BEFORE AN INDEPENDENT HEARINGS PANEL OF THE WAIKATO REGIONAL COUNCIL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of an application by Watercare Services Limited for regional resource consents required for the Pukekohe Wastewater Treatment Plant at Parker Lane, Buckland

STATEMENT OF EVIDENCE OF JAMES WILLIAM BRADLEY ON BEHALF OF WATERCARE SERVICES LIMITED

1. INTRODUCTION

1.1 My full name is James William Bradley. I am a Senior Consultant - Wastewater and Public Health Engineer at Stantec New Zealand Limited (**Stantec**), which was formerly MWH New Zealand Limited. I have been employed by this firm and its predecessor firms for my 47 year professional career. A summary of my experience is set out in **Attachment A**.

1.2 I hold the degrees of Bachelor of Civil Engineering with first class honours from the University of Canterbury (1969) and a postgraduate Diploma in Sanitary Engineering, Master's Equivalent with distinction, from the Delft (Netherlands) International Courses 1973. I am a Chartered Professional Engineer (Civil/Environmental (Public Health)) in New Zealand, an International Professional Engineer, a Distinguished Fellow of the Institution of Professional Engineers New Zealand (IPENZ) and a Diplomat of the American Academy of Environmental Engineers. I am an Accredited RMA Decision Maker.

1.3 I have read and I am familiar with the Environment Court's Code of Conduct for Expert Witnesses December 2014. For the purpose of this hearing, I agree to be bound by that Code of Conduct and have familiarised myself with the requirements as set out in the Code.

1.4 This evidence is provided in support of the three regional resource consents sought by Watercare in relation to the Pukekohe Consents Project (**Project**).

2. SCOPE OF EVIDENCE

2.1 My evidence will address the following matters:

(a) My involvement in the application to date;

(b) Overall approach to this consenting Project;

(c) Methodology used for assessment of alternatives (in terms of RMA terminology hereafter referred to as **options**);

(d) Information on the shortlisted options;

(e) Proposed Enhanced Membrane Bioreactor (**Enhanced MBR**) and Ultra Violet Light (**UV**) disinfection system treatment plant processes;

(f) Consent duration;

(g) Conclusion.

3 SUMMARY

3.1 I consider the overall approach to this Project, from a wastewater technical assessment viewpoint, has been well developed, well resourced, thorough and robust.

3.2 The stepwise evaluation of 44 alternatives/options **(options)** through, firstly the Phase One Project, and secondly the Phase Two Project, ensured a thorough assessment that progressively addressed matters raised through the consultation process by tangata whenua, and other stakeholders and interested parties that led to the confirmation of the Proposed Wastewater Scheme.

3.3 In my opinion the choice of the Enhanced Membrane Bioreactor and UV disinfection (**Enhanced MBR & UV**) treatment system, with discharge to Parker Lane Stream after the wetlands, is an appropriate technical solution.

3.4 I support the use of the term "Enhanced Membrane Bioreactor" as this term is now in international usage.

3.5 I note the Officers Report similarly supports the current and proposed technology and further records that "the proposed upgrade" is considered at the top of the technology for treatment of wastewater of this nature.

3.6 The Proposed Wastewater Scheme provides flexibility to accommodate future capacity, treated wastewater quality, and any discharge/beneficial reuse opportunities in the longer term, should these be necessary and appropriate.

3.7 I support the technical conditions Watercare have suggested be applied to the consents sought, and also the 35 year consent durations sought.

3.8 I do not agree with the Officers report on the matter of requiring a drinking water technology in order to support the issue of a 35 consent duration.

4 INVOLVEMENT WITH APPLICATION TO DATE

4.1 My main role in this Project was to assist with the development of a robust options assessment, firstly for the Phase One Project, and then the Phase Two Project. Mr Bourne covers in his evidence the background to the change from Phase One, to the Phase Two approach of seeking long term consents from the outset.

4.2 I was initially involved in the Phase One options assessment, and the associated parts of the Phase 1 February 2015 Assessment of Effects documentation, lodged with the short term consent applications in March 2015.

4.3 When Watercare decided to change to the long term Phase Two consenting process, I was further involved in the Phase 2 options assessment and related discussions on the Project as a whole. I assisted with the preparation of the options assessment in the Assessment of Effects on the Environment Volumes 1 and 2 September 2016 (**AEE**).

4.4 I also provided input into other aspects of the Project drawing on my experience gained from many other municipal wastewater consenting projects. This input involved aspects of the future wastewater flows and loads assessment, timing implementation of new physical works, suggested consent conditions and consent duration.

5 OVERALL APPROACH

5.1 Based on my experience in, and often leading, the technical aspects of municipal wastewater consenting projects throughout New Zealand, I consider that the overall Project approach followed was well-developed and resourced. I specifically refer to Section 1.4 and Figure 1-1 of the AEE that overviews the approach to the

Project. Mr Mark Bourne has included in his evidence as Attachment A Figure 1-1 from the AEE which diagrammatically shows the project development activities.

5.2 I note that advancing the Phase Two consent applications before the Phase One applications were processed could be considered somewhat unusual. The timing and reasons why Watercare chose to do this, rather than continuing with the Phase One application, are in my opinion sound as provided long term consents are issued, this gives certainty for growth to take place in line with projections over the 35 year duration sought. The end result achieves a better overall result in terms of responding to tangata whenua's concerns as expressed in the Cultural Impact Statements that have been prepared. It also achieves a better result for the freshwater receiving environment, as a higher (more stringent) level of wastewater treatment is achieved. Summary Tables E2 and E3 (Executive Summary) of the AEE illustrate this. Aspects of these tables are covered by other witnesses.

6 METHODOLOGY USED FOR ASSESSMENT OF OPTIONS

6.1 I was closely involved in the development and implementation of the options process and in the compilation of Section 6 of the AEE and Volume 2, AEE Supporting Document No. 1 (which includes more extensive information on the approach and on the full range of options considered).

6.2 In the Phase One Project, a number of options were evaluated along with the identification of additional options that would be further considered when the long term consents were prepared.

6.3 Following Watercare's decision to move straight into the longer-term Phase Two Project, these additional options were investigated in some detail as part of the stepwise process followed.

6.4 In all a total of 44 options were identified and evaluated.

6.5 The stepwise process followed is set out in Attachment B of my evidence (Table 6-2 from the AEE) and Attachment C (Figure 6-1 of the AEE). These attachments show how the progressive stepwise approach through Steps A to F was followed. Step F is the Phase Two process of shortlisting options, from which the preferred solution (denoted Option F3) was selected i.e. Enhanced Nutrient Removal and UV disinfection, followed by a discharge to Parker Lane Stream. The preferred solution then became the Proposed Wastewater Scheme (**Proposed Scheme**) as outlined in the AEE.

6.6 To summarise, steps A to F involved (refer also to my **Attachments B and C**):

Step A This involved assessment of earlier Watercare and the former Franklin District Council’s stand-alone reports each of which had a different focus, but provided a useful starting point for the Project.

Step B This identified the four categories of options that were to be considered, namely options in respect of wastewater management; generating less wastewater; treatment processes and locations; and wastewater discharge and beneficial reuse.

Step C This identified some 18 options that fitted under the four Step B categories. This was the Phase One shortlist, from which a proposal (a 3 year discharge to Parker Lane Stream, followed by a 4 year discharge, after MBR treatment, directly to the Waikato River) was chosen to form the basis of the 2015 (Phase 1) resource consent application.

Step D This involved a broadening of the Phase One options beyond those involving a discharge direct to the Waikato River. This was in response to feedback on the 2015 resource consent application received and through consultation with tangata whenua.

Step E This involved further consideration of Phase One options based on discharge either to Parker Lane Stream or directly to the Waikato River. These options again reflected further output from consultation with tangata whenua. Nine options were included in this step of the evaluation.

Steps A to E were part of the Phase One Project.

Step F This step incorporates the Phase Two, two options assessment and shortlists five options (F1 to F5) from which the Proposed Scheme was selected. I elaborate on each of these short listed options below.

6.7 Attachment C shows in green the progressive stepwise identification of the options developed that feed into the selected option in Step F, being the Proposed Wastewater Scheme.

7 SHORTLISTED OPTIONS

7.1 As set out above, Step F of the evaluation shortlisted five options and the detailed assessment of these detail against the criteria of technology, estimated costs, positive and potential and actual adverse effects, advantages and disadvantages and social and Māori cultural considerations. Table 6.3 of the AEE summarises this evaluation with further information included in Volume 2 AEE Supporting Document No 1. The five shortlisted options are summarised below. All options included were compared on a projected wastewater volume for 2051 and the effects associated with discharge/reuse etc. of those volumes of treated wastewater.

Shortlisted Option F1 – Land Application

7.2 This option was investigated at a high level. To dispose of the median daily discharge volume of 20,960m^3/day via land application through to (35 year consent duration) 2051 would require an irrigation field of between 655 and 873 hectares. The land purchase and scheme construction were estimated at a capital cost of between $229M and $249M excluding GST (2016 values). A discharge of treated wastewater to water or use of large storage facilities would also be required to handle high wet weather wastewater inflows to the Pukekohe Wastewater Treatment Plant (**WWTP**) as the investigation was based on median flows. High wet weather flows would require extensively more land and be at a time when the ground is likely to be wet and less able and possibly not able to absorb the applied treated wastewater.

Shortlisted Option F2 – Tasman Sea Offshore Outfall

7.3 This option involves a pumping station or stations for the conveyance of the treated wastewater from the WWTP for approximately 33km to an offshore ocean outfall with multiport diffuser. The outfall was assumed be about 2km long. A lesser quality of treated wastewater could be acceptable for this discharge, such as that achieved by the existing, (but expanded in size), Sequencing Batch Reactor (**SBR**) and UV disinfection treatment plant. Even with a lesser degree of treatment, the indicative capital cost estimated was in the order of $462.3M (2016 values).

Shortlisted Option F3– The Proposed Wastewater Scheme

7.4 This scheme involves a two staged to a full upgrade of the Pukekohe WWTP with an enhanced nutrient removal MBR and UV treatment followed by a discharge to

Parker Lane Stream. This Scheme has been elaborated on by Messrs Bourne and Morgan in their evidence. The Scheme is considered to be the Best Practicable Option (**BPO**) by Watercare and its advisors.

Shortlisted Option F4 – Managed Aquifer Recharge

7.5 Managed aquifer recharge, which is in effect a beneficial reuse technique, was initially identified as a Phase Two option. When this Project was changed to include Phase Two, investigations by groundwater consultants PDP for Watercare's South West Sub-Regional Wastewater Servicing project were reviewed in the context of this Project. Those investigations identified that a managed aquifer recharge scheme for the assumed 2051 median daily flow (20,960 m^3/day) would require:

a) installation of an Advanced Water Treatment Plant (as referred in Section 9.1 (b) of my evidence) after the MBR and UV treatment plant

b) an injection well field with 10 to 15 wells

c) a wet weather treated wastewater flow elsewhere to handle greater than median daily flows.

7.6 An indicative capital cost of $280M (2016 values) was developed for a scheme in the general Pukekohe/South Auckland area. As noted however, in Section 9.1(b) below such a scheme, or a smaller scheme to handle part of the daily median volume, could always be installed at a future date.

Shortlisted Option F5 – Beneficial Reuse

7.7 This option is seen as an "add on" option should there be a sustainable and cost effective beneficial reuse option, for all or part of the daily treated wastewater volume. The treated wastewater is often called "reclaimed water" when a very high quality is required for beneficial reuse. Watercare's approach (refer Section 6.4.5 of the AEE) is that it would consider facilitating such an approach if there is a "fit for purpose" opportunity.

8 ENHANCED MBR AND UV DISINFECTION SYSTEM TREATMENT PLANT PROCESSES

8.1 The Proposed Wastewater Scheme and the reasons for selecting it have been covered by the Watercare witnesses. I support this decision and the use of the

terminology of "Enhanced MBR". The reasons why I support the Proposed Scheme are as follows:

a) The proposed Enhanced MBR and UV treatment process is an appropriate choice for the technology required to achieve acceptable environmental outcomes as determined by others

   There are many examples of the application of this technology globally and approximately five in New Zealand to confirm successful applications.

b) The proposed technology is modern, and consistent with recent global trends in Wastewater management. I elaborate on this in Section 8 below and refer to Attachments D and E.

c) The combination of the MBR and UV disinfection provides a "double barrier" system for disinfection of pathogenic organisms, thereby providing very effective public health protection as is outline by Mr Pete Loughran in his evidence.

d) Experience elsewhere in New Zealand confirms that the proposed upgrade to the existing treatment plant can be implemented within the time frames Watercare has set out, namely four years from the issue of consents, should they be issued.

e) In terms of the Proposed Scheme being a Best Practicable Option (BPO) as set out in Table 4-8 of the AEE, the proposed Scheme in my opinion well meets one of RMA BPO requirements in terms of :-

   "the current state of technical knowledge and the likelihood that the options can be successfully applied".

8.2 As referred to by Messrs Bourne and Morgan in their evidence, the combination of the Enhanced MBR and UV disinfection provides a "double barrier" approach to the removal of pathogenic microorganisms. Along with the proposed upgrade of Rotorua's wastewater treatment plant to full MBR with UV disinfection for discharge to Lake Rotorua, the Proposed Scheme will be a first of this type in New Zealand for a relatively large sized municipal treatment plant. There are at least five smaller municipal plants using MBRs, and there are likely to be more in the future. Watercare is also planning to use MBRs for the South-West Sub-Regional Scheme and Snells Beach Scheme.

8.3 Internationally, membrane technologies are playing an increasingly vital role in providing an effective treatment process to produce high quality treated wastewater. For example, during the last 10 years the annual growth globally of MBR's has been 15%. The reasons for the popularity for these plants is that:

a) they remove much higher rates of total nitrogen, total phosphorus, suspended solids and microorganisms

b) capital costs are similar to other traditionally used conventional biological nutrient removal (**BNR**) processes

c) they have smaller foot print requirements and fewer chemical requirements.

d) energy costs requirements and while relatively high, have also been reducing as refinements to the technology advances.

8.4 **Attachment E** includes a paper prepared by the International Water Association's Specialist Membrane Committee. This paper is included in the Associations 2015 publication – "Compendium of Hot Topics and Features". This publication sets out global trends in the use of membranes. It is my opinion that the paper well supports Watercare's selection the MBR treatment process for the Pukekohe WWTP.

8.5 The term "Enhanced MBR" has been adopted by Watercare in this Project. Use of this term is entirely consistent with international terminology. The word "Enhanced" is used to indicate that biological nutrient removal (**BNR**) of nitrogen and phosphorus is to be, or is being, achieved at higher levels than those normally achieved by other Biological Nutrient Removal (BNR) treatment configurations.

8.6 This is highlighted in a recent technical paper published by WaterWorld titled "Wastewater Industry Moving Toward Enhanced Nutrient Standards". This paper is included as **Attachment D**. The introduction and conclusion of the paper is reprecuced below:

> *Introduction*
> *Most people involved in the wastewater industry are familiar with biological nutrient removal (BNR) where biological processes are incorporated into wastewater treatment systems to reduce effluent total nitrogen to an average level of 8 to 10 mg/L and total phosphorus to an average of 1 to 3 mg/L before being discharged into a receiving water. Certain receiving waters are showing evidence that BNR limits are not strict enough to protect water quality and, as a result, these levels are still causing unbalanced ecosystems.*

A new acronym is therefore being thrown into the mix: enhanced nutrient removal or ENR. ENR further refines the BNR process and removes total nitrogen to levels as low as 3 mg/L and total phosphorus to 0.3 mg/L or less. "

. . .

Conclusion

In essence, ENR is simply the next step in the natural technological progression of wastewater treatment processes, starting with primary treatment, through secondary and advanced treatment, then biological nutrient removal, and now enhanced nutrient removal. Regardless of a facility's particular circumstances, a variety of innovative technologies and cost-effective processes can be called upon to meet these new challenges.

8.7 In comparison to the concentration figures mentioned above, the average total nitrogen concentration of the proposed Plant will be 4.2mg/L with an average total phosphorus of 1.0mg/L. A much lower phosphorus concentration could be achieved in the future if required by dosing with alum.

8.8 Section 9 of the Officer's report includes the following statements in support of the proposed treatment upgrade:

"I am of the opinion that the current and proposed technology is at this stage the most appropriate treatment for the type of wastewater it is required to treat"[1]

and also

"Whilst the proposed upgrade is considered at the top of the technology for the treatment of wastewater of this nature…"[2]

9 FUTURE SCHEME FLEXIBILITY

9.1 Best practice wastewater management planning and infrastructure installation for wastewater treatment and discharge systems normally requires that future flexibility is built into the scheme components. The flexibility ensures that the components are able to be expanded, modified or retrofitted to meet future needs which cannot be predicted with certainty or are not affordable, at the time of seeking consents and installing new infrastructure. The Proposed Wastewater Scheme has future flexibility in terms of a number of its components including:

1 Officer's Report, Section 9, p. 24.
2 Ibid.

(a) The WWTP can incorporate additional treatment modules to meet future increases in wastewater volumes in excess of those consented and to accommodate new treatment infrastructure.

(b) The WWTP can incorporate additional treatment processes and/or operational modifications to meet higher quality standards if required in the future. Standards could, for example, be required for aquifer recharge or other beneficial reuse for industrial/agriculture/horticultural purposes. Additional treatment could be achieved through Ultrafiltration and Reverse Osmosis (UF/RO) processes with possibly hydrogen peroxide included to operate in conjunction with UV disinfection. That is for example an Advanced Water Treatment Plant as I refer to elsewhere in this evidence. These additional processes would constitute an Advanced Water Treatment Plant as referred to in Section 7.6 above and also in the Officer's Report. There are other beneficial reuse options that would not require such a high degree of treatment.

10 OFFICER'S REPORT

10.1 In Section 8.8 above, I referred to the Officer's comments supporting Watercare's proposed Enhanced MBR and UV treatment system.

10.2 I now specifically comment on the Officer's position in respect to suggesting additional existing technology to support a 35 year consent duration Section 9 of the Officers Report states:

"I am aware of the additional existing technology can provide even better water quality of the discharge. For example I am aware that the treatment of water for drinking water supplies provides for a higher level of treatment again than is proposed as part of this process. If this technology were to be in place for the discharge within 20-25 years then the applicant's requested duration would likely be supported."

10.3 I concur that proven and currently used technology is available to produce drinking water quality from municipal wastewater. These types of plants are often referred to as Advanced Water Treatment Plants. Sections 9.1(b) and Section 7.6 of my evidence refer to these types of plants.

10.4 In my experience through many municipal wastewater consent projects, the principle driver as to the technology adopted is the output from the assessment of the effects on the environment. That is an "effects driven solution". Just applying

an Advanced Water Treatment Plant when not supported by environmental effects assessments is in my opinion a technology driven solution.

10.5 By contrast installing technology for what may appear to be for technologies sake, when not supported by the effects assessment, does not in my opinion, mean that technology should be applied. This is what I term a “technology driven solution” in contrast to “an effects driven solution”.

10.6 It is also important to note that an Advanced Water Treatment Plant produces what is known as a reject concentrate discharge which contains high salt levels and other contaminants removed from the treatment process. This normally accounts is 20-30% of the volume of treated water produced. The issue arises as to what to do with this concentrate and where can it be discharged. Mr Garrett Hall covers this matter in his evidence. He identifies that there could be a range of significant adverse effects associated with the discharge of this contaminant. This was identified as a major issue for this type of pant in the options assessment that I have been involved in for Rotorua District Council’s Wastewater Consents Project. I note that there are no wastewater treatment plants in New Zealand that include an Advanced Water Treatment Plant.

10.7 An Advanced Water Treatment System to produce drinking water would be very expensive both to install (estimated capital cost $80M June 2016 basis AEE Support Document 1 – Section 5.6.3) and to operate.

11 CONSENT DURATION

11.1 As covered in the evidence of Mr Cunis and Mr Bourne, 35 year duration consents have been sought. Such an approach is in my opinion appropriate. It provides Watercare with a level of infrastructure security that is important in terms of the value of their investment and the need for on-going long term strategic planning.

11.2 There are many long term (35 year duration) consents for appropriately treated municipal wastewater discharge that have been issued in recent years. In all cases the consent applications have in my opinion been supported by well researched and documented considerations of alternatives, sound consultation and thorough assessments of effects. I have been involved in a number of these consenting projects.

11.3 I have compiled Tables 1 and 2 which summarises a number of municipal wastewater consents in the Waikato Region and also in other regions of New Zealand. I have prepared this table in an endeavour to compare where Watercare's application fits in relation to other consents. In making these comparisons I am mindful however that each situation needs to be considered in terms of the local planning and environmental context. Tables 1 and 2 provides some national context for how municipal wastewater consents discharge are being treated. .

11.4 Table 1 sets out the position with a number of other treated wastewater discharge permits in the Waikato Region particularly the Waikato River catchment. The purpose of preparing this is to be able to compare consent duration, nutrient (nitrogen and phosphorus) treated wastewater concentrations and levels of financial investment.

11.5 The key points I consider important coming out of Table 1 in terms of the consent duration Watercare is seeking are that:

a) The proposed Enhanced MBR and UV disinfection plant needs to achieve at the end of the consent term a lower total nitrogen and total phosphorous concentration than any of the other consents listed in Table 1 that discharge within the Waikato River Catchment.
b) As set out in Mr Hall's evidence the proposed discharge is into the lower reaches of the Waikato River where the proposed discharge will result in lower contributions towards chlorophyll a (algal biomass) concentrations downstream when compared to the existing discharge.
c) The proposed plant will provide a higher level of treatment than any of the other plants included in Table 1. In my view the plant is "state of the art" technology.
d) Watercare is making a very substantial investment ($143M September 2016 basis) in the proposed new treatment technology which when considered in the context of Table 2 supports the granting of a 35 year consent in terms of the need to have financial security to support the investment in the asset.

11.6 Table 2 includes a selection of 35 and other long term Municipal Wastewater consents (discharge and coastal permits) from other regions in New Zealand that cover discharges to fresh water, land and marine waters.

11.7 The key points I consider important coming out of Table 2 in terms of the consent duration Watercare is seeking are:

a) Demonstrating that there are a significant number of 35 duration resource consents for municipal wastewater discharges in New Zealand.

b) In almost all cases there has been significant investment in upgrading treatment technologies and discharge infrastructure by the local authorities and this has been a key factor supporting the seeking of a 35 year duration.

11.8 My experience in many other municipal wastewater consent projects has highlighted how local authorities in seeking new consents especially where substantial expenditure is required have stressed the need in their applications for financial security for the infrastructure investment they are making. The granting of long term consents provides this level of financial security as far as the provisions of the RMA can. It is noted that the economic asset life is very much longer than 35 year consent duration especially for civil engineering structures (tankage etc) and pipelines. Mr Jaduram clearly highlights this matter.

11.9 For long term consents (35 year duration), it is appropriate in my opinion, to have specific reviews and other scheme-specific conditions put in place. This has been the case with the wastewater consent projects I have been involved with. These conditions are often included in the General Conditions section of a consent. In this respect Watercare has suggested a condition requiring a Monitoring and Technology Review Report be undertaken firstly by 30 September 2026 and thereafter at 10 yearly intervals. Refer to Watercare's currently suggested Conditions 20 and 21.

11.10 I have been involved in undertaking Hamilton City Council's and Whangarei District Council's Ruakaka five yearly wastewater consent reviews which is required by similar consent conditions. This has demonstrated the effectiveness of this approach in terms of keeping up to date with technology advances and any environmental changes. They provide the consent holder and the consent authority with the information to consider whether there is a need to make changes to conditions or such matters as treatment processes. Mr Scrafton elaborates on this proposed condition.

11.11 Based on my experience of being involved in many municipal wastewater consents, I consider all of the above matters need to be considered in determining the duration of consents.

Table 1: Selection of Local Authority Municipal Wastewater Schemes and related treated wastewater discharge consents in the Waikato Region highlighting consent duration, key treated wastewater qualities and level of new investment to meet new consents.

Location/Local Authority Wastewater scheme	Treatment Technology – Prior to issue of current consent	Treatment technology – required to meet current consent	Year Current Consent Issued Date	Consent Term Years (Expiry Date)	Median/Average Total Nitrogen Concentration gm/m³	Median/Average Total Phosphorus Concentration gm/m³	Treated Wastewater Discharged To	Level of new investment to meet current consent
Waikato River Catchment								
Te Kuiti	Oxidation ponds and activated sludge reactor	Biological Nutrient Removal (BNR) upgrading and tertiary filtration and UV disinfection	2014	25 (2039) (as sought)	6.2[1]	4.3[1]	Mangaokewa Stream	Major upgrade of BNR reactor plus tertiary filtration and UV disinfection
Otorohanga	Oxidation Pond + wetlands	Oxidation Pond + wetlands	2012	25 (2037) (as sought)	18.5	3.3	Mangaorongo Stream	Upgraded oxidation ponds and wetlands
Hamilton	Biological Nutrient Removal (BNR) plant and UV disinfection	Progressive expansion of plant with growth to remove more nitrogen and phosphorus	2006	20 (2026)	8.6[1 2] Summer	1.6[1 2] Summer	Waikato River	Considerable, new treatment units with growth
Huntly	Oxidation pond and wetland	Oxidation pond and UV disinfection and wetland	2011	18 (2029)	20	8	Waikato River	Upgraded oxidation ponds and wetlands and gravel filter bed

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Location/Local Authority Wastewater scheme	Treatment Technology – Prior to issue of current consent	Treatment technology – required to meet current consent	Year Current Consent Issued Date	Consent Term Years (Expiry Date)	Median/Average Total Nitrogen Concentration gm/m^3	Median/Average Total Phosphorus Concentration gm/m^3	Treated Wastewater Discharged To	Level of new investment to meet current consent
Ngaruawahia	Oxidation pond and wetlands	Oxidation pond and Actiflo (nitrogen and phosphorus removal) and UV disinfection	2011	18 (2029)	25	8	Waikato River	Actiflo (for TN and TP removal and clarity improvement and new gravel filter bed)
Te Kauwhata	Oxidation pond and wetlands	Aqua Matts and plus wetlands	2013	15 (2028)	8	5.6	Lake Waikare	Significant (aqua mats)
Others in Waikato Region								
Whitianga	?	Biological Nutrient Removal (BNR) Plant	2011	30 (2041)	Not exceeded 150kg/Ha/year	No loading rate	Land (Eucalyptus Trees)	?
Pauanui/Tairua	?	New treatment plant	2010	20 (2030)	10[3]	5[3]	Land	?
Whangamata	?	?	2011	25 (2036)	No limit bore measurement	No limit bore measurement	Tairua Forest	?
For Comparison								
Pukekohe Watercare These consent applications	Sequencing Batch Reactor (SBR) and UV disinfection and wetland	Proposed Enhanced MBR and UV disinfection and wetland	Hearing August 2017	35 years sought by Watercare	4.2[4]	1.0[4] (or lower)	Parker Lane Stream and then Waikato River	Very substantial upgraded treatment plant, estimated costs $143M (Sept 2016 basis)

Notes:

1. Concentration calculated consented mass load and consented volume
2. Based on Note 1 approach and projected Average Dry weather flow (ADWF) at end of 20 year consent duration – Table 4-4 AEE at 56,000 m^3/day
3. Maximum to meet 10 out of 12 samples
4. Based on mass load and Average Dry week Flow (ADWF) at end of the sought after 35 year duration

Table 2: Selection of Local Authority Municipal Wastewater Schemes and related treated wastewater discharge consents other than in the Waikato Region highlighting consent duration and level of new investment to meet new consents.

Location/Local Authority Wastewater scheme	Treatment Technology – Prior to issue of current consent	Treatment technology – required to meet current consent	Year Current Consent Issued	Consent Term (Expiry Date)	Treated Wastewater Discharged To	Level of new investment to meet current consent
Milton Clutha DC (Environment Court decision)	Trickling filter	Upgraded plant	2009	35 (2004)	Tokomairaro River	Significant upgrade plant to also accept Otago Corrections Facility - Milton
Cromwell Central Otago DC	Oxidation Ponds	Aeration and UV upgrade to oxidation ponds	2014	35 (2049)	Clutha River	Aeration upgrade and UV disinfection proposed to meet new consent.
Alexandra Central Otago DC	Extended aeration activated sludge	Extended aeration activated sludge and UV disinfection	2010	35 (2045)	Clutha River	Modern in tank aeration upgraded post 2010 by flow balancing and UV disinfection.
Pines 2 Rolleston Selwyn DC		New biologic al nutrient removal (BNR)	2015	25 (2040)	Land	Total new BNR treatment plant and centre pivot irrigation system $50M
Roxburgh Central Otago DC	Oxidation Pond	Rapid Infiltration Beds	2011	35 (2045)	Land	Rapid Infiltration Beds Approx $0.2M
Westport Buller DC	Raw sewage	New extended aeration activated sludge plant	2004	(2039) 35 but agreed with DOC 25) (2029)	Buller River	Very substantial total new activated sludge extended aeration plant
Mangere Watercare Auckland Council	Primary trickling filter, oxidation ponds	Major upgrade with biological nutrient removal (BNR) filtration and UV disinfection	1998	35 (2023)	Manukau Harbour on outgoing tide	Very substantial new plant upgrades with BNR reactors plus filtration and UV disinfection

Cont…

Location/Local Authority Wastewater scheme	Treatment Technology – Prior to issue of current consent	Treatment technology – required to meet current consent	Year Current Consent Issued	Consent Term (Expiry Date)	Treated Wastewater Discharged To	Level of new investment to meet current consent
Lyttelton (Formerly Banks Peninsula DC)	Raw Sewage discharge	Extended Aeration Activated Sludge Plant	1999	35 (2039)	Lyttelton Harbour	Substantial new activated sludge plant
Hastings Hastings DC	Milli-screened sewage	Biological Trickling Filter Plant	2014	35 (2049)	Hawke Bay	Total new Biological Trickling Filter Treatment approx. $30M (implemented for the 2001 consent)
Gisborne Gisborne DC	Milli-screened sewage	Biological Trickling Filter Plant	2007	35 (2042)	Pacific Ocean	Total new Biological Trickling Filter treatment plant $??M
Tauranga Tauranga CC	Secondary (Biological) Treatment + wetlands	Two activated sludge treatment plants + UV + wetlands	2005	35 (2040)	Bay of Plenty	Treatment upgrade and new UV disinfection plant
Ruakaka/Marsden Point area Whangarei DC	Small oxidation pond and wetland	Proposed BNR plant and UV and offshore ocean outfall	2012	35 (2047)	Breen Bay With a small proportion to land	For total Biological Nutrient Removal Plant (land application area for part of volume) and 3,000m long off shore ocean outfall – Capital cost estimate $58M – Nov 2010 basis
Christchurch Christchurch CC	Extensive secondary treatment plant and oxidation ponds	New 3000m offshore ocean outfall	2006	35 (2041)	Pegasus Bay formerly Heathcote Estuary	New 3,000m long offshore ocean outfall – large cost
Waimakariri DC (Rangiora, Kaiapoi, Wooded etc)	Oxidation pond and wetland schemes	Existing oxidation and ponds upgrade and new 2,000m offshore ocean outfall	2006	35 (2041)	Pegasus Bay formerly Heathcote Estuary	High cost for conveyance and 200m ocean outfall

James William Bradley

14 August 2017

ATTACHMENT A Summary Experience

1. In recent years I have been extensively involved in many Local Authority small, medium sized and major city wastewater management treatment and discharge Resource Consent projects carried out under the Resource Management Act 1991 (RMA). These include:

Bluff

Cambridge (in progress)

Christchurch City Council (as a Hearing Commissioner)

Dunedin City Council - main City (Tahuna) and Green Island Schemes

Gisborne City Council

Hamilton City Council

Hastings 1997 – 2000 and 2013-15

Hutt City

Masterton- advisor to Iwi

Nelson – Bell Island (in progress)

Ngaruawahia and Huntly and other schemes

Otorohanga

Palmerston North City Council (Previous and current)

Rotorua (in progress)

Ruakaka – Whangarei District Council

Tauranga City Council

Te Awamutu (in progress)

Waihou

Watercare -Auckland Mangere Plant and South West Sub-Regional Scheme (in progress) and Pukekohe (in progress)

Wellington City Moa Point (main scheme) and Western Scheme

And other schemes

2. I have been a Working Group Member advising Central Government on the following activities all of which have some relevance to this Project:

   - Preparation of the MfE's "Sustainable Wastewater Management Handbook (2003).
   - Preparation of New Zealand's (first) Waste Strategy
   - NZ Standards Model General Bylaws Part 23 – Trade Waste (2004).
   - Development of the Ministry for the Environment (MfE) I Local Government New Zealand's "NZ Waste Strategy (2002).
   - Proposed National Environmental Standard on Water Measurement.

3. I am currently a committee member of the International Water Association's (IWA) Specialist Outfall Committee and have presented papers on the New Zealand scene in respect to both marine and freshwater outfalls for treated wastewater discharge.

4. Throughout my professional career I have been invited to present a number of key note presentations on wastewater management and RMA consent matters both nationally and internationally. I have written or presented over 80 papers and presentations on these subjects. I am the recipient of a number of awards including the inaugural William Pickering award for Engineering Leadership in New Zealand, the inaugural Engineering Excellence Award for sustainability and the Inaugural Engineering Excellence Award for the NZ Trade and Industry Forum Environmental Champion.

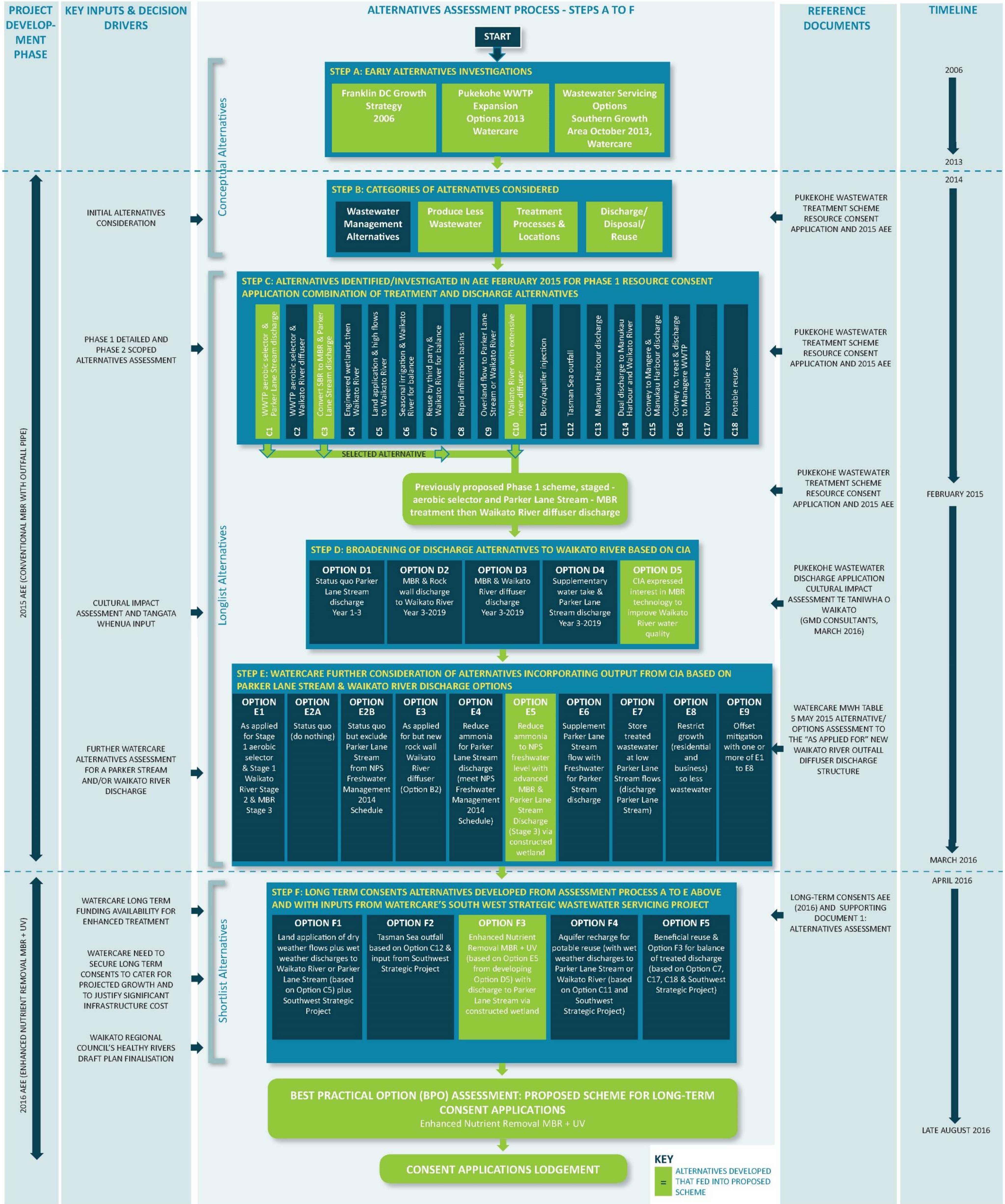
ATTACHMENT B Alternative (Options) Assessment Progressive Approach (Table 6-2 of the AEE)

NOTE: This table is expanded to show overall evaluation process in Figure 6-1

	Progressive Alternatives (Options) Evaluative Approach Steps		Alternatives (Options) Included in each Evaluative Approach Step		
Conceptual Alternatives	A	Early alternatives investigations	A1	Franklin District Council Growth Strategy 2006	2006
			A2	Pukekohe Wastewater Treatment Plant Expansion Options 2013 Watercare	
			A3	Wastewater Servicing Options Southern Growth Area October 2013 Watercare	2013
	B	Categories of alternatives considered	B1	Wastewater management alternatives	2014
			B2	Produce less wastewater	
			B3	Treatment processes and locations	
			B4	Discharge/disposal/reuse	
Longlist Alternatives	C	Alternatives identified/ investigated in AEE February 2015 for Phase 1 Resource Consent Application combination of treatment and discharge alternatives	C1	Wastewater Treatment Plant aerobic selector and Parker Lane Stream discharge	
			C2	Wastewater Treatment Plant aerobic selector and Waikato River diffuser	
			C3	Convert SBR to MBR and Parker Lane Stream discharge	
			C4	Engineered wetlands then Waikato River	
			C5	Land application and high flows to Waikato River	
			C6	Seasonal irrigation and Waikato River for balance	
			C7	Reuse by third party and Waikato River for balance	
			C8	Rapid infiltration basins	
			C9	Overland flow to Parker Lane Stream or Waikato River	
			C10	Waikato River with extensive river diffuser	
			C11	Bore/aquifer injection	
			C12	Tasman Sea outfall	
			C13	Manukau Harbour discharge	
			C14	Dual discharge to Manukau Harbour and Waikato River	
			C15	Convey to Mangere and Manukau Harbour discharge	
			C16	Convey to, treat and discharge to Mangere Wastewater Treatment Plant	
			C17	Non potable reuse	
			C18	Potable reuse	Feb 2015
	D	Broadening of discharge alternatives to Waikato River based on Cultural Impact Assessment output	D1	Status quo Parker Lane Stream discharge Year 1-3	
			D2	MBR and rock wall discharge to Waikato River Year 3-2019	
			D3	MBR and Waikato River diffuser discharge Year 3-2019	
			D4	Supplementary water take and Parker Lane Stream discharge Year 3-2019	
			D5	Interest in MBR technology to improve Waikato River water quality	
	E	Watercare's further consideration of alternatives incorporating output from Cultural Impact Assessment based on Parker Lane Stream and Waikato River discharge options	E1	As applied for Stage 1 aerobic selector and Stage 2 Waikato River discharge and MBR Stage 3 (conventional MBR)	
			E2A	Status quo (do nothing)	
			E2B	Status quo but exclude Parker Lane Stream from NPS Freshwater Management Schedule 2014	
			E3	As applied for but new rock wall Waikato River diffuser (Option B2)	
			E4	Reduce ammonia for Parker Lane Stream discharge (meet NPS Freshwater Schedule)	
			E5	Reduce ammonia to NPS freshwater level with advanced MBR and Parker Lane Stream discharge (Stage 3)	
			E6	Supplement Parker Lane Stream flow with freshwater for Parker Lane Stream discharge	
			E7	Store treated wastewater at low Parker Lane Stream flows (discharge Parker Lane Stream)	
			E8	Restrict growth (residential and business) so less wastewater	
			E9	Offset mitigation with one or more of E1 to E8	Mar 2016
Shortlist Alternatives	F	Long term consents alternatives developed from assessment process A to E above	F1	Land application of dry weather flows plus wet weather discharges to Waikato River or Parker Lane Stream (based on Option C5)	Apr 2016
			F2	Tasman Sea Outfall based on Option C12	
			F3	Enhanced Nutrient Removal MBR + UV (based on Option E5 from developing Option D5) with Parker Lane Stream discharge via constructed wetland	
			F4	Aquifer recharge for potable reuse (with wet weather discharge to Parker Lane Stream or Waikato River (based on Option C11)	
			F5	Beneficial reuse and Option F3 for balance of treatment discharge (based on Option C7, C17, C18)	Aug 2016

ATTACHMENT C **Schematic of Alternative Option Identification and Evaluation Process**

(Figure 6-1 of the AEE)



Prepared by MWH September 2016

ATTACHMENT D **WorldWater (Publication)**
Wastewater Industry Moving Toward Enhanced Nutrient Removal Standards by Tony Freed – Volume 23 – Issue 1

WaterWorld

WASTEWATER INDUSTRY MOVING TOWARD ENHANCED NUTRIENT REMOVAL STANDARDS

By Tony Freed

Most people involved in the wastewater industry are familiar with biological nutrient removal (BNR) where biological processes are incorporated into wastewater treatment systems to reduce effluent total nitrogen to an average level of 8 to 10 mg/L and total phosphorus to an average of 1 to 3 mg/L before being discharged into a receiving water. Certain receiving waters are showing evidence that BNR limits are not strict enough to protect water quality and, as a result, these levels are still causing unbalanced ecosystems.

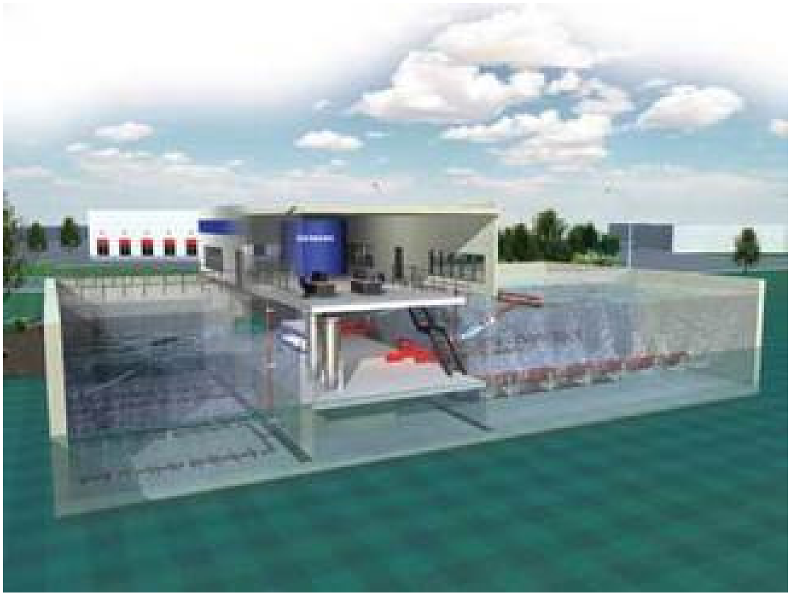
Denitrification filters such as continuous backwash filters are an easy and economical addition to existing treatment systems that use biological processes to convert harmful nitrate-nitrogen into nitrogen gas, thus reducing effluent total nitrogen to 3 mg/L or less.

Click here to enlarge image

A new acronym is therefore being thrown into the mix: enhanced nutrient removal or ENR. ENR further refines the BNR process and removes total nitrogen to levels as low as 3 mg/L and total phosphorus to 0.3 mg/L or less.

Low effluent nutrient limits are not necessarily a new concept. For decades, a few states such as Florida have had strict effluent nutrient regulations, similar to the new ENR limits, for surface water discharge. Not until the recent focus around the Chesapeake Bay has the term ENR gained recognition. This region is well under way to implementing strict water quality standards by 2010, under the Chesapeake Bay 2000 Agreement. The agreement was signed by Maryland, Virginia, Pennsylvania, and the District of Columbia to further reduce nitrogen and phosphorus entering the Bay by 20 million pounds and 1 million pounds per year, respectively.

The Pacific Northwest is another region where point source dischargers such as wastewater treatment plants are under growing pressure for nutrient removal. Receiving waters such as the Spokane River in Washington and Idaho have oxygen levels that are too low to support healthy fish populations. This low level of oxygen is caused by high nutrient concentrations, in this case primarily phosphorus.



One possible ENR solution consists of pairing a sequencing batch reactor with continuous backwash filtration, such as this system from Siemens.

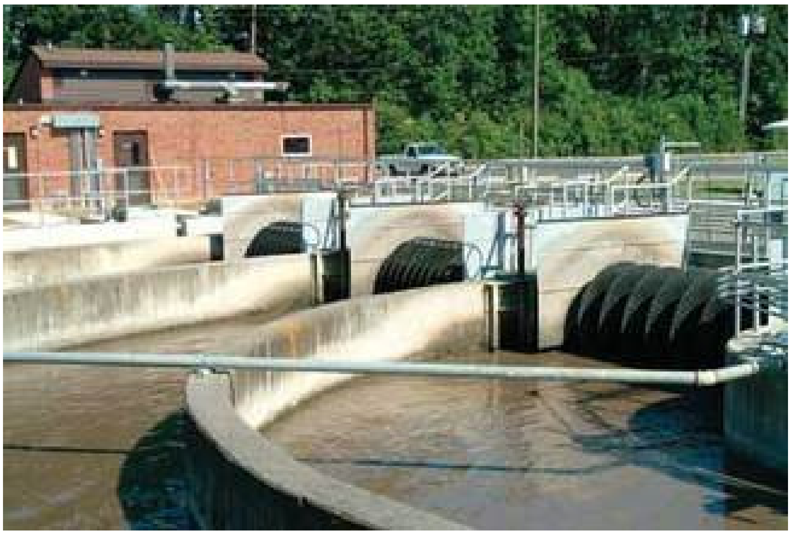
Click here to enlarge image

With other state regulators taking a closer look at the quality of their receiving waters, what does this mean to the world of wastewater treatment? It means that wastewater treatment facilities have to plan their upgrades and expansions to include treatment processes to meet current compliance issues as well as those water quality standards anticipated in the future. Municipalities and utilities that proactively design and implement wastewater processes to

meet the inevitable tightening of effluent nutrient limits may save time, money and headaches in the long run.

Achieving ENR Levels

How does a treatment system or facility reach those lower levels of nitrogen and phosphorus, or ENR? It is relatively simple for those wastewater facilities already achieving BNR. Usually tertiary filtration can be added to the existing treatment process with minimal alterations. Denitrification filters such as deep-bed or continuous backwash filters are an easy and economical addition to existing treatment systems that use biological processes tc convert harmful nitrate-nitrogen into nitrogen gas, thus reducing effluent total nitrogen to 3 mg/L or less. In addition to biological denitrification, these filters provide physical/chemical treatment, using chemical phosphorus precipitation to achieve total phosphorus levels as low as 0.3 mg/L.



The city of Fruitland, Md., installed a 1-mgd SBR system to meet the more stringent limits at a significantly lower cost than building an entirely new wastewater treatment plant.

Click here to enlarge image

On the western shore of the Chesapeake Bay, Aberdeen (Md.) Proving Grounds WWTP has incorporated a continuous backwash filter to reduce its total nitrogen discharge from 7 mg/L to 3 mg/L. Applications requiring extremely low levels of phosphorus can benefit from such a packaged two-stage clarifier and filter combination system. Similarly, a paper mill near Spokane, Wash., is in the process of installing this technology after a successful pilot study proved phosphorus levels of 0.1 mg/L could be reliably achieved.

The Dahlgren WWTP in Virginia discharges into a tributary of the Potomac River that eventually empties into the Chesapeake Bay. In anticipation of the new ENR discharge limits, the King George Service Authority that owns the Dahlgren facility recently began expanding its existing oxidation ditch process and implementing an advanced process

control system. Using these relatively inexpensive improvements, the authority anticipates meeting the stricter nutrient removal limits without requiring a major capital intensive upgrade.

The Dahlgren WWTP in Virginia installed Orbal® Oxidation Ditch Technology to meet expected lower nutrient discharge limits. (Photo courtesy of Bob Roop, Timmons Group, Virginia).

Click here to enlarge image

For those treatment facilities that are not already achieving BNR, more capital costs may be involved. Fortunately, existing treatment facilities can benefit from simple upgrade or retrofit technologies provided by experienced water and wastewater treatment equipment suppliers. Many times, advanced technologies such as sequencing batch reactors, membrane bioreactors, or oxidation ditch and vertical loop reactors can be incorporated into existing treatment designs, taking advantage of existing tankage wherever possible. For example, the city of Fruitland, Md., upgraded its wastewater treatment from an antiquated trickling filter process to a 1 mgd sequencing batch reactor system to meet the more stringent limits at a significantly lower cost than building an entirely new treatment plant.

Conclusion

In essence, ENR is simply the next step in the natural technological progression of wastewater treatment processes, starting with primary treatment, through secondary and advanced treatment, then biological nutrient removal, and now enhanced nutrient removal. Regardless of a facility’s particular circumstances, a variety of innovative technologies and cost-effective processes can be called upon to meet these new challenges

About the Author:

Tony Freed is a product manager for Davco biological systems at Siemens Water Technologies in Thomasville, GA. He joined Siemens in 1989 and has worked in the industry since 1985. Freed has a BS degree in Microbiology from Central Michigan University in Mount Pleasant, Mich., and a MS degree in Environmental Microbiology from Georgia Tech University in Atlanta. He can be reached at 229-227-8749 or at anthony.freed@siemens.com.

ATTACHMENT E **International Water Association (IWA)**
Global Trends & Challenges in Water Science, Research and Management – 2015

A compendium of hot topics and features from IWA Specialist Groups – Membrane Specialist Group Paper

Membrane Technology

Written by *Val S. Frenkel, Xia Huang, Kuo-Lun Tung and Franz Frechen* on behalf of the Membrane Technology Specialist Group

Introduction

In recent years, membrane technologies have started to play a vital role in solving water scarcity on the planet, which is in close association with global climate change. The major reasons are that membranes allow not only effective separation of various contaminants from water sources to achieve the required quality, but also exploration of water resources from non-traditional sources such as wastewater and seawater for direct or indirect portable reuse.

The objective of the Membrane Technology Specialist Group (MTSG) is to educate professionals and public around the globe without barriers about membrane technologies and to promote and exchange knowledge on membrane technology. Special attention is paid to the young professionals who will increasingly encounter membrane technologies in their professional life. The group consists of a vast spectrum of active members (scientists, researchers, engineers, membrane industry professionals and end-users.) in academic, industrial and public sectors. The group has grown to be one of the largest Specialist Groups within IWA.

Existing MTSG knowledge

Membrane market

Membrane technologies have infiltrated every corner of water and wastewater treatment such as municipal and industrial water, advanced wastewater treatment and reuse, sea and brackish water desalination (Frenkel 2010). The major reasons are the unique features of membranes in providing complete treatment and solving the water shortage problems that are in close association with global climate change. This has helped in accelerating the growing rate of membrane market (Frenkel and Lee 2011).

Membrane market: current situation

During the past 10 years, the annual growth rate of reverse osmosis (RO) desalination, microfiltration (MF)/ultrafiltration (UF) membranes for drinking water treatment, and membrane bioreactors (MBRs) for wastewater treatment and reuse has been 17, 20 and 15% respectively. The reasons for this have been the similar capital, operation and maintenance costs as that of conventional treatment processes, a smaller footprint, fewer chemical requirements and much better pollutant removals. The energy requirement has been relatively high, although this is reducing with the rapid advance in R&D activities in this field.

The membrane market was strong in 2010 while it was quite different between market sectors and particular places, regions and countries around the globe. In general in 2010 the strongest membrane markets were sea water desalination by reverse osmosis (SWRO) and MBR technologies. A similar trend can be expected in 2011–2016, as shown in the Table 1.

The growth rate of the SWRO market has been driven by the needs of the recent water supplies in places that are in the reasonable proximity to the ocean. Recent SWRO plants are large, with a capacity of 100,000 m^3/day or more. For example, the largest operating membrane desalination plant in the USA was the Tampa Bay SWRO, with a capacity of 25,000 m^3/day. In 2015 the Carslbad SWRO plant with a capacity of 50,000 m^3/day started to produce desalinated water in California. The largest SWRO plant in the world was the Magta plant in Algeria, with a capacity of 500,000 m^3/day (Kurihara 2011), while in 2013 the Soreq SWRO desalination plant in Israel with a capacity of 624,000 m^3/day started operation.

Table 1. Forecast on membrane market (billions US$) for 2011–2016 (Kwok *et al.* 2010)

Market sectors using membranes	**2011**	**2016**
Desalination pretreatment	0.05	0.13
Membrane bioreactors	0.53	0.90
Drinking water	0.17	0.33
Tertiary wastewater treatment	0.16	0.39
Industrial applications	0.16	0.30
Subtotal MF/UF membranes	**1.07**	**2.05**
RO/NF (nanofiltration) Industrial applications	0.33	0.51
RO/NF Desalination	0.42	0.67
Subtotal NF/RO membranes	**0.75**	**1.18**
Total MF/UF/NF/RO membranes	**1.81**	**3.25**

The membrane market in 2011 was forecasted to be US$1.8 billion, but it is estimated to increase to US$ 3.25 billion over the next 5 years (about 80% growth) and reaching US$ 3.44 billion by ear 2018, taking into account only the MF/UF/NF/RO membranes. However, it is worth noting that the estimation of membrane market has great fluctuation depending on the data sources. For example, global world market of membranes for water and wastewater treatment in 2011 was also evaluated at about 4 billion dollars (http://www.oecdrccseoul.org/article/global-membrane-market-for-water-and-wastewater-treatment). In addition, MBR world market in 2011 was also estimated at about US$380 million (http://bccresearch.blogspot.com/2011/07/global-membrane-bioreactors-mbr-market.html).

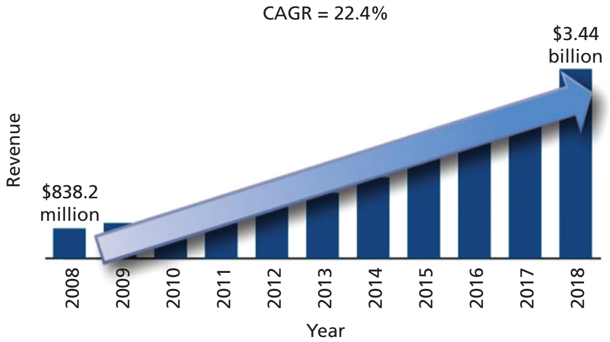


Figure 1. Global MBR market: treatment volume and revenue forecast (global), 2008–2018. Source: *Water & Wastewater International.*

The MBR market has been driven by needs for recycled water, upgrading of ageing facilities with challenged acquisition of the additional land and by the need for additional water by the industrial sector. In Europe, GE Water Technologies-Zenon (hollow-fibre) and Kubota (flat-sheet) have supplied most membrane equipment for the large MBR plants. However, new companies with novel concepts of membrane module design are slowly penetrating into municipal and industrial MBR markets. Therefore fierce competition in the MBR membrane and equipment market supply can be expected in the coming years and exponential growth of the MBR market as a result (Lesjean *et al.* 2011).

There is important growth in MBR plant sizes around the world, as shown in Table 2. More than 40 largest MBRs commissioned have a peak daily flow of more than 100,000 m^3/day. Especially the engineering application of MBR in China has attained tremendous development recently. The total treatment capacity reached 7.5×10^6 m^3/d by 2015 (Xiao et al., 2014).

Membrane market: current challenges

In general, much current R&D on membrane technologies is related to analysis and control of membrane fouling, which is a chronic trouble for the operation of all membrane types. The reason is that the reduction of the relatively high energy demand to operate membrane plants still remains one of the key considerations for membrane processes over conventional treatment technologies, and the higher energy consumption is in close association with membrane fouling. In the coming years, similarly to the previous years, many efforts will be dedicated to managing membrane fouling and reducing operational energy.

Disposal of membrane concentrate associated with high pressure membranes, NF and RO operation is another challenge of membrane processes, especially if high pressure NF and/or RO membrane systems are used for salty and high concentrated industrial effluents and wastewater reuse. Recently, many studies on membrane distillation/crystallisation, forward osmosis and pressure-retarded osmosis have started to address the disposal of membrane concentrate.

Membrane market: current drivers

There are also many factors influencing membrane market. These are decreasing investment and operational costs, new and more stringent legislations on effluent discharges, local water scarcity, increasing confidence in membrane technologies, compact footprint of membrane plants compared with other technologies, and high efficiency of salt removals, which will accelerate penetration of membrane technology to several market areas in the near future. Latest needs by Oil and Gas industry when exploring fracking technologies for oil and gas exploration triggered significant interest in membrane technologies and development of the treatment processes based on already available membrane applications and requiring new membrane technology based processes.

Membrane standardisation

The high pressure membranes such as RO and NF became commodities items well standardised across the industry and the most common high pressure element sized 8 inches × 40 inches (200 mm × 1,000 mm) can be found in any RO/NF facility around the world. As RO/NF facilities becoming larger in size the high diameter RO sized 16 inches (400 mm) diameter or 18¼ inches (450 mm) found their place in the design of the new desalination plants.

Low-pressure membranes are still not standardised across the industry and this situation complicates the development of the MF/UF projects including MBR. More time is required to develop and procure MF/UF projects than is otherwise possible, resulting in more costly projects. However, there are numerous signs of the standardisation of low-pressure membranes with MF/UF as membrane manufacturers are following up the after-sale market offering membrane replacement to the operational MF/UF and MBR facilities (Frenkel 2010).As part of the Amedeus European research project, a report about MBR standardisation including recommendations has been published (De Wilde *et al.* 2007, www.mbr-network.eu)

Enhancing membrane performance with nanomaterials

Next-generation membranes are being developed that incorporate nanomaterials, such as zeolites, carbon nanotubes, silver nanoparticles and others to improve membrane properties and performance. These membranes have higher fluxes, resist breakage to a much greater extent, and/or exhibit reduced biofouling. Membrane processes based on even more advanced nanoscale control of membrane architecture may ultimately allow for multi-functional membranes that not only separate water from contaminants, but also actively clean themselves and check for damage, detect contaminants, or combine detection, reaction and separation.

Several nanomaterials are used for the formation of organic–inorganic porous composite membranes such as Al_2O_3, TiO_2, SiO_2, nAg (silver nanoparticles), CNT (carbon nanotube), chitosan and others. These nanomaterials improve membrane properties, such as (1) increased skin layer thickness, (2) higher surface porosity of the skin, (3) suppressed macrovoid formation, and (4) higher permeability of the membrane (Taurozzi *et al.* 2008).

The very efficient transport of water through CNT membranes seems promising for energy reduction in seawater desalination. However, the road to useful industrial

Table 2. The largest MBR plants worldwide*

Installations	Location	Technology Provider	(Expected) date of commissioning	PDF (MLD)	ADF (MLD)
Henriksdal, Sweden	nr Stockholm, Sweden	GEWPT	2016-2019	864	536
Seine Aval	Acheres, France	GEWPT	2016	357	224
Canton WWTP	Ohio, USA	Ovivo USA/ Kubota	2015-2017	333	159
Water Affairs Integrative EPC	Xingyi, Guizhou, China	OW		307	
Euclid, OH, USA	Ohio, USA	GEWPT	2018	250	83
9th and 10th WWTP	Kunming, Yunnan, China	OW	2013	250	
Shunyi	Beijing, China	GEWPT	2016	234	180
Macau	Macau Special Administrative Region, China	GEWPT	2017	210	210
Wuhan Sanjintang WWTP	Hubei Province, China	OW	2015	200	
Jilin WWTP (Phase 1, upgrade)	Jilin Province, China	OW	2015	200	
Caotan WWTP PPP project	Xian, Shaanxi, China	OW		200	
Brussels Sud	Brussels, Belgium	GEWPT	2017	190	86
Macau	China	GEWPT	2014	189	137
Riverside	California, USA	GEWPT	2014	186	124
Brightwater	Washington, USA	GEWPT	2011	175	122
Visalia	California, USA	GEWPT	2014	171	85
Qinghe WRP (Phase 2)	Beijing, China	OW	2011	150	
Nanjing East City WWTP (Phase 3)	Jiangsu Province, China	OW	2014	150	
Yantai TaoziWan WWTP (Phase 2)	Shandong Province, China	OW	2014	150	
Jilin WWPT (Phase 2)	Jilin Province, China	OW	2014	150	
Qinghe	China	OW/MRC	2011	150	150
Changsha 2nd WWTP	Hunan Province, China	OW	2014	140	
North Las Vegas	Nevada, USA	GEWPT	2011	136	97
Ballenger McKinney ENR WWTP	Maryland, USA	GEWPT	2013	135	58
Assago	Milan, Italy	GEWPT	2016	125	55
Daxing Huangcun WRP	Beijing, China	OW	2012	120	
Jinyang WWTP (Phase 1)	Shanxi Province, China	OW	2015	120	
Cox Creek WRF	Maryland, USA	GEWPT	2015	116	58
Yellow River	Georgia, USA	GEWPT	2011	114	71
Shiyan Shendinghe	China	OW/MRC	2009	110	110
Aquaviva	Cannes, France	GEWPT	2013	108	60
Urumqi Ganquanpu WRP	Xinjiang Uygur Autonomous Region, China	OW	2014	105	
Busan City	Korea	GEWPT	2012	102	102
Wenyuhe River Water Treatment (Phase 2)	Beijing, China	OW-MRC	2010	100	
Hebei Zhengdi WWTP	Hubei Province, China	OW	2014	100	
ZhuHai Qianshan WWTP	Guangdong Province, China	OW	2016	100	
Guangzhou	China	Memstar	2010	100	
Wenyuhe	Beijing, China	OW/Asahi Kasei	2007	100	100
Beijiao WWTP renovation project	Ordos, Inner Mongolia	OW		100	
Xianlin WWTP PPP project	Nanjing, Jiangsu, China	OW		100	
Beijiao WWTP	Ordos, Inner Mongolia	OW		100	
Zhengding new district WWTP	Zhengding, Hebei, China	OW		100	
Chengxiang WWTP Phase I	Haiyan,Zhejiang, China	OW		100	
Chengxiang WWTP Phase I	Haiyan,Zhejiang, China	OW			

*Last updated February 2016. PDF: Peak daily flow, Megalitres per day. ADF: Average daily flow, Megalitres per day. GEWPT: GE Water and Process Technologies. OW: (Beijing) Origin Water. MRC: Mitsubishi Rayon Corporation.

applications of CNT membranes may be yet a long and arduous one owing to the selectivity and cost requirements (Verweij 2007). Maximous *et al*. (2009) prepared PES ultrafiltration membrane with entrapping Al_2O_3 nanoparticles and used this membrane at the activated sludge filtration. Al_2O_3 nanoparticles decreased the adhesion or the adsorption of the EPS on the membrane surface and increased the filtration performance of membrane.

In particular, incorporation of quorum quenching nanomaterials makes the membranes 'reactive' instead of a simple physical barrier. Kim *et al*. (2011) prepared an acylase-immobilised nanofiltration membrane with quorum quenching activity. This membrane prohibited biofouling, namely the formation of mature biofilm on the membrane surface owing to the reduced secretion of EPS.

Overall, these nanomaterials could contribute to the development of specific membranes in many desired ways. One challenge in the future will be to use these developments to tailor membranes for processes that rely on driving forces other than pressure, such as forward osmosis or membrane distillation.

Forward osmosis (FO) and membrane distillation (MD)

In the context of climate change, the environmental and energy issues become essential and must be taken into account in the design of membrane systems and in their mode of operation, so that membrane processes remain or become competitive. The relatively high energy demand to operate conventional pressure driven membrane processes (NF, RO) still remains a challenge to be managed. As alternatives to reverse osmosis (RO), membrane distillation (MD) and forward osmosis (FO) are being considered for low-energy seawater desalination and wastewater reuse

Forward osmosis (FO)

FO, a novel low-energy and natural process, has been developed in the past few years as an alternative membrane technology for desalination. Many studies on the use of FO for industrial and domestic applications can be found in literature. During the past decade, FO has been studied in wastewater treatment, seawater desalination, the food industry for stream concentration, for fracking and produced water volume minimisation as well as for purifying water in emergency situations. New and high performance FO membranes are being researched (Chou *et al*. 2010; Wang *et al*. 2010).

In September 2008, Modern Water (Guildford, UK) built the world's first FO+RO desalination plant in Gibraltar on the Mediterranean Sea. This local plant successfully completed testing procedures of the product water and, since May 2009, water has been supplied to the local community. A year later, in September 2009, a larger desalination plant was commissioned in the Sultanate of Oman at Al Khaluf. This new plant shares pre-treatment facilities with an existing RO desalination plant, providing a good opportunity to compare both technologies. Results were better than expectations, especially on resistance to fouling and product water quality. Moreover, despite the very bad quality of the source seawater, the FO membranes as a pre-treatment to RO have not been cleaned or replaced over the year of operation. In contrast, when not using FO as a pre-treatment the RO membranes from the other desalination plant had to be cleaned every two to four weeks and had been replaced over the 1-year operation time. This clearly demonstrates the low fouling propensity of the FO process compared with the other pre-treatment technologies to RO membrane process.

Other key advantages of the FO desalination process are (1) the energy consumption is lower by more than 30% compared with conventional pre-treatment to RO, (2) chlorine tolerance and compatibility with a variety of biocides with FO membranes, (3) inherently low product boron levels, and (4) higher availability than conventional RO plant owing to low fouling and simple cleaning when required.

The success of the FO process at the industrial level depends on how to prepare an efficient FO membrane having minimal internal and external concentration polarisations as well as how to separate salt free water effectively from the draw solution (Ng *et al*. 2006).

Membrane distillation (MD)

MD uses hydrophobic porous membranes as supports for a liquid/vapour interface and the vapour is transported in the membrane pores by diffusion. Indeed MD is particularly interesting because the principle itself of the transfer and selectivity of these membranes does not depend on the osmotic pressure of the solution as for the RO or the FO.

Recent work has shown the use of the MD process for the over-concentration of brines up to very high salt concentrations and thus for improving the recovery of RO plants (Méricq *et al*. 2010), for the crystallisation of salts for their valorisation (Ji 2010). Another interesting application is when coupling the MD process with solar energies (Méricq *et al*. 2011; Guillén-Burrieza *et al*. 2011) or the recovery of heat, which can make MD become a sustainable process. The work in progress on this topic throughout the world relates to the design and development of new membrane modules (Winter *et al*. 2011) and integrated systems, and on the characterisation and long-term control of membrane fouling and its properties (Krivorot *et al*. 2011). Some platforms with long-term testing of the MD system coupled with solar energy or waste heat recovery are under operation in many countries such as the Netherlands, Spain, Tunisia and Singapore.

Conclusions and outlook

Membrane fouling and energy consumption when operating membrane processes are still important challenges that need to be optimised and improved using innovative tools and technologies, as well as best operational practices. Nevertheless, for a wide range of applications in several areas, membrane treatment is becoming a competitive and economically viable option.

The main factors influencing the rapid growth of membrane technology are the following:

(1) multiple global challenges such as energy/resource shortage, climate change and rapid population growth; (2) improvement in membrane materials and modules; and (3) operational stability such as better antifouling, integrity testing of membrane processes.

The key drawbacks of membrane technologies are high energy consumption and relatively high cost. In addition, questions still remain about the durability and lifespan of the membranes: the 20-year lifespan claimed by manufacturers in continuous MBRs has yet to be proved through operational experience.

Owing to its aforementioned intrinsic properties, membrane technology will be the centre of one of the core technologies for us to face multiple challenges in the future. Membrane technology will provide great help to meet five of the fifteen Global Challenges (TMP 2011) for Humanity, namely sustainable development and climate change, water scarcity and water quality, balance population and resources, health issues and reduction of diseases and immune microbes, renewable energy and energy conversion.

One of the manufacturers of FO membranes in the US, the California based company Porifera confirmed similar results when comparing FO to UF as a pre-treatment to RO to desalinate water. FO demonstrated lower fouling comparing to UF pre-treatment. When using FO as a pre-treatment to desalinate water there are many opportunities to use different draw solutions other than Sodium Chloride to keep process running and optimise it.

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