, high evaporation, low runoff • All surface water sources within 500 km of the city had been exploited • Further water sources were expensive and obtaining them controversial • Maximum groundwater utilisation was already occurring • Demand management had already been implemented • No other option but wastewater reclamation
UOSA: • Indirect Potable Reuse occurred as a result of development and population growth in the area • Quality of water in the receiving water (Occoquan Reservoir) was deteriorating • On-going IPR necessitated major upgrade to quality of reclaimed water
OCWD's GWRS: • Demand management - implemented, but still will not meet the projected water requirements • Seawater desalination - too expensive, compared to GWRS • Additional percolation basins - no land • Agricultural transfers – too difficult, no water rights • Purchase additional imported water - costly, may not be available • Groundwater replenishment using reclaimed water – cost effective, reliable and with added environmental benefits.
Singapore: • 50% of the Island's fresh water supplies are imported • This supply is subject to on-going negotiations • Steps taken to reduce reliance on this large supply, through sea water desalination and water reclamation (NEWater)

Technological Change

It is unlikely that the treatment train that was initially implemented at Windhoek in 1968 will ever be used again; it was considered appropriate at the time but would fall far short of acceptance today. There have been four technology changes/upgrades at Windhoek since1968, with the most recent being in 2000 when, amongst other changes, an ultrafiltration (UF) membrane filtration system was installed.

The treatment trains adopted at the Windhoek, UOSA and Singapore plants are presented in Table 2 for comparison. OCWD's GWR System, the first phase of which is due to be operational in 2004 will use treatment train similar to that being used in Singapore; dual membranes followed by UV disinfection.

Table 2: Comparison of Technologies

Windhoek	Windhoek	UOSA	Singapore
1968 Secondary Treatment followed by: • Algae flotation • Foam fractionation • Chem Clarification • Sand filtration • GAC • Chlorination Reclaimed Water Flow: 4.8 ML/d Reclaimed water contribution: 4%	2000 Improved Sec Treat followed by: • Pre-ozonation (for Fe and Mn) • Dissolved air flotation • Sand filtration • Ozonation • GAC • Membrane filtration (UF) • Chlorination Reclaimed Water Flow: 21 ML/d Reclaimed water contribution: 25%	1974 Secondary Treatment followed by: • High lime treatment • Clarification • Recarbonation • Sand filtration • GAC • Ion Exchange • Chlorination Reclaimed Water Flow: 200 ML/d Reclaimed water contribution: 10-45%	2002 Secondary Treatment followed by: • Membrane filtration (MF or UF) • Reverse Osmosis • UV Disinfection • Stability control • Chlorination Reclaimed Water Flow: 82 ML/d Reclaimed water contribution: 1% initially and increasing

The trend towards membrane treatment systems is clearly shown.

It is of interest to note that OCWD's original reclamation plant – Water Factory 21 – used a treatment train similar to that used at UOSA as pretreatment for the reverse osmosis units; high lime followed by recarbonation and sand filtration. Research into the use of microfiltration membranes clearly showed an added benefit of these systems over the more traditional lime system – land area required reduced by 75% and operating and maintenance costs reduced by 50% [1].

Health Effects Studies

Technology is one part of the equation. Proving that it works and that the reclaimed water is safe and wholesome is the other. These studies into health effects evaluate both the short and long-term health effects and they generally include extensive sampling and monitoring programmes coupled with *in-vitro* and/or *in-vivo* toxicological studies in some shape or form.

A comparison of the health effects studies carried out at Windhoek, UOSA, Water Factory 21 and Singapore is presented in Table 3.

Table 3: Comparison of Health Effects Studies

Windhoek	UOSA	Water Factory 21	Singapore
Toxicological Studies: • Ames test • Urease enzyme activity & bacterial growth inhibition • In-vivo studies include water flea lethality and fish (guppy) biomonitoring Epidemiological Study (1976-1983)	Toxicological Studies: • None to-date	Toxicological Studies: • On-line biomonitoring using Medaka fish tested.	Toxicological Studies: • 2 year in-vivo chronic toxicity study with mice • 2 generation study with Medaka fish
Sampling & Monitoring Program	Sampling & Monitoring Program	Comprehensive Sampling & Monitoring Program	Comprehensive Sampling & Monitoring Program
On-going quality monitoring	On-going quality monitoring by an independent panel of review	On-line fish biomonitoring with external review panel	On-going quality monitoring by an independent panel of review

The Health Effects studies carried out as part of the NEWater ‘proving period’ in Singapore were the first in the world to use two different species – mice and fish.

Using fish is in line with the growing trend worldwide as this does obviate the necessity of having to concentrate the organics, as is required for the mice alternative.

An extensive sampling and monitoring program was also incorporated in the Singapore studies and carried out over the period. This program was carried out over a two and a half year period, commencing in 2000 and monitored for a range of parameters at a number of locations; some 190 individual parameters in total – refer to Table 4 below. It was regularly updated with ‘new’ parameters as they became ‘known’ – such as N-nitrosodimethylamine (NDMA) and 1,4 Dioxane.

With this extensive database of results and the results from the Health Effects Study, the Singapore Government had a sound basis on which to make their decision to proceed with planned indirect potable reuse in February 2003. A sampling and monitoring program that has a similar range of analytes is currently in place and is audited on a quarterly basis by independent specialists.

Table 4: Singapore's Sampling & Monitoring Program

	Water Quality Parameter	Plant Feedwater (1)	MF Filtrate (2)	RO Permeate (3)	UV Effluent (4)	NEWater (5)	PUB Raw Water	PUB Drinking Water
	Physical	9	3	3	2	9	9	9
Inorganic	Disinfection Byproducts	6	1	2	1	6	6	6
Inorganic	Inorganic - Other	38	2	34		38	38	38
Organic	Disinfection Byproducts	21		21		21	21	21
Organic	Other Compounds	40				40	40	40
	Pesticides/Herbicides	49				49	49	49
	Radionuclides	6				6	6	6
	Wastewater Signature Compounds	1				4	4	4
	Synthetic & Natural Hormones	3	3	3		3	3	3
	Microbiological	10	8	6		10	6	3
	Totals	**183**	**17**	**69**	**3**	**186**	**182**	**179**

4. FACTS, PERCEPTIONS AND OPINIONS

"Water, like religion and ideology, has the power to move millions of people. Since the very birth of human civilisation, people have moved to settle close to it. People move when there is too little left. People move when there is too much of it. People journey down it. People write, sing and dance about it. People fight over it. And all people, everywhere and every day, need it." **Mikhail Gorbachev, former President of the Soviet Union**

The practice of returning a reclaimed water to a reservoir to augment water supplies– be it surface water or groundwater – has certainly created much debate and discussion in both the professional and lay sections of our societies.

There are many instances of Unplanned Indirect Potable Reuse (UIPR), whereby treated municipal wastewater and sometimes, untreated agricultural or industrial wastes are returned to a water body upstream of an off-take for a drinking water treatment plant, being practiced in the world to-day. Examples include the Yangtze River in China, the Thames River in the UK, the Murray-Darling and Nepean Rivers in Australia, the Rhine River in Europe and the Mississippi and Santa Anna Rivers in the US.

Problems, in terms of drinking water quality, have occurred in these and other UIPR applications as a result of the natural assimilative capacity of the receiving water body becoming overwhelmed as waste inflows increase with time. In addition, the increase in the use of synthetic chemicals has resulted in such chemicals often being present in the drinking water as they are generally poorly removed with conventional water treatment technologies.

Stander [2], often referred to as the father of research into water reclamation and reuse in South Africa, stated, nearly 20 years ago, that:

"It can be unequivocally stated that situations reported on the incidence of micro-organics in drinking water are largely due to an over assessment of firstly, the capacity of self-purification processes and of the role of dilution of the water environment in degrading and dissipating these compounds and secondly, the adequacy of the physical chemical unit processes of conventional water purification systems to remove compounds which are present in the raw water intake at micro-concentration levels".

The corollary to this is that if treatment is improved at the wastewater treatment plants, industrial wastes are controlled (or diverted) and total catchment control procedures are implemented, then the quality of the receiving waters and hence the raw water supplies to downstream water treatment plants must improve.

Much has recently been reported on the presence of Endocrine Active Substances (EASs) in drinking water supplies and effluents discharged from wastewater treatment plants. Many of these EASs have the potential to be Endocrine Disrupting Compounds (EDCs) and their presence is one of the most sensitive issues facing water suppliers in the US. Examples of EASs are:

- Natural hormones – both human and animal
- Natural chemicals – such as substances produced by plants – e.g phyto-estrogens
- Synthetic pharmaceuticals intended to be hormonally active – such as the contraceptive pill
- Other man-made chemicals. A very wide range including cosmetics and medical compounds, pesticides, industrial chemicals. Included in this latter group are: alkylphenols, polycyclic aromatic hydrocarbons, organohalogens and triorganotins.

Research work overseas [3] and within Queensland, Australia [4] has shown that activated sludge treatment using long Solids Retention Times (SRTs) and coupled with bio N removal achieve high levels of EAS removal. The Queensland work showed that 'activated sludge treatment was very effective at removing EDC from sewage' and it also noted that the comparatively higher levels of EDCs reported in effluent in the UK may well be due to the fact that trickling filters are still widely used as the form of secondary treatment.

Work carried out in the US, Singapore, Australia, Korea and Europe has also shown that:

- Reverse Osmosis (RO) is particularly effective against PhACs and most identified EASs – provided membrane integrity is maintained and care taken with cleaning at high pH values.
- Ozone, GAC, H_2O_2/UV are effective as post treatment, if required.

There are now many examples of advanced water reclamation plants that have reliably produced a reclaimed water of a quality that is equal to or better than that of the local raw water supply or drinking water - San Diego, Denver, Cape Town, Pretoria, Windhoek, Water Factory 21 …and now NEWater in Singapore.

However, compliance with drinking water standards is not always cause to state that a reclaimed water is safe as these standards are intended for water obtained from relatively uncontaminated sources of fresh water, and not for a reclaimed water obtained from an effluent from a municipal wastewater treatment plant. In addition, these drinking water standards generally cover only a limited number of contaminants. This apparent conflict is often raised as reason not to proceed with potable reuse but it can be taken to the extreme. For example, many conventional sources of fresh water are becoming so contaminated that water reclaimed from a municipal effluent can be of a superior quality and be a perfectly adequate source of water – planned indirect potable reuse is viable in this case.

An example of the difference between a contaminated surface water and a high quality reclaimed water can be taken from Orange County, California where the following organic compounds have been used as signature compounds for contamination with municipal wastewater [5]:

- Ethylenediamine tetraacetic acid (EDTA)
- Napthalene dicarboxylic acid (NDC)
- Nitroloacetic acid (NTA)
- Alkylphenol polyethoxylates (APEO) and carboxylates (APEC)

Figure 2 compares the occurrence of these organics in the Santa Ana River in southern California with the Orange County Sanitary District secondary effluent (the feedwater to the Water Factory 21 water reclamation plant) and the permeate from the reverse osmosis plant at Water Factory 21 [5].

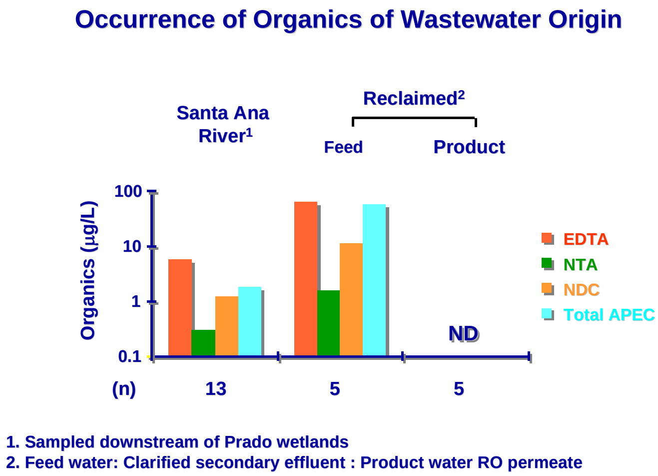

Figure 2: Occurrence of Organics of Wastewater Origin

This Figure clearly shows the higher quality of the reclaimed water as compared to the Santa Ana River and lends support for the concept of indirect potable reuse.

The effectiveness of reverse osmosis in the removal of soluble intractable organics, such as hormones and Pharmaceutically Active Substances (PhACs), has also been reported by others in Australia [6] and overseas [5].

It is pleasing to see professional bodies and other organisations agreeing that indirect potable reuse can play a role in extending water supplies. For example, the Executive Committee of the Water Environment Federation (WEF) approved the following statement in October 1998:

WEF recognizes that the world's water supply is a finite resource and the practice of water reuse is key to the conservation of this natural resource. Thus, WEF supports the use of reclaimed water for non-potable purposes as a means of conserving potable water supplies. Also, WEF supports the consideration and use of highly treated reclaimed water for indirect potable reuse and encourages public involvement in all aspects of water reuse projects. The reuse of municipal wastewater for beneficial purposes is an important element of the world's total water resources management. The use of reclaimed water for domestic, industrial, commercial, agricultural, environmental, and other purposes can conserve and extend freshwater supplies.

Indirect potable reuse is the introduction of highly treated reclaimed water to a surface water or groundwater system that ultimately is used as a potable water supply. Current engineering practice can provide treatment systems that are capable of reliably eliminating pathogens and reducing organic and inorganic contaminant concentrations to very low levels in reclaimed water. Therefore, local authorities should consider indirect potable reuse of reclaimed water as part of an integrated water resources management strategy. The viability of reclaimed water for indirect potable reuse should be assessed with regard to quantity and reliability of raw water supplies, the quality of reclaimed water, and cost effectiveness. These management criteria should always be used in decision making related to the use of highly treated reclaimed water for indirect potable reuse.

Owners and operators of wastewater treatment systems producing reclaimed water for beneficial applications are urged to adopt the attitude that they are performing resource recovery rather tan wastewater disposal and that their operations have public health significance. WEF also urges owners and operators of wastewater treatment systems and reclaimed water use areas to provide public education programs and involve the public in the planning, development, and operation of water reuse projects.

The National Research Council [7] in 1998 stated that:

Our general conclusion is that planned, indirect potable reuse is a viable application of reclaimed water – but only when there is a careful, thorough, project-specific assessment that includes contaminant monitoring, health and safety testing and system reliability evaluation.

Further, it goes on to state:

Indirect potable reuse is an option of last resort. It should be adopted only if other measures – including other water sources, non-potable reuse and water conservation – have been evaluated and rejected as technically or economically infeasible.

5. TECHNOLOGY DRIVEN BY INCREASING ANALYTICAL CAPABILITY

"Water sustains all" **Thales of Miletus, 600 BC**

Despite the fact that our analytical capability has increased immensely in recent times we can still only identify and quantify some 10-15% of the residual organic fraction in a reclaimed water. It is for this reason that Regulators often specify surrogate parameters (such as Total Organic Carbon, TOC) as well as treatment technologies for advanced reclamation and reuse applications.

Improvements in detection technology now allows us to detect known contaminants at much lower levels and also to 'discover new contaminants'. This ability has in some instances confirmed the presence of trace organics at low concentrations in both surface and reclaimed waters – compounds such as NDMA, 1,4 Dioxane and those chemicals that are classified as endocrine disrupting compounds (EDCs) being examples.

This has resulted in a review of the appropriate level for the TOC surrogate as well as an added requirement for appropriate treatment technologies for those contaminants not contributing to TOC, such as NDMA.

For example, the California Department of Health Services is considering additional treatment and assay requirements for any groundwater recharge projects in that State which result in more than 50% of reclaimed water being in the groundwater basins. The regulations are expected to include a TOC of less than 0.5 mg/L of wastewater origin with additional testing for specified trace organic compounds, post RO treatment with advanced oxidation using UV and hydrogen peroxide, and possible *in-vivo* bioassay [8].

This likely reduction in TOC values and greater emphasis on treatment technologies will surely support the trend towards the use of membranes as a core technology in future advanced water reclamation plants.

However, we must keep this improved analytical capability in perspective. The levels of trace organic compounds in reclaimed water must be compared with the levels found in other sources to evaluate the true significance of using the reclaimed water for human consumption. It has been shown that with the exception of NDMA, intake of most chemicals through ingestion via the water route could be less significant than the intake from other sources such as food [8].

6. INTO THE FUTURE

"Water is healthy, it's in our body, and I drink a lot of water. You don't realise that it is so important because it is always there, it is just water. But it is the liquid that we live from, that we are from" **Johan Cruyff, World Cup Soccer Star and Coach, Chairman of the Johan Cruyff Welfare Foundation.**

How will the timeline presented in Figure 1 look in the next decade or so ? What developments can we expect to see on both the macro and micro levels ?

Starting at the macro level, it is, to the Author's mind, a given that there will be an increase in the number of locations around the world that will either be planning, or will already have planned and implemented, advanced reuse systems. There will be pressure on those *unplanned* IPR applications to revert to the more responsible *planned* alternative as a means of protecting the quality of water distributed to the public and of maximising the sometimes meager fresh water supplies available in many countries.

Advanced reuse has already become a cornerstone of the practice of Total Water Management.

Total Water Management (TWM), a term that is often interchanged *with Water Cycle Management* or *Integrated Water Management*, will be a common practice as it focuses on creating value for a commodity that is essential to our survival. It also strives to introduce the issue of 'sustainability' into our management procedures, with the overall aim of being to safeguard the meager freshwater supplies that exist in many parts of our world and yet still cater for increasing populations and economies.

TWM covers the following tenets [9]:

- Water is viewed as a resource to be used and reused – essentially speeding up the water cycle;
- Stormwater is viewed as a resource rather than a ‘waste’;
- Water demand is managed concurrently with supply through conservation, pricing and incentives;
- Higher levels of wastewater treatment are provided with the volumes released back into the environment being greatly reduced;
- Catchment Management is an integral component; all point and non-point sources are identified and managed;
- Ecosystem management important – environmental flows identified and catered for;
- Total integration of water, air and land issues;
- Biosolids reused, not disposed; and
- Water is used to create recreational and aesthetic focal points for the community.

On the micro scale, on-going research into topics related to advanced reuse is required and a summary of those topics suggested by the National Research Council in 1998 [8] is:

- Detection of emerging pathogens
- Better indicator organisms
- Rapid on-line monitoring techniques
- Organic chemical identification & fate
- Treatment performance & reliability
- Continuous (on-line) toxicological testing
- Effect of dilution, soil interaction, and aquifer injection on organic chemicals
- Effectiveness of environmental buffers

To this list could be added ‘effective public communication and education programmes’ for it is crucially important that the community is ‘brought along’ as any advanced reuse project is planned and implemented.

There are obviously many sub-sets to each of the above and they will all have to be addressed to ensure that advanced reuse is viewed as a safe and sustainable way forward.

7. CONCLUSIONS

The freshwater supplies in the world are finite and unfortunately we have not regarded them as such. We have polluted and over-used these precious resources and unless we act now, the future generations will not thank us.

Advanced reuse systems do have a role to play in securing some of our water supplies into the future. Much has been done and we have some ‘trophy’ projects either operating or under design; but there is still a lot to be done. While we have the technology to produce whatever quality is required, we do have to ensure that all regulators, water professionals and the community-at-large accept planned indirect potable reuse as a viable way of augmenting our dwindling fresh water supplies – this is the ultimate challenge.

We also know that advanced reuse systems produce a high quality of water at a fraction of the cost of other more energy-intensive options such as sweater desalination.

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