Membrane Bioreactors (MBR) for Municipal Wastewater Treatment – An Australian Perspective

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EXECUTIVE SUMMARY

With the current focus on water reuse projects and the role they play in the water cycle, the search for cost competitive advanced wastewater treatment technologies has never before been so important. Australia in particular has a need to develop new strategies for water management and will continue to move towards water reuse where such projects are shown to be financially viable. This paper discusses the Membrane Bioreactor (MBR) process and its suitability for Australian water reuse applications.

The MBR process involves a suspended growth activated sludge system that utilises microporous membranes for solid/liquid separation in lieu of secondary clarifiers. This very compact arrangement produces a MF/UF quality effluent suitable for reuse applications or as a high quality feed water source for Reverse Osmosis treatment. Indicative output quality of MF/UF systems include SS < 1mg/L, turbidity <0.2 NTU and up to 4 log removal of virus (depending on the membrane nominal pore size). In addition, it provides a barrier to certain chlorine resistant pathogens such as Cryptosporidium and Giardia.

The MBR process is an emerging advanced wastewater treatment technology that has been successfully applied at an ever increasing number of locations around the world. In addition to their steady increase in number, MBR installations are also increasing in terms of scale. A number of plants with a treatment capacity of around 5 to 10 ML/d have been in operation for several years now whilst the next generation (presently undergoing commissioning or under contract) have design capacities up to 45 ML/d.

Whilst there is currently only a small number of MBR examples in Australia and its surrounding regional area, the trend experienced globally over the last few years is likely to follow in Australia as well.

Based on global research and local knowledge, this paper aims to discuss MBR design considerations from an Australian perspective. It includes discussion on how applicable (or otherwise) this technology may be for Australian conditions and it lists some of the local opportunities and local barriers that this technology may experience. Some of the existing Australian MBR examples are listed and a commentary is offered regarding their project drivers. This paper also highlights some of the difficulties that may be experienced in terms of MBR scale-up and it discusses some of the “lessons” gained from projects involving the scale-up of tertiary filtration membranes elsewhere.

Compared with those in parts of Canada, the United States and the United Kingdom who have embraced the technology so far, many Australian water authorities will require the use of different design information. Particular local considerations such as effluent licence targets, wastewater characteristics, wet weather hydraulic peaking factors, climatic

considerations (temperature), land availability, reuse potential and the characterisation of existing infrastructure are all examined in this paper. This paper concludes that in order to deliver successful MBR wastewater reuse projects in Australia, design teams must fully utilise local expertise in addition to the expertise on offer from those involved in the delivery of previous MBR projects in other parts of the world.

INTRODUCTION

Overview of the Technology

The Membrane Bioreactor (MBR) process is an emerging advanced wastewater treatment technology that has been successfully applied at an ever increasing number of locations around the world. In addition to their steady increase in number, MBR installations are also increasing in terms of scale. A number of plants with a treatment capacity of around 5 to 10 ML/d have been in operation for several years now whilst the next generation (presently undergoing commissioning or under contract) have design capacities up to 45 ML/d.

Whilst there is currently only a small number of MBR examples in Australia and its surrounding regional area, the trend experienced globally over the last few years is likely to follow in Australia as well.

MBR Process Description

The MBR process is a suspended growth activated sludge system that utilises microporous membranes for solid/liquid separation in lieu of secondary clarifiers. The typical arrangement shown in Figure 1 includes submerged membranes in the aerated portion of the bioreactor, an anoxic zone and internal mixed liquor recycle (e.g Modified Lutzack-Ettinger configuration). Incorporation of anaerobic zones for biological phosphorus removal has been the focus of recent research, and there is at least one full scale facility of this type being designed presently in North America. As a further alternative to Figure 1, some plants have used pressure membranes (rather than submerged membranes) external to the bioreactor.

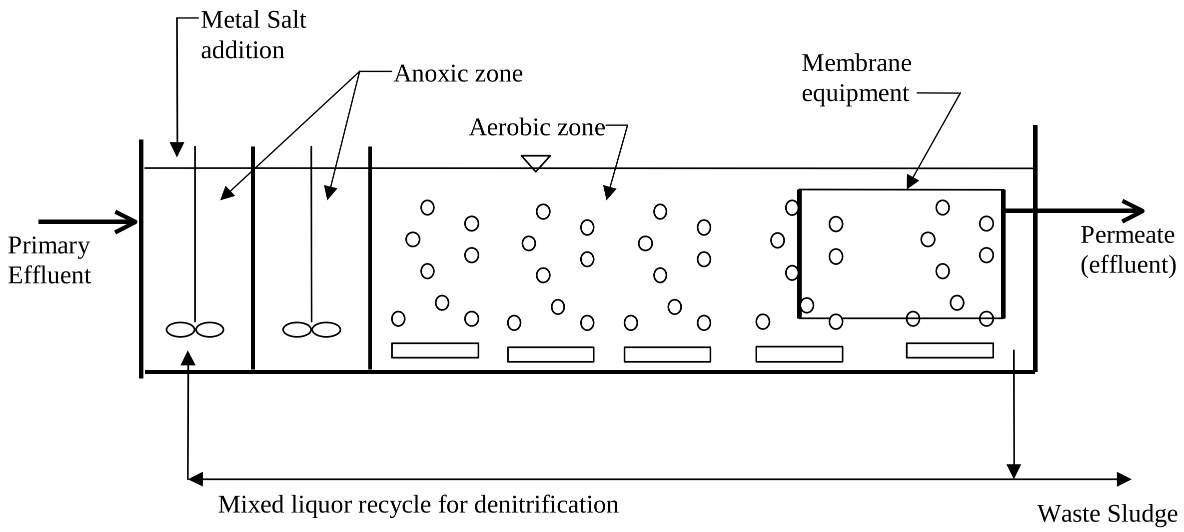
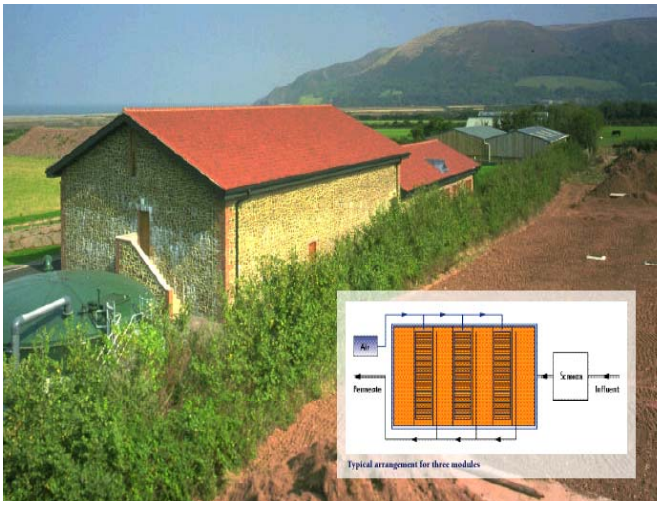


Figure 1: Typical schematic for membrane bioreactor system

Advantages of MBR Systems

The advantages of MBR include :

- Secondary clarifiers and tertiary filtration processes are eliminated, thereby reducing plant footprint. In certain instances, footprint can be further reduced because other process units such as digesters or UV disinfection can also be eliminated/minimised (dependent upon governing regulations).
- Unlike secondary clarifiers, the quality of solids separation is not dependent on the mixed liquor suspended solids concentration or characteristics. Since elevated mixed liquor concentrations are possible, the aeration basin volume can be reduced, further reducing the plant footprint.
- No reliance upon achieving good sludge settleability, hence quite amenable to remote operation.
- Can be designed with long sludge age, hence low sludge production.
- Produces a MF/UF quality effluent suitable for reuse applications or as a high quality feed water source for Reverse Osmosis treatment. Indicative output quality of MF/UF systems include SS < 1mg/L, turbidity <0.2 NTU and up to 4 log removal of virus (depending on the membrane nominal pore size). In addition, MF/UF provides a barrier to certain chlorine resistant pathogens such as Cryptosporidium and Giardia.
- The resultant small footprint can be a feature used to address issues of visual amenity, noise and odour. Example MBR plants exist where the entire process is housed in a building designed to blend in with its surrounding landuse. This can reduce the buffer distance required between the plant and the nearest neighbour and can increase the surrounding land values (ref. Figures 1 and 2 below).



Figures 1 and 2: MBR sewage treatment plants designed to blend in with surrounding landuses

Cost Comparison – MBR Versus Alternative Process Trains

A detailed holistic cost comparison may reveal reasonably comparable results between the cost of the MBR option versus other advanced treatment options, especially if land value is considered. Furthermore, whilst the costs for conventional technologies are slowly rising with labour costs and inflationary pressures, the costs for all membrane equipment (both for direct filtration and MBR) has been falling steadily during each of the last 10 years. Hence on a capital cost basis for any given project, the likelihood of MBR becoming a favoured option is increasing with time. Designers are therefore advised to continuously re-assess the cost information for their particular project as it progresses through the various planning stages over time.

EXISTING MBR INSTALLATIONS – THE GLOBAL EXPERIENCE

Major MBR Equipment Suppliers

There are currently three major suppliers of MBR membrane equipment engaged in large scale municipal wastewater projects. Each is listed in **Table 2** below with a snapshot summary of reference facilities as it currently stands. Many other membrane suppliers are now marketing their own MBR systems and they will no doubt add to this reference list in the near future.

Table 2: Summary of municipal wastewater MBRs

Supplier References	Year of installation of 1st MBR >1 ML/d	No. of MBRs with capacity >1 ML/d	Largest operational MBR	Largest MBR currently under contract
Zenon Environmental	1997	22	38 ML/d Brescia, Italy	45 ML/d Nordkanal, Germany
Kubota	1998	5	8.5 ML/d Daldowie, UK	4 ML/d Seattle, USA
US Filter	2002	1	1 ML/d Park Place,GA	4 ML/d Olympia, WA

It must be noted that this table focuses only on the larger municipal wastewater plants. A full reference list of all MBR installations (inclusive of small scale and industrial applications) would be much more extensive and would include other industrial focussed suppliers.

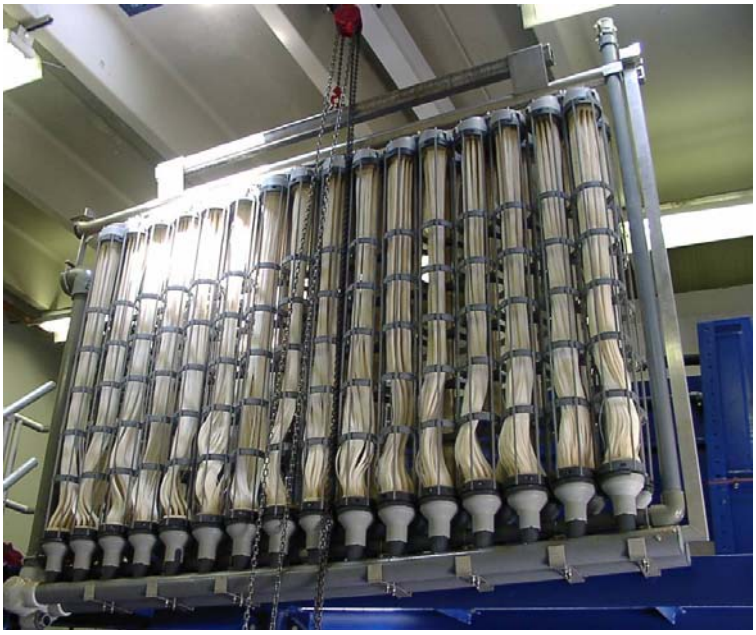


Figure 3: Membranes destined for installation at one of the MBR sites currently under construction

Global MBR Survey

CH2M HILL Australia was commissioned by the South Australian Water Corporation to undertake a global survey of MBR facilities, including those that CH2M HILL helped deliver in North America in recent years. Sites selected for the survey were inspected first-hand by representatives from CH2M HILL. A summary of key information from some of the surveyed sites follows in **Table 3**.

Table 3. Key Information From Global MBR Survey

Location	Capacity		HRT at Peak (hours)	MCRT (days)	Average Flux ($L/m^2.h$)	MLSS (mg/L)	Year	Chemical Clean Interval (weeks)
	Average (ML/d)	Peak (ML/d)						
Cohasset, USA	1.1	2.2	3.5	>100	15.3	12,000	2000	TBD
Porlock, UK	1.1	1.9	5.5	50	13	12-18,000	1998	26
Swanage, UK	6.0	13.0	3	50	10	12-18,000	2000	26
Powell River, CAN	5.4	7.0	3.5	30	18.9	10,000	1998	3
Port McNicol, CAN	1.1	1.6	2.6	TBD	TBD	14-16,000		TBD
American Canyon, USA	9.5	13.6	5.3	30	24.3	10,000		TBD
Creemore, CAN	1.4	2.8	3	25	16	12,000		TBD
Milton, CAN	1.0	2.0	1.5	15	14.8	15,000	1997	52*
Arapahoe County, USA	4.5	6.8	3	20	22.4	13-15,000	1998	6
Anthem, USA	1.0	2.8	3.5	30	24.5	10,000	1999	52*
Lehigh Acres, USA	1.9	2.8	4.6	15	30	13,000	1999	16
Laguna County, USA	1.9	1.9	2.6	TBD	35	10-15,000		TBD
Key Colony, USA	1.3	3.2	5	90	18	13-15,000	1999	16*

** To achieve this interval for ex-situ clean, an automatic in-situ maintenance clean is performed 3 times per week.*
TBD = To be determined.
*** The information presented in this table is based on information supplied by engineers/owners and reflects the operating or design conditions at the time of the interview.*

The global MBR survey provided a snapshot of the current level of development of the MBR technology and provided an insight into the direction in which this technology is heading. The broad range of sites canvassed in the survey included those in very warm and very cold climates and included flat sheet and hollow fibre variants.

The site inspections and dialogue with owners and operators revealed several lessons to be heeded for future projects. This new knowledge coupled with other previous MBR experience has alerted CH2M HILL to "municipal scale issues" such as oxygenation limitation, activities that lead to fibre damage, need for effective pre-treatment, gravity versus suction membranes, dewaterability issues and choice of MCRT and flux. Other general engineering challenges for membrane plant scale-up have also been encountered throughout design of the "NEWater" plants in Singapore (discussion below).

In addition to its valuable contribution to local knowledge of MBR design and operational details, the survey highlighted some of the reasons why MBR was the selected technology for these particular sites. An attempt was made to understand the drivers and design inputs for each project. From this information, parallels and distinctions can be drawn between these sites and potential MBR sites in Australia.

Experience From Large-Scale Tertiary Filtration Membrane Installations

In recent years the Republic of Singapore has invested heavily in high grade water reclamation plants, and has coined the term “NEWater” to describe their potable reuse projects. The production of NEWater via the microporous membrane/reverse osmosis treatment of secondary effluent is currently 72 ML/d in Singapore with the procurement of further capacity already underway. The NEWater is primarily intended to supply the wafer fabrication plants and thereby reduce industry’s demand for potable water. Production of NEWater in excess of the industrial demand will be used to augment fresh water reservoirs for general consumption. Given Singapore’s experience with membrane technologies, MBR is now being given due consideration for future wastewater projects. With recognition of the barriers to be worked through in terms of scale-up, it is still likely that future NEWater facilities could utilise a MBR/RO process at a municipal scale.

Singapore and the Province of Ontario are funding a MBR cooperative research project led by a team made up of the National University of Singapore and the University of Toronto. The purpose is to conduct research including pilot studies into the combination of MBR with UV disinfection as a method to achieve a water quality suitable for reuse. CH2M HILL (Canada) is an Industry Partner, providing support and specialist expertise.

Recent experience from Singapore contributes significantly to the global knowledge pool pertaining to large scale membrane treatment of wastewater.

LOCAL CONSIDERATIONS (LOCAL OPPORTUNITIES AND BARRIERS)

General

Compared with those in Canada, the United States and the United Kingdom who have embraced the technology so far, many Australian water authorities will require the use of different design information. There may be different drivers and opportunities as well as new barriers for this technology. Particular local considerations such as water reuse potential, effluent licence targets, wastewater characteristics, wet weather hydraulic peaking factors, climatic considerations, land availability, and the characterisation of existing infrastructure are all worthy of attention.

Water Reuse Potential (Opportunity)

Australia is the second driest continent in the world (second only to Antarctica). As a direct result of the continent’s water scarcity, most of the population is concentrated along the higher rainfall areas of the East coast. Aside from this geographic dimension of water availability, the other crucial dimension of Australia's water resource is its extreme variability over time. Australia routinely experiences prolonged periods of drought followed by extreme flooding. Large cities such as Sydney and Melbourne utilise large expanses of impounded water to cater for such variability. Despite this, water restrictions and discontinuity of supply in many parts of the country are commonplace during periods of drought.

High quality, effectively disinfected effluent from advanced wastewater treatment systems (such as MBR) are suitable for agriculture, river flow replenishment and many other reuse markets. This is of particular interest as agriculture accounts for around two thirds of all water used in Australia.

For some reuse scenarios, the lower cost alternative of conventional secondary treatment is a suitable standard. However, conventional secondary treatment lacks the ability to effectively inactivate or remove certain pathogens. Residual bacteria, viruses and protozoa may be of concern where the reclaimed water is intended for production of crops eaten raw or where human contact with irrigation water is likely. Hence, basic secondary treatment alone may not satisfy the requirements of some reuse schemes.

Given these factors, it can be seen that Australia has an inherent affinity for advanced technology water reuse projects. In fact, most water authorities in Australia now have a mandate to increase the percentage of wastewater they beneficially reuse – and this mandate is likely to generate further interest in technologies such as MBR.

Effluent Quality Targets (Opportunity)
To cater for the variability of rainfall in Australia, dams have traditionally been constructed on the upper reaches of river systems in an attempt to achieve continuity of water supply. These dams result in a reduction in the natural river flows thereby reducing the river flushing effect. Without effective flushing, nutrients from wastewater treatment plants are somewhat retained in river systems and can contribute to summer algal blooms.

For these and other reasons, Australian authorities now impose some of the most stringent effluent quality requirements for inland wastewater treatment plants found anywhere. Recent plant upgrades have specified TP targets of 0.05 mg/L and others have specified TN targets of 3 mg/L. In contrast, many of the MBR sites surveyed overseas were not required to reduce TP at all and many were not required to reduce TN.

In addition to the limits on nutrients, Australian authorities are also imposing very strict disinfection standards (especially with reuse projects). The recent drafts of reuse guidelines produced in Queensland, Victoria and New South Wales each contain stringent virus standards not seen elsewhere (e.g <2 virus per 50L).

These stringent effluent quality targets result in significant expenditure on wastewater projects in Australia. The clear requirement for advanced treatment provides an opportunity for technologies such as MBR to be cost competitive amongst comparable upgrade alternatives.

Wastewater Characteristics (Barrier)
Whilst raw wastewater characteristics do vary somewhat between catchments anywhere, for coarse design purposes most domestic catchments are fairly comparable on the whole. However, one particular difference seen in Australian catchments compared to those areas surveyed in North America is with influent phosphorus concentrations. The typical value for influent TP in North America appears to be around 5 mg/L, whilst in many parts of Australia this value is more like 10 to 12 mg/L.

This difference heavily influences the quantity of chemical dosing required to reduce TP down to low levels (unless Biological Phosphorus Removal is successfully employed). Reports from Milton (Ontario) suggest that TP can be reduced to 0.05 mg/L using 105 mg/L of Alum. However, for plants with influent TP of 10 - 12 mg/L (rather than 5mg/L), the usage of Alum may double if the same effluent quality is to be achieved. The relevance of this (aside from the chemical consumption costs) is that Australian MBRs with a comparable capacity and MCRT to Milton, would need to be significantly larger to accommodate the additional accumulation of metal sludges.

Therefore, MBR tank dimensions from overseas examples are not directly applicable for sizing MBR plants for local catchments.

Wet Weather Hydraulic Peaking Factors (Barrier)
Despite the separation of drainage and sewerage, East coast sewers evidently suffer from unusually high levels of wet weather infiltration. Various initiatives have been undertaken (such as sewer renewals and smoke testing) in an attempt to reduce the infiltration but these have met with only limited success. Approximately 15 catchments from within the Sydney basin as well as other example catchments from coastal New South Wales, Victoria and Queensland all experience wet weather flows in the vicinity of six to eight times the average dry weather flows.

Other systems in the more arid regions of Australia and other systems overseas, on the most part experience much less pronounced wet weather peaks. Each of the MBR facilities installed to date have had either a low 'peak to average' ratio (around 2 to 3) or they have incorporated large flow balancing tanks upstream of the MBR.

The high levels of wet weather infiltration in parts of Australia certainly represents a challenge/barrier to the use of this technology because the cost of membrane equipment is proportional to the peak hydraulic rate. Any economic neutrality (or advantage) is lost if hydraulic peaks cannot be kept below 2 to 3 times average. It would be cheaper to install flow balance tanks or an alternative wet weather process train than it would be to install additional membrane capacity, however, the installation of large tanks would relinquish the advantage of having a small footprint design.

One option for dealing with high wet weather peaks may be to incorporate a contact stabilisation zone, although this has not been applied anywhere to date. A step feed would allow most of the flow to go through the whole reactor whilst some level of treatment would be given to the remainder in the downstream end of the bioreactor. This design would require a clarifier sized only for the balance of flows exceeding the membrane capacity. This may be an area of future research and design effort.

Needless to say, projects without wet weather issues will be preferred by MBR proponents. Wet weather issues are not present in projects utilising sewer mining, or in projects where a specific reuse train is required to treat only a sub-set of the total flow (say a consistent 5 ML/d from a total 50 ML/d plant flow).

For the case of new development areas, designers are now considering alternatives to the traditional gravity sewerage systems (e.g grinder pump or vacuum systems) to alleviate problems caused by wet weather peaks. There would appear to be a synergistic advantage of using MBR treatment plants in conjunction with these types of collection systems.

Other Climatic Considerations (Opportunity)
A MBR plant located in a warm climate will be less costly to construct than one with an identical capacity located in a cold climate. This is due to the effect that liquid viscosity has on the flow rate of a liquid through the membrane pores (N.B. liquid viscosity is dependant upon its temperature). The minimum wastewater temperature is therefore a major factor in determining the number of membrane modules required to meet a given MBR treatment capacity. Fewer membranes translates to lower costs. Australia's warmer climate is therefore an advantage which will help the technology be cost competitive in this country.

Land Abundance (Barrier)
Generally, the availability of land in Australia is such that very few wastewater treatment plant sites have space limitations. In fact, many sites have allocations of land set aside for

future amplifications. Hence the trademark advantage of MBR, the reduced plant footprint, is not as significant as it may be elsewhere.

However, despite the general availability of land, there will still be many examples where a compact plant footprint is a financial advantage or indeed a necessity.

Examples of where the MBR's compact plant footprint will prove to be an advantage, even in Australia are:

- Coastal plants where the sites are bordered by the coast on one side and high levels of city development on the other.
- Sites encircled by other natural borders such as rivers and natural heritage areas.
- Sites where significant piling is required for all civil structures.
- Neighbour issues (noise, odour, aesthetics) have lead to entire plants being housed within a building designed to blend in to the local environment. MBR lends itself well to this concept e.g. Porlock, Swannage, Cremore, Elm St and Westview are all MBR plants contained entirely within a building. This concept can lead to reduced buffer zones around the plants, which in turn can result in reduced project costs for new plants being built in developed areas.

Characterisation of Existing Infrastructure (Barrier)

Many existing wastewater treatment plants in Australia do not lend themselves very well to the retrofitting of membranes into their existing bioreactors. Pasveer ditches, carousel bioreactors and intermittent processes each present significant challenges to such retrofits. Each of these types of plant are unusually prevalent in Australia compared to many other parts of the world.

The high horizontal linear velocity inherent in a ditch or carousel bioreactor is not compatible with the need to provide a perfectly vertical air scour to the outside of the membranes. Hence direct immersion of membranes into the ditch or carousel would not be feasible. It may be feasible to design a retrofit upgrade where mixed liquor is diverted into a new box containing the membranes, however, the additional civil costs and additional pumping would significantly impact on the project costs.

With intermittent processes (e.g. SBR, IDAL, IDEA), the retrofit of membranes into the bioreactor would appear to be incompatible if the process is envisaged to continue to be intermittent. However, in Arapahoe County, Colorado, an existing SBR civil structure was successfully converted into a continuous MBR process.

Of the MBR facilities surveyed in North America and the United Kingdom, only half were retrofit projects, so the characterisation of existing infrastructure is only partially relevant.

AUSTRALIAN MBR PROJECTS

General

A number of local MBR projects have already been initiated. The types of projects considered to date range from pilot studies and demonstrations through to full scale applications, some of which are described below.

Several observations can be made from the following examples. Firstly, the interest in this technology is spread right across the country and secondly, at least three major suppliers are already actively involved in local projects.

Picnic Bay (Magnetic Island),Queensland
Commissioned in October 2002, Picnic Bay is the first 'full-scale' or permanent membrane bioreactor facility in Australia. Although expandable, the plant has an initial capacity of only 0.54 ML/d. Aquatec-Maxcon was awarded the prime contract, utilising Kubota flat sheet membranes. The membranes and associated process expertise were provided via Aquator MBR Technology, UK. Some of the project drivers or factors leading to the selection of this technology include the benefits of modular expansion and the need to produce a very high water quality (environmentally sensitive area located in the world heritage protected Great Barrier Reef).

Victor Harbor, South Australia
Following an expression of interest and tendering process, SA Water and a preferred tenderer are finalising negotiations for the Victor Harbor MBR wastewater treatment plant, to be delivered under a 20 year BOOT contract. Plant capacity is based on an annual average flow of 5.2 ML/day and a peak day flow of 9.2 ML/day. SA Water did not specify the type of MBR system, and further details of this aspect of the project are yet to be announced.

King's Domain Gardens Demonstration Plant (Melbourne), Victoria
This MBR was operated as a demonstration project from late February to April 2002. The pilot scale facility was housed in a shipping container and delivered around 30 kL/d of recycled water to the King's Domain Gardens in Melbourne. The project was aimed at increasing community awareness about water recycling and is a good example of the sewer mining approach. Delivery of the project was managed by Earth Tech Engineering, utilising Zenon membranes. Some of the project drivers or factors leading to the selection of this technology include the benefits of small footprint, the benefits of stable operation and the need to produce a very high water quality.

Rouse Hill Pilot Study (Sydney), New South Wales
A trial was carried out from March to May 2003 at the Sydney Water Rouse Hill Recycled Water Plant in conjunction with Veolia Water and Memcor Australia. The project involved trialling a 24 kL/d low-pressure hollow fibre membrane system. Mixed liquor from the treatment plant's existing BNR process was concentrated to around 12,000mg/L and fed to the submerged membrane pilot module. The study included simulations of various operating conditions such as diurnal flow and peak flow studies, low dissolved oxygen and high mixed liquor concentration studies. Pathogen testing was included as part of the trial. This project was performed to increase understanding within Sydney Water of low-pressure membrane systems and to gain an understanding of the resultant effluent quality compared to existing systems.

Other Projects
Other MBR pilots and full scale plant proposals continue to be considered by all sections of the Water industry. The trend seems to be for an increased interest in MBR within Australia and the region.

CONCLUSION

The global trend is for an increase in the number of MBR installations, largely due to the declining membrane costs and the increasing demand for water.

It appears that the projects most likely to favour MBR have an alignment of factors such as a requirement for reduced plant footprint coupled with a need for high quality reuse water.

In order to deliver successful MBR projects in Australia, design teams would fully utilise local experience in addition to the experience gained from previous membrane/MBR projects elsewhere in the world, thereby streamlining the design process and avoiding all of the known pitfalls.

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