ADVANCED REUSE - FROM WINDHOEK TO SINGAPORE AND BEYOND

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Abstract

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.

"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

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 treatment plants; as highlighted by the recent NEWater plants in Singapore.

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.

Advanced Reuse Milestones

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 (IPR) scheme, involving

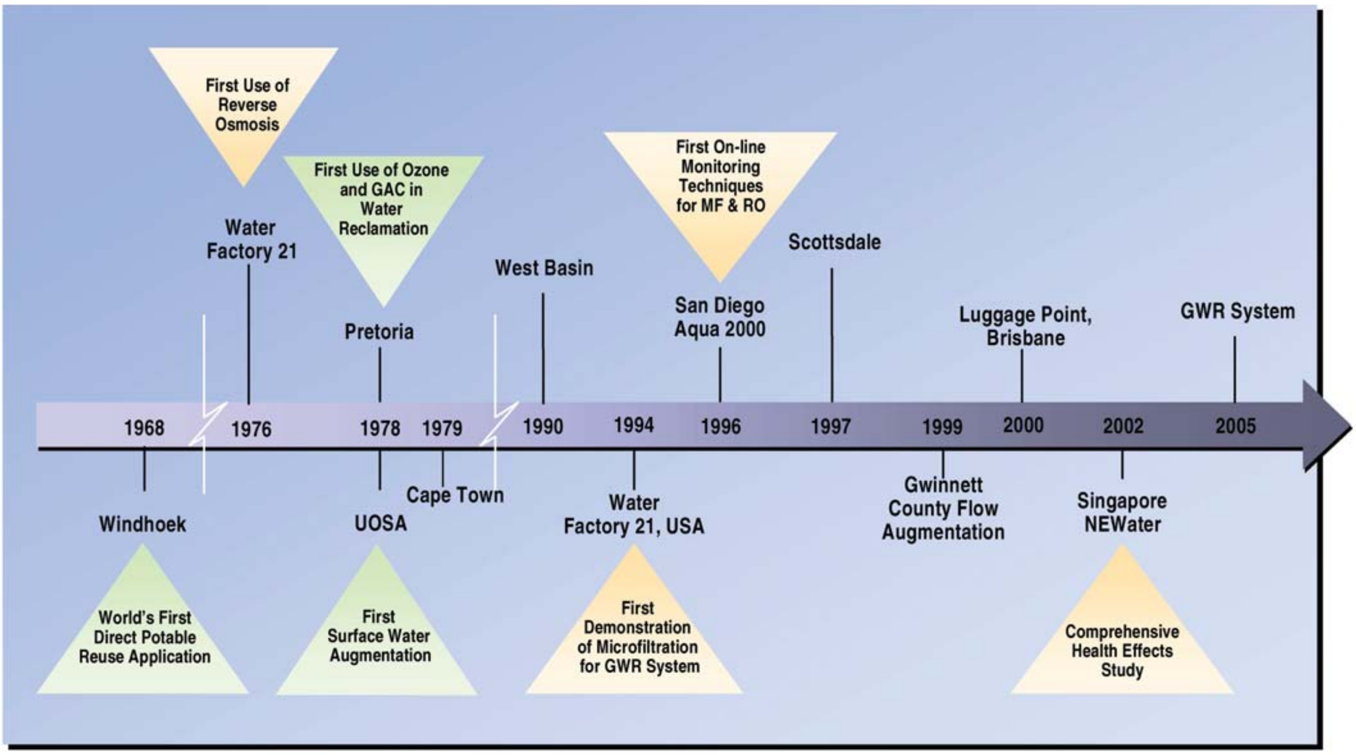

Figure 1. Salient Milestones in Advanced Reuse Applications.

the return of reclaimed water to a surface water reservoir, was commissioned in 1978 at Upper Occoquan Sewage Authority (UOSA) plant in North Virginia, USA.

- 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 MF/RO plant was commissioned at Luggage Point, Brisbane supplying high quality reclaimed water to an adjacent oil refinery
- 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 NEWater plants operational in 2002, initially serving the high-tech industry, but with indirect potable re-use being implemented in February 2003.

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

Figure 2 shows the growth in microfiltration membrane applications for both surface water and water reclamation plants over the period 1990 –1999, showing the exponential growth in membrane usage.

This growth is 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

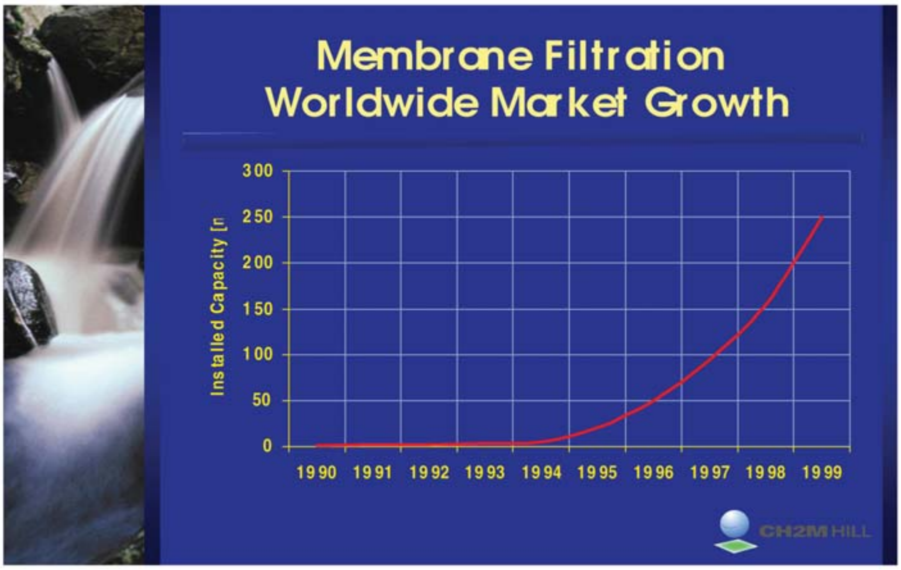

Figure 2. Growth in the Membrane Filtration Market.

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.

Project Drivers and Technologies Applied

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

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 from Malaysia
- 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)

> *"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 1970s.**

Table 2. Comparison of Technologies

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

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 future 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.

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 a treatment train similar to that being used in Singapore; dual membranes followed by UV disinfection.

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% (Leslie *et al* 1998)

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 programs 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.

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. This program was carried out over a two and a half year period and monitored for a range of parameters at a number of locations. It was updated with 'new' parameters as they became 'known' – such as N-nitrosodimethylamine (NDMA) and 1,4 Dioxane.

The number of parameters analysed, by location, is summarised in Table 4. The frequency of analysis varied for each parameter; some weekly, some monthly and some quarterly. It can be seen that,

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:	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

with this extensive database of results and the results from the Health Effects Study, the Government had a sound basis on which to base their decision to proceed with planned indirect potable reuse.

Facts, Perceptions and Opinions

The practice of returning reclaimed water to a reservoir to augment water supplies- be it surface water or ground-water – has certainly created much debate and discussion in both the profes-sional 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 (1979) ,often referred to as the father of research into water reclamation and reuse in South Africa, stated, over 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 purifi-cation 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, if industrial wastes are controlled (or diverted) and if 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.

Table 4. Singapore's Sampling and 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

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

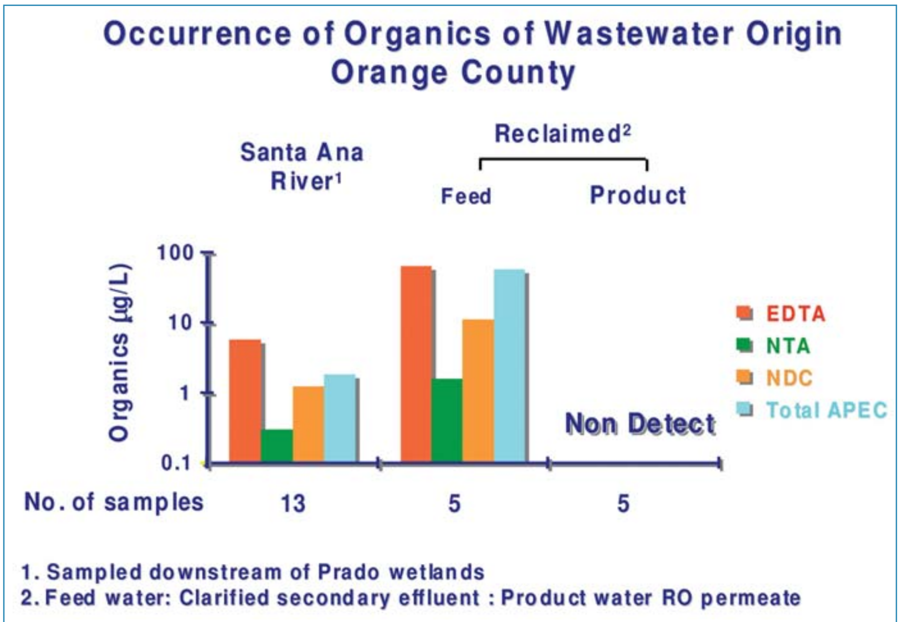

Figure 3. Occurrence of Organics of Wastewater Origin.

used as signature compounds for contamination with municipal wastewater (Leslie *et al* 1999):

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

Figure 3 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 (Leslie *et al* 1999)

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.

It is pleasing to see professional bodies and other organisations agreeing that indirect potable reuse can play a role in prolonging 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 than 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 USA National Research Council (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.

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 individually 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 (Tsuchihashi R *et al* 2002)

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 (Tsuchihashi *et al* 2002)

Into The Future

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 (Law 2002) covers the following tenets

- 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 or Watershed 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.

There will be many instances of reclaimed water being incorporated into *Aquifer Storage and Recovery (ASR)* schemes, whereby it is injected and stored in groundwater aquifers for subsequent abstraction and reuse – much along the lines of schemes already exist around the world – in the UK, the US, Taiwan and Australia to name but a few. This practice serves to augment dwindling groundwater supplies while at the same time affording an extra 'barrier' of treatment to the reclaimed water (Toze *et al* 2001) – an important aspect if the abstracted water is to be used as a potable water supply.

There will be increased application of *Sewer Mining* for advanced reuse applications in cities. Sewer mining involves drawing raw wastewater or treated effluent from a major trunk or carrier sewer direct into a membrane-based treatment plant. The effluent from such a plant is then reused in adjacent industries, houses, public amenity areas etc with all by-products of the treatment process being returned to the sewer for subsequent processing at a centralised WWTP.

Sewer mining has the dual advantage of not only being located near to the 'point of reuse' but of also relieving the hydraulic load on existing major sewer systems. The system was first applied in South Africa in the 1970s with the Alexandra plant and in Australia with the membrane-based facility installed in Canberra in 1994. Developments in membranes over the last decade or so has spawned increasing interest in the system in Australia – in Melbourne and more recently in Geelong. The system is also being considered as part of the infrastructure work being planned for the Beijing 2008 Olympic Games.

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 is:

- Detection of emerging pathogens
- Better indicator organisms
- Rapid on-line monitoring techniques
- Organic chemical identification & fate
- Treatment performance and 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'.

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.

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.

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References

Law I B (2002), *'Total Water Management - the Future is Now'* Paper presented at the CIWEM International Conference on Wastewater Management & Technologies for Highly Urbanized Coastal Cities 2002, Hong Kong, June.

Leslie G L, Mills W R, Wehner M P, Rigby M G, Dunivin W R and Sudak R G (1998), *Treatment Costs for Membrane Processes in Water Reuse Applications; A Sensitivity Analysis*. Proc. American Desalting Association Biennial Conference & Exposition, Williamsburg, Virginia, August.

Leslie G L. Dawes T M, Snow T S, Mills W R.and MacIntyre D (1999), *Meeting the Demand for Potable Water in Orange County in the 21st Century: The Role of Membrane Processes*. Proc. American Water Works Association, Membrane Technology Conference, Long Beach, CA, March

National Research Council (1998), *Issues in Potable Reuse - The Viability of Augmenting Drinking Water Supplies with Reclaimed Water*, National Academy Press, Washington D.C.

Stander G J (1979) *'Micro-Organic Compounds in the Water Environment and their Impact on the Quality of Potable Water Supplies'* Paper presented at the 26th Convention of the South African Chemical Institute, Port Elizabeth, South Africa

Toze S, Dillon P, Pavelic P, Nicholson B and Gibert M(2001), *Aquifer Storage and Recovery: Removal of Contaminants from Stored Water, Water,* **28**, 7, October.

Tsuchihashi R, Sakaji R and Asano T (2002), *Health Aspects of Groundwater Recharge with Reclaimed Water,* Paper presented at 4th International Symposium on Artificial Recharge of Groundwater, Adelaide, Australia.