Reverse osmosis (RO) membranes have been used in water reuse since the 1960s; however, the use of membranes in full-scale reuse applications has changed dramatically. The goal for membrane facilities in water reuse applications is finding the balance between cleaning frequency and chemical and energy costs. This manual presents a comprehensive description of the issues related to applying membrane technologies in water reuse projects. In addition, this manual devotes an entire chapter to case studies to showcase a variety of real world applications.
Membrane Applications for Water Reuse

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Chapter 10: Future Technology Trends and Contaminants of Emerging Concerns
   Joseph Wong, Arun Subramani, and Robert McCandless
Preface

Reverse osmosis (RO) membranes have been used in water reuse since the 1960s. Cellulose acetate membranes for treating conventionally clarified municipal effluent was initially applied to small industrial applications and as irrigation water for golf courses. In the 1970s, Orange County Water District in southern California used cellulose acetate membranes to produce 5 mgd of RO permeate that was blended with imported water for injection into seawater intrusion barrier wells. The use of membranes in full-scale reuse applications has changed dramatically based on research performed in the 1980s and 1990s. Those efforts demonstrated that microfiltration–ultrafiltration (MF–UF) membranes can offer superior pretreatment compared to RO when treating municipal effluents. Those efforts also incorporated polyamide membrane, which has all but replaced cellulose acetate in this application.

In the 1990s, many municipal agencies began operating full-scale MF–UF and polyamide RO membrane systems to treat secondary and tertiary municipal effluents. At that time, early adopters of large-scale membrane treatment processes for water reuse were rare. These membrane users transitioned the industry from theoretical and pilot-scale investigations into full-scale operations, bringing about a new facet of water reuse. In the years since, the industry has learned much about membrane performance and sustainability over long-term operation, including handling unanticipated operational challenges brought on by organic-laden, variable feed sources that can change not only year to year but sometimes day to day.

Operational considerations for low- and high-pressure membrane technologies in water reuse applications are similar to their potable system analogs. However, there are subtle differences that can pose additional problems or issues to the water reuse operator if these are not considered or anticipated. Membrane system operators in reuse applications need to understand that “industry guidance” has historically been based on potable water treatment applications. Irreversible fouling and flux loss that lead to increased cleaning intervals and reduced membrane life are constant challenges in this environment. Finding the balance between cleaning frequency and chemical and energy costs is often the goal for membrane facilities in water reuse applications. Fiber breakage and loss of RO membrane rejection are significant problems that can be accelerated by this source water. This manual presents a comprehensive description of the issues related to applying membrane technologies in water reuse projects.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ACH</td>
<td>aluminum chlorhydrate</td>
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<tr>
<td>ANL</td>
<td>Argonne National Laboratory</td>
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<td>ANSI</td>
<td>American National Standards Institute</td>
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<tr>
<td>AOC</td>
<td>assimilable organic carbon</td>
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<td>AOP</td>
<td>advanced oxidation process</td>
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<tr>
<td>ASR</td>
<td>aquifer storage and recovery</td>
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<td>AWT</td>
<td>advanced water treatment</td>
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<td>AWWA</td>
<td>American Water Works Association</td>
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<tr>
<td>BAC</td>
<td>biologically active carbon</td>
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<tr>
<td>BIRM</td>
<td>biological immune response modulator</td>
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<td>BNR</td>
<td>biological nutrient removal</td>
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<td>BOD</td>
<td>biological oxygen demand</td>
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<tr>
<td>CA</td>
<td>cellulose acetate</td>
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<tr>
<td>Ca(OCl)₂</td>
<td>calcium hypochlorite</td>
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<tr>
<td>CEC</td>
<td>chemicals of emerging concern</td>
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<tr>
<td>CIP</td>
<td>clean in place</td>
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<tr>
<td>COC</td>
<td>cycles of concentration</td>
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<tr>
<td>COD</td>
<td>chemical oxygen demand</td>
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<tr>
<td>CTA</td>
<td>cellulose triacetate</td>
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<tr>
<td>DAF</td>
<td>dissolved air flotation</td>
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<tr>
<td>DALY</td>
<td>disability-adjusted life year</td>
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<tr>
<td>DOE</td>
<td>Department of Energy</td>
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<tr>
<td>DPR</td>
<td>direct potable reuse</td>
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<tr>
<td>EC</td>
<td>electrical conductivity</td>
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<tr>
<td>ED</td>
<td>electrodialysis</td>
</tr>
<tr>
<td>ED–EDR</td>
<td>electrodialysis–electrodialysis reversal</td>
</tr>
<tr>
<td>EDC</td>
<td>endocrine-disrupting chemical</td>
</tr>
<tr>
<td>EDR</td>
<td>electrodialysis reversal</td>
</tr>
<tr>
<td>efOM</td>
<td>effluent organic matter</td>
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<tr>
<td>ESA</td>
<td>Endangered Species Act</td>
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<tr>
<td>FAC</td>
<td>free available chlorine</td>
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<tr>
<td>FeCl₃</td>
<td>ferric chloride</td>
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<tr>
<td>GRRP</td>
<td>groundwater recharge reuse projects</td>
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<td>GWI</td>
<td>Global Water Intelligence</td>
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<tr>
<td>GWRRD</td>
<td>Groundwater Replenishment Reuse Draft Regulation</td>
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<tr>
<td>HPM</td>
<td>high-pressure membrane</td>
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<tr>
<td>IMS</td>
<td>integrated membrane system</td>
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</tbody>
</table>
IPR  indirect potable reuse
LPM  low-pressure membrane
LRV  log-reduction value
MBR  membrane bioreactor
MCL  maximum contaminant limit
MF   microfiltration
MFI  modified fouling index
MGD  million gallons per day
MIC  microbiologically induced corrosion
MMFI mini-plugging factor index
NaOCl sodium hypochlorite
NDMA N-nitrosodimethylamine
NF   nanofiltration
NOM  natural organic matter
NPDES National Pollutant Discharge Elimination System
NTU  nephelometric turbidity unit
NWRI National Water Research Institute
O&M  operations and maintenance
PA   polyamide
PAC  powdered activated carbon
PACl polyaluminum chloride
PES  polyether sulfone
PP   polypropylene
PPCP pharmaceuticals and personal care products
ppm  parts per million
PSU  polysulfone
PVDF polyvinyl fluoride
RIB  rapid infiltration basins
RO   reverse osmosis
RWC  recycled water contribution
RWQCB regional water quality control board
SAR  soil adsorption ratio
SAT  soil aquifer treatment
SBS  sodium bisulfite
SDI  silt density index
SMP  soluble microbial products
TCEQ Texas Commission on Environmental Quality
TDC  total direct cell
TDS  total dissolved solids
TKN  total Kjeldahl nitrogen
TMDL total maximum daily load
TOC  total organic carbon
TSS  total suspended solids
UF   ultrafiltration
USEPA US Environmental Protection Agency
VOC  volatile organic compound
WHO  World Health Organization
WRA  WaterReuse Association
WTP  water treatment plant
WWTP wastewater treatment plant
Development of Water Reuse Practices

HISTORY OF WATER REUSE

Reuse of water has occurred for centuries beginning with reuse of liquid waste in agricultural practice. Sewage farming was practiced in the United States in the 1800s and peaked in California in 1923, with 70 communities applying their municipal wastewater directly on food crops (NRC 2012). Agricultural water reuse was prominent in Texas south of San Antonio starting in the 1880s, with a formal contract between the City of San Antonio and the San Antonio Irrigation Company in 1901. Other Texas cities followed—Amarillo in 1920, Lubbock in 1930, Odessa in 1940, and Abilene in 1960—providing reclaimed water to farmers and ranchers. As cities grew, centralized wastewater treatment was more widely used and improved water quality, allowing for the first small urban water reuse system for irrigation of Golden Gate Park in San Francisco in 1912 (WRA 2012).

Industrial reuse of water reclaimed from treated municipal wastewater was documented in the 1940s, with the city of Big Spring, Texas, supplying the Cosden Oil and Chemical refinery in 1944. The cities of Odessa and Amarillo followed in the 1950s and the 1960s; this was the beginning of reclaimed water use for power plant cooling in several Texas cities (Texas Water Development Board 2011). In the early 1970s, Bethlehem Steel in Baltimore, Md., began using 100 mgd of reclaimed water for industrial purposes (USEPA 2004). By 2010, 57 power plants in 16 states were using reclaimed water for power plant cooling (DOE–ANL 2007).

TERMINOLOGY

ANSI/AWWA G481 (2014), Reclaimed Water Program for Operation and Management, describes the critical requirements for effective operation and management of a reclaimed water program and defines reclaimed water as water recovered following treatment of domestic