AwwaRF/US Bureau of Reclamation Membrane Workshop

Membrane Research Forum

Discuss this report and membrane research needs at the AwwaRF Membrane Research Forum

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Workshop Summary

Water utility interest in membrane technology continues to grow. Recent advances in technology, regulatory pressure, decreased costs, and the growing number of facilities applying this technology are driving this interest. Research has played a vital role in making this technology more accessible and easier to apply.

The key to continued advancement of membrane technology will be well-designed research efforts that continue to feed the development of the technology and improve operations and maintenance of the systems. The Awwa Research Foundation (AwwaRF) began long-term planning of membrane research efforts in 1989 with the publication of the report, *Assessment of Potable Water Membrane Applications and Research Needs*. Research needs were re-evaluated in 1995, when 21 of the leading membrane experts met for three-days to assess the research needs and make recommendations for future funding. This report describes the latest effort for updating this research strategy.

On July 27-28, 2000, AwwaRF and the U.S. Bureau of Reclamation (USBR) sponsored a two-day workshop to identify issues that need to be addressed to improve the applicability of membrane technology for drinking water utilities. The goal of the workshop was to identify design, operations, maintenance, and regulatory issues that are limiting the widespread application of membrane technologies and develop a five-year research strategy to address these issues. The potential for research partnerships was also identified and will continued to be pursued in follow-up efforts.

Jim Lozier (CH2M Hill) and Nilaksh Kothari (Manitowoc Public Utilities) co-chaired the workshop. The co-chairs, in conjunction with the sponsoring agencies, selected workshop participants from a list of more than 120 people who had been involved in membrane research or had practical operating experience. Twenty-nine experts from six nations were selected to represent a broad cross section of the water supply community (i.e., water utilities, academia, consulting engineers, manufacturers, regulators, and research organizations). The list of participants is provided in Appendix 1.

How will the results of the workshop be used?

AwwaRF and USBR will use the results of this workshop to plan future research activities. AwwaRF's Research Advisory Council (RAC) will use the results from the workshop in developing the foundation’s annual research agenda. The RAC will balance the outcome from this workshop with other pressing water supply issues to develop recommendations for the Board of Trustee's (BOT). The RAC meets annually in October, and project recommendations

will be considered by the BOT in January of the following year. Requests for proposals will be issued in March.

The USBR will use the project recommendations to develop a research road map guiding future activities for the Desalination and Water Purification Research (DWPR) program. The USBR management will incorporate the road map recommendations into the specific task areas in the DWPR. Opportunities to leverage research dollars will be pursued by identifying projects that may be jointly funded with other research organizations. The specific projects will then be advertised, evaluated, and funded under the federal procurement process.

Representatives from four international research organizations, Kiwa (the Netherlands), Anjou Recherche (France), Water Technology Center of the German Waterworks Association (DVGW-TZW, Germany), and CSIRO (Australia) participated in the workshop and will use the results in their strategic planning. There was interest in developing cooperative efforts between these organizations, and informal discussion was initiated at the workshop.

Workshop Process

Prior to the workshop, participants were surveyed to identify the top issues that were constraining the use membrane technology in drinking water treatment. These issues are listed in Appendix 2. While there was no clear consensus on the top issues, differences were observed based on membrane class. Therefore, discussions in the workshop were separated into two groups. One group discussed reverse osmosis and nanofiltration [RO/NF]) and the other microfiltration and ultrafiltration [MF/UF]. Integrated membrane systems, where membrane processes are combined or coupled with other treatment processes, were open for either group to discuss. Results from small group discussions were combined during full group discussions.

The first task of the workgroups was to identify the primary issues constraining membrane technology. For each membrane class, the top four issues were identified. Issues for both membrane classes (total of eight issues) were discussed and prioritized by all participants. Eight issues was considered to be the maximum that could be adequately developed during the limited workshop time and realistically addressed with the limited research funding available. The workgroups then developed research plans and projects that specifically addressed the eight issues. Finally, key projects for the first year of funding were prioritized.

This report should be considered to be a living document. AwwaRF will update workshop participants on the status of research suggestions and request their continued input as this plan and the technology continue to evolve. Other interested parties are also welcome to comment on this plan. Comments can be submitted to Kim Linton at AwwaRF .

Issues Identified

Eight key issues that are limiting the applications of membrane technologies by the water supply community were identified. These issues were ranked in order of priority (with item 1 being the highest priority) based on their potential impact and are described in the following paragraphs.

Issue #1 - Integrated membrane systems (IMS): Integrating membranes into existing or new water treatment systems offers many advantages in addressing multiple water quality concerns. These advantages include meeting Surface Water Treatment Rule requirements, reducing fouling, providing a multiple barrier, and providing economic benefits to water treatment systems. Currently there is a limited amount of published information for decision makers about design and performance of installed systems. Information is needed on the cost, performance, sequencing with other treatment processes, retrofitting, chemical compatibility, and compatibility with regulatory and aesthetic treatment goals. Key projects to address the IMS issues are the following:

Click here to see descriptions of the projects listed below)

- Integration of membranes into existing water treatment systems
- Investigation of cartridge microfiltration to enhance microbial removal in conventional treatment plants
- Optimization of membranes for direct or clarified water filtration
- Development and verification of nanofiltration and reverse osmosis models for water quality and productivity
- Cost and performance of integrated membrane systems.

Issue #2 - Fouling/scaling: Operating efficiency of RO/NF systems can be improved through minimization and control of fouling and scaling. Fouling and scaling can decrease the recovery of feed water and increase the amount of residuals (brine) produced. Research is needed to understand scaling and fouling mechanisms, predict the impact of antiscalants, develop indices for fouling, develop methods for on-line prediction, and improve membranes to resist biofouling. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Development and evaluation of methods for accurately determining conditions to maximize conversion and monitoring of scaling in full-scale RO/NF plants
- Development of an improved understanding of the chemistry of membrane fouling caused by natural organic matter and interaction with commercial antiscalants and dispersants
- Development, standardization, and evaluation of a fouling index using ultrafiltration membranes to measure fouling potential of RO/NF and UF/MF feedwaters due to particles
- Demonstration and verification of new biofouling-resistant and chlorine-tolerant membranes.

Issue # 3 - Concentrate issues: One of the most significant barriers to the implementation of RO/NF systems is the cost-effective and permittable disposal of concentrates (the by-product of treatment). Current regulations on concentrate disposal are inconsistent even though extensive research has been conducted. Accurate and concise information regarding environmental issues associated with disposal is needed for decision makers to make informed choices. Development of innovative technologies to maximize recovery and reduce concentrate quantity is also needed. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Develop effective communications tools regarding RO/NF concentrate issues
- Evaluate and confirm innovative, non-chemical approaches to maximize RO/NF/UF/MF recovery rates.

Issue # 4 - Knowledge base/rationale for membrane selection: Rapid deployment of MF/UF systems has resulted in a fragmented data and experience base. Integration and evaluation of this database are needed to enable informed decisions on design, installation, operations, and regulation of future membrane facilities, in particular for large membrane systems. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Development of microporous membrane knowledge database
- Development of a decision-making tool to assist in the selection of membrane processes.

Issue # 5 - Design of MF/UF plant: The scale of MF/UF plants has been increasing, and very large systems (>50 mgd) are currently under development. Information is needed to identify where developments in MF/UF membrane technology can lead to improvements in cost, performance, and reliability of membrane systems. For very large systems, information is needed about scale-up issues, the cost/benefit of MF/UF membrane systems over the life of the system, and standardization of system components. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Innovation in the design of large (>50 MGD [200 ML/D]) MF/UF membrane systems
- Development of life-cycle approaches to support MF/UF process selection
- Identification of generic and proprietary components in MF/UF systems
- Accelerated failure analysis of MF/UF membrane modules.

Issue #6 - Standardization of test methods: The use of MF/UF membranes has increased dramatically over the past decade. There has also been a proliferation of commercially available membrane systems. Standardized methods are needed for membrane evaluation to ensure quality and performance (i.e., database management and analysis, predictive modeling, flow problems, fouling vs. cleaning regimes, membrane disposal, plant sizing). Of the methods needed, the highest priority was given to developing a method for understanding and predicting MF/UF fouling. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Bench-scale assessment of MF/UF fouling: development of a fouling-assessment protocol and associated fouling indices
- Evaluation of MF/UF performance and operation: pilot- and full-scale studies.

Issue # 7 - Development of uniform permitting criteria: Requirements for membrane system design, operation, and monitoring vary between states. A base, or minimum, set of criteria is needed that can be used for permitting of membrane treatment plants. Criteria should consider residuals issues (recycling and disposal), integrity/control/monitoring, appropriate regulatory

measures, and operational criteria. There also needs to be an understanding of criteria that are membrane-specific or in which flexibility and discretion is required. Key projects include the following:

Click here to see descriptions of the projects listed below)

- Benchmarking study of MF/UF membrane systems vs. conventional water treatment systems
- Development of operating criteria for MF/UF membranes
- Testing of standardized predictive tools for on-line, real-time integrity monitoring of MF/UF systems.

Issue # 8 -Water Quality: Questions surrounding water quality will remain an important issue for utilities. Understanding the effectiveness of membrane systems for removal of emerging contaminants and aesthetic parameters is needed. It is also important to understand the impacts of membrane-treated water on distribution system water quality and the impacts of blending. Key research projects in this area include the following:

Click here to see descriptions of the projects listed below)

- Effect of membrane systems on distribution system water quality
- Development and verification of NF and RO models for water quality and productivity.

Matrix of issues and projects

A matrix of issues and projects needed to address them is presented in Table 1. The matrix shows the recommended sequence of projects for each issue and takes into account ongoing research and the need to build on some projects that are started during the first year of the plan.

For the first year of the plan, eight projects with a cost of $1.6 million were identified. These projects were prioritized in order of importance to the water supply community to provide additional information to the funding agencies. Results of this ranking are provided in Table 2.

Descriptions for all projects developed during the workshop are provided in Appendix 3. These descriptions describe the need for the project, background information, scope of work, and recommended funding level.

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Membrane Workshop Matrix of Issues and Projects

Table 1: Issue and Project Matrix

Table 2: Ranking of Year 1 Projects

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Table 1: Issue and Project Matrix (listed in order of issue priority)

PRIORITY	ISSUE	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1	INTEGRATED MEMBRANE SYSTEMS	Integration of Membranes into Existing Water Treatment Systems ($150K)	Optimization of Membranes for Direct or Clarified Water Filtration ($400K)		Cost and Performance of Integrated Membrane Systems ($200K)	
		Assessment of Cartridge MF to Enhance Microbial Removal in Conventional Water Treatment Plants ($300K)				
2	FOULING AND SCALING	Development, Standardization, and Evaluation of a Fouling Indicies Using UF Membranes to Measure Fouling Potential of RO/NF and UF/MF Feed Waters Due to Particles ($250K)	Development and Evaluation of Method(s) for Accurately Determining Conditions to Maximize Recovery and Monitoring of Scaling in Full-Scale RO/NF Plants ($400K)	Demonstration and Verification of New Biofouling-Resistant and Chlorine-Tolerant Membranes ($300K)		
			Develop Improved Understanding of Chemistry of Membrane Fouling caused by NOM and Interaction with Commercial Antiscalants and Dispersants and Membranes ($350K)			

3	CONCENTRATE ISSUES	Development Of Effective Communication Tools Regarding Current Information On RO/NF Concentrate Issues ($100K)			Evaluate and Confirm Innovative, Non-Chemical Approaches to Maximize RO/NF/UF/MF Recovery Rates ($260K)	
4	KNOWLEDGE BASE/RATIONALE FOR MEMBRANE SELECTION	Development of Microporous Membrane Knowledge Database ($250K)		The Development of a Decision-Making Tool to Assist in the Selection of Membrane Process ($150K)		
5	DESIGN OF MF/UF PLANTS	Innovation in the Design of Large (>50 MGD / 200 ML/D) MF/UF Membrane Systems ($200K)		Identification of Generic and Proprietary Components in MF/UF Systems ($200K)		
		Development of Life Cycle Approaches to Support MF/UF Process Selection ($200K)				
					Accelerated Failure Analysis of MF/UF Membrane Modules ($350K)	
6	STANDARDIZATION OF TEST METHODS, O&M	Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling Assessment Protocol and Associated Fouling Indicies ($250K)				Evaluation of MF/UF Performance and Operation: Pilot-and Full-Scale Studies ($350K)
7	DEVELOP UNIF0RM PERMITTING CRITERIA		Benchmarking Study of MF/UF Membrane Systems vs Conventional Treatment Systems ($200K)		Develop Operating Criteria for MF/UF Membranes ($250K)	

		`			**Testing of Standardized Predictive Tools for On-Line, Real-Time Integrity Monitoring of MF/UF Systems ($250K)**	
8	**WATER QUALITY**		**Effect of Membrane Systems on Distribution System Water Quality ($500K)**	**Multi-contaminant Removal from Surface Waters Using NF and RO Membranes ($400K)**	**Development and Verification of Nanofiltration and Reverse Osmosis Models for Water Quality and Productivity ($240K)**	

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Table 2: Ranking of Year 1 Projects (listed in order of issue priority) [1]

Please note: The links below take you to a listing of projects by issue. In some cases, you may need to scroll down to find the project description

Project	Score [2]
Integration of Membranes Into Existing Water Treatment Systems	154
Development of a Microporous Membrane Knowledge Base	139
Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling Assessment Protocol and Associated Fouling Indices	109
Development of Effective Communication Tools Regarding Current Information on Reverse Osmosis/Nanofiltration Concentrate Issues	106
Assessment of Cartridge MF to Enhance Microbial Removall in Conventional Water Treatment Plants	103
Development, Standardization, and Evaluation of Fouling Indices Using UF Membranes to Measure Fouling Potential of RO/NF and UF/MF Feed Waters Due to Particles	103
Innovations in the Design of Large (> 50 MGD / 200 MGD) MF/UF Systems	103
Development of Life Cycle Approaches to Support MF/UF Process Selection	58

1 Ranking of Year 1 Projects - 8 projects were identified that should be conducted in year one. These projects were ranked for their individual value as opposed to issue value as given in Table 1.

2 Relative score - the higher the score, the higher the priority.

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AwwaRF Membrane Workshop Project Descriptions

Issue 1: Integrated Membrane Systems

Project Title: Integration of Membranes Into Existing Water Treatment Systems

Description of Issue: Development of existing and pending regulations has created an environment for upgrading water treatment systems. Membranes can be used as a part of or a total water treatment system to meet regulatory constraints. However, there is no documentation available to the water community that describes the integration of membrane technology into existing water treatment systems to satisfy existing and pending regulatory and aesthetic constraints.

Objective: The objective of this project would be to develop documentation for the water community that describes the integration of membrane technology into existing and newly developed water treatment systems to satisfy existing and pending regulatory and aesthetic constraints. The researcher would review and compile existing membrane literature, regulations, operational history and other pertinent information into a easily understood document. In addition, a computer application that could be utilized on personal computers and from web based applications would be developed.

Recommended Funding: $150,000.

Proposal Source: 2000 Membrane Workshop

Potential Partners: United States Bureau of Reclamation (USBR), United States Environmental Protection Agency (USEPA), Kiwa (Netherlands), Water Education Foundation (WEF), National Research Counsel-Canada (NRC), National Sanitary Foundation (NSF)

Background

Membrane technology has and is being utilized by the water treatment community to meet regulatory constraints for turbidity or pathogen control and disinfection by-product control for new water treatment systems. There are very few facilities that have integrated membranes into existing water treatment plants. However integration of membrane processes into water treatment facilities is one of the least-cost and most beneficial applications of membrane technology. Existing plants are located in Appleton, Wisconsin; San Patricio, Texas; and Marco Island, Florida.

Research Approach

This project would be a desktop study that develops existing membrane literature, regulations, operational history and other pertinent information into a easily understood

document in a report and a computer application that could be utilized on personal computers and from web based applications.

This project would include the following tasks:

- Gather and compile literature into a document that describes membrane based technology for water treatment decision makers. This document would not be highly technical.
- Develop a brief report utilizing existing literature to document the capability of membrane technology including cost and performance to meet existing regulatory and aesthetic constraints.
- Gather and describe cost and performance data of existing facilities that have integrated membranes as unit operations into water treatment systems.
- Develop a report based on the first 3 tasks that describes the advantages and disadvantages of integration of membrane technology into existing water treatment systems.
- Develop a very simple computer based model that requires interactive input of water treatment system information, which generates an evaluation of integration of membranes into existing facilities.

The final report would be a compilation of existing information.

Name: Jim Taylor, University of Central Florida, (407) 823-2785, taylor@pegasus.cc.ucf.edu.

Project Title: Assessment of Cartridge Microfiltration to Enhance Microbial Removal in Conventional Water Treatment Plants

Description of Issue: Many utilities operating direct filtration and conventional water treatment facilities (coagulation/flocculation/sedimentation/filtration) will need to provide additional log reductions of *Giardia* and *Cryptosporidium* to comply with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2 ESWTR) requirements. A potentially inexpensive means of achieving such removals would be to polish filter effluent or finished water using microfiltration (MF) membranes configured as cartridge filters. These filters are capable of providing up to 3 log cyst/oocyst removal using integrity-testable, flat-sheet microporous membranes [in either disposal (single use) or backwashable (multiple use) configurations]. Such filters offer the benefit of incrementally improving plant performance without having to use hollow fiber filters of <1 um pore size. Such an approach would provide utilities with a potentially inexpensive approach to meet the requirements of LT2 ESWTR regulations.

Objective: This project would assess the performance and cost effectiveness of using single-use and multiple-use microfiltration cartridge filters for supplemental removal of *Giardia* cysts and *Cryptosporidium* oocysts.

Recommended Funding: $300,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: USEPA [through the NSF Emerging Technology Verification (ETV) program], NRC-Canada

Background

There are many utilities in the US operating direct filtration and conventional water treatment plants that currently meet requirements of the Surface Water Treatment Rule (SWTR) and interim Enhanced SWTR. These utilities will soon be required to provide enhanced removal of *Giardia* and *Cryptosporidium* to comply with the LT2 ESWTR. Additional removals could range from 0.5 log to >2 logs depending upon the level of cysts/oocysts detected in the plant raw water. Currently, the industry is focused on alternative disinfection methods (ozone and UV) as well as hollow-fiber continuous MF and UF to achieve this requirement. Cartridge filters, utilizing microporous, flat sheet MF membranes offer the potential to provide additional control at low capital and operating costs without the introduction of oxidative byproducts. These filters are designed to filter low turbidity feedwaters at low differential pressure (>15 psig). Further, cartridge filters have a very small footprint and operating requirements, making them ideal for supplemental pathogen control with little process, hydraulic, or operational impact on existing treatment facilities. These filters have been applied for, and in certain cases, certified for *Giardia* and *Cryptosporidium* removal for small capacity water systems.

Research Approach
The focus of this research would be an investigation of cartridge MF filters that utilize flat sheet membranes (either disposable or backwashable). This would be in contrast to continuous-flow MF and UF products that are currently being applied for treatment of surface and clarified waters. The continuous-flow MF and UF membranes require significantly larger footprint area, operational complexity, and capital cost.

Phase 1 would include a literature review/market survey to identify applicable products and any testing that has been conducted in relation of pathogen removal. This would include products/testing conducted under related drinking water venues, including NSF 61. The outcome of this phase would be a list of candidate products to be evaluated at bench scale.

The second phase would consist of bench testing of selected products to confirm and quantify pathogen removal capability, verify absolute pore size, and develop correlations between pathogen removals and integrity verification under cleaned and fouled conditions. The third and final phase would be field verification of bench results at selected water treatment facilities to determine/demonstrate on a variety of treated waters at pilot-scale longer term performance with respect to the following criteria:

- Filter life as a function of solids and filter loading rate (single-use type cartridge filters)
- Backwash frequency and effectiveness as a function of solids and filter loading rate (multiple-use type cartridge filters)
- Impact of filter fouling on microbial removal efficiency
- Capital and operating costs
- Sensitivity to fouling and production to feedwater upsets

The results of this investigation would be documented in a report that would provide the water industry with applicability and cost information for implementing this technology with direct filtration and conventional treatment plants.

Contact: Jim Lozier, CH2M Hill, (480) 966-8188, jlozier@ch2m.com

Project Name: Optimization of Membranes for Direct or Clarified Water Filtration

Description of Issue: Ultrafiltration (UF) or microfiltration (MF) membranes can be utilized for filtration of coagulated or clarified waters, which will increase turbidity removal, increase pathogen removal credits, eliminate the need for conventional filtration and possibly eliminate the need for succeeding disinfection for cyst removal. However very little information exists regarding chemical compatibility, sequencing and design for the retrofitting UF/MF membranes into exiting water treatment plants.

Objective: The objective of this project would be to comprehensively document all issues associated with retrofitting UF/MF membranes into existing or newly designed water treatment plants.

Recommended Funding: $400,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: Kiwa, Membrane Manufacturers, Consulting Engineering Firms, Utilities via TCP, WEF, USEPA

Background

Research Approach

The following approach should be used:

(a) Existing literature review: Front-end literature review using AwwaRF projects and other literature as needed. This project follows the desktop evaluation of membrane integration into water treatment systems.
(b) Evaluation of existing facilities: Gathering historical information on design and operational issues at plants where membranes have been retrofitted or integrated into newly designed process for filtration of coagulated or settled waters.
(c) Conceptual Assessment: Evaluation of potential problems based on theoretical issues for interaction between water column and membrane surface, design and installation of retrofitted or newly designed processes for filtration of coagulated or settled waters that were not covered in (b).
(d) Bench Investigation: Bench scale study based on issues identified in (a), (b) and (c) for the evaluation of interaction, limitations and performance of chemicals used for coagulation-sedimentation and UF/MF membranes. Data collection related to UF/MF performance includes membrane surface and coagulation characterization, membrane flux, pressure and recovery, temperature, mass balances and pertinent water quality.
(e) Field Evaluation. Pilot demonstration of selected pilot systems identified from (d) preferably at a water treatment plant with an existing UF/MF installation for evaluation and verification of issues identified in (a), (b), (c) and (d).

(f) Final Report

Contact: J. S. Taylor, University of Central Florida, (407) 823-2785, taylor@pegasus.cc.ucf.edu

Project Title: Cost and Performance of Integrated Membrane Systems

Description of Issue: Drinking water utilities are faced with an increasing array of drinking water treatment objectives, driven by more stringent regulations, additional water quality concerns, aesthetics and public perception of drinking water. This array of often competing objectives is motivation for many utilities to consider membrane technologies as a plant retrofit or various configurations of membranes in a range of pore-sizes for a new plant. In many cases, an integrated membrane system (IMS) enables the utility to meet these multiple objectives at an acceptable rate of production. However, there is a limited knowledge base for IMS applications within the industry.

Objective: Develop a comprehensive assessment of the capabilities of IMS to meet a variety of drinking water treatment objectives, and evaluate the costs associated with this approach. The product from this project would be an instrument illustrating the capabilities, limitations and relative costs of various IMSs. This instrument could take the form of a report, database or interactive tool.

Recommended Funding: $200,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: United States Bureau of Reclamation (USBR), United States Environmental Protection Agency (USEPA), Kiwa (Netherlands), Water Education Foundation (WEF), National Research Counsel-Canada (NRC), National Sanitary Foundation (NSF), TZW (Germany)

Background:
Integrated membrane systems have been investigated for multi-contaminant removal as well as providing pretreatment necessary to control fouling of membrane processes. Existing facilities in the United States have achieved increased log removal credits for pathogens using membrane technology without implementing ozone or other advanced disinfection technologies. This anecdotal information relating to use of IMSs by water treatment plants has not been compiled in a manner that provides useable information to the industry regarding this technology.

More complex IMSs are currently operating in the Netherlands and France where the process has enhanced pathogen and particle removal as well as improved distribution system water quality. Replacement of enhanced coagulation, ozone and BAC with an IMS at a plant in Paris, France improved microbial , organic and aesthetic water quality in the distribution system.

Research Approach:
This project would develop a comprehensive assessment of the capabilities of IMSs to meet a variety of drinking water treatment objectives, and evaluate the costs associated with this advanced treatment process.

This project would require the compilation and analysis of data from the literature as well as field data demonstrating the performance and cost of IMSs. In general, the project would include the following tasks:

- Review of existing literature and information including utilities and consultants.
- Evaluation of field data from existing full-scale IMSs as well as pilot and demonstration-scale studies.
- Analysis and compilation of information collected from the literature and field sites.
- Conduct an engineering evaluation of IMSs. This analysis should consider additional process combinations and applications as well as those identified in the literature review and field evaluations.
- Prepare final product (could be in the form of a report, database or interactive tool).

Contact: Steve Allgeier, USEPA, (513) 569-7131, allgeier.steve@epa.gov.

AwwaRF Membrane Workshop Project Descriptions

Issue 4: Knowledge Base/Rationale for Membrane Selection

Project Title: Development of Microporous Membrane Knowledge Database

Description of issue: Microfiltration (MF) and ultrafiltration (UF) membrane processes are at a critical stage in their development. A recent rapid increase in the installation of MF/UF systems in water treatment plants has resulted in a fragmented data and experience base. Although this situation has not impeded the use of MF/UF systems in smaller utility applications, larger metropolitan utilities will need to draw on an integrated knowledge base when making decisions during the planning, permitting, installation start-up, and operation of membrane systems in their facilities.

Objective: This project would compile and develop a comprehensive information database on existing MF/UF facilities greater than 20,000 m^3/day (5 mgd) located throughout the world. This database would be developed with the intent of delivery and dissemination through the internet.

Recommended Funding: $250,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
General knowledge of MF/UF membrane system planning, permitting, start-up, operations/maintenance, and costs is fragmented among consultants, membrane manufacturers, and different research organizations. A utility considering applying MF/UF systems should be able to access one location or source for this type of information. This database would provide an easy-to-use and accessible knowledge and experience source for MF/UF applications.

Research Approach:
The first phase of the project would be the development and distribution of a questionnaire (survey) designed to glean information pertinent to the planning, development, permitting, and long-term operation and maintenance of large [20,000 m^3/day (5 mgd)] MF/UF drinking water plants. The questionnaire would be distributed to manufacturers, consultants, utilities, and regulatory agencies involved in membrane installations. Data should be collected from a geographically representative number of large MF/UF drinking water facilities. The information collected should include:

Characteristics of municipality/service area

- population demographics and growth
- age of infrastructure
- water rates and revenue base

Overall water quality and treatment objectives

- influent (source) water quality
- final water quality objectives

Facilities planning

- existing pumping and distribution facilities
- membrane selection criteria
- alternative water treatment processes considered
- alternative membrane processes considered
- pretreatment requirements
- disinfection requirements
- post treatment and distribution system requirements
- projected capital and operation costs

Environmental impacts

- noise/sound abatement
- concentrate disposal
- chemical handling and on-site storage issues
- issues related to provision of primary and standby power
- traffic impacts

Identification of regulatory requirements

- permitting requirements
- plant monitoring and reporting requirements
- membrane system integrity monitoring requirements

Design and start-up issues

- use of existing facilities
- plant layouts (footprints)
- project delivery methods
- pilot vs Full scale performance
- start up and installation issues
- operation issues

Outcomes and Recommendations

- actual capital and O&M costs
- impacts on water rates
- impacts on distribution system and water quality at the tap
- good and bad experiences during project development and implementation
- suggested improvements for other facilities

The second phase of this project would focus on selected follow-up interviews and site visits to consolidate and validate the information collected in the survey. The database would be structured to provide the ability to easily access facility information through key

categories including location, source water, regulatory requirements, process type, operation history and costs.

The final product of this project would be a report and interactive web site for the purposes of disseminating information on MF/UF facilities and providing links to individuals, institutions, and manufacturers involved in each facility.

Contact: Greg Leslie, Orange County Water District/CH2M Hill, 011 61 2 9966 1166, gleslie@ocwd.com

Project Title: The Development of a Decision-Making Tool to Assist in the Selection of a Membrane Process

Description of Issue: Once a utility has made the commitment to use a membrane technology (e.g., MF or UF) for the production of drinking water, the process to select an appropriate membrane technology (i.e., the specific configuration) based on specific source or site characteristics begins. The decision-making process needs to integrate several related and non-related issues into the selection of a specific membrane technology. Because these issues may have different priorities, their level of importance, and hence their influence on the overall decision making may vary between locations. No decision-making process is completely linear considering issues such as source water quality; current and future water quality requirements; physical siting needs; and operation and maintenance costs. There is a need to ensure the optimal or "best" solution can be derived from the assemblage and coalescence of these various factors.

Objective: The objective of this project would be to develop a decision-making tool that would facilitate the selection of a membrane system. It would create a means of assisting utilities and their consultants in the selection of a suitable membrane technology (or technologies) for a specific source water application prior to pilot studies. In addition, the decision-making tool should provide appropriate membrane process design guidance for the scale-up to larger facilities.

Recommended Funding: $150,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: US Bureau of Reclamation, AMWA, NWRI

Background:
Once the "Development of a Microporous Knowledge Database" project has been completed, data derived from the project can be used to facilitate the selection of future membrane processes. While there are current efforts to benchmark conventional and membrane processes, such benchmarks would be used to facilitate the selection of conventional or membrane processes.

Research Approach:
The development of a decision-making tool project would build on the results of the "Development of a Microporous Knowledge Database" project. Data from the project "Development of Life Cycle Approaches to Support MF/UF Process Selection" (Issue #5), should also be used. Using the database and information derived from that project, the investigator should outline how they would develop a decision-making tool that would assist utilities in the selection of an appropriate membrane technology for the production of drinking water. The decision-making tool should aid in the selection of a membrane process and membrane process design. Since the basis for the decision-making tool would

be data from operating facilities equal to or greater than 5 MGD, the output from the decision-making tool should also delineate the impacts on large-scale membrane applications.

The decision-making tool itself would not be limited to a computer or computer-based model. The tool might also take the form of a non-computer based decision tree or guidance manual. The product from this project should be integrated into the decision-making tool that facilitates the selection of a membrane process over conventional treatment.

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AwwaRF Membrane Workshop Project Descriptions

Issue 6: Standardization of Test Methods, O&M

Project Title: Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling-Assessment Protocol and Associated Fouling Indices

Description of Issue: The membrane industry has developed fouling indices (e.g., SDI) for the assessment and prediction of fouling of spiral-wound (RO and NF) membranes. There is a need to develop a bench-scale protocol(s) to assess fouling trends and delineate fouling indices for hollow fiber (MF and UF) membranes as a function of water quality (e.g., SUVA) and simulated operational conditions (e.g., pretreatment and chemical cleaning).

Objectives: The objectives of this project would be: (i) to develop a bench-scale protocol(s) to assess MF and UF fouling trends; (ii) to define the influence of water quality and simulated operational conditions on fouling; (iii) to preliminarily define quantitative fouling indices (e.g., flux decline trends) to describe fouling; (iv) to classify combinations of source water-membrane types in terms of fouling propensity; and (v) to identify problematic foulants and cleaning strategies.

Recommended Funding: $250,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
Utilities considering implementation of UF or MF membrane systems have limited protocols available to assess the fouling trends of those membranes. The application of membrane technologies is limited greatly by membrane fouling. Fouling deteriorates membrane performance and ultimately shortens membrane life, causing an increase in operation and maintenance costs. There is a need to develop protocols to assess fouling potential for MF and UF membranes.

Research Approach:
This project should develop a bench-scale protocol(s) (conceptually similar to a stirred cell to assess disk specimens of spiral wound membranes) to assess MF and UF fouling. This would be accomplished with the following considerations:

- MF and UF manufacturers should be contacted to determine the present range of practice in bench-scale assessment.
- Different membrane materials and configurations (e.g., inside-out vs. outside-in, pressure-driven vs. vacuum) should be tested.

- A range of natural source waters should be studied, possibly augmented by synthetic waters (e.g., model colloids). Feed-water quality should be defined in terms of parameters/analytical protocols potentially predictive of fouling trends (e.g., SUVA).
- The focus should be on NOM and colloidal fouling, recognizing the size continuum of macromolecules (e.g., < 0.01 um) to (organic) colloids (e.g., >0.01 um). Resultant fouling indices are not intended to be fully predictive of fouling at the pilot-/full-scale (e.g., hydraulic cleaning/backwashing cannot be simulated) but rather to quantitatively describe bench-scale fouling trends (it is intended that a subsequent project focusing on pilot-/full-scale fouling would adjust the indices for predictive purposes).
- Various pretreatments (e.g., coagulation, PAC, oxidant) should be simulated. Consideration should be given to chemical cleaning strategies (combinations/sequence) on flux recovery, as well as foulant(s) identification. It is expected that fouling indices would be based on flux decline trends and related to water quality.

A guidance matrix should be developed that relates fouling to water quality and membrane material. A synthesis of previous research on MF and UF fouling (including AWWARF studies) should also be provided. The product of this research would be protocol that assesses fouling and associated fouling indices for MF and UF membranes.

Contact: Gary Amy, University of Colorado – Boulder, (303) 492-6274, gary.amy@colorado.edu

Project Title: Evaluation of MF/Uf Performance and Operation: Pilot- and Full-Scale Studies

Description of Issue: Quantifying and evaluating MF and UF fouling continues to be an impediment to the wide application of membrane technologies, especially at larger plant scales. A tool for prediction of fouling would be developed under the project entitled "Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling Assessment Protocol and Associated Fouling Indices." However, no tool is useful unless it can be validated. This project would focus upon validating the fouling trends predicted by the fouling indices developed in the aforementioned project. This project would use pilot scale testing to focus upon making adjustments to the indices developed in the previous project.

Objective: The objective of this study would be to validate, calibrate, and adjust the MF and UF fouling indices developed in the project entitled "Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling Assessment Protocol and Associated Fouling Indices." The fouling indices would be validated under pilot- and full-scale conditions.

Recommended Funding: $350,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: USBR, KIWA, CRC for Water Quality and Treatment (Australia)

Background

The use of MF and UF membranes has increased dramatically over the past decade. Decreases in adequate water resources, an emphasis on water reuse, and an increased sensitivity to less operator-intensive water treatment processes have also contributed to increased membrane use. Additionally, there have been substantial decreases in membrane costs due to technological advancements, thus promoting their use as alternatives to long established conventional water treatment methods. Nonetheless, membrane fouling still remains a salient issue when considering the use of MF and UF membranes. In order to better assess fouling, MF/UF fouling indices would be developed in the project entitled "Bench-Scale Assessment of MF and UF Fouling: Development of a Fouling Assessment Protocol and Associated Fouling Indices." However, any tool to predict fouling must be validated in the field. Thus, a study that focuses on validating and calibrating the predictive tool is warranted.

Research Approach

This study should be conducted at two scales: pilot- and full-scale. Pilot studies should be undertaken at utilities that have full-scale plants so that side by side comparisons could be made. Plants that would allow evaluation of a wide range of water qualities, particularly as pertains to natural organic matter and particulate material, should be

employed as test sites. Additionally, the investigator should consider some plants that use pretreatment (such as coagulation or PAC adsorption) to the membranes.

In addition to water quality variations, the investigator should also evaluate as many different types of membrane systems as possible. At least one UF and one MF, as well as one pressure-driven and one vacuum driven system should be included in the study.

The project should be executed in two phases. The first phase would be at pilot scale. The bench-scale fouling indices developed in the aforementioned project should be reviewed and then validated through a carefully controlled-pilot study at each site. Based on results obtained, the fouling indices (as developed using the standardized bench-scale protocol) should be adjusted to better reflect performance under real-world operating conditions. Operational parameters that cannot be adequately evaluated at bench scale, such as backwash frequency and duration, and chemical cleaning, should be considered in the adjustment of the indices.

The second phase of the project would be conducted at a full-scale operating facility. The indices that were refined at pilot-scale should then be used to predict full-scale performance of the membrane plant. Attention should be paid to the operational strategy of the full-scale plant so that accurate prediction of fouling tendencies can be made.

The end product of this study should be a validated MF and UF fouling index that can be used by current and potential users of these processes to help predict the fouling tendency of their source water.

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AwwaRF Membrane Workshop Project Descriptions
Issue 3: Concentrate Issues

Project Title: Development of Effective Communication Tools Regarding Current Information on Reverse Osmosis/Nanofiltration (RO/NF) Concentrate Issues

Description of Issue: Regulatory and applicable political entities require current and accurate information regarding environmental issues associated with discharging concentrate streams from Reverse Osmosis and Nanofiltration (RO/NF) plants. A lack of current, accurate, concise information in an applicable format may cause regulatory criteria to be inconsistent and overly strenuous.

Objective: Develop communication tools that would provide current, accurate, concise information associated with concentrate disposal from RO/NF facilities. These RO/NF concentrate communication tools would incorporate scientific findings associated with environmental impacts, in combination with value and benefit information. This cost/benefit analysis would enhance the ability of decision-makers to make informed decisions.

Recommended Funding: $100,000

Phase I: $70,000 for development of tools
Phase II: $15,000 for up-dating and evaluation
Phase III: $15,000 for up-dating and evaluation

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified

Background:

Communities in need of additional water supply or supplies of improved quality often have limited options today. Traditional water supply alternatives may be too costly or have such severe environmental impacts that they are not acceptable to today's societal values. RO and NF technologies can offer many of these communities additional options that will augment or improve their water supply. Significant barriers exist in many states and communities that prevent utilization of RO/NF technologies due to rigid concentrate disposal regulations that are inconsistent between states.

AWWARF, the U.S. Bureau of Reclamation, and others have funded and conducted a number of scientific studies that investigate the environmental impacts of residuals and concentrate disposal from RO/NF plants. An effective tool that communicates the science and cost/benefit information that exists in the research and consultant community is not readily available to the appropriate decision-makers at the local, state, and national level in a format that can be easily used to make regulatory decisions. In addition, there currently is not an adequate method to ensure that scientific information regarding

concentrate/residuals in a cost/benefit format can consistently be up-dated and communicated on a regular basis.

Research Approach:
This project would provide information regarding pertinent RO/NF concentrate issues, the associated environmental impacts, and current research in a cost/benefit format for use by regulators and decision-makers.

Phase I: Development of Tools
Review and synthesize current literature and existing scientific findings:

- Evaluate existing literature and ongoing research activities to determine environmental impacts of concentrate discharge under different conditions and treatment scenarios;
- Determine any data gaps that exist;
- Develop summary of findings.

Develop benefit and value documentation for communities of different size and economic standing:

- Evaluate case studies and literature, and interview community leaders and project developers to develop benefit and value data;
- Develop classification of communities based on size and economic standing;
- Create comprehensive summary compilation of benefit and value data for the different classification of communities.

Develop deliverables (tools)

- Meet with appropriate groups which could play a role in implementation, in order to gain their insight into how best to structure and format the deliverables, what information is most critical, etc.
- Document overall findings into a 7 to10 page White Paper, including documentation of reference material
- Develop a 2 to 3 page visually stimulating document which provides an overview of the White Paper, focusing on the most critical issues, including graphics, photos, quotations, etc, to increase its effectiveness and ability to be read.

Create a recommended approach for implementation:

- Document appropriate entities and groups which are the “Audience” which should be provided with the developed tools;
- Document appropriate groups which can act as the “Implementation Teams” to deliver the tools;
- Develop and include a suggested “Game Plan” in the report by which to most effectively reach the Audience.
- Implementing the plan is beyond the intended scope of work.

Phase II: Evaluation of the Effectiveness of the Developed Tools and Up-date the Information
Evaluate effectiveness of the information provided

- Utilize a network of key individuals, including representatives from the Implementation Teams, to provide an assessment of the effectiveness of the development tools
- Utilize the above feedback to structure needed changes to the tools or implementation approach

Revise tools

Phase III: Evaluation of the Effectiveness of the Developed Tools and Up-date the Information
Same as Phase II above.

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Project: Evaluate and Confirm Innovative, Non-Chemical Approaches to Maximize RO/NF/UF/MF Recovery Rates

Description of Issue: Innovative new technologies have been introduced that claim to increase and maximize the water recovery of RO/NF/UF/MF membrane systems using magnetic fields, vibration, alternate geometries, and other non-chemical techniques. Data is needed to clearly evaluate and confirm the efficacy of these innovations to maximize system recovery.

Objectives: This project would evaluate and test non-chemical approaches to maximize recovery rates in all types of membranes. This would be done by screening candidate innovations and selecting three or less for further evaluation. Field testing would evaluate and confirm maximum recovery, operating in parallel with conventional membrane systems where appropriate.

Recommended Budget: $260,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified

Background:
Membrane systems have recently been introduced that claim to operate at higher water recovery than conventional membrane system designs. These innovations appear interesting but there is little or no data comparing performance to a typical membrane system. Technical and economic data needs to be gathered to evaluate and confirm these innovations. This information is needed for utilities who need to maximize their water resource and minimize costs associated with the disposal of residuals.

Research Approach:
Phase 1: Screen new innovations such as magnetic fields, vibration, alternate geometry RO/NF/UF/MF systems. Examples include Mineral Water Development International (magnetic field and alternate geometry), New Logic (vibration), and Rochem (high pressure), and others. Review published materials and rank based on potential for successful increased recovery. Select three or less candidates for confirmation evaluation.

Phase 2: Acquire test equipment and locate appropriate site for testing. Where necessary/appropriate test equipment in parallel to conventional membrane technology or system. Conduct controlled experiments to test and gather data to evaluate and confirm increased/maximum recovery operation, including but not limited to fouling rate, cleaning cycles (if needed), chemical consumption, differential pressure change, flux, and maximum recovery.

Phase 3: Publish data complete with normalized comparative graphs that confirm increased/maximum recovery. Where possible, comment on economic impact of innovation, specifically operating cost reductions (if any).

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AwwaRF Membrane Workshop Project Descriptions

Issue 2: Fouling and Scaling

Project: Development, Standardization, and Evaluation of Fouling Indices Using Ultrafiltration Membranes to Measure Fouling Potential of RO/NF and UF/MF Feedwaters Due to Particles

Description of Issue: A substantial number of Reverse Osmosis/Nanofiltration (RO/NF) plants are suffering from fouling. The control and reduction of fouling is severely hindered by lack of reliable fouling indices for the raw and pretreated wastes. Fouling can be categorized in four groups:

1. Scaling
2. Organic fouling
3. Biofouling
4. Particulate fouling

This project deals with improved fouling indices for particulate fouling. The Silt Density Index (SDI) is commonly applied to indicate the colloidal fouling potential of water as it flows through a RO/NF membrane system. However, the general feeling is that it does not accurately and reliably predict the fouling potential of RO/NF feedwater. There are strong indications that particles much smaller than 0.45 microns are responsible for particulate fouling.

The water treatment industry needs a reliable method to indicate the fouling potential of feed water for RO/NF systems. There is also a need to predict the rate of flux decline or pressure increase in Ultrafiltration/Microfiltration UF/MF membrane systems. Furthermore, there is a need for standardizing methods worldwide.

In response the poor ability of SDI to predict fouling, the MFI UF, which makes use of ultrafiltration membranes, was developed. This index may more accurately predict the fouling potential of RO/NF feedwater. Additionally, it potentially predicts the rate of flux decline or pressure increase in UF/MF membranes systems between backwash cycles. This system needs further evaluation for use as an index to predict fouling.

Objective: Develop and evaluate the MFI-UF index including approaches to record and control the system with software.

Recommended Funding: $250,000

Proposal Source: 2000 membrane Workshop

Potential Partners: KIWA (Netherlands), Vivendi (France), TZW (Germany)

Background:
The SDI, which has been generally used for many years, does not reliably measure fouling potential due to particles. The deficiencies and drawbacks of the SDI method are:

- It is not based on a filtration mechanism (lack of scientific base);
- There is no linear relationship to the concentration of colloids;
- It is not corrected for temperature;
- It utilizes membranes with 0.45-micron pores even though there are strong indications that particles much smaller cause fouling of RO/NF membranes;
- The reproducibility and accuracy are doubtful.

The MFI-UF index, which makes use of ultrafiltration membranes, is based on the formation of a cake/gel layer on the membrane and does not suffer from the deficiencies and drawbacks of the SDI. A linear relationship between indices and colloid concentration exists. These indices can be measured in either constant flux mode or constant pressure mode. The constant pressure mode is close to a stage where it can be evaluated. The constant flux mode is even more promising but needs further development before it can be evaluated. These indices are derived from MFI (0.45 micron).

Research Approach:
1. Develop the MFI-UF measured at constant flux to a stage where it can be implemented.
2. Develop methods to calibrate the membranes to be used and to correct for quality variations in membrane material.
3. Select preferable membrane (maybe two, one for MF as well) to become a world standard.
4. Build and make available prototypes of apparatus (including software) for testing.
5. Evaluate performance and reproducibility of MFI-UF index using both constant pressure and constant flux modes. Recommend which of these modes is most appropriate to become world standard.
6. Describe how MFI-UF should be measured.

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Project Title: Development and Evaluation of Method(s) to Maximize Recovery Conditions and Effectively Monitor Scaling in Full-Scale RO/NF Plants

Description of the Issue: Water utilities are faced with the strong need to maximize recovery in Reverse Osmosis/Nanofiltration (RO/NF) plants. This is to save raw water and to minimize the cost of concentrate disposal. Maximization of recovery is held back due to the lack of a method to accurately determine when scaling is threatening an RO or NF process. One of the reasons that this problem exists is that utilities do not have an accurate and realistic method(s) to determine the required dose of synthetic antiscalants, or presence of natural antiscalants, and the associated acid dose requirement. In addition, utilities need an operational method and/or equipment to continuously monitor scaling before irreversible membrane damage is done.

Objective: To develop a method for determining the dose of antiscalant required for maximizing recovery in RO/NF plants. To develop and evaluate accurate/realistic lab-scale method(s) for detecting scaling in a full-scale plant. Develop and test a continuous, on-line monitor that detects scaling continuously in an early stage.

Recommended Funding: $400,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: KIWA, Vivendi

Background:
Water utilities often operate plants without scaling, with or without the addition of antiscalants. Plants are designed conservatively to avoid scaling. The actual conversion or recovery estimates and antiscalant doses are based either on jar tests, which lack a fundamental scientific base, and/or recommendations of antiscalant suppliers. These recommendations tend to be conservative.

In addition, adequate methods are not available to monitor scaling in full-scale plants. Existing methods to monitor scaling measure the development of MTC and are inadequate. Determining the deposition rate of sparingly soluble compounds by calculating mass balances is very costly, time consuming, and inaccurate.

Research Approach:
The result of this research would be a method to better determine the dose of antiscalants required for an RO/NF treatment process.

The research should investigate and develop one or more lab tests that are more accurate than the currently applied jar tests. Using induction time to determine

recovery/conversion should be evaluated and calibrated with data from pilot tests and full-scale plants as well. Scaling monitors are essential for this research.

A prototype of a scaling monitor is under development. This prototype configuration, including software, should be further developed to a point where it can be applied in full-scale plants. For this purpose, the performance and accuracy of the monitor should be evaluated in pilot plants and different full-scale RO/NF plants.

Contact: Jan Schippers, KIWA, 011 31 3 0606 9532 (Netherlands), jan.schippers@kiwa.nl

Project Title: Develop Improved Understanding of Chemistry of Membrane Fouling Caused by Natural Organic Materials (NOM) and Interaction With Commercial Antiscalants and Dispersants and Membranes

Description of Issue: There is a severe membrane fouling problem associated with Natural Organic Matter (NOM), particularly humic acids that occur in surface waters, surficial well waters, and treated wastewaters used in Nanofiltration (NF) and reverse osmosis (RO) processes**.**

Objective: Characterize the fundamental chemistry of how NOM is attracted to and absorbed onto the Membrane, including effects of pH, presence or absence of other major ions, and compare effects of various classes of antiscalants and dispersants on fouling rates.

Recommended Budget: $350, 000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
A majority of the large municipal nanofiltration plants in the USA are used to soften water, remove disinfection by product (DBP) precursors, and remove color. The DBP precursors and color are a result of NOM, predominantly humic acids. Fouling of the membrane occurs as the NOM is drawn to the membrane along with water permeating across the membrane. Typically the membrane and the humic acids both exhibit a negative charge and therefore have a net repulsive force keeping them apart. It is suspected that lowering the pH and / or adding certain antiscalants or dispersants alters the repulsive charges allowing the NOM to be absorbed onto the membrane surface causing a loss of flux.

There is a current AWWARF project being conducted by University of Colorado, University of Illinois, and National Institute of Standards and Technology entitled NOM rejection by, and fouling of, Nanofiltration and Ultrafiltration membranes. The project description states that it will assess the mechanisms of NOM-membrane surface interaction. This project may overlap the work by the current AWWARF project. The approach and methodologies proposed for this project would be different from the current project cited above because it would focus on interactions with antiscalants and dispersants typically used in RO/NF plants.

Recent tests by Professors Winters and Suratt at the Boca Raton, Florida facility have shown that it is possible to operate without fouling by NOM at 85% recovery rates without lowering the pH or using antiscalants or dispersants. These tests indicate that the

NOM is acting as effective antiscalant and that use of acid and antiscalants increased fouling by NOM.

Research Approach:

Phase I – Bench Scale Studies

1. Select candidate feed waters from various regions of country where this type of fouling is apparent. Also examine those waters where current pretreatment is relying on the use of large quantities of acid for pH adjustment or antiscalants and dispersants to control fouling. Also include some sample reclaimed water that is being used in an RO system

2. Develop test matrix of currently available nanofilters and reverse osmosis membranes that are in widespread use at municipal membrane plants.

3. Develop test matrix of a representative number of antiscalants and dispersants. Determine the major classes and types of chemical antiscalants and dispersants

4. Conduct electrophoresis and Zeta Potential tests to measure attraction between NOM and the membrane surface. Test runs would include the following:

- Measure effect of pH;
- Measure effect in presence of variety of antiscalants and dispersants;
- Measure effect in presence or absence of other major ions;
- Compare effects with different membrane surfaces;
- Measure effects on membrane already fouled by NOM.

Part Two – Second Phase – Conduct Pilot Scale Tests

Conduct Pilot Scale Tests to confirm findings from Phase I – Bench Scale Testing
Using four-inch two-stage 80 to 85% recovery pilot unit. Arrange pilot to be able to test two or more membranes or chemicals in same pilot at same time to run accurate side-by-side tests.

Contact: Bill Suratt, Camp, Dresser and McKee, (954) 776-1731, surattwb@cdm.com

Project Title: Demonstration and Verification of New Biofouling-Resistant and Chlorine-Tolerant Membranes

Description of Issue: Biofouling of reverse osmosis (RO) and nanofiltration (NF) membranes has limited the widespread application of these technologies in the water industry. Uncontrolled biofouling will decrease membrane performance and increase O&M costs significantly. A common way to control biofouling is to add an oxidant (e.g. chlorine or chloramines) to the process water and then dechlorinate prior to the membranes. Development of chlorine-resistant membranes would eliminate the dechlorination step and reduce O&M costs. Another method to control biofouling is by using robust, biofouling-resistant membranes. Membrane manufacturers have recently developed experimental membranes that minimize the growth and colonization of bacteria on the membrane surface. If proven effective, these membranes could make RO/NF technologies viable for many water utilities.

Objective: The objectives of this research would be to evaluate and verify the performance of new, robust biofouling-resistant RO and NF membranes using multiple natural waters including brackish surface water and reclaimed municipal wastewater. It would also evaluate and verify the performance of new chlorine-tolerant RO and NF membranes using multiple natural waters including brackish surface water and reclaimed municipal wastewater.

Recommended Funding: $300,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:

Research Approach:
General tasks would include 1) literature surveys, 2) manufacturer surveys, and 3) bench- and pilot-scale evaluations. In order to evaluate different water matrices, at least three different water utilities should be involved. The research approach would include the following tasks:

1. Conduct a literature search of all pertinent data to help identify products which merit evaluation.
2. Survey manufacturers to identify promising membranes which merit further evaluation and verification.
3. Conduct bench-scale studies of new experimental products. Side-by-side comparisons should be made with similar membranes which are not biofouling-resistant and chlorine-tolerant. Appropriate membrane performance indices should be collected and monitored. Microscopic analyses, including scanning electron microscopy and atomic

force microscopy, should be conducted to identify and characterize biological fouling. For chlorine-tolerant membranes, methods to detect and quantify oxidative damage should be used. Bench-scale testing should last approximately 12 months.

4. Conduct pilot-scale studies of products which performed well in Task #3. Run side-by-side comparisons. Collect and monitor performance indices including SEM and AFM analyses. Pilot-scale testing should last 12-18 months.
5. Interpret findings and prepare final reports.

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AwwaRF Membrane Workshop Project Descriptions

Issue 5: Design of MF/UF Plants

Project Title: Innovation in the Design of Large (>50 MGD / 200 ML/D) MF/UF Membrane Systems

Description of Issue: Existing MF/UF membrane plants have production capacities in the range of 1 to 20 MGD. They are based on building blocks of 1 to 2 MGD capacities that are not optimized for larger plants. While membranes are currently being considered for implementation in larger plants, the various approaches proposed by membrane manufacturers and consultants to provide economies of scale must be evaluated on a common basis.

Objective: This project would address changes in membrane equipment, system design, engineering, construction, operations, and monitoring techniques required to realize economies of scale for plants larger that 50 MGD. The outcome would be conceptual design and operation strategies for large plants. All designs would be evaluated using a uniform life cycle approach developed in a separate project.

Recommended Funding: $200,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
The economies of scale for membrane systems are lower than for conventional processes. Membrane surface area scales-up linearly (doubling the flow rate requires doubling the membrane surface area). Therefore, economies of scale must be sought in building large membrane and system modules. Both approaches reduce the relative importance of ancillary equipment with impact on both capital and operating cost.

Current system module sizes of 1 to 2 MGD are too small for larger plants and thus limit the applicability of MF/UF systems. Membrane manufacturers have introduced several concepts to allow for the construction of larger system modules. Ideally, the system module size should be dictated by operational requirements and not by technological limitations.

Research Approach:
This project would focus on design, engineering, and costing of large MF/UF water treatment plants. The research should include the following:

- Design concepts for both pressurized and immersed membranes

- Preliminary designs for both new plants and retrofitting of existing plants for 2 sizes, 50 and 200 MGD
- Design packages to include design basis, process flow diagram, process and instrumentation diagram, plant layout, bill of materials.
- Operation and maintenance package to include operation procedures, maintenance schedule.
- Life cycle cost analysis (using standard methodology developed in another project)
- Analysis and identification of needs for technology developments and further research needed to enable this transition.

Contact : Pierre Côté, Zenon Environmental, Inc., 905-465-3030 ext 3080, pcote@zenonenv.com

Project Title: Development of Life Cycle Approaches to Support Mf/Uf Process Selection

Description of issue: The design and use of MF and UF membrane systems in water treatment plants is normally based on a balance between performance and operating requirements and capital and operating costs. The selection of the most appropriate system for a particular application should not be based on any single criterion. Rather, it should be based consideration of all the criteria over the life of the water treatment plant. Life cycle analysis (LCA) tools potentially allow researchers to consider and manipulate all of the criteria and come up with a rational basis for design.

Objective: This project would develop a protocol for life cycle approaches (LCA) of UF and MF membrane processes to assist plant designers and utilities in selecting appropriate membrane technologies. This project would identify the necessary criteria for such an analysis and use real data collected from operating membrane systems to demonstrate the LCA protocol. The protocol would be used to perform a sensitivity analysis on UF and MF systems to identify where development in these technologies would provide a major benefit to the drinking water industry.

Recommended Funding: $200,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: CRC for Water Quality and Treatment (Australia)

Background:
Process selection for water treatment technologies is normally based on an analysis of performance and costs. Depending on the utility, the decision to choose a particular technology or process configuration may be made purely on its ability to meet a particular performance standard at the lowest possible capital cost. With conventional water treatment technologies, there is significant knowledge of how system components behave over the life of a project. For membrane systems, this is not so clear and the following issues need to be included in any analysis of the technology:

- Size/capacity
- Hydraulic considerations
- Membrane life and replacement costs
- Pretreatment issues - fouling
- Membrane materials – eg. Hydrophobic vs hydrophilic
- Backwashing, cleaning, and waste disposal issues
- Disposal of elements, etc.
- Operational considerations – remote control/telemetry

- Redundancy
- Operating costs
- Capital costs

Research Approach

This project would develop an LCA protocol for UF and MF membrane process design. It should focus on the design constraints for MF and UF plants with a capacity of greater than 50 MGD.

In order to develop an LCA protocol, the project should accomplish the following tasks:

- Define criteria and identify data necessary for LCA of UF and MF membrane processes
- Gather data to fit criteria for a range of sizes and configurations of MF and UF plants
- Develop LCA protocol for MF and UF water treatment plants
  - Perform LCA using collected data for existing and conceptual design configurations Check sensitivity of LCA to various system components and procedures
  - Report on recommended system configurations and operating practices that would yield least cost while also meeting performance requirements
  - Follow on research could include:
  - A complimentary LCA study of conventional technologies to enable a comparative assessment of UF and MF systems with these technologies

The final product of this research would be a protocol for LCA that utilities could use to select and design MF and UF membrane technologies for water treatment. This protocol could also be used to perform a sensitivity analysis on UF and MF systems to identify where development in these technologies would provide a major benefit to the drinking water industry.

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Project Title: Identification of Generic and Proprietary Components in MF/UF Systems

Description Of Issue: Utilities operating MF/UF plants have to deal with the lack of standardization of UF/MF components in developing cost-effective long-term maintenance and upgrading strategies for such plants. While the membrane modules and specific operating conditions are usually specific to each vendor, there is a need to identify which component of MF/UF systems could be reused, upgraded, or interchanged while upgrading a plant or replacing modules with different ones. Such information is needed not only to optimize operating and maintenance strategies of existing plants but also in the early design of new membrane projects as design criteria to increase the flexibility of membrane plants (ie. provision for VFD, provision for extra blower capacities, requirement for flexible SCADA systems,…).

Objective: The purpose of this research would be to identify interchangeable and standardizeable components amongst different types of membrane systems. This research should include recommendations and options for optimizing the flexibility of membrane plants to be upgraded or revamped with different module configurations, and give cost estimations for such options.

Recommended Funding: $200,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
Little or no standardization exists in MF/UF systems. This lack of standardization, which translates into less flexibility and more long-term risks for utilities, has been identified as a limiting factor in the use of membrane applications (in particular to the development of large MF/UF plants). While membrane modules and specific operating conditions vary between vendors, it is often feasible to upgrade or revamp a MF/UF plant with different modules keeping most of the existing infrastructure. Very little hard data exists however, that clearly identifies plant components which need to be changed or modified in such scenarios. There is also a question of cost implications. This project is expected to enhance membrane acceptability among utilities having to choose between a growing number of membrane technology vendors and configurations in a more competitive MF/UF market.

Research Approach:
This project would be a desktop study to be carried out in close collaboration with membrane manufacturers and engineering companies. The following tasks would need to be conducted:

- Identification of key interchangeable and standardizeable components in MF/UF plants (including pressurized and vacuum types) as well as of proprietary components and operating procedures (patents);
- Identification of process strategies and technological options to allow for more flexibility and interchangeability in such plants;
- Development of case studies for full-scale medium sized (5-20 MGD) and large (>50 MGD) plants in which different scenarios should be evaluated and for which cost implications should be given.

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Project Title: Accelerated Failure Analysis of MF/UF Membrane Modules

Description of Issue: All previous membrane studies have considered integrity monitoring, fouling, and water quality issues that pertain to relatively short time periods (of the order of weeks). Even though these studies have produced much useful information on membrane operation and performance, to date no protocols have been developed to predict long-term membrane behavior. Thus, very little information is available on the changes in structural and mechanical properties of membranes over long periods of time (on the order of years). When membranes are subjected to various stresses during operation (e.g. backwashing, chemical cleaning, and aeration) individual fibers may break and compromise system integrity. Additionally, as MF/UF membranes age, changes in their surface chemical properties may impact their water permeability as well as rejection.

Objective: This project would develop a protocol for evaluating the long-term (order of years) failure of hollow fiber MF/UF membrane modules over shorter time frames (order of weeks). A standardized procedure for exposing membranes to various chemical, structural, and mechanical stresses in order to accelerate membrane failure should be documented. A framework to forecast results from these accelerated testing experiments to long-term failure should also be identified.

Recommended Funding: $350,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
Currently, there is no scientific basis for predicting failure rates or expected life of membranes. Membrane replacement frequency is typically based on empirical recommendation from respective manufacturers. As more membrane plants are constructed, the effects of aging and failure need to be better understood. Results from this study will allow the development of a technical basis for predicting membrane life.

Research Approach:
This project would proceed in three phases. During Phase I, historical information on module failures would be collected from existing MF/UF installations in order to identify aging and failure mechanisms. During Phase II, researchers would develop and verify experimental methods for accelerating module failure. Failure resulting from exposure to stresses induced during filtration, backwashing, and aeration, as well as the effects of attrition introduced by adsorbents and coagulants would also need to be included. The effects of chemicals employed intermittently (cleaning) and continuously (oxidants and carry over of pretreatment chemicals such as polymers) should be studied. Experimental design should span the range of all commercially available membranes employed in

municipal water treatment. Variables should include membrane structure (asymmetric and symmetric), mechanical properties (tensile strength and elongation), and module potting (static, centrifugal, and the use of elastomers). During the final phase of this study, the research team would develop a method to forecast long-term failure of modules based on experimental data collected in Phase II.

The final product of this research would be a standardized protocol for accelerated failure analysis of NF/UF membrane modules. The protocol would include experimental methods for accelerating module failure and methods to forecast long-term failure of modules.

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Membrane Workshop

Appendix 1

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APPENDIX 2

Summary of the Major Issues From Pre-Workshop Survey

Regulatory approval/ permitting - What can be done to make it easier to obtain regulatory approval?

Integrity concerns
Log removal credit
Residuals issues
Lack of standardization
Monitoring to ensure reliability
Concerns/compatibility with different regulatory requirements

Design issues

No standardization of systems
Integration with other technologies
Biding problems for different systems
Designing very large systems

Water quality

Lack of predictive modeling (contaminant removal and fouling)
Compatibility with other water quality objectives

Operations and maintenance issues

Fouling
Cleaning
Life cycle/ replacement schedules
Training for operators

New applications

Reclaimed water
Treatment of backwash water

Relative advantages/ disadvantages of membrane technology over conventional technologies

Why would a water utility select membranes over conventional technologies?
What are the competitive weaknesses of low-pressure membranes when competing against conventional-based technologies (high rate clarification, ozone, biological filtration, or high rate clarification, filtration, UV)? How can these advantages be improved?
Will consumers pay more for a higher water quality?

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Appendix 3: Project Descriptions

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AwwaRF Membrane Workshop Project Descriptions

Issue 7: Develop Uniform Permitting Criteria

Project Title: Benchmarking Study of MF/UF Membrane Systems vs Conventional Water Treatment Systems

Description of Issue: Current regulations do not adequately reflect the state of art of membrane-based treatment systems. Regulations and regulatory approaches to new treatment technologies are not consistent nationwide. Because the application of membrane technologies to water treatment systems is relatively new, the federal government has not provided satisfactory guidance related to membrane water treatment technologies. In order to promote membrane water treatment technologies, a uniform regulatory approach must be developed.

Objective: This project would be compare MF/UF systems to conventional water treatment unit processes through a benchmarking study. Unit process comparisons would be performed for any and all specific removal/inactivation/neutralization capabilities. These analyses would then be compared to federal regulations in order to determine how consistent regulations can be promulgated that do not negatively impact the ability of membrane systems to successfully be implemented. This project would develop recommendations and a strategy to provide federal guidance to states and local authorities. It would also develop a transition strategy to allow utilities to move toward applying membrane technologies.

Recommended Funding: $200,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
MF/UF membrane systems are being considered and utilized more frequently to address water quality and regulatory requirements at drinking water treatment facilities. Regulations are becoming more stringent and are impacting the ability of conventional water treatment systems to meet the regulatory standards. Membrane systems are a viable alternative to conventional unit processes due to their ability to provide a higher quality water product. Regulations have not kept pace with new technology developments. Regulations and technology must be matched to insure the most appropriate options are selected to insure regulatory compliance and to protect public health.

Research Approach:
This project would compare MF/UF membrane systems to conventional water treatment processes with a benchmarking study. The study would include the following tasks:

- Compile a list of state and federal regulations that impact the ability of MF/UF membrane systems to be successfully implemented in water treatment facilities.
- Develop sets of conventional and MF/UF membrane processes that are utilized for similar water treatment objectives (eg.pathogen removal/inactivation). Compile lists of similarities and differences between the conventional processes and the membrane processes using the conventional treatment unit process as the benchmark.
- Relate the benchmarked unit processes to existing and proposed regulations to determine if the conventional and membrane technologies are treated equitably. Document areas of inequity.
- Develop a strategy to ensure that future regulations take into account the reality of membrane technologies.
- Develop and implement a strategy to gain federal guidance to states related to the preparation of uniform equitable regulations that do not put any technology at a strategic disadvantage.

The final product of this project would provide recommendations and strategies to provide federal guidance to the states concerning the application of membrane technologies in water treatment plants. The final product would also provide a transition strategy for water utilities to apply membrane technologies to reach water quality and regulatory goals.

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Project Title: Develop Operating Criteria for MF/UF Membranes

Description of Issue: For membrane filtration systems there is limited or no experience base for treatment plant operators on the relationship between measured parameters and the operational impact of a change in those parameters on system efficiency or effluent water quality. Development of a guidance manual for treatment plant operators outlining the operating criteria for MF/UF membranes is needed for efficient and effective plant operation.

Objective: This project would determine the relationship between measurable predictive tools and the resultant operational impact in MF/UF membrane systems. It would also develop operational criteria to address the issues identified.

Recommended Funding: $ 250,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
The traditional methods for measuring conventional plant performance, turbidity, and particle counting have been shown not to be well suited for measuring membrane filter performance. In general, neither measure has the sensitivity necessary that is necessary to maintain optimal performance from membrane systems. In addition, there are no indicators available to measure membrane fouling, degradation of the membranes and the results of membrane degradation.

Research Approach:
The first phase of this project would be a literature review/utility survey to obtain the following information:

- parameters typically measured to measure plant performance
- operational issues experienced with using traditional methods for measuring plant performance
- a review of the AWWARF Predictive Tools Report
- a review of the AWWARF Benchmarking Report

The research team would then conduct a field study with:

- utility visits
- data review

A pilot plant study would then be conducted to assess the potential for application to plant operations by:

- Determining the relationship of the measured parameter to plant operations
- Developing operational guidance

Test Results

- Verify by testing the operational guidance criteria

The final product of this research would be an operational guidance manual for treatment plant operators that outlines the criteria needed for efficient and effective MF/UF membrane plant operations.

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Project Title: Testing of Standardized Predictive Tools For On-Line, Real-Time Integrity Monitoring of MF/UF Systems

Description of Issue: Integrity monitoring of MF/UF membrane systems is a critical component of the regulatory compliance scheme. Integrity monitoring must be able to detect small problems with the membranes that may affect water quality and public health. The monitoring techniques must be inexpensive, reliable, accurate, and precise. Development and documentation of such tools are necessary when implementing MF/UF membrane applications.

Objective: This project would field-test integrity monitoring techniques developed in AWWARF Project 2681 "Low Pressure Membrane Integrity Monitoring Tools." Monitoring equipment of the same type (e.g., particle counters) would be used to confirm the results of AWWARF Project 2681. A guidance manual would be prepared to assist designers, operators, and regulators in selecting monitoring schemes and equipment to ensure integrity of MF/UF membranes.

Recommended Funding: $250,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: None identified.

Background:
Conventional methods of determining unit process performance and regulatory compliance are not necessarily applicable to MF/UF membrane systems. Since most MF/UF systems are comprised of bundles of hollow fibers, detection of compromised fibers is the most direct way to ensure unit process performance. Online, real-time integrity monitoring techniques need to be developed, so that compromised fibers can be detected and repaired before water quality is adversely affected.

Research Approach:
This project would focus on further developing and field-testing the monitoring techniques developed in AWWARF Project 2681.

This project would include the following tasks:

- A literature review of previous studies should be performed to compile results of completed integrity monitoring work.
- Develop an experimental plan for the side-by-side comparison of the range of available integrity monitoring methods and systems. The experimental plan should include work to determine the sensitivity and precision of the various monitoring methods and the relationship to influent water quality.
- Perform monitoring studies on a range of influent water types with various membrane systems using the monitoring equipment identified. Compare

performance, ease of operation, reliability, cost, and precision of the various systems tested. Relate monitoring systems tested to regulatory compliance parameters (eg. log pathogen removal).

The final report would be a guidance manual on the selection and operation of integrity monitoring equipment and systems. The manual should relate monitoring systems to potential regulatory compliance schemes.

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AwwaRF Membrane Workshop Project Descriptions
Issue 8: Water Quality

Project Title: Effect of Membrane Systems on Distribution System Water Quality

Description of Issue: Regulations and consumer demand will continue to become more challenging to treatment processes. Changes in the treatment process impact the existing water supply, treatment and distribution systems. Although plant finished water meets and exceeds all drinking water regulations, the water delivered to the consumer often fails to meet expectations and regulatory requirements. These changes are determined by physical, chemical and biological interactions within the distribution system that deteriorate the quality of water delivered.

Objectives: 1) Comprehensive assessment of changes in water quality delivered to the consumer after implementation of a membrane system into existing water supply, treatment and distribution system; and 2) determine methods to mitigate adverse effects in aesthetic and regulatory water quality issues addressing blended water from existing and state of the art treatment processes and conveyance systems.

Recommended Funding: $500,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: USEPA, Pipe Manufacturers, KIWA

Background:
Several water utilities have installed or are contemplating the installation of membrane processes to achieve stringent drinking water regulations and provide optimum quality drinking water. As these processes are installed in existing systems the consumer expects and demands water equal to that produced by state-of-the-art treatment plants. The impact of membrane treated water on the existing distribution systems previously conveying "conventional process" water has not been elucidated. Studies conducted by the French have demonstrated beneficial impacts from the introduction of membrane permeates into existing distribution systems. In order to avoid any detrimental consequences in the delivery of the water or blending with existing treatment processes, it is critical that utility and distribution system operators understand the fundamental changes in water quality that occur from various blending scenarios or within the water supply/distribution network.

The current knowledge of the effects of blending or introduction of newer technologies on the distribution system quality is largely unknown or conflicting. Anecdotal evidence from U.S. plants suggests that there is a loss of disinfection and increase of disinfection by-products, deterioration of aesthetics (color, taste, odor), an unacceptable increase in iron, and changes in stability.

Expected products from this investigation will include definitive documentation of the effects on distribution system water quality delivered to the consumer. The effects of varying physical, chemical, and biological parameters will be interpreted for mitigation of adverse aesthetic and regulatory impacts. The chemical and biological changes that will be identified and mitigated will provide invaluable information to the water community.

Research Approach:

- Development of project organization and task work plans
- Assessment of existing water quality and review of existing literature
- Determination of field operating conditions with laboratory assessment
- Map of all historical and current water quality complaints and type and size of pipe at impacted area
- Identification of water quality changes and research of change
- Bench and pilot-scale investigations of changes in distribution system water quality before and after introduction of membrane treated waters (or blending)
- Development of guidance on operation, maintenance and system changes within distribution systems
- Preparation of final report

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Project Title: Multi-Contaminant Removal From Surface Waters Using Nanofiltration and Reverse Osmosis Membranes

Description of Issue: Membrane processes are increasingly being applied for treatment of surface water or surficial ground water under the influence of surface water. There is a need to collect and document the effectiveness of reverse osmosis and nanofiltration (RO/NF) processes for the treatment of surface and surficial ground water, particularly with respect to the removal of microbial (virus, bacteria and pathogens), taste, odor, and pharmaceutically active contaminants.

Objective: Document the effectiveness of removing microbial, taste, odor and pharmaceutically active contaminants using nanofiltration and reverse osmosis membranes.

Recommended Funding: $400,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: USEPA; USBR; NSF-ETV; Kiwa; CIRSO (Australia); TZW (Germany)

Background:

Membrane technology comprises microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) membranes. These membrane processes are increasingly being used in potable water treatment because of their unique treatment capability regarding most if not all of the new and impending drinking water contaminants. Although much work has been performed in recent years relative to microbe (virus, bacteria and pathogen) removal using MF and UF for the treatment of surface water, little work has been accomplished regarding the removal effectiveness of NF and RO for microbial removal. In recent years, RO and NF membranes have been employed for removal of microbes to meet the Surface Water Treatment Rule (SWTR), as well as for removal of disinfection by-product (DBP) precursor material, synthetic organic compounds (SOCs), hardness, arsenic, radionuclides and total dissolved solids (TDS). Since NF and RO membranes are semi-permeable, non-porous synthetic films, it has been assumed to remove all pathogens without demonstrated performance. The basis for this assumption was that pathogens are generally much larger than the molecules that are designed to be removed by NF and RO membranes. In practice, however, the removal of microbes by NF and RO is less than absolute. This is most likely due to small amounts of leakage either through the membrane itself, the glue lines, the o-ring and stub-tube adapters, and seals in the pressure vessels.

In order for membranes to receive log-removal credits under the provision of the SWTR and its amended forms, additional information is needed on the effectiveness of NF and RO for treatment of surface water and surficial ground water under the influence of surface water. Moreover, little to no work has been performed relative to the assessment of NF and RO for taste and odor (T&O) and pharmaceutically active contaminants (PhACs). Although some work has been performed relative to SOC and pesticide removal, no information is available relative to PhACs and little information has been published relative to T&O control. Consequently, there is

a need to investigate the effectiveness of NF and RO for the treatment of surface water for microbial (virus, bacteria and pathogen), T&O, odor and PhACs.

Research Approach:
The major elements of this research will include the following:

- Document from the literature the levels of microbial (virus, bacteria and pathogens), T&O and PhAC contaminant removal achieved by NF and RO, if such data is available.

- Conduct flat-sheet laboratory-scale investigations of laboratory-derived synthetic waters containing mixtures of T&O (to include geosmin and methyl-isoborneal), microbial surrogates (MS2 Phage, Clostridium and or a comparable spore, HPC, coliform) and PhACs (estrogen, representative endocrine disrupters, etc) in a controlled fashion. Several different NF and RO membrane films from several different membrane manufacturers will be evaluated at the laboratory-scale.

- Conduct single element bench-scale or multi-stage pilot plant testing using 4-inch by 40-inch spiral wound NF and RO elements. At least two different types of NF and RO membranes commercially available will be tested. The single-element bench-scale test equipment will be developed with recycle per the guidelines established in the USEPA ICR Guidance Manual. The pilot phase of this work will be conducted in the field using a by-pass stream of actual operating water treatment plants treating surface and/or surficial ground water under the influence of surface water. The feed water will be spiked with microbial (unless already present), T&O, and PhAC chemicals and water samples evaluated using Standard Methods.

Operational parameters to be documented include membrane recovery, normalized flux, water mass transfer coefficient, and feed, permeate, concentrate and recycle (if applicable) water flow and pressure. Data on performance shall be documented in terms of percent removal and solute mass transfer rates should partial removals be delineated for T&O and PhAC testing constituents. Microbial removals shall be evaluated using spiking studies and log-removal information shall be reported.

Relative to assessing NF and RO for microbial (virus, bacteria and pathogen) removal, compounds will be identified (either organic or inorganic), particulate and/or dissolved, that could be added to the feed water and be used for evaluating removal effectiveness and delineating log removal information. The compounds used in the testing shall be non-reactive and not represent a membrane foulant or promote fouling of a spiral-wound element.

The information collected will be summarized and evaluated with respect to removal performance and treatment effectiveness. Mass balances will be conducted on the feed, permeate, concentrate and recycle process streams (if applicable). All laboratory work will be performed using approved QA and QC protocols and industry certifications shall be required for private laboratories. The final report will delineate differences between different NF and RO membranes and provide recommendations on what order of log-removal credits for microbes could be granted to NF and RO membranes.

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Project Title: Development and Verification of NF and RO Models for Water Quality and Productivity

Description of Issue: Membrane processes are increasingly being applied for treatment of drinking water supplies, however there is no available model that accurately predict water quality and productivity of NF/RO. Systems, system level process evaluation, operations evaluation and design evaluations are significantly limited as a result of the lack of predictive models.

Objective: Develop and verify water quality and productivity models for nanofiltration and reverse osmosis processes.

Recommended Funding: $240,000

Proposal Source: 2000 Membrane Workshop

Potential Partners: United States Environmental Protection Agency (USEPA), United States Bureau of Reclamation (USBR); Kiwa (Netherlands); CIRSO (Australia); TZW (Germany).

Background:

Models that reliably predict the performance of water treatment processes are beneficial in that cost and performance can be delineated and supported using the models, and models are useful in identifying in an operation sense when fouling and non-ideal operating conditions exists. However, in many instances, models used for predicting water quality and productivity often do not accurately predict full-scale installation performance for productivity decline, and hardness, bromides, pathogen rejection and other pertinent water quality parameters. New models that incorporate fouling and permeate water quality need to be developed.

Research Approach:
This project would support the creation and field verification of a model that would predict water quality and productivity for nanofiltration and reverse osmosis membrane treatment processes.

This project would include the following tasks:

- Data Collection: Compile NF/RO operational and water quality data from existing databases including the Information Collection Rule (ICR), universities, manufactures, and consultants.
- Review and evaluate existing models using the database compiled in the first task.
- Develop new productivity and water quality model using the compiled database
- Design and conduct bench scale studies evaluating the productivity and water quality model developed with this project and determine model conflicts for modification and verification.

- Verify final model using actual full scale field data as available.

The final product resulting from this research would be a computer model that would predict water quality and productivity of NF/RO processes under fouling or non-ideal operating conditions.

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Membrane WorkShop Participants

Front (L to R): Traci Case, Jeff Oxenford, Kim Linton, AWWARF
Row 2: Joe Jacangelo, Montgomery Watson; Paul Gagliardo, San Diego Water; Pia Lipp, TZW; Adam Kramer, Minneapolis Water Works; Kevin Price, USBR
Row 3: Rick Sakaji, Calif. Dept. of Health; Jim Lozier, CH2M Hill; Shankar Chellam, Univ. of Houston; Scott Irvine, USBR; Gary Amy, Univ. of Colorado
Row 4: Randy Truby, Koch Membrane Systems; Steve Allgeier, USEPA; Nilaksh Kothari, Manitowoc Public Utilities; Herve Buisson, Vivendi Water; Jim Green, Metropolitan Water Dist. of S. Calif.; Bob Kenyon, Boynton Beach Utilities
Row 5: Larry Landness, Wisconsin Dept. of Nat. Res.; Nic Booker, CSIRO; Steve Duranceau, Boyle Engineering; Greg Leslie, Orange County Water; Warren Johnson, US Filter; Bill Suratt, Camp, Dresser & McKee
Row 6: Jan Schippers, Kiwa; Jim Taylor, Univ. of Central Florida; Pierre Cote, Zenon Environmental

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