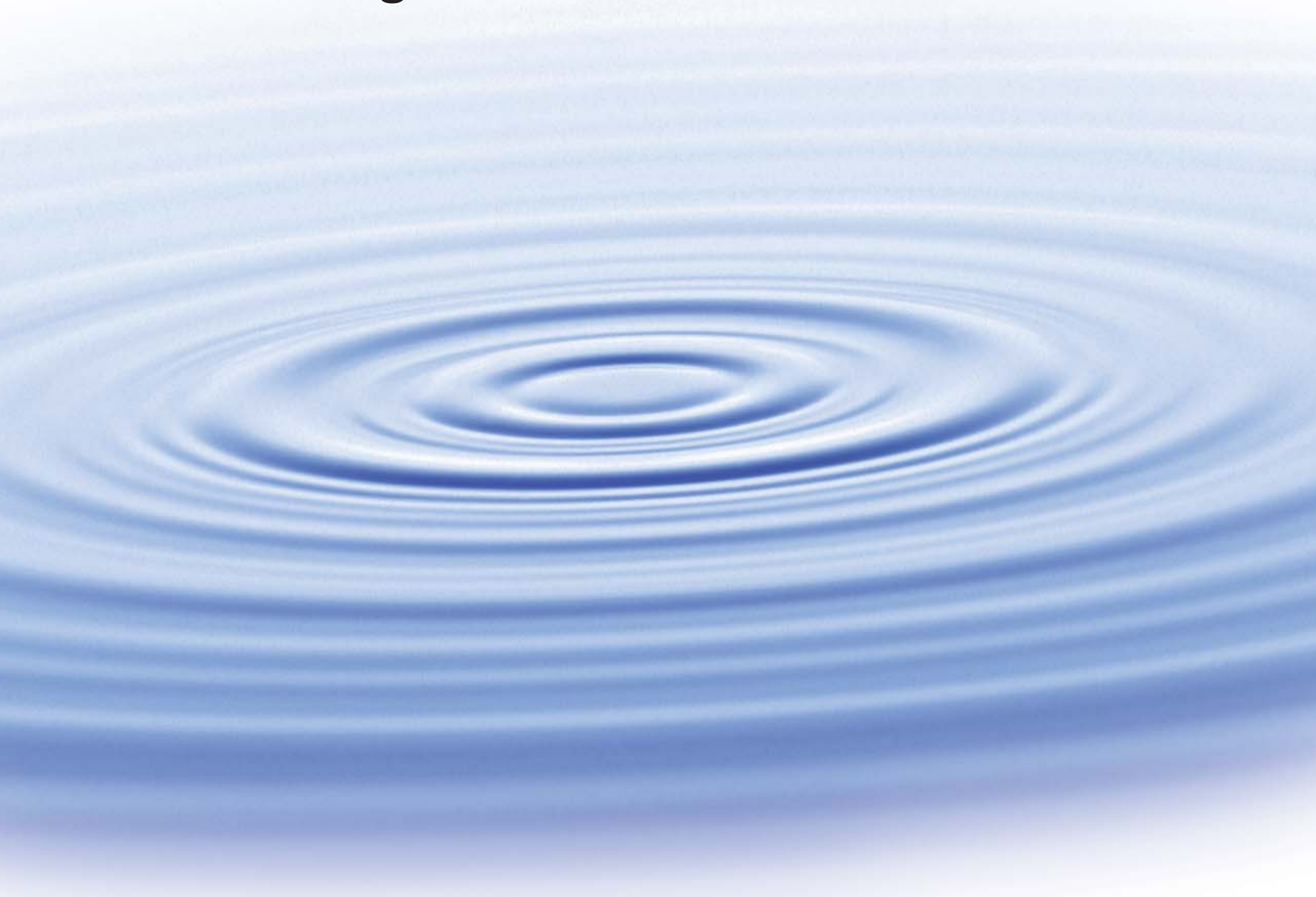
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WATEREUSE RESEARCH

Development of a Knowledge Base on Desalination Concentrate and Salt Management



WateReuse Research Foundation

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About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high-quality water through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, salinity management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of increasing reliability and quality.

The Foundation's funding partners include the Bureau of Reclamation, the California State Water Resources Control Board, the California Energy Commission, and the California Department of Water Resources. Funding is also provided by the Foundation's subscribers, water and wastewater agencies, and other interested organizations.

Development of a Knowledge Base on Desalination Concentrate and Salt Management

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Acronyms

AMTA	American Membrane Technology Association
ASR	aquifer storage and recovery
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BC	brine concentrator
BOD	biological oxygen demand
BWRO	brackish water reverse osmosis
CAA	Clean Air Act
CAP	Central Arizona Project
CF	concentration factor
CHIWAWA	Consortium for High Technology and Investment in Water and Wastewater
CM	concentrate management
CO_2e	carbon dioxide equivalent
CWA	Clean Water Act
DO	dissolved oxygen
DWI	deep well injection
ED	electrodialysis
EDC	endocrine-disrupting chemicals
EDR	electrodialysis reversal
ELWRF	Edward C. Little Water Recycling Facility
ERD	energy recovery device
FDEP	Florida Department of Environmental Protection
FDER	Florida Department of Environmental Regulation
FO	forward osmosis
g/L	gram per liter
GHG	greenhouse gases
GWI	Global Water Intelligence
HR	higher recovery
LA	land application
LC_{50}	50% lethal concentration
MD	membrane distillation
MED	multi-effect desalination
MF	microfiltration
mgd	million gallons per day
mg/L	milligram per liter
MSF	multistage flash
MT	million tons
NF	nanofiltration

NOEC	no observable effect concentration
NORM	naturally occurring radioactive material
NPDES	National Pollutant Discharge Elimination System
NRC	National Resource Council
NRWS	non-reclaimable water system
NSF	National Sanitation Foundation
NWRI	National Water Research Institute
O&M	operating and maintenance
OCWD	Orange County Water District
PAC	Project Advisory Committee
PDFB	percent difference from balance
POTW	publicly owned treatment works
ppt	part per thousand
PSD	prevention of significant deterioration
PVC	poly vinyl chloride
R	recovery
RO	reverse osmosis
SAR	sodium adsorption ratio
SARI	Santa Ana River Interceptor
SWRO	seawater reverse osmosis
U.S.	United States
TDS	total dissolved solids
TMDL	total maximum daily load
TSS	total suspended solids
UF	ultrafiltration
UIC	underground injection control
USDA	United States Department of Agriculture
USDW	underground source of drinking water
U.S. EPA	U.S. Environmental Protection Agency
WET	whole effluent toxicity
WRF	Water Research Foundation
WRRF	WateReuse Research Foundation
WTP	water treatment plant
WWTP	wastewater treatment plant
ZID	zone of initial dilution
ZLD	zero liquid discharge

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse research topics including:

- Defining and addressing emerging contaminants
- Public perceptions of the benefits and risks of water reuse
- Management practices related to indirect potable reuse
- Groundwater recharge and aquifer storage and recovery
- Evaluation and methods for managing salinity and desalination
- Economics and marketing of water reuse

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project and provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

The Foundation's primary funding partners include the Bureau of Reclamation, the California State Water Resources Control Board, the California Energy Commission, Foundation subscribers, water and wastewater agencies, and other interested organizations. The Foundation leverages its financial and intellectual capital through these partnerships and other funding relationships.

This report is a precursor to a concentrate management guidance manual to be developed in Phase II of this project. The guidance manual will assist utilities in making informed short- and long-term decisions concerning concentrate management, whereas the Phase I report provides a knowledge base that may be useful to a larger audience including regulators, consultants, and engineering companies.

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More than 150 utilities provided in-kind participation in the project in the form of taking part in the municipal membrane desalination plant survey. Several utilities also committed in-kind support at the time of the project proposal. These included

- Eastern Municipal Water District (CA)
- City of Abilene (KS)
- City of Chandler (AZ)
- PUB Singapore
- Sweetwater Authority (CA)
- Tampa Bay Water (FL)
- Metro Water District—Tucson (AZ)
- City of Vero Beach (FL)
- City of Goodyear (AZ)
- El Paso Water Utilities (TX)
- City of Chesapeake (VA)
- Collier County Water Sewer District (FL)
- City of Marco Island (FL)
- City of Palm Coast (FL)
- Sarasota County Utilities (FL)
- City of Scottsdale (AZ)
- West Basin Municipal Water District (CA)

The Project Advisory Committee was helpful in reviewing progress reports and the draft final report and offering constructive suggestions. Finally, the author thanks the WateReuse Research Foundation Project Manager, Julie Minton, for continual helpful understanding and guidance.

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Executive Summary

Background, Objectives, and Technical Approach

Desalination, using various forms of membrane treatment technologies to provide potable and higher quality reuse water, has increased steadily in the United States. A byproduct of these technologies is a waste stream containing elevated total dissolved solids, known as concentrate. Of the estimated 320 U.S. municipal desalination facilities, 96% are inland brackish water plants and only 4% seawater plants. Yet a recent study of desalination by the National Resource Council (NRC, 2008) stated that "Few, if any, cost-effective environmentally sustainable concentrate management options exist for inland desalination facilities."

- For the first time in the past decade, some municipal desalination plants have not been built in the United States because a suitable concentrate management (CM) option could not be defined.
- Source water quality has declined because of human activities and drinking water standards have become more stringent. As a result, a strong case can be made for increased application of desalination. However, the same environmental and health concerns that have led to tighter drinking water standards have also resulted in increased protection of water sources.
- This presents a challenge to CM, as 80% of the municipal desalination plants discharge concentrate via options that can affect source waters (surface water discharge, discharge to sewers, and land application).
- CM costs have become a growing percentage of overall desalination plant costs and CM has become a significant, if not the most significant, factor in determining the feasibility of building new desalination plants.

Therefore, a comprehensive knowledge base is needed, defining the issues surrounding CM and providing support material.

An ultimate goal is to develop a CM guidance manual for municipal desalination. The purpose of the present effort is to gather, analyze, and synthesize information that will

- *identify and define CM issues* that can affect municipal desalination facility decisions
- *provide an up-to-date information base*
- *define a recommended approach* and outline for a CM guidance manual

In broad terms, the project has two objectives:

1. To gather, analyze, and synthesize information concerning CM and render it into a form suitable for a background or reference document concerning CM.
2. To make recommendations for an approach to and technical content of a guidance manual for CM.

The project position taken is that a guidance manual for CM should be aimed at giving utilities guidance in decision making. As such, the future manual is envisioned as a clear, straightforward, easy-to-comprehend document without an unnecessary amount of detail. The detail is best provided in a reference document containing background and supporting information. The present report is this knowledge base, and the report can be useful for a broad audience including utilities, regulators, consultants, academics, and equipment and engineering companies.

A multifaceted approach was used to gather information for the report. Information was obtained from

- an extensive survey of more than150 municipal desalination plants, most of which were built after 2003
- telephone conversations with several U.S. EPA and state regulators to determine protocols and trends in regulation of concentrate
- participation in several workshops whose purpose was to define research needs for different areas of desalination, including CM
- review of desalination literature from both municipal and nonmunicipal industries having to do with CM
- a workshop conducted at a membrane conference to get an early read on important CM issues

The breadth and scope of the literature search was very wide and the results are referred to in individual chapters rather than in a summary chapter.

Project Findings

The survey conducted represents an update of past surveys (Mickley et al., 1993; Mickley, 2001; Mickley, 2006), allowing comparison of data obtained with past data. Findings from the survey of municipal desalination plants include the following:

- More than 98% of the municipal desalination plants utilize one of the five conventional disposal options (surface water discharge, discharge to sewers, deep well injection, evaporation ponds, and land application).
- Florida alone accounts for nearly 49% of the U.S. municipal desalination plants and three states (Florida, California, Texas) together account for 77% of the plants. The remaining 23% spread over 29 other states.
- The more recent data show a greater percentage of plants using deep well injection (DWI) and smaller percentage of plants using evaporation ponds or land application for concentrate disposal, yet nearly all DWI locations remain in Florida.
- An increased number of plants are treating source water for removal of contaminants as well as for salinity reduction.
- An increased number of plants have concentrate containing contaminants that restrict CM options or require treatment to remove the contaminants prior to disposal.
- Some desalination plants have not been built because of CM issues.

- Increasing CM challenges have led to consideration during the planning phase of plants of high recovery of concentrate. A few nanofiltration (NF) plants now incorporate high-recovery processing and there is now one zero liquid discharge (ZLD) plant.

Other findings from the various information gathering efforts include the following:

- CM is increasingly being considered in the context of integrated watershed water resource management where conservation, reuse, and desalination are to be applied in a balanced manner appropriate to the watershed in question.
- Discharge/disposal regulations are likely to become more stringent because of numerical nutrient standards, emerging contaminants, and other contaminants being considered for regulation. As one regulator pointed out with regard to surface water discharge and NPDES permits, "NPDES stands for national pollutant discharge ELIMINATION system and this is what is happening."
- With more stringent drinking water standards and new contaminants being regulated, desalination treatment processing will become more complex and will produce concentrate that will require additional treatment before the use of some CM options.
- Because of these and other CM challenges, there has been increased interest in high-recovery processing, usually under the labels of volume reduction or concentrate/brine minimization.
- Similarly, there has been an increased interest in salt recovery from concentrate as a means of reducing waste and providing a product of value whose sale can offset operating costs.
- The issues most frequently mentioned in discussions with desalination facilities have to do with regulation and permitting of concentrate. More specifically, these issues are with

    - the time, effort, and thus cost of obtaining the concentrate disposal permit
    - the time, effort, and thus cost of monitoring concentrate characteristics for permit compliance.

CM challenges are evident, and there is a substantial indication that the challenges will continue to increase and will involve more and more facilities. The project is meeting a timely need, as CM has now evolved to be a critical factor in determining desalination plant feasibility.

Report Organization

The report begins with five chapters providing background and contextual information:

- Chapter 1—Introduction—Project Background and Overview
- Chapter 2—Methodology
- Chapter 3—Municipal Desalination and Concentrate Management
- Chapter 4—Nonmunicipal Desalination Concentrate Management
- Chapter 5—Evaluation of Concentrate Management Options

Chapter 1 provides the purpose and objectives for the project and places CM within the context of desalination and water resource management. The problem of CM is discussed along with definitions of selected terms used in the report. Chapter 2 presents the methodology undertaken to gather and analyze information on CM practices and issues. Chapter 3 discusses CM within the context of the U.S. municipal desalination industry and reviews both the status of the industry and CM practices. Chapter 4 examines CM within the global context of saline water management as practiced in other industries. Finally, Chapter 5 presents an approach that has been successfully used in screening and evaluating CM options.

The next 10 chapters focus on individual CM options:

- Chapter 6—Regulation of Surface Water Discharge
- Chapter 7—Surface Water Discharge—Inland
- Chapter 8—Surface Water Discharge—Coastal
- Chapter 9—Discharge to Sewers
- Chapter 10—Subsurface Injection
- Chapter 11—Evaporation Ponds
- Chapter 12—Land Application
- Chapter 13—Landfill
- Chapter 14—Beneficial Uses
- Chapter 15—Solids Management and Recovery of Values from Concentrate

The subjects of volume reduction of concentrate, concentrate minimization, and ZLD are considered high-recovery processing options, as opposed to CM options. Concentrate or solids produced in high-recovery processing use the same disposal options as conventional lower recovery processing. Thus, high-recovery processing is addressed in each of these chapters through consideration of the impact of salinity and composition on option feasibility. In addition, each chapter provides detailed information about option design, regulatory issues, and cost factors, as well as a discussion of issues to consider in evaluating option feasibility.

Four final chapters summarize the report:

- Chapter 16—Emerging Issues
- Chapter 17—Summary of Issues
- Chapter 18—Conclusions and Recommendations
- Chapter 19—Technical Approach for Development of a Guidance Manual for Concentrate Management

Appendices include

- Appendix A: Survey of U.S. Municipal Desalination Plants
- Appendix B: High-Recovery Processing
- Appendix C: Workshop Report

Chapter 1

Introduction—Project Background and Overview

1.1 Project Goal and Purpose

The present report is a Phase I deliverable of a two-phase project. It is a reference document designed to provide a more detailed information source for users of a concentrate management (CM) guidance manual, to be developed in Phase II. The guidance manual will assist utilities in making informed short- and long-term decisions concerning CM. It should be a document understandable by decision makers. The present report as a knowledge base may be useful to a larger audience including regulators, consultants, and engineering companies involved in municipal desalination CM.

The purpose of this Phase I effort is to gather, analyze, and synthesize information that will support the objectives of

- *identifying and defining issues* that can affect municipal desalination facility decision-making needs—in regard to CM
- *providing an up-to-date information base* supporting the understanding of CM
- *defining a recommended approach* for preparing a CM guidance manual to be generated in a following project

1.2 Broad Context of Concentrate Management

Water resource management challenges are driven by population growth, economic expansion, decreasing groundwater supplies, and the pollution of many surface and near-surface water resources. Environmental regulations are increasingly driving water managers to limit increased groundwater or surface water withdrawals for potable water production. Increased focus on alternative water supply is prevalent.

Desalination of lower quality water to fresh water/potable standards is the only practical new source of water. Desalination is a water management tool that will be important for balancing demand and supply in the future. Conservation and water reuse are key strategies to meet increasing demands while minimizing raw water-supply impacts. However, treatment technologies such as desalination achieve the higher quality treatment increasingly demanded for contaminant-compromised waters, offer a drought-proof source of water, and position utilities to meet future changes in drinking water standards.

More broadly, the primary reasons for using desalination technologies are to treat water to

- meet potable, industrial, or agricultural requirements (treat original source water)
- meet discharge/disposal requirements (treat wastewater)

- meet reuse requirements (treat wastewater)
- maintain aquifer quality of shallow coastal aquifers (e.g., prevent seawater intrusion)

These applications treat waters of widely varying qualities from several possible sources. Municipal applications in the United States are, in general, in the lower salinity range of those addressed in treatment of wastewater from other industries. Municipal desalination is beginning to consider high-recovery processing, as used in other industries, as a possible means of meeting growing challenges in areas of limited water resources.

Municipal desalination CM may be viewed as a subcategory of global CM, which itself is a subcategory of global saline water management. The project considered CM from this broader perspective as a means of supporting full identification and consideration of present and future management issues.

1.3 The Concentrate Management Problem

Desalination is of growing importance in meeting the needs for greater quantity and improved quality of drinking water. Its application is also of growing importance in providing higher quality reused water.

In addition to more water, these growing applications produce more concentrate. The CM problem is that it is getting more difficult to manage concentrate in a cost-effective and environmentally safe manner. The result is that the cost and general feasibility of municipal desalination are increasingly dependent on CM.

The challenge of managing concentrate is related to its salinity and composition. Concentrate contains greater concentrations of all constituents found in the feed water that are concentrated/rejected to any degree by the membrane process. Thus, the concentrate is of higher salinity than the feed water and has higher concentrations of nearly all feed water constituents.

The same health and environmental concerns that have resulted in the need for higher quality drinking water have resulted in increased regulations for the protection of source waters. Because nearly all CM options (see Section 1.5.8) have the potential to negatively impact source water, regulation of CM options has increased. In particular, regulations protecting receiving waters (surface and groundwaters) have become more stringent, making it more difficult to utilize CM options.

The impact of concentrate on receiving waters is related to its volume. Along with the number of desalination plants, the size of desalination plants and the volume of concentrate per site have been increasing. Consequently, concentrate minimization (higher recovery processing) has become a topic of increased interest. In this case the volume of concentrate is reduced, whereas the salinity and concentration of most constituents increase. Although the impact of volume has been reduced and the salt load remains substantially the same, salinity and composition proportionally increase and may remain CM challenges (see Chapter 3).

As a result of these and other factors, there is a need for a comprehensive approach to and guidelines for CM. The present work aims to provide this needed information.

1.4 Project Approach

Several approaches were applied for gathering and analysis of information related to CM, including

- a survey of municipal desalination facilities
- telephone conversations with U.S. EPA and state regulators
- participation in various desalination research workshops
- a review of the desalination and saline management literature
- an information-gathering workshop with utilities, consultants, and regulators

Information was obtained from municipal and nonmunicipal industries, including international as well as U.S. sources. Other industries and countries were included to ensure a broad understanding of technologies, salinity management options and practices, and emerging issues.

The information obtained was used to develop a characterization of CM options, practices, trends, and needs and to define present and future issues related to CM. This information base was then used to make recommendations for development of a guidance manual.

1.5 Definitions

The following definitions set the context for the report content and for the recommendations provided for potential development of a CM guidance manual.

1.5.1 Concentrate Management

Concentrate is defined as the waste stream from a desalination process that contains constituents removed from feed water used to produce lower-salinity product water. CM refers to the effort involved with either disposal or use of this waste stream.

1.5.2 Solids and Salt Management

In municipal desalination processing, solids may be produced in pretreatment steps (e.g., lime softening) by selective recovery of salts and other products of value from concentrate, and from final processing of concentrate to mixed solids. The later may occur through sending concentrate to evaporation ponds or by thermal desalination of concentrate to produce solids. The primary focus in this report is on recovery of salts for subsequent use, a potentially important future CM practice and approach to greater sustainability.

1.5.3 Knowledge Base

This "knowledge base" document is not an exhaustive tally of papers, presentations, articles, etc. dealing with CM. Rather, it is an examination of information and a concise description of CM issues, along with detailed supportive information.

1.5.4 Issues

An issue may be defined as any constraint (environmental, social, economic, technical) that affects CM options, or any concern that relates to CM options. This can be related to design, cost, operational practices, or associated decisions. The range of issues covers both technical and institutional categories (regulations and permitting, energy, health, environmental impacts, economics, and public acceptance).

The stages of a desalination plant and CM situation include planning, engineering design, permitting, construction, and operation. A wide variety of issues and challenges can occur at each of these stages. Many issues are specific to a particular CM option.

In this report, most issues are distinguished by three aspects:

- type of issue (technical or institutional)
- desalination plant stage
- specific CM option

1.5.5 Guidance Manual

A guidance document needs to cover both technical CM system issues (e.g., intricacies of various CM options) and a broad suite of "institutional" issues (e.g., regulations and permitting; energy, health, and environmental impacts; economics; and public acceptance) that create many of the critical implementation barriers.

From these considerations, a guidance manual for CM is defined here as an informal document (i.e.,, not focused on design specifications) that can help utilities to

- review CM options, practices, and issues
- identify and prioritize issues associated with their site-specific CM situations
- make decisions with regard to CM

1.5.6 Municipal Concentrate Management Situations

The information provided in this document covers two different municipal desalination situations:

- production of potable water
- treatment of domestic wastewater

Treatment of domestic wastewater using desalination is for the purpose of water reuse. A secondary application is treatment of wastewater for the purpose of groundwater recharge (commonly referred to as indirect potable reuse) to maintain or improve the quality of groundwater for later use.

These situations are discussed more fully in Chapter 3.

Table 1.1. Concentrate Management Options[a, b]

1. Five conventional CM options (for concentrate of any salinity)
   - Surface water discharge
     - Direct ocean outfall (includes brine line when direct to ocean)
     - Shore outfall
     - Co-located outfall (with power plant cooling water or WWTP effluent discharges)
     - Discharge to river, canal, lake
   - Disposal to sewers
     - Sewer line
     - Direct line to WWTP
     - Brine line (where brine line goes to WWTP)
   - Subsurface injection
     - Deep well injection
     - Shallow well (beach well)
   - Evaporation pond
     - Conventional pond
     - Enhanced evaporation ponds/schemes
   - Land application
     - Percolation pond/rapid infiltration basin
     - Irrigation

2. Landfill (for solids)
   - Dedicated monofill
   - Landfill accepting industrial waste

3. Beneficial use (other than irrigation)
   - Several potential uses (for concentrate or solids): see Section 3.11 and Chapter 14

[a]The options apply to concentrate of any salinity, thus to concentrate from high-recovery (including ZLD)/brine minimization processes as well as from conventional recovery processes.

[b]The options also apply to desalination processing involving salt recovery.

1.5.7 Conventional Disposal Options

The five conventional options are so called because they are used at more than 98% of U.S. municipal desalination facilities. They are general categories having several subcategories (see item 1 of Table 1.1). The options are

- surface water discharge
- disposal to sewer
- subsurface injection
- evaporation pond
- land application

1.5.8 Beneficial Use

Is some instances, concentrate can be used in a beneficial way. The use may represent a final fate solution, as when concentrate is used for irrigation with no recovering drainage system. More often, the use is an intermediate step prior to final disposal, as when concentrate is used for irrigation with a recovering drainage system or when concentrate is used at an aqua farm. In these situations concentrate still requires disposal after use.

1.5.9 High Recovery

High-recovery (HR) processing achieves water recovery beyond the typical membrane step recovery limits. Although recovery is dependent on many factors (including salinity and composition), these limits are typically

- brackish water reverse osmosis 85%
- seawater reverse osmosis 60%
- nanofiltration 90%
- electrodialysis reversal 95%

Based on this definition, HR processing requires additional processing steps that may include one or more of the following:

- more extensive pretreatment prior to the initial membrane step
- chemical treatment of concentrate to remove recovery limiting scalants and foulants
- additional desalination steps which may be membrane or thermal

HR processing has been discussed in the literature as volume reduction, concentrate/brine minimization, and zero liquid discharge (ZLD).

1.5.10 Zero Liquid Discharge

ZLD is a special case of HR processing where no liquid is discharged across the plant boundary. This is accomplished by sending concentrate to an evaporation pond within the plant boundary or by additional processing of the concentrate to solids by a crystallizer or a spray dryer.

The term ZLD has been used incorrectly to refer to processes utilizing thermal technology, such as brine concentrators or crystallizers. However, some ZLD systems do not include any thermal steps, being membrane-based systems with a final evaporation pond step. The term ZLD has also been incorrectly used to mean directly processing water all the way to solids. This definition, however, does not recognize the use of evaporation ponds as a final ZLD processing step.

1.5.11 Sustainability

An ultimate goal of CM is sustainability, meaning sustainable management of resources and waste in a manner that balances environmental, social, and economic aspects of a desalination project. Relative to present practices, it means more efficient use of resources and a reduction in final wastewater and solids. Beneficial use of concentrate or products obtained from concentrate represents a step on the sustainability path, whether or not the use represents a final fate CM solution. An additional step on the path is taken when the use reduces the ultimate disposal of wastewater or solids.

1.6 Concentrate Management Options

CM, when viewed from a historical perspective on municipal desalination practices, includes five conventional disposal options:

- discharge to surface water
- discharge to sewer
- subsurface injection (deep well and shallow well injection)
- evaporation pond
- land application

Over 98% of the more than 300 inland municipal desalination facilities have used these options as disposal options—meaning that the options account for the final fate of the concentrate. Most literature published before 2000 describes these options as "concentrate disposal" options.

More recently, the term "concentrate management" has been used to recognize the possibility of managing concentrate in a more beneficial way and to reflect that concentrate might be considered a resource. These efforts have been focused in three areas:

- beneficial use of concentrate
- concentrate minimization
- selective salt recovery from concentrate

As yet, none of these areas have been widely practiced in municipal desalination, but each reflects the interest in more efficient use of water resources.

A major report has been published describing beneficial use options for concentrate (Jordahl, 2006). Although such options exist, they are mostly unproven and unavailable. Many do not represent final fate options for concentrate, as they result in the need for disposal of wastewater after beneficial use.

Concentrate minimization occurs when concentrate is further processed to reduce its volume while increasing the amount of resource water turned into product water. This approach amounts to HR processing of the original feed water.

Selective salt recovery is the production of individual salts of commercial quality from concentrate. It represents the specialized treatment of concentrate as part of a typically HR desalination process.

HR processing involves additional treatment equipment and is thus more costly than conventional recovery practices historically used in municipal desalination. HR processing is widely practiced in other industries where treatment costs are less of a constraint.

In this broader context, HR processing (including the special case of ZLD, where no liquid crosses the plant boundary) is simply a processing option, not a CM option.

Figure 1.1 gives two views on representing CM options. The first, represented in Figure 1.1a, is from the perspective of historical municipal desalination. Here, beneficial use of concentrate and concentrate minimization (HR processing) are listed as CM options. The second view, represented in Figure 1.1b, is from the perspective of desalination as practiced in other industries. Here, concentrate minimization is considered a processing option as opposed to a CM option.

Final brine or solids from HR processing may be disposed of by the five conventional disposal options and, for solids, by landfill. Both Figures 1a and 1b also show beneficial use of concentrate as an additional CM option.

The report defines CM options from the second perspective, that of Figure 1b. This approach views CM options as the same for concentrate of any salinity. Each CM option in the report is discussed in a separate chapter, and within each chapter, the effects of salinity and composition on the management option are addressed.

A more detailed listing of CM options from this perspective is provided in Table 1.1. A detailed discussion of options is provided in Chapter 3.

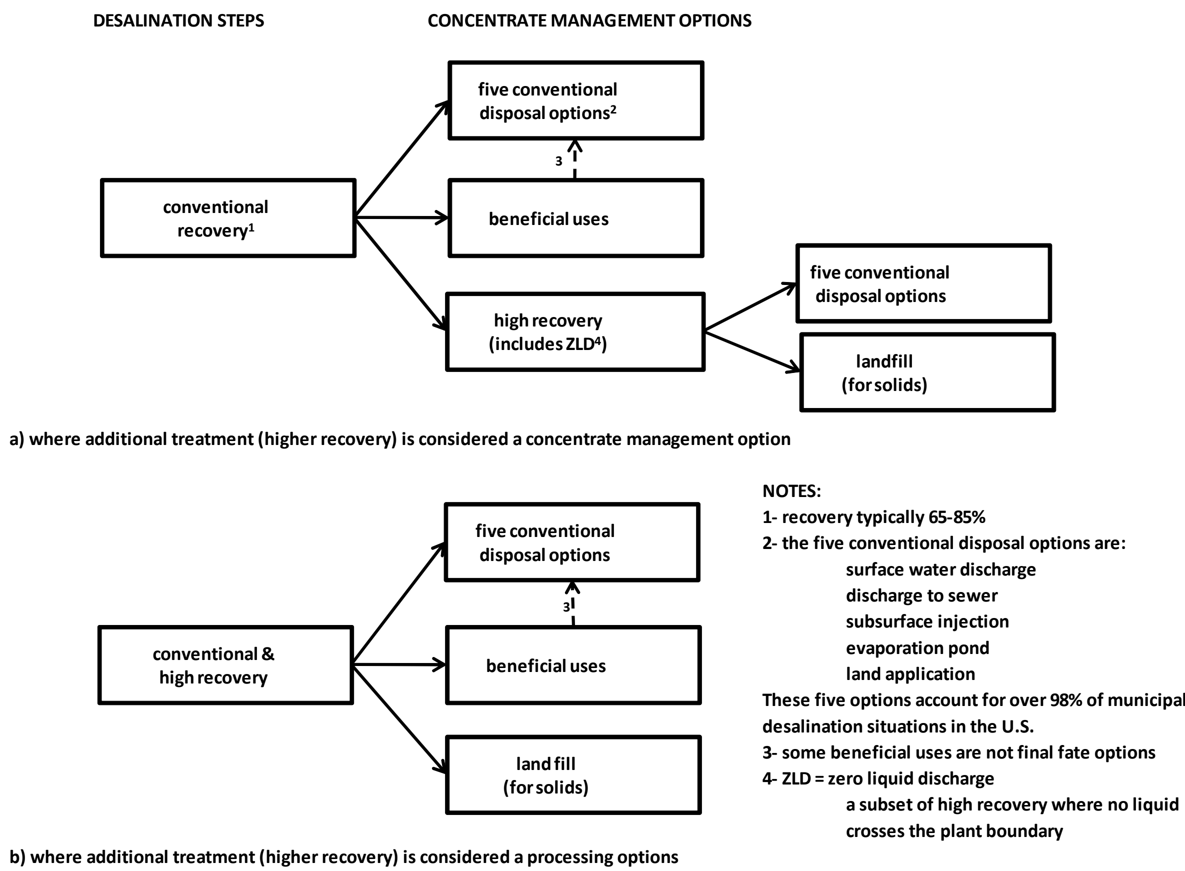


Figure 1.1. Representation of CM options.

1.7 Desalination Technologies Considered

With very few exceptions, the desalination technologies used in the municipal applications considered are

- brackish water reverse osmosis (BWRO)
- seawater reverse osmosis (SWRO)
- electrodialysis and electrodialysis reversal (ED and EDR)
- nanofiltration (NF)

Each of these technologies is discussed further in Chapter 3.

The use of thermal evaporative technology such as brine concentrators (BCs) to achieve HR for potable water production is receiving considerable attention, given the high cost of obtaining new water resources. Although the first thermal HR potable water plant has been built in Tracy, California (HPD, 2007), the technology remains cost prohibitive for most municipal situations and therefore is not included as a technology option.

1.8 Seawater Desalination

Although seawater desalination is of growing importance in the United States, it currently represents only about 4% of municipal desalination sites (see Chapter 3). The only practical CM option for seawater desalination is ocean discharge or some other form of discharge to estuaries or coastal habitats, where salt impacts on the receiving water can be demonstrated not to be ecologically significant. Most of the report focuses on inland desalination. Chapter 7 specifically addresses ocean discharge. Where appropriate, other chapters may contain sections addressing seawater desalination.

Chapter 2

Methodology

2.1 General Project Approach and Efforts

This chapter describes the approach and efforts taken to meet project objectives including development of this report.

Project tasks mainly involved information gathering followed by analysis and synthesis. There were five broad activities used to collect information to get an accurate reading of current and emerging CM issues. These were

- survey of municipal desalination facilities
- telephone conversations with U.S. EPA and state regulators
- participation in various desalination-based research workshops
- review of desalination and saline management literature
- an information-gathering workshop with utilities, consultants, and regulators

2.2 Survey of Municipal Desalination Facilities

Although interaction with consultants, equipment and engineering company representatives, regulators, and others peripherally associated with municipal desalination plants was important to the information-gathering effort, direct interaction with facilities was necessary to fully understand CM issues and challenges experienced by the utilities. Direct contact with facilities was also the best way to get an accurate statistical representation of facility practices and trends.

The survey included several subtasks, beginning with identifying facilities and obtaining contact information for further interaction. The focus was on identifying plants that had begun operation after 2002, as this was the date of the last broad survey conducted by Mickley & Associates (Mickley, 2006). As in past surveys, the goal was to identify and gather information from every U.S. municipal desalination facility over 25,000 gpd in size, rather than accept a typical survey response rate of 10–30% and assume that the information would be representative of the whole.

Several approaches were used to identify facilities, including

- Internet searches on equipment, membrane, and engineering company websites
- review of literature from journals and conference proceedings
- search of plant lists from state regulatory websites
- search of state tabulations of permits issued
- telephone discussions with various state regulatory agencies
- review of DesalData.com database (by subscription)

Initial contact information was obtained either from these sources of information or by researching city websites for water utility telephone numbers, after the city was identified as having a desalination facility. City websites were frequently a source of information about their desalination plants.

A website was set up to house a database where individual facilities could enter information about their plants through use of a user name and password. Information sought included description of the facility's membrane system, including how concentrate was managed. Additionally, the survey asked for identification of any issues the facility had encountered with regard to CM.

Use of the online survey proved to be cumbersome because of its complexity. This approach was later dropped in favor of direct telephone interviews with each facility. As in past surveys, this approach is time-consuming, with some facilities requiring 10 or more phone calls before a knowledgeable person was available for discussion. Once contact was made, however, this was a very efficient way of gathering the sought-after information.

The information obtained was then used to

- produce a list of the facilities along with descriptive information about them (Table A.1 in Appendix A)
- develop statistics to describe facility practices
- compare resulting statistics with those from previous surveys to determine changes and trends (statistics and trends are discussed in Chapter 3)
- identify examples of different practices or CM issues (such examples are presented throughout the remaining chapters)

Some of the facilities contacted were built prior to 2002, some facilities were still in the planning stage, and some were being constructed. The effort resulted in telephone interviews with personnel of more than 150 municipal desalination facilities.

The Internet website and database were not used further for the project. However, at some future time, the database may prove useful as a means of holding information from past, current, and perhaps future surveys.

2.3 Telephone Conversations with U.S. EPA and State Regulators

U.S. EPA guidelines provide the framework for environmental regulations affecting concentrate disposal options. Within this framework, final regulations differ from state to state. Regulations also change with time.

Various U.S. EPA and state regulators were called to discuss the status of regulations affecting concentrate disposal options. Most of the calls focused on regulations pertaining to surface water discharge and deep well injection (DWI), as the National Pollutant Discharge Elimination System (NPDES) Program and the Underground Injection Control (UIC) Program are the two federal programs most widely affecting concentrate disposal. Discharge to a sewer does not require a permit but does require permission by the wastewater treatment plant (WWTP) receiving the concentrate. The least often used concentrate disposal options are land application and evaporation ponds. Permitting of both is overseen by state programs.

Most of the calls concerned regulation in Florida, California and Texas—the top three states in terms of numbers of existing municipal desalination facilities.

The telephone calls were helpful in getting regulators' perspectives on regulation issues and trends affecting CM, including what changes in regulations might be forthcoming.

2.4 Participation in Research Workshops

Attendance at two research workshops yielded information that helped to identify and understand CM issues from the perspective of experts in desalination and water reuse. Experts were from industry, regulatory agencies, and academia. The two workshops attended were

- the Third Water Reuse and Desalination Research Needs Workshop, San Diego, CA, December 1–3, 2009
- the Concentrate Management Program Priorities Workshop held by the Consortium for High Technology Investment on Water and Wastewater (CHIWAWA), El Paso, TX, March 17, 2010

The two workshops followed similar agendas. White papers were prepared in advance and presentations based on the white papers were given at the start of the workshops. Most of the workshop time was spent in smaller groups focusing on specific aspects of desalination and CM. The small group sessions were to propose, discuss, screen, and recommend research projects for later review by an executive committee. Discussion of issues and needs involving people from different desalination-related perspectives was helpful in both defining and reaching a clearer appreciation of CM issues.

2.5 Review of Desalination Literature

The research team conducted a literature survey to provide supplemental information regarding issues that were identified. The literature search included review of conference proceedings, research reports, and journal articles.

2.6 2009 Workshop at Austin AMTA Conference

A special workshop was held on CM at the 2009 American Membrane Technology Association (AMTA) Conference and Exposition in Austin, TX on July 15, 2009. The purpose of the workshop was to discuss CM issues, to solicit stakeholder input regarding what a guidance manual for CM should include, and to encourage participation in the project survey.

The workshop was helpful in getting stakeholder input on CM issues. A workshop summary is included in Appendix B.

Chapter 3

Municipal Desalination and Concentrate Management

3.1 Introduction

In this chapter the general nature and characteristics of U.S. municipal desalination are reviewed. Where appropriate, U.S. practices are compared with global applications.

3.1.1 Brief History—1980 Through 1990

In the 1980s, environmental impacts were background issues of growing regulatory concern. In 1990, there were fewer than one-third the number of municipal desalination plants in the United States that there are in 2010. Most of the plants built in the 1980s were in Florida, where, despite heavy rainfall, the relatively flat topography does not lend itself to capture or storage of the water. With large increases in population, inland desalination of groundwater became an important source of drinking water. In 1986, the Florida Department of Environmental Regulation (FDER, now the Florida Department of Environmental Protection, FDEP), conducted a study gathering concentrate data from 36 municipal sites. Baker et al.(1990) presented data from 26 sites that revealed that hydrogen sulfide needed to be removed, chloride (or specific conductance or both) criteria were not being met, and radionuclides (gross alpha and combined Ra-226 and Ra-228) were elevated above background levels. Historical causes of whole effluent toxicity (WET) test failures at municipal membrane plants included high H_2S and low dissolved oxygen (DO) levels in concentrate from groundwater sources. The FDER began requiring more data with discharge permit applications, and began to develop more complete guidelines and strategies for addressing site-specific problems (Mickley et al., 1993). Since this time, it has become standard practice to degasify/aerate concentrate before surface water discharge when these problems occur.

3.1.2 Brief History—1991 Through 2000

The first major study of membrane concentrate, funded by AwwaRF (now the Water Research Foundation), was published in 1993 (Mickley et al., 1993). It contained information about design, costs, and regulation of CM options as well as the first comprehensive survey of CM practices in the United States. The 1990s were characterized by documentation of practices and issues. This was a period of accelerated growth, with an increasing number of states having municipal desalination facilities. Florida began requiring more monitoring data and instituted WET test requirements for surface water discharge. Several Florida plants encountered challenges in meeting more stringent disposal requirements, but all received variances/allowances that permitted continued operation.

In 1995, in reaction to several failed WET tests at inland Florida municipal desalination plants, the FDEP published *Protocols for Determining Major-Seawater-Ion Toxicity in Membrane-Technology Water-Treatment Concentrate*. In 2000, AwwaRF published the report *Major Ion Toxicity in Membrane Concentrate* (Mickley, 2000), which determined (through extensive laboratory analysis) that toxicity in nine Florida membrane concentrates was due to high levels of calcium (four cases), high levels of fluoride (two cases), high levels of both calcium and fluoride (two cases), and a low level of potassium along with a high level of calcium (one case). The report identified toxicity levels for mysid shrimp exposed to major ions at seawater composition background salinities of 10, 20, and 31 ppt (parts per thousand) and developed a method of predicting occurrence of major ion toxicity in groundwater membrane concentrate based on raw water quality.

3.1.3 Brief History, Milestones, and Other Events—2001 Through 2010

From 2001 to 2010, there was dramatic growth on several fronts involving CM: amount of research funded, visibility of issues at conferences, and recognition of the critical role in desalination plant feasibility. For the first time, because of concentrate disposal challenges, some desalination plants were not built.

A selection of key milestones are summarized in Table 3.1.

In general, this most recent period was characterized by

- Increased funding of research projects related to CM.
- Increased focus on HR processing, under the headings of volume reduction and concentrate minimization.
- Emergence of waste minimization via salt recovery as an important topic on the path toward sustainability. Patents and commercialization for this were established by Gerry Groot of Superior Salt, Inc., Aro Arakel of Geo-Processors Pty Limited, and Tom Davis of ZDD, Inc. and the University of Texas at El Paso (UTEP).
- Increased numbers of professional conference sessions devoted to CM at water-related conferences.
- Increased focus on CM from a watershed–regional perspective.
- Absolute awareness that CM is one of the major, if not *the* major, limitations on further development of desalination. Desalination plants have experienced this in different ways, largely dependent on location.

Along with the increased activity in the 2001–2010 period, there have been changes in the terms used to describe the subject area:

- "Concentrate management" came to replace "concentrate disposal"—a much broader, more general term that includes beneficial use of concentrate in addition to direct disposal.
- "Beneficial use" has entered the vocabulary as a new category under CM. The term represents the use or reuse of concentrate. Beneficial use is discussed in Chapter 14.
- "Volume reduction," "concentrate or brine minimization," "high recovery," and "zero liquid discharge" have become familiar words within the CM community. These terms and the technologies and characteristics of the areas in general are discussed in Section 3.9 and Appendix B.
- "Sustainability" has increasingly been used in papers, presentations, and reports in regard to environmental concerns, issues, and goals associated with CM. Most broadly, the term implies applying CM in a manner that is sustainable within a social,

economic, and environmental context. Frequently, the term has been used to imply increasing recovery of both water and salts, and minimizing final disposal amounts.

- "Brine" and "concentrate" are used interchangeably in the literature and by many in the treatment industry. Historically brine refers to higher salinity water, typically taken to mean water of seawater salinity and higher (i.e.,, water above about 33,000 mg/L). According to this definition, some concentrates are brine and some are not. The term concentrate is the more general term and is used throughout this report.

3.2 Desalination Applications

Most global applications of desalination technologies occur in one of three situations:

- primary treatment of surface water or groundwater for
  - potable use—municipal application
  - industrial use
- treatment for reuse/use or disposal (including discharge) of water/wastewater from
  - wastewater treatment plants (WWTPs)—municipal application
  - industrial sites
  - agricultural sites
  - groundwater (such as for direct industrial use)
- treatment of by-product water for use or disposal
  - produced water
  - mine water

The largest desalination plants treat surface water and groundwater to produce drinking water. These plants typically serve a segment of the local population and require a distribution system to provide product water to the many users. Plants dedicated to a given industrial site serve more geographically limited areas. Although more desalination plants are built for industrial purposes (DesalData, 2010), the cumulative capacity of municipal drinking water plants far exceeds that of plants built for other purposes. This is true globally and in the United States. Industrial desalination plants treat water to meet various processing needs, such as for boiler feed and high-purity applications in the pharmaceutical and semiconductor industries, as well as the treatment of process water for discharge.

> **Example**. *KBH Desalination Plant, El Paso*: The 27.5-mgd KBH El Paso desalination plant began operating in 2007 and is the world's largest inland reverse osmosis desalination plant. As a result of high pumping, groundwater levels have declined and brackish groundwater has intruded into areas that historically yielded fresh groundwater. El Paso Water Utilities (EPWU) began reducing pumping in 1989. This action was made possible by a variety of water management initiatives including increased water conservation, increased surface water diversion, and increased reclaimed water use. The reduction in pumping has resulted in stabilized groundwater levels in many areas. However, brackish groundwater intrusion remains an issue. The desalination plant reduces brackish groundwater intrusion and allows EPWU to better utilize its fresh groundwater wells during droughts. The location of the pumping wells will provide an opportunity to intercept the brackish groundwater before it intrudes into historically fresh groundwater areas. Up to 3 mgd of concentrate is injected into three deep injection wells located about 22 mi from the plant.

Table 3.1. Selected Concentrate Management Milestones from 2003 to the Present

Year	Reference	Significance for Concentrate Management
2003	*St. Johns River Water Management District Project: Investigation of Demineralization Concentrate Management Project* by Reiss Environmental (2003)	Early detailed analysis of regional CM options, survey and analysis of concentrate permitting in Florida, extensive concentrate bibliography.
2003	*Desalination and Water Purification Technology Roadmap*	Major technology planning activity completed by U.S. Bureau of Reclamation and Sandia National Laboratories; subsequently referred to as the Roadmap (Roadmap, 2003).
2003	*Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee*, U.S. Bureau of Reclamation and Sandia National Laboratory	First detailed U.S. roadmap for desalination; included detailed recommendations for addressing CM needs.
2003	*Seawater Desalination: Impacts of Brine and Chemical Discharge on the Marine Environment* (Lattemann and Hopner, 2003)	First comprehensive study of environmental effects of seawater discharge.
2004	Committee Report: Current Perspectives on Residuals Management for Desalting Membranes. AWWA Membrane Residuals Management Subcommittee. *AwwA Journal* (Malmrose, 2004)	Very good comprehensive discussion of CM.
2006	*St. Johns Water Management District Project: Demineralization Concentrate Ocean Outfall Feasibility Study: Evaluation of Additional Information Needs* by CH2M HILL (CH2M, 2006)	NOAA-AOML and CH2M HILL recommendations for regional ocean outfalls for RO concentrate discharge feasibility study.
2006	*Membrane Concentrate Disposal: Practices and Regulation*. 2nd ed. U.S. Bureau of Reclamation Report (Mickley, 2006)	Update of 2001 report that included an updated survey of U.S. municipal membrane facilities, and updated design and cost models for concentrate disposal options.
2006	Update of National Desalination Roadmap	Update of 2003 roadmap.
2006	Concentrate Management – State-of-the-Science	Comprehensive examination of CM practices and issues in the United States; report prepared for the implementation/updating of the National Desalination Roadmap
2006	*St. Johns Water Management District Project: Demineralization Concentrate Outfall Feasibility Study- Evaluation of Additional Information Needs*	Review of needs for outfall modeling and design
2006	*Beneficial and Nontraditional Uses of Concentrate.* WateReuse Foundation report by CH2M HILL (Jordahl, 2006)	First comprehensive report on beneficial uses of concentrate.
2006	*Zero Discharge Seawater Desalination: Integrating the Production of Freshwater, Salt, Magnesium, and Bromine,* Bureau of Reclamation (Davis, 2006)	Early funded research report on salt recovery from concentrate.
2006	*Environmental Literature Review and Position Paper for Perth Seawater Desalination Plant Two and Sydney Seawater Reverse Osmosis Plant,* for Water Corporation of Western Australia (Pankratz et al., 2006)	Extensive literature review of seawater desalination environmental issues.
2007	*Zero Liquid Discharge for Inland Desalination,* AwwaRF project by Black & Veatch (Bond and Veerapaneni, 2007)	Early report with in-depth consideration of ZLD processing of municipal concentrate. Included piloting.

Year	Reference	Significance for Concentrate Management
2007	Tampa Bay Desalination Plant begins operation	The Tampa Bay plant at 25 mgd was by far the largest seawater plant in the United States. The detailed discharge modeling and extensive monitoring of discharge from the facility were beyond that previously done with any U.S. desalination plant.
2007	Operation of the 27.5-mgd KBH desalination plant in El Paso	In addition to being the largest inland desalination plant in the United States, extensive study of CM options and the first large scale use of deep well injection for concentrate disposal outside of Florida were noteworthy.
2007	Brackish Groundwater National Desalination Research Facility opened at Alamogordo NM	Extensive research facility with considerable focus on inland CM.
2008	*Desalination—A National Perspective.* Extensive report by National Research Council (NRC, 2008)	Major study built on National Roadmap and further identified CM as major research need. States, "Few, if any, cost-effective environmentally sustainable CM options exist for inland desalination facilities."
2008	*Regional Solutions to Concentrate Management,* WateReuse Foundation Report by Carollo Engineers (Mackey and Secord, 2008)	Another major study focusing on CM; presented regional approach for addressing issues.
2008	*Survey of Volume Reduction and Zero Liquid Discharge Technologies for Water Utilities,* WateReuse Foundation Report (Mickley, 2008)	First extensive study of the costs of ZLD processing approaches as a function of salinity, composition, and plant size.
2008	*St. Johns Water Management District Project: Demineralization Concentrate Outfall Feasibility Study, Phase 2A: Conceptual Ocean Outfall Evaluation* (CH2M, 2008)	Mixing zone modeling of concentrate water qualities and conceptual outfalls for three study area zones off of Central and North Florida.
2008	Orange County Groundwater Replenishment System (GWRS, 2011)	Operation of world's largest wastewater purification system for indirect potable reuse.
2008	Feasibility study for St. Johns River Membrane Water Plant Demineralization Concentrate Management (CH2M, 2008)	Modeling of conceptual mixing zones for RO concentrate discharge to the St. Johns River, Florida.
2009	*Treatment of Concentrate,* U.S. Bureau of Reclamation Report #155 (Mickley, 2009)	Broad consideration of how concentrate might be further treated to facilitate concentrate disposal.
2009	Opening of Center for Inland Desalination Systems at UTEP	Center for research focused on researching technologies and approaches that would maximize the benefits of desalination, while minimizing the input energy and negative environmental impacts.
2009	Australian National Center of Excellence in Desalination opened in Murdoch University, Perth 3.10.2	Large research center heavily funded by Australian government; CM as one of the focus areas.
2009	*Desalination Product Water Recovery and Concentrate Volume Minimization,* Water Research Foundation Report 91240 by Carollo Engineers (Sethi et al., 2009)	Major study on concentrate volume reduction.
2009	*Southern California Regional Brine-Concentrate Management Study* by CH2M HILL (CH2M, 2009a, 2009b)	Broad regional study of CM needs.
2010	*White Paper: Brackish Groundwater Concentrate Management* prepared for NMSU and CHIWAWA (Mickley, 2010)	Comprehensive discussion of inland CM practices and issues in the United States.

The second category includes the growing municipal application of desalination in treating WWTP effluent for reuse.

> **Example.** *West Basin's Water Recycling Program, Californi*a: The Edward C. Little Water Recycling Facility (ELWRF) is the largest water recycling facility of its kind in the United States. Thirty million (and eventually 70 million) gallons a day of wastewater and 5 tons of biosolids (eventually 10 tons) are no longer discharged each day into Santa Monica Bay. Fifteen mgd are processed by BWRO, with the concentrate discharged to the ocean via the Hyperion WWTP outfall. The biosolids are recycled daily into landfill covers and roadbed fill. The program serves parks, golf courses, office buildings, and others, recently producing its 100 billionth gallon of recycled water, and works with more than 300 customers, from Chevron, Exxon-Mobil, BP, Toyota, and Honda to the Home Depot Center, the Marriott, and others. The ELWRF is the only treatment facility in the country that produces five different qualities of "designer" or custom-made recycled water that meet the unique needs of West Basin's municipal, commercial, and industrial customers. The five types of designer water include
>
> - tertiary water (Title 22) for a wide variety of industrial and irrigation uses
> - nitrified water for industrial cooling towers
> - softened reverse osmosis water: secondary treated wastewater purified by microfiltration (MF), followed by reverse osmosis (RO) and disinfection for groundwater recharge
> - pure reverse osmosis water for refinery low-pressure boiler feed water
> - ultrapure reverse osmosis water for refinery high-pressure boiler feed water

WWTP effluent salinity is typically one to several hundred mg/L total dissolved solids (TDS) higher than for the local drinking water. In locations with heavy industrial and agricultural discharge to sewers, the salinity increase can be even greater. In such cases, desalination may be used to reduce salinity as well as provide a removal step for other constituents. Treatment of water for aquifer recharge or aquifer storage and recovery (ASR) falls under this category when desalination processing is used.

> **Example**. *Orange County Water District's groundwater replenishment system:* The 70-mgd system takes highly treated wastewater that would have previously been discharged into the Pacific Ocean and purifies it using a three-step advanced treatment process consisting of microfiltration, reverse osmosis, and ultraviolet light with hydrogen peroxide. The process produces high-quality water that exceeds all state and federal drinking water standards. The plant is the world's largest wastewater purification system for indirect potable reuse. Approximately 35 million gpd is injected into OCWD's expanded seawater barrier to prevent ocean water from contaminating the groundwater supply. The remaining 35 million gpd is pumped to OCWD's spreading basins in Anaheim, where it mixes with Santa Ana River water and other imported water sources, and percolates into the groundwater basin. The system became operational in 2008 and is currently being expanded to 134 mgd. Benefits include
>
> - reducing energy consumption, as less power is required to purify wastewater than to import a similar amount of water from northern California or the Colorado River
> - conserving other water resources

- preventing ocean water contamination by reducing the amount of treated wastewater released into the ocean, delaying the need for an additional ocean outfall
- helping droughtproof water production capabilities
- improving and protecting overall water quality in the groundwater basin by reducing the mineral content

Several industries have made impressive strides in reducing their water footprints by minimizing water usage and incorporating water recycling into their operations (Senge, 2008). In many cases, desalination is used to treat industrial wastewater to enable its disposal (including discharge). Meeting pretreatment program requirements to allow discharge to sewer collection systems falls under this category.

In the third general category, water resulting from drilling and oil and gas production or mining of mineral resources requires treatment to permit nonpotable use or disposal (including discharge). Water produced from coal bed methane/coal seam gas operations, oil shale gas operations, and other oil/gas drilling operations is a major example in this category.

> **Example**. *CONSOL's West Virginia Buchanan Coal Mine:* As a result of hundreds of violations of pollution discharge limits in the past 4 years from one of the nation's largest underground mines, CONSOL Energy, Inc. is implementing a 5-mgd membrane-based desalination system comprising ultrafiltration (UF), reverse osmosis, brine concentrators, and salt crystallizer technologies. Up to 99% of the water will be reused in part of the company's preparation plant facility.

3.3 Global Versus U.S. Desalination

Two general technologies dominate global desalination: thermal and membrane. Both technologies were substantially the result of U.S. Government funding as part of Office of Saline Water and later Office of Water Research and Technology programs in the years 1952 to 1982 (NRC, 2008). Modern large-scale thermal desalination technologies, such as multistage flash (MSF) and multi-effect distillation (MED), reached commercialization sooner, as they were extensions of age-old evaporative and distillative processes well known for producing high-quality water. Thermal desalination is energy-intensive, and the first wide-scale use of thermal desalination was in the Middle East, where energy abundance permitted cost-effective operation. Thermal technologies such as MED and MSF require large amounts of cooling water and are thus best suited to coastal situations where water is abundant. As a result, most early desalination plants treated seawater.

Membrane desalination required the development of membranes capable of rejecting salts. Because of the much higher energy costs in the United States relative to the Middle East and to the predominance of inland brackish water desalination plants in the United States, membrane desalination was the technology of choice. Whereas desalination in the Middle East began in the early 1960s, it was a decade later before membrane desalination began in the United States. Globally, improvements in membrane technologies have resulted in an increasing number of membrane plants relative to thermal plants. Figure 3.1 shows the percentage of total capacity by technology (a) worldwide and (b) in the United States.

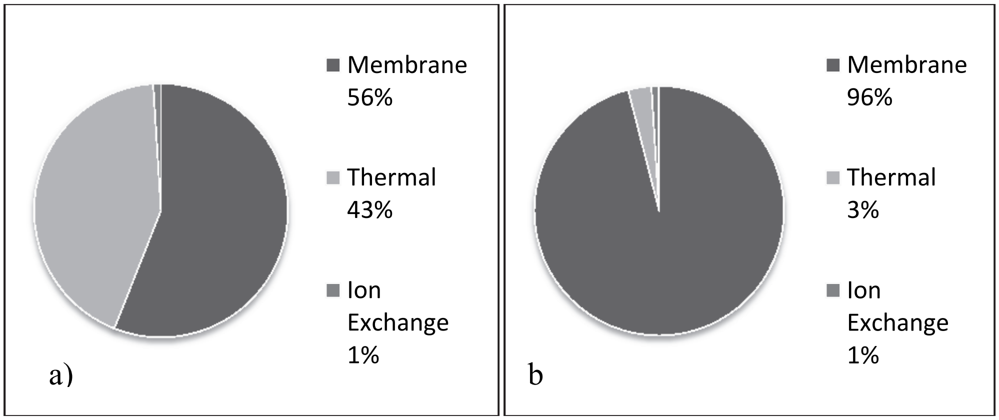


Figure 3.1. Percentage of total capacity of currently operating desalination plants by technology (a) worldwide and (b) in the United States (GWI, 2006).

As stated previously, desalination in the United States is predominantly inland brackish water desalination. According to Global Water Intelligence (GWI) (2006), seawater desalination accounts for 8% of the U.S. desalination *capacity;* according to Mickley (2006) (and the present survey in Appendix A), for municipal desalination plants, the *number* of seawater plants is about 4% of the U.S. plants.

3.4 U.S. Municipal Desalination

Figure 3.2 shows the growth in the number of municipal desalination plants by year since 1980 (Mickley, 2006). The 2010 estimate is based on the survey in Appendix A. Currently, there are an estimated 314 operating municipal desalination plants in the United States of size 0.025 mgd or greater.

The municipal desalination plants are located in 32 states (up from 26 states in 2003), with the distribution of plants shown in Table 3.2 (Mickley, 2006, and Appendix A). Florida has 49% of the plants, followed by California and Texas with 16% and 12%, respectively. Together these states account for 77% of the U.S. municipal plants. Thus the remaining 23% of the plants are spread over 29 other states. Table 3.2 shows these values along with those from the 2003 survey. In the period since 2003, Florida has been by far the most active state, with 31 new plants being built. Thirty-nine percent of the plants were built in states other than Florida, California, and Texas—up from 19% prior to 2003.

Most municipal desalination applications are one of three types:

- water treatment plants (WTPs) producing potable water
- WWTPs producing water for discharge or reuse
- facilities producing water for aquifer recharge or ASR (these may be WWTPs)

Potable water desalination plants far outnumber water reuse plants, which outnumber recharge/ASR plants.

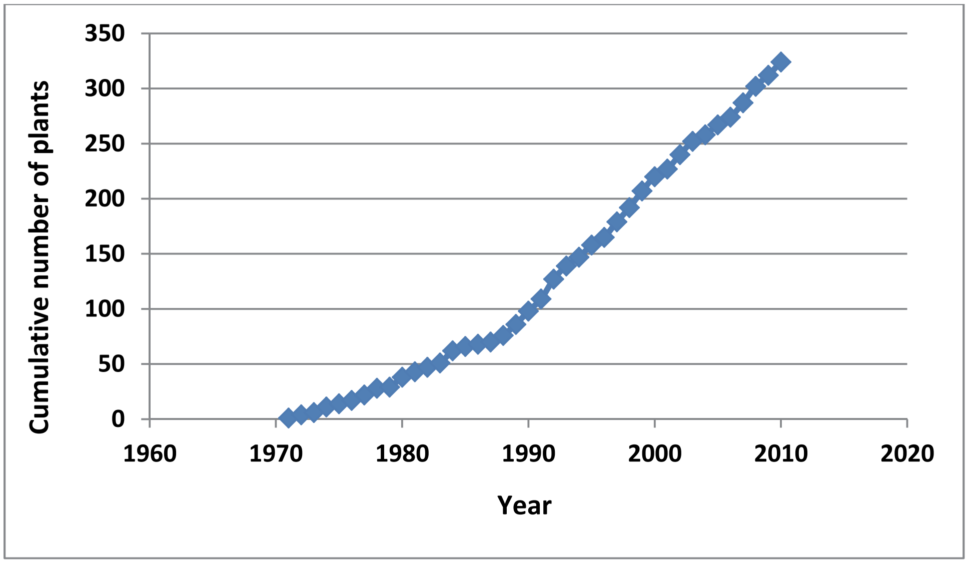


Figure 3.2. Cumulative number of U.S. municipal desalination plants by year with capacities of ≥0.025 mgd.

3.5 Desalination Technologies Used

There are currently no municipal thermal (evaporation/distillation) desalination plants in the 50 U.S. states. The membrane processes used are BWRO, NF, SWRO, and EDR.

Reverse osmosis (RO), both BWRO and SWRO, and NF are pressure-driven membrane processes that allow separation of dissolved ions in addition to suspended and larger constituents from feed water. NF is capable of removing divalent ions (calcium, magnesium, etc.) to a high degree and monovalent ions (sodium, chloride, etc.) to a lesser degree as well as removing dissolved organic matter and compounds responsible for taste and odor in water. Competing processes for NF include lime/soda softening and ion exchange. RO removes all constituents that NF removes and all ions regardless of valance. However, removal efficiency of ions varies depending upon physical-chemical properties of constituents, the water quality matrix, characteristics of the membrane, and operating conditions of the RO or NF system (i.e., flow, recovery).

RO and NF involve the phenomena of osmosis. Osmosis is the transport of water across a semipermeable membrane from a region of higher chemical potential (concentration) to a region of lower chemical potential (concentration). RO and NF operation require countering the natural osmotic force by applying pressure on the higher concentration feed side to drive water movement in the direction opposite to that dictated by the osmotic force. This results in purified water moving through the membrane from the more concentrated feed water side to the other side (permeate or product side). Because the NF membrane is more permeable than the RO membrane, the osmotic force to be overcome is less. Thus, operating pressures for NF are lower than for RO.

Table 3.2. Number of U.S. Municipal Desalination Plants by State[a]

	2003 data		2004–2010 data		Total	
State	**# Plants**	**%**	**New Plants**	**%**	**# Plants**	**%**
Florida	124	53	31	39	155	49
California	41	18	8	10	49	16
Texas	25	11	12	12	37	12
Others	44	19	29	39	73	23
Total	234		80		314	

[a]Plants are ≥0.25 mgd.

Osmotic force increases with salinity, and as a result, higher operating pressures are required for SWRO operation to counter the increased osmotic force of higher salinity feed water. Operating pressures and other operating characteristics of BWRO, NF, and SWRO systems are given in Table 3.3. Recovery is often fixed at the highest level that maximizes permeate flow while preventing precipitation of supersaturated salts ($CaCO_3$, $CaSO_4$, $BaSO_4$, etc.) and silica within the membrane system.

Competing processes in the United States include electrodialysis (ED) and EDR. ED is an electrically driven process that operates at ambient pressures. An ED system consists of a stack of anion- and cation-exchange membrane pairs, with an anode at one end of the stack and a cathode at the other. The electrodes are connected to an outside source of direct current that results in an electric current being carried through the solutions. Ions migrate to the electrode with the opposite charge. An anion will migrate through the nearest anion-exchange membrane, but be blocked from further migration by the adjacent cation-exchange membrane. In the same manner, cations will migrate through the nearest cation-exchange membrane. Through this movement, concentrated and diluted solutions are created in the adjacent flow channels between membrane pairs. Brackish water can be fed into the dilution channel inlet and undergo demineralization, with product water exiting at the outlet. EDR operates on the same general principles as ED, with the polarity of the electrodes changing periodically with time. This reverses the flow through the membranes and reduces the buildup of highly concentrated regions, which in turn allows operation with feed water with greater scaling and fouling tendencies (MEDINA, 2007). Therefore, all recent applications use EDR. Operating characteristics of EDR are also given in Table 3.3.

NF is used to treat lower-salinity feed water and in general for situations requiring TDS removal, primarily for softening, and where emphasis is on organic removal, in which TDS removal is unimportant. EDR is also used for lower-salinity feed water because of increased energy requirements as salinity increases. Because EDR does not concentrate nonionic species, EDR is also used in situations with high silica levels, where BWRO recovery may be limited. High-pressure RO or SWRO is used for higher salinity feed water.

Several references are available for detailed description of these technologies (Malmrose, 2004, MEDINA, 2007; Mickley et al., 1993).

Table 3.4 shows an estimate of the frequency of use of the different municipal membrane processes in the United States, based on past and present surveys (Mickley, 2006, and present survey).

Table 3.3. Operating Characteristics of U.S. Membrane Desalination Processes in Municipal Applications Based on Membrane Process

Membrane Process	Feed TDS (mg/L)	Operating Pressure (psi)	Rejection Characteristics	Recovery Range (%)	Concentrate TDS (mg/L)[a]
BWRO	500–10,000	100–600	Monovalent ions: 90–99.8 Divalent ions: 98–99.9	65–85	2000–40,000 (75% recovery)
NF	300–1000	50–150	Monovalent ions: 40–90 Divalent ions: 80–99	75–90	1900–6300 (90% recovery)
EDR	300–5000	Not applicable	Not applicable	75–95	2000–33,000 (80% recovery)
SWRO	15,000–40,000	800–1,200	Similar to or slightly greater than BWRO membranes	30–60	30,000–80,000 (50% recovery)

[a]The concentrate TDS ranges given assume 100% rejection for RO and 80% for NF. See Section 3.7. Rejection ranges are given in the fourth column.

3.6 Source Water Salinity and Composition

3.6.1 Source Water for Water Treatment Plants

Raw water to be treated in a desalination plant can vary in composition because of several factors:

- type of source water (surface water versus groundwater; brackish versus seawater)
- specific location, including degree of impairment by human activities

Table 3.4. Percentage Use of U.S. Municipal Membrane Desalination Processes

Membrane Process	2003 Data (% use)	2004-2010 Data (% use)	Combined Data (% use)
BWRO	78	79	78
NF	10	17	13
EDR	7	2	5
SWRO	5	2	4

For water considered for municipal applications, unimpaired groundwater varies in composition to a much greater degree than unimpaired surface water—whether inland or seawater. Chapter 4 discusses classification of waters by major ion composition. Some locations have naturally occurring inorganic contaminants (such as naturally occurring radioactive materials—NORMs) and organic contaminants (microorganisms; dissolved and particulate organic matter). A growing number of locations have contaminants from human activities (such as nitrate, perchlorate, pesticides, herbicides, synthetic organic compounds, and other emerging contaminants). According to data from the United Nations, 40% of U.S. rivers are categorized as heavily polluted (Maxwell, 2010). One of the emerging issues discussed in Chapter 16 is the continuing deterioration of water quality in the nation's source waters.

Table 3.5 lists general characteristics of the various source waters used in municipal desalination.

Table 3.5. General Characteristics of Source Water

Characteristic	Surface	Groundwater	Seawater	WWTP Effluent
Source	Rivers, lakes, and reservoirs	Well water	Coastal water	WWTPs
TDS, mg/L	50–1000	50–1000 for fresh, 1000–10,000 for brackish	10–50 g/L	500–1500
Level of scaling salts	Low	High	High[a]	High
Typical scaling salts/ions	Not applicable	Many (silica, $CaCO_3$, $CaSO_4$, $BaSO_4$, $SrSO_4$, etc.)	$CaCO_3$, $Mg(OH)_2$	Ca/PO_4 salts, Metal hydroxides
Iron, manganese	None, except in eutrophication situations in lakes and ponds	Usually some	Trace	Usually high
Suspended solids	High (rivers), low (lakes)	Usually low	Variable	Usually high
Turbidity	Usually high	Usually low	Variable	Usually high
Organics	Usually high	Usually low	Variable	Usually high
Microorganisms	High	Low	High	High
CO_2	Low	High	Low	Low
O_2	High	Low	High	High
H_2S	None	Often present	Usually low	Low
NH_3	Low	Sometimes	Low	Can be high
Temperature	Varies with season	Relatively constant	Varies with season	Varies with season

[a]Recovery is dictated by the osmotic pressure of the concentrate stream

3.6.2 Source Water for Wastewater Treatment Plants and Water Recharge Desalination Plants

Most water reuse treatment facilities do not require desalination, because of the relatively low TDS of the WWTP inflow. Salinity of the WWTP inflow is dependent on the dischargers to the sewer system. In situations where there is a minimal contribution from industrial dischargers, the inflow is frequently 100 to 300 mg/L greater than the TDS of the drinking water produced by the local WTP. The increase in TDS is due to chemical additions and uses of the drinking water prior to discharge to the sewer. In cases with sizable contributions from industrial and agricultural sources, the difference between inflow TDS to the WWTP and drinking water TDS can be much greater, but rarely is influent TDS to a WWTP greater than 1500 mg/L. Possible exceptions to this generalization might occur in coastal areas, where sewer system infiltration by saline groundwater can elevate TDS in WWTP inflows.

Desalination is used in WWTP facilities (1) when TDS removal is required to meet reuse application needs and/or (2) when more specific contaminant removal is required to meet reuse application needs.

One of the primary differences between feed water for WTP desalination processing and WWTP desalination processing is the high nutrient and synthetic organic load frequently found in the reuse feed water. More generally, because of possible contributions from a range of dischargers to the sewer system, the contaminant load seen in WWTP desalination processing can be much higher than that seen in WTP desalination processing. This is particularly true of organics, including many of the emerging contaminants. The California Department of Public Health has drafted requirements for all water, if necessary to meet total organic carbon and emerging contaminant limits, to be treated with RO in groundwater recharge projects (CDPH, 2008). Higher levels of microorganisms are also encountered in WWTPs. With higher constituent concentrations in these feed waters, environmental concerns regarding concentrate disposal may be similarly elevated.

3.7 Salinity and Composition of Concentrate

Feed water composition to the membranes in a desalination process is dependent on

- composition of the source (raw) water supplied to the desalination plant
- residuals left from pretreatment steps
- added chemicals used to minimize membrane scaling and fouling

Concentrate is made up of the species in the feed water according to the relative rejection/separation by the membrane process. Rejection is species-dependent, and it is the system recovery along with the membrane rejection/separation efficiency for a given feed water species that determines its concentrate concentration. Table 3.6 gives ranges of typical concentrate salinity associated with use of the membrane processes in municipal applications. The concentration factor, CF, is defined here as the ratio of concentrate TDS to feed water TDS. It is directly related to the recovery, *R*, expressed as a fraction:

$CF = 1/(1 - R)$ where the rejection is assumed to be 100%

$CF = (1 - R)^{-r}$ where *r* is the rejection (Mickley et al, 1993).

Table 3.6. Typical Municipal Desalination Membrane System Design Parameters Based on Source Water

Parameter	Surface Water	Fresh Groundwater	Brackish Groundwater	Seawater	WWTP Effluent
Feed water TDS (mg/L)	200–400	200–500	500–10,000	30,000–40,000	500–1500
Water recovery (%)	80–90	80–90	65–85	40–60	70–90
Concentrate quantity (%)	10–20	10–20	15–35	40–60	10–30
Concentrate TDS (mg/L)	1330–2660 (85%)	2660–3330 (85%)	2000–40,000 (75%)	60,000–80,000 (50%)	2000–6000 (80%)
Concentration factor[a]	5–10	5–10	2.9–6.7	1.7–2.5	3.33–10
Membrane process	BWRO, NF, EDR	BWRO, NF, EDR	BWRO, NF (in lower TDS range), EDR (in lower TDS range)	SWRO	BWRO, NF, EDR

[a]Assumes 100% rejection.

Wastes from cleaning solutions may be blended with concentrate. Typically, the spent cleaning solution volume is an extremely small percentage of the treated flow (< 0.1%). Spent cleaning solutions, which may be diluted with rinse water (feed or permeate), can contain detergents, surfactants, or acid, caustic, or other chemicals used to remove scalants and foulants from the membrane system (Malmrose, 2004).

3.8 Concentrate Management Options

General CM options were described in Chapter 1. For convenience, the list is provided here as Table 3.7. Later chapters provide extensive definition and characterization of each of these options, along with discussions of issues that impact feasibility.

The five conventional disposal options account for more than 98% of municipal desalination sites (Mickley, 2006, and the present survey). Despite the more general and more appropriate term “concentrate management,” most concentrate is disposed by one of the five options. The possible exception is where concentrate is used for crop or landscape irrigation and irrigation water is captured by a drainage system. Currently, land application, including irrigation and percolation ponds, account for 7% of the municipal desalination sites. Thus, more than 93% of municipal desalination concentrates are being disposed of rather than reused.

Table 3.8 lists the overall frequency of use of the five options in terms of percentage and number of states. Discharge to a surface water or a sewer account for 73% of the cases nationwide, but 100% of the cases for 27 of the 33 states having municipal desalination plants. As shown in Table 3.9, the other three conventional disposal options (DWI, land application, and evaporation ponds) have limited widespread application, primarily because of hydrogeological and climate requirements. For municipal desalination concentrate, deep well injection occurs in only five states, and both land application and evaporation pond use occur in only three states.

Nearly all DWI sites are in Florida, as are most land application sites. Outside of Florida, only 18 plants (out of approximately 150) utilize concentrate disposal options other than surface water discharge and discharge to sewers. In general, few options are available at any given desalination plant site, and in an increasing number of cases under planning, no cost-effective management options have been found.

Figure 3.3 shows the frequency of CM strategy use as a function of the size of the desalination plant (Mickley, 2006). The columns in Figure 3.3 show that discharge to surface water has a high level of application regardless of plant size. Discharge to sewers, however, is used less frequently as the size of the plant increases. This is because of the impact of the concentrate salinity and volume on the WWTP operation. Deep well injection has the opposite pattern because of high costs associated with feasibility determination, regardless of the plant size. These costs are less of a burden to larger facilities. Disposal by land application (mainly irrigation) and to evaporation ponds are both land-intensive and climate-dependent. They have little economy of scale and are used only for small plants.

Table 3.7. Concentrate Management Options[a, b]

1. Five Conventional Disposal Options
   - Surface water discharge
     - Direct ocean outfall (includes brine line when direct to ocean)
     - Shore outfall
     - Co-located outfall
     - Discharge to river, canal, lake
   - Disposal to sewers
     - Sewer line
     - Direct line to WWTP
     - Brine line (where brine line goes to WWTP)
   - Subsurface injection
     - Deep well injection
     - Shallow well (beach well)
   - Evaporation pond
     - Conventional pond
     - Enhanced evaporation ponds/schemes
   - Land application
     - Percolation pond/rapid infiltration basin
     - Irrigation

2. Landfill (for solids)
   - Dedicated monofill
   - Industrial landfill

3. Beneficial Use (other than irrigation)
   - Several potential uses (for concentrate or solids)—see Section 3.10 and Chapter 14

[a]The options apply to concentrate of any salinity, including concentrate from high-recovery processes (such as concentrate minimization and ZLD processes) as well as from conventional recovery processes.
[b]The options also apply to desalination processing involving salt recovery.

Table 3.8. Frequency of Use of Disposal Options at U.S. Municipal Desalination Plants (Mickley, 2006 and present survey)[a]

	2003 Data		2004–2010 Data		Combined Data	
Disposal Option	**# Plants**	**# States**	**New Plants**	**# States**	**# Plants**	**# States**
Surface discharge	97 (48%)	17	43 (51%)	16	140 (49%)	21
Sewer discharge	51 (25%)	15	17 (20%)	9	68 (24%)	18
Deep well injection	26 (13%)	2	22 (26%)	3	48 (16%)	5
Land application	20 (10%)	2	1 (1%)	1	21 (7%)	3
Evaporation pond	9 (4%)	3	2 (2%)	2	11 (4%)	3

[a]Only 288 plants represented; some 2003 survey plants did not provide full information.

Table 3.7 lists landfill as a disposal option for solids that may be created as part of a HR processing scheme. Beneficial uses (in addition to irrigation) are rarely available, are mostly unproven, and seldom represent a final fate solution to the concentrate. However, because of the challenges of finding cost-effective CM options, beneficial uses should always be considered (Jordahl, 2006). Together, Table 3.9 and Figure 3.3 illustrate that there are both location and size limitations on the practical implementation of the five conventional concentrate disposal options.

The primary environmental concern with disposal of concentrate to surface water, to sewers, or by land application is salt loading of receiving waters, whether surface water or groundwater.

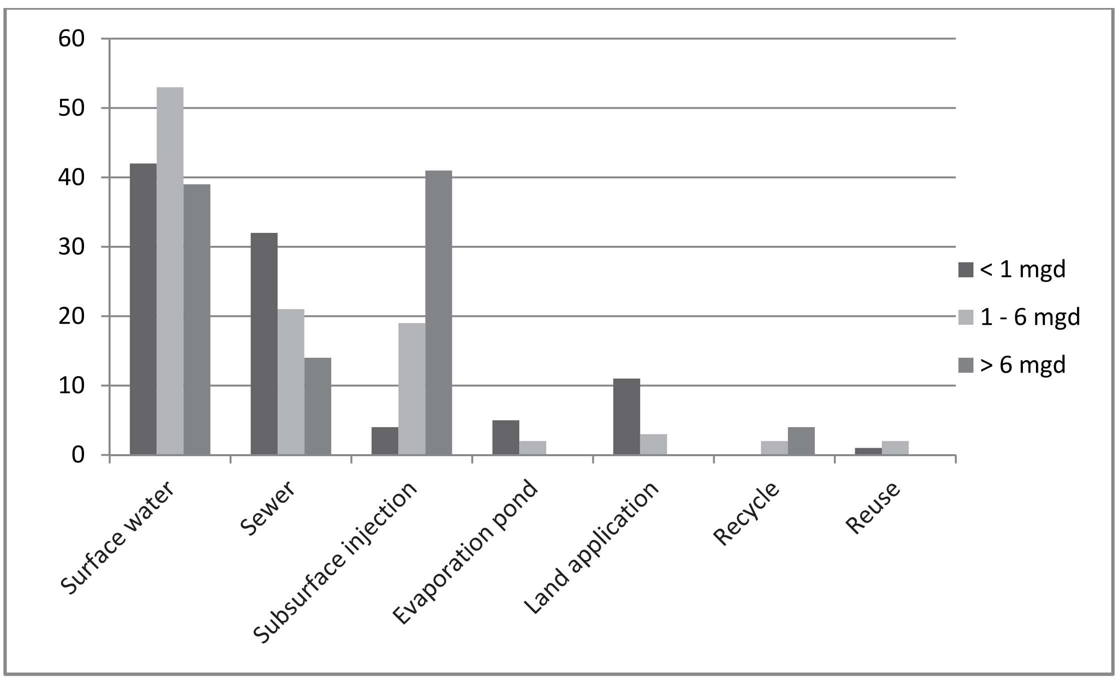


Figure 3.3. Percentage frequency of use of management options as function of plant size (Mickley, 2006).

Table 3.9. Locations and Numbers of Lesser Used Disposal Options

Disposal Option	States and Number of Plants in State Using Option					
	FL	**CA**	**TX**	**CO**	**KS**	**AZ**
Deep Well Injection	44	1	1	1	1	0
Land Application	18	1	2	0	0	0
Evaporation Pond	3	0	6	0	0	2

Challenges associated with CM include the following (Mickley, 2006):

- *Increasing size of plants:* Desalination plant size has been increasing, and the increased volume of the concentrate represents an increased impact on receiving waters and, relative to Figure 3.3, less likelihood of disposal to sewers, land application, and evaporation ponds.
- *Increasing number of plants in a region:* An increasing number of plants in a given region increases the risk of cumulative impact.
- *Increasing regulation of discharge:* The trend is for regulations, particularly for discharges affecting receiving waters (surface water discharge, disposal to sewer, land application), to become more restrictive as salinity and contaminant levels in both surface water and groundwater continue to increase.
- *Increasing public awareness:* Part of the challenge in getting a desalination plant implemented in a timely manner is resolving public concerns. Frequently the public has a limited understanding of the issues involved and often it has misconceptions about the nature of the desalination process and the actual risk of concentrate effects on the environment. The public may be unaware of the benefits of desalination technology relative to conventional water-treatment technologies.
- *Increasing costs:* The treatment cost of desalination has decreased considerably because of more efficient, longer-lasting, and less expensive membranes, use of energy recovery devices, and increased competition among equipment manufacturers and system suppliers. CM costs, however, have not decreased. Capital costs associated with conventional disposal options have not decreased (with one exception being enhanced evaporation ponds), and operating costs have increased because of more detailed monitoring requirements. As a result, CM costs have become an increasing percentage of total desalination plant costs.

Although in many parts of the United States conventional disposal options will continue to play an important role in determining the feasibility of desalination, there are a growing number of locations, particularly in the arid southwest, where use of most conventional disposal options is not possible or cost-effective, and alternative CM options are needed. Other driving forces for developing alternative disposal options include increased consideration and use of high-recovery processes and altered concentrate water quality, increased concern for concentrate being a lost water resource, and realization of longer-term goals of developing sustainable technologies/solutions.

3.9 High-Recovery and Zero Liquid Discharge Processing

HR processing of feed water is a widely used treatment approach in several industries. However, it has been used in only a few municipal desalination plants because of high capital costs. As a result of increasing CM challenges, particularly in the arid southwestern United States, HR processing is increasingly being considered as a means of more efficiently using resource water and has been the subject of several funded research projects. HR processing will play an increasing role in desalination and CM and represents a strong emerging trend. Thus, because of its growing importance, HR is discussed here (and in Appendix B) to bring greater clarity and understanding to the role it may play in municipal desalination and, more importantly, in CM.

3.9.1 Definition and Reasons for High-Recovery Processing

HR processing is defined here as processing feed water to attain recoveries of 90% or higher. The technical challenge of achieving HR depends on feed water quality and primarily the presence of sparingly soluble salts and silica. There are instances where high recovery levels can be achieved in a one-step membrane process. More typically, however, brackish feed water recoveries above 90% require additional treatment steps beyond the initial membrane step—and thus additional treatment of the concentrate.

The additional treatment steps may be membrane (additional RO step) or thermal evaporation (brine concentrator and crystallizer). In most instances, the cost-effective process of choice is a second RO step, whether or not followed by a thermal step (Mickley, 2008). Additional treatment steps add cost to the desalination process. The added cost is weighed against the possible advantages of HR processing, including

- maximizing utilization of the water resource; minimizing lost resource water
- providing a feasible solution where otherwise none might be possible
- reducing dependence on location
- in some cases, greatly simplifying the permitting process

In the case of an existing desalination facility considering increasing recovery, the costs of increasing recovery are weighed against the costs of expanding the existing process. Both situations will produce more product water, but the effects on concentrate are different. Expansion of the existing facility will result in increased volume and increased salt load (volume times concentration) of the concentrate. Moving to HR will result in a concentrate of reduced volume and roughly the same salt load. The effect of HR processing on the feasibility of CM options depends on the specific circumstances. In some cases it may result in a solution to site-specific CM challenges. There are situations such as discharge to brine lines going to the ocean, disposal to deep wells, or disposal to evaporation ponds where reduced volume/higher salinity concentrate may pose few new challenges. The impact of reduced volume/higher salinity concentrate on discharge to inland surface water and to sewers, however, is highly dependent on state regulations and the water quality of the concentrate.

The effects of higher salinity and higher constituent concentrations on CM options are discussed in Appendix B and in each of the chapters devoted to specific CM options.

3.9.2 Definition of Zero Liquid Discharge

ZLD is often a misunderstood and misused term. The original definition means that there is no liquid discharge across the plant boundary. The first ZLD plants were mandated for the power industry, so that plants near the Colorado River would not discharge into it and further increase its salinity. The early mechanical vapor recompression evaporators, wastewater brine concentrators, were developed for this purpose. ZLD systems originally consisted of brine concentrators treating cooling tower blowdown, with the resulting brine going to either thermal crystallizers (evaporators) or spray dryers, depending on the volume, or to evaporation ponds within the plant boundary. In an effort to reduce the volume of water going to the energy- and cost-intensive brine concentrators, next-generation ZLD systems used an RO step to reduce the wastewater volume prior to its being processed by the thermal system. Later yet, some ZLD systems eliminated the thermal evaporators altogether and used membrane-only treatment systems. Thus the term ZLD does not mean processing by thermal evaporators, nor does it mean taking feed water all the way to solids. Because of the more extensive use of HR processing in other industries and in other countries (see Chapter 4), ZLD can be considered to be a subset of HR processing (where the final residuals meet the definition of ZLD).

3.9.3 Status of High-Recovery Processing for Municipal Applications

Appendix B discusses the technical approaches to achieving HR, along with how the concentrate and solids from HR processing might impact the feasibility of CM disposal options.

An early evaluation of membrane disposal options for the municipal setting (Mickley et al., 1993) identified typical capital and operating costs for industrial ZLD processing and clearly represented ZLD processing as a cost-prohibitive option. More recently, the challenges of CM, particularly in the arid southwest, have increased interest in how the benefits of HR processing (including ZLD) might be realized.

Several research projects have shown that HR is not a technical challenge but a cost challenge. More recently, funded research has focused on reducing the costs of HR processing. Improvements in current desalination technologies and commercialization of new technologies may decrease the cost of HR processing. The high cost of final disposal of concentrate, brine, or mixed solids, however, remains a limiting factor in reducing HR costs.

As a result, there is considerable interest in the use and possible sale of salts and other chemical species obtained from concentrate. This path can reduce wastes and defray costs associated with HR processing. As with HR technology in general, the technical means of selective salt recovery exists and has been used in other industries.

HR processing remains cost-prohibitive for most municipal desalination situations. The exception would be some low-salinity NF operations, where HR has provided a means of avoiding costly disposal options while providing a beneficial use of concentrate.

> **Example.** The city of Palm Coast, FL WTP #2 is a 6.4-mgd NF facility currently discharging concentrate to a canal. Permit renewal was denied in 2006, as a mixing zone was no longer allowed. The facility was given a 48-month administrative order to allow continued operation. After study of several alternatives, a pilot lime softening/MF/RO system to treat the NF concentrate was successfully operated.

> More than 80% of the concentrate was recovered, to give an overall recovery of 98%. The final concentrate was mixed with lime process sludge, which is further mixed with sludge from WTP #1 and used for road base stabilization. This approach avoids concerns with surface water discharge including upcoming numerical nutrient criteria (see Chapter 16, Emerging Issues).

It is likely that HR processing and salt recovery will play an increasing role in municipal desalination CM practices. More widespread application, however, will require cost reductions.

3.10 Beneficial Use of Concentrate

3.10.1 Range and Nature of Beneficial Uses

The promise of beneficial use of concentrate is that the same drop of water can be used more than once. This is an important consideration. However, from the perspective of CM, beneficial uses will likely play only a minor role. The 2006 WateReuse Foundation report *Beneficial and Non-Traditional Uses of Concentrate* (Jordahl, 2006) extensively reviewed beneficial uses. In general,

- most beneficial uses do not have widespread applicability
- most are unproven
- most do not provide for final disposal
- (*but*) because of the challenges in finding CM solutions, it is important to consider local beneficial uses at the planning stage of every new desalination facility.

Table 3.10 lists several potentially beneficial uses of concentrate.

Some of the limitations of beneficial use options include the following:

- Long-term use of concentrate requires that the use be available throughout the life of the desalination plant; this is a problem for oil/gas well injection use.
- Although aquaculture use may result in a new economic entity employing people and having other benefits, the concentrate picks up an organic load and must be disposed of or treated and recycled.
- Dust control requires large amounts of dirt road for a relatively small volume of concentrate.
- A major concern with irrigation of salt-tolerant plants is the effect of high-salinity concentrate on underlying groundwater. This requires an efficient drainage system to capture the applied irrigation water. The drainage water will need treatment, such as ZLD processing, to produce salts for disposal.

Beneficial uses are discussed more fully in Chapter 14.

3.10.2 Salt Recovery

One area of beneficial use that has received increasing attention is the recovery of salt from concentrate (Ahmed et al., 2001, 2003; Arakel and Mickley, 2007; Davis, 2006; He et al., 2010; Jordahl, 2006; Mickley 2008, 2009, 2010).

Table 3.10. Summary of Potential Beneficial Uses of Concentrate

Beneficial Use Concept	Description
Oil well field injection	Make-up water to pressurize oil reservoirs to extract additional oil
Energy generation (solar ponds, etc.)	Feedstock and make-up water for solar ponds that capture solar energy and heat water
Land application/irrigation (discussed in Chapter 12)	Low salinity concentrates can be used to irrigate salt-tolerant crops
Aquaculture	Feedstock for marine (salt water) aquaculture
Wetland creation/restoration	Creation or restoration of brackish or salt marsh wetlands
Treatment wetlands	Constructed treatment wetlands can be used to remove some problematic constituents, and allow discharges that would otherwise not be possible
Stormwater/wastewater blending	Where low salinity discharges are problematic, such as to estuaries, concentrate could provide a source of soluble salts
Feedstock for sodium hypochlorite generation	Concentrate could provide a source of chloride
Cooling water	Source of additional makeup water
Dust control and de-icing	Salts such as calcium chloride could be separated and applied for these uses
Cement manufacture	Proprietary processes (e.g., Calera, 2010) can utilize alkalinity obtained from salt solutions to precipitate carbonate compounds, which in turn may be useful cements for construction materials
Greenhouse gas sequestration/air pollution scrubbing	Proprietary processes (e.g., Calera, 2010) provide the potential to sequester CO_2, SO_2, and concentrate is a potential feedstock
Separation of individual salts from concentrate (introduced in Chapter 3 and discussed in detail in Chapter 15)	Potential for industrial or other reuse

One of the findings from examination of desalination practices in other industries, and in particular in other countries (Chapter 4), was that salt recovery as part of desalination processing is more prevalent outside the United States.

> **Example.** In several Middle Eastern countries, salts are imported at significant cost. Thus HR treatment of produced water has been considered as a means of providing salt while producing usable water, minimizing waste, and in total, providing a viable solution for managing the produced water. A major oil producer in Oman is providing produced water to a company that is abstracting salts for commercial use. The oil company recently commissioned a study to determine feasibility of processing produced water from many sites to do salt recovery from their own water. (Personal communication, Dr. A. Arakel, 2009)

There are companies that make thermal evaporators specifically for the purpose of recovering salts. This is in contrast to the wastewater thermal evaporators used in many U.S. nonmunicipal HR/ZLD situations.

Selective salt recovery has received increasing attention in the past few years because of

- the growing need for alternative CM options
- the tie-in of salt recovery with high-recovery processing
- the potential benefits of selective salt recovery in
  - avoiding negative environmental impacts associated with concentrate, brine, and solids disposal
  - defraying operating costs through sale of recovered salts
  - providing a means of approaching the ideal of maximizing water recovery and minimizing waste, an attribute of sustainability
  - decreasing the CO_2 footprint of the desalination process through removal of carbonate species

The feasibility of a site-specific operation to recover and market salts, however, depends on several factors, including

- volume of concentrate
- water quality (salts obtainable from the concentrate)
- quality (form and purity) of salts obtained
- reliability and consistency of salt quality
- types of applications for the obtainable salts (types of markets)
- existence of a local market
- size of the local market
- reliability of the local market
- combined income from sale of the different salts

Each site-specific consideration of selective salt recovery will require a feasibility analysis to address these and other issues prior to commitment to the process. It is also important to note that market value is not directly related to economic feasibility. A sufficient mass of salts must be available to make processing and recovery feasible. The marketing of recovered salts and other products of value from concentrate should be undertaken by a third party who purchases the products form the desalination facility.

In general, salt separation and marketing of salts hold promise for providing CM solutions for some locations—including locations in the arid southwestern United States, where CM challenges are most significant.

Salt recovery involves HR processing and some specialized steps in recovering salts in commercial grade sizes and purity. Salt sales can defray processing costs, depending on the particular salts and the amounts that can be produced per feed volume. It is possible in some cases for salt sales to result in a net operating income. To date there has not been a municipal pilot or demonstration study done in the United States at the scale required to demonstrate the feasibility and benefits of product recovery. As with HR processing in general, cost reductions are likely necessary before salt recovery will be applicable in most municipal settings.

Of importance beyond providing viable concentrate disposal solutions, the separation of salts and their marketing are strong steps toward a sustainable, environment-supporting solution where water recovery is maximized and salts are recycled. Salt recovery is addressed in Chapter 15, *Solids Management and Recovery of Values from Concentrate.*

3.11 New Membrane Technologies

Several membrane desalination technologies are under research and may, for some application areas, offer alternatives to reverse osmosis in the future. They have the potential to lower energy requirements and costs. As with any desalination technology, a concentrated waste stream is still produced, sparingly soluble salts and silica can still limit performance, and the concentrate still needs to be managed.

3.11.1 Membrane Distillation

Membrane distillation (MD) is a water purification technique where water is transported across a hydrophobic membrane because of differences in water vapor partial pressures. Figure 3.4 shows a schematic of the MD process. Water on the feed side is heated to increase its vapor pressure. Low pressure on the permeate side causes the water on the feed side to be vaporized at the membrane pore inlet and diffuse across the membrane. The water vapor on the permeate side is condensed outside of the membrane module. The membrane acts as a support for the liquid/vapor interface and has no influence on the process selectivity. The membrane, however, must be hydrophobic to prevent water from entering the membrane, and the pore size must be small enough to offer some resistance to water breakthrough. Typically, pore sizes on the order of 0.1 μm and slightly higher are used.

Although MD does require considerable energy to heat the feed water from 30°C to 90°C, any low-quality heat source (solar energy, geothermal energy, or waste heat) can be used. The process takes place at normal pressure and thus avoids osmotic pressure limitations associated with seawater RO. Theoretically, high water recovery may be possible for seawater desalination. Like other distillation processes, MD is capable of achieving very low–TDS product water.

Technology improvements in terms of better performing membranes (lower fouling, and lower–thermal conductivity membranes with the desired hydrophobicity and porosity, achieving higher flux), are required to bring MD closer to commercialization.

MD, like all desalination processes, produces a concentrate. As the feed solution becomes more concentrated, precipitation of sparingly soluble salts and silica will still present operational challenges. Solubility limits will be reached and precipitation will occur, just as in RO systems. Differences in the nature of the hydrodynamics, membranes, and operating temperatures may result in somewhat different impacts of precipitation on the system performance; however, precipitation can be performance-limiting. The potential impacts of MD on CM include the following:

- Seawater RO recoveries may be considerably greater than current limits of 60%. Similarly, recoveries in a second RO step (SWRO) following an initial RO step (BWRO) in a HR processing scheme may no longer be limited by osmotic pressure.

- It is likely that membrane scaling that is due to sparingly soluble salts and silica may become performance-limiting.

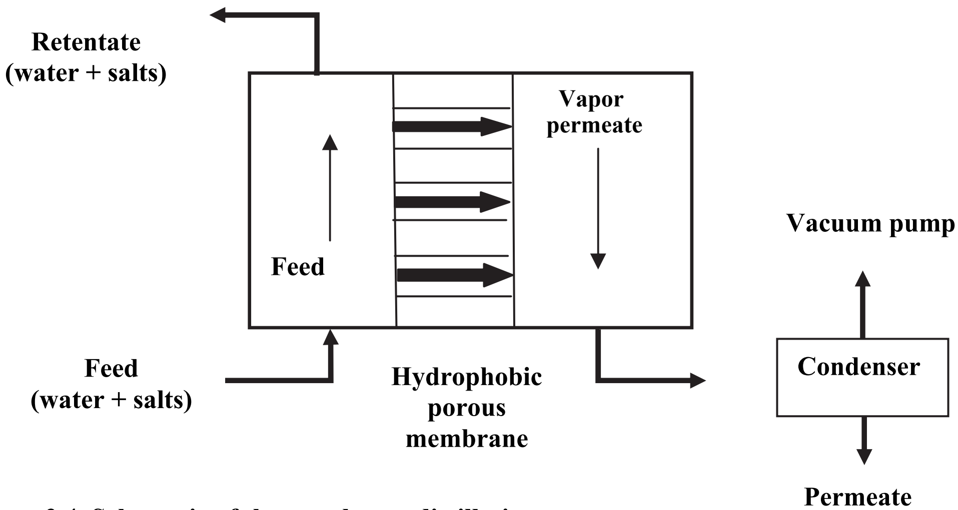


Figure 3.4. Schematic of the membrane distillation process.

- This will result in concentrates of higher salinity with correspondingly greater concentrations of all constituents. Disposal challenges associated with higher salinity brines will be more frequently encountered.
- For SWRO and discharge to the ocean, the resulting higher concentrate salinity will require more dilution prior to discharge.
- The costs of desalination may be reduced and thus make SWRO and HR processing more cost-effective and lead to their greater use in municipal desalination.

Modification of operating conditions to allow HR can result in salt precipitation. However, MD offers fine control over the supersaturated condition and a version of MD, referred to as membrane crystallization (Drioli and Macedonio, 2010), has been studied and is being considered for salt recovery. A filter installed after the MD device is used to recover the salts.

3.11.2 Forward Osmosis

Instead of employing hydraulic pressure as the driving force for separation, as in the RO process, forward osmosis (FO) uses the osmotic pressure gradient across the membrane to induce a net flow of water from the feed solution through the membrane into a concentrated draw solution, thus efficiently separating the freshwater from its solutes. Figure 3.5 shows a schematic of the FO process. The solutes/solution components making up the draw solution are then separated from the otherwise fresh water and recirculated as draw solution. FO does not require significant energy input, only stirring or pumping of the solutions involved. As with MD, FO is not limited by osmotic pressure, as is the RO system.

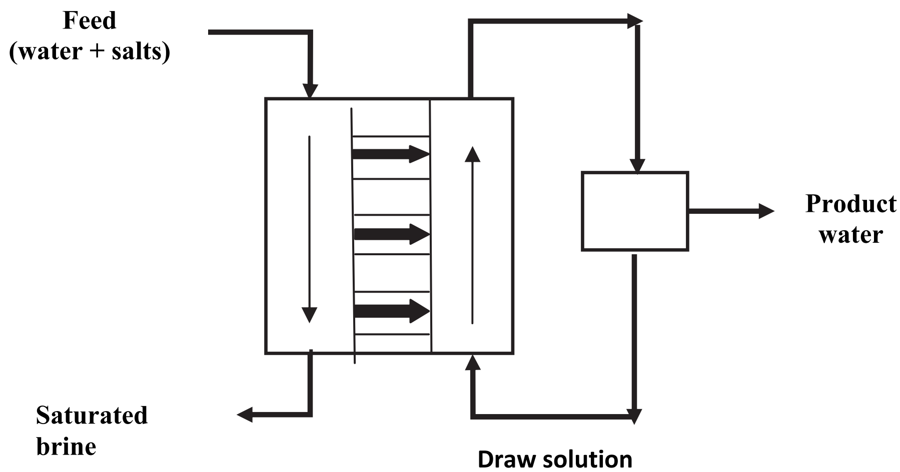


Figure 3.5. Schematic of the forward osmosis process.

As with all concentration systems, concentration of sparingly soluble salts and silica on the feed side of the FO system will eventually lead to precipitation, and that can limit recovery. As with MD, differences in the nature of the FO system may result in a somewhat different impact of precipitation on the system performance. The effects of FO on CM are the same as those for MD: namely, greater recovery in seawater desalination and less expensive HR processing, both resulting in more instances of higher salinity concentrate.

3.11.3 Impacts of New Desalination Technologies on Concentrate Management

New desalination technologies may offer advantages over existing technologies, including

- avoiding performance limitations of current technologies (enabling higher recoveries)
- requiring less energy
- requiring lower amounts of chemicals
- producing lower amounts of nonconcentrate residuals (pretreatment solids and cleaning wastes)
- reducing costs
- reducing physical footprint

New desalination technologies do not offer new solutions to CM; however, they can impact CM in the following ways:

- increasing the occurrence of higher salinity concentrate (by lowering the costs of HR processing)
- changing the chemical makeup (slightly) by reducing the use of pretreatment chemicals
    - reducing residuals from pretreatment processing
    - reducing the use/amount of antiscalant

3.12 Summary

3.12.1 Municipal Desalination Industry Trends

Current trends include the following:

- The average size of plants continues to increase.
- There has been increased focus on effluent treatment for water reuse (this may become the fastest-growing application of municipal desalination).
- There is greater consideration of SWRO in the U.S. in terms of feasibility and pilot studies.
- There has been more frequent treatment of waters to remove contaminants, in addition to reducing salinity.
- Significant progress has been made in decreasing RO energy requirements.
- New technologies are under research and may have commercial application in the future (e.g., forward osmosis, membrane distillation).

These trends reflect the increasing application of desalination and the role that desalination is playing as a water management tool. At the same time, as water management needs have become more critical, conservation practices have been increasingly implemented and have shown dramatic effects in reducing per capita water needs. It is difficult to predict the balance of roles that desalination, nondesalination water reuse, and conservation will play in the future, other than that all three will be important and necessary water management tools.

3.12.2 Current Concentrate Management

Five conventional concentrate disposal options have been used by nearly all U.S. municipal desalination plants: surface water discharge, discharge to sewers, DWI, land application, and discharge to evaporation ponds. The application of these options is a function of plant size, water quality, location, and regulatory policy.

The primary challenges faced by utilities in seeking a suitable disposal option are as follows:

- Typically there are few local options available at a given site because of climate, permitting constraints, hydrogeology, and land availability.
- Locally available options may not be cost-effective.
- The regulatory interactions can be complex and time-consuming.
- Unlike desalination production costs, concentrate disposal option costs have not, in general, been decreasing.
- The challenges are further complicated by the costs of more stringent regulation, increased public concern, and the growing need for water in the arid Southwest (where conventional disposal options are, in general, not feasible).

"Few if any cost-effective, environmentally sustainable CM options exist for inland desalination facilities." This statement is from the 2008 National Research Council critical analysis of current desalination technologies and the barriers to broader implementation (NRC, 2008). The study was undertaken in order to address the development of a national strategic research agenda for desalination.

In terms of items directly related to CM, the past several years have resulted in increased consideration and investigation of DWI in states other than Florida and of enhanced evaporation. Neither, however, has yet had much impact on practices.

Although several possible beneficial uses of concentrate have been identified, none are widely applicable, most are unproven, and most do not address the concentrate disposal challenge. There are very few viable uses of concentrate demonstrated thus far.

Since 2002, there has been increasing consideration of HR processing, usually under the name of volume reduction or concentrate minimization. This consideration was driven in large part by the urgent challenges of finding a suitable CM option for several locations in the southwestern United States. A largely unexplored question, however, is how HR processing affects concentrate disposal. This is addressed more fully in Appendix B.

There is a promise of modifying or treating concentrate to produce useful products, such as in selective recovery of commercial grade salts. Although the commercial technology exists, in the United States there have been only a few investigations into its application for municipal desalination concentrates and no pilot/demonstration plant study has been undertaken at a scale allowing feasibility and benefits to be demonstrated.

3.12.3 Future Directions

Although challenges of CM abound, a clearer picture has emerged out of this project's investigations and of developments and research in the past decade:

- Desalination and CM costs, and more generally municipal water treatment costs, must be viewed within the present context of water not being valued in line with its true value. As a result, technologies and approaches that are cost-effective in many other industries are not cost-effective in the municipal setting.
- The increased application of desalination to produce potable water and higher quality reuse water seems ensured because of the lack of technology alternatives that can reduce higher salinity/lower-quality feed water and/or remove in a single step a wide range and growing list of contaminants. A result of this will likely be a growing number of facilities requiring CM solutions.
- Because of deteriorating source water quality, concentrates will increasingly contain contaminants, unless they are removed in pretreatment steps prior to the desalination step. A growing number of concentrates will need to be treated to enable surface discharges to meet existing regulations.
- At the same time, regulations for discharge, including concentrate discharge to surface water, sewers, and land applications, all of which can affect source waters used to produce drinking water, are becoming more stringent.
- Consequently, the challenge of finding a cost-effective CM option will increase in difficulty.
- Use of HR processing will increase. Volume reduction/concentrate minimization will find application for some situations, but in general will not likely be a widely applicable solution to municipal CM challenges until costs are reduced.
- Similarly, HR processing to solids (one version of ZLD processing) will find only limited application because of the high cost of solids disposal to landfill.

- Recovery of salts from concentrate will continue to receive increased attention. The municipal industry awaits demonstration of the feasibility and benefits of salt and other product recovery. The application of salt and other product recovery from concentrate will benefit from reduction in costs of HR processing.
- Several of these points represent the need for additional treatment of concentrate. Such treatment has been demonstrated in other industries and in other countries, but not for the U.S. municipal industry. The rate at which this greater treatment is implemented will be dependent on cost-effectiveness. Unless there are processing cost reductions (or an unlikely but much needed revaluing of water through increased cost of water to consumers), the rate of implementation in municipal industry will be limited.
- Optimal integrated water management practices using conservation, reuse, and desalination will become increasingly important. A broad focus on CM is one aspect of this management.
- Desalination as part of water reuse will likely grow as an applied treatment technology supporting improved strategies for managing water resources.

As discussed previously, HR processing holds some promise for future solutions to CM challenges when incorporated with cost reduction in desalination technologies. Cost reduction may be affected by new technologies and eventually, perhaps, by sale of recovered salts and possibly other chemicals. In this way, water resource sustainability can be approached through increased recovery of water and recovery of some of the waste products as valued materials.

Meanwhile, the challenges of CM remain. Subsequent chapters discuss individual CM options and related challenges and issues associated with them in detail. First, however, CM is considered from a broad perspective—that of global saline water management—to see how practices in other industries and other countries might affect municipal desalination CM here in the United States in the future.

Chapter 4

Nonmunicipal Desalination Concentrate Management

4.1 Introduction

In this chapter, global saline water management practices are reviewed and observations based on this review are highlighted with relevance to municipal CM. There is considerable experience from other industries in treatment of complex and high salinity waters—experience that may be useful for municipal desalination as source water qualities are worsening and HR processing is increasingly being considered.

Municipal desalination CM may be viewed as a subcategory of saline water management. Many other industries than the municipal desalination industry must deal with liquid and solid residuals from desalination. As with municipal CM, the general management options for unwanted saline water are (1) disposal and (2) use—either as is or after treatment. Uses of saline water are few and treatment (desalination) is frequently required to produce lower-salinity water suitable for use or disposal. In desalination, a concentrate is also produced that itself requires management.

Historically, most of the waters chosen for potable water treatment were “natural” in the sense of being relatively unaffected by human activity. Few waters, however, remain unaffected. The main impacts of humanity on surface water are point-source and non–point source discharges, rain-carried contaminants, air pollution, and pollution from activities on and under surface waters. Groundwater is affected by a variety of activities that result in land being exposed to industrial and agricultural chemicals, human and animal wastes (treated or untreated), rain, mining and drilling operations, and many other substances and activities.

Although developed countries have made considerable efforts to protect water quality, surface and groundwater in many developing countries are highly polluted because of mixture of wastes from many activities. From a desalination treatment perspective, the water quality can be quite complex, in terms of the mix of contaminants.

Water treated in municipal WTPs in developed countries represents an extreme in terms of high source-water quality with regard to major ions and most commonly recognized historical “contaminants.” With the increasing list of emerging contaminants, however, the effects of human activity on water quality has become more evident. Municipal desalination is a technology of choice when the feed water is of lesser quality in terms of salinity and increasingly in terms of contaminants.

4.2 General Applications of Desalination

In Chapter 3, the following general applications of desalination were discussed:

- primary treatment of surface water or groundwater (e.g., potable use, industrial use, and agricultural use)

- treatment of water/wastewater for reuse/use or disposal (water from WWTPs, industrial sites, agricultural sites, and groundwater—such as for direct industrial use)
- treatment of by-product water for use or disposal (e.g., produced water and mine water)

The two primary municipal applications were noted previously. Treatment of WWTP effluent is mostly for discharge or reuse purposes with some treatment of effluent for recharge or storage and reuse. The nonmunicipal applications discussed in this chapter include: industrial use/reuse, agricultural use/reuse, water from dewatering operations, produced water, and mine water.

4.3 Global Nonmunicipal Saline Water Challenges

Desalination has been considered and/or used in each of these management situations. Common characteristics of saline water management in these industries include

- high-salinity feed water—typically higher than municipal concentrate
- high-recovery processing
- use of DWI, evaporation ponds, and landfill for disposal
- some consideration of salt recovery

These broad areas are reviewed and examples are provided.

4.3.1 Oil- and Gas-Produced Water

The salinity of water produced along with oil and gas from drilled wells ranges from a few thousand mg/L to several hundred thousand mg/L. The volume of water produced with oil is a function of the age of the well. A worldwide estimate of the ratio of water to oil is 2:1 to 3:1. The United States has relatively mature oil fields with an estimated ratio of 7:1 (Veil et al., 2004). Water management issues have held up development of oil and gas fields in several locations, including the Wyoming/Montana/Colorado coal bed methane region, the Marcellus Shale Gas in Pennsylvania and West Virginia, and Australian coal seam gas locations in Queensland. Salinity is frequently too high to permit simple discharge or land application of the water, and produced waters frequently have sodium adsorption ratio values too high to permit land application.

The sodium adsorption ratio (SAR) is a measure of the suitability of water for irrigating crops and is based on the sodium, calcium, and magnesium concentrations in the water. The formula for calculating the SAR is

$$SAR = [Na^+]/\{([Ca^{2+}] + [Mg^{2+}])/2\}^{1/2}$$

where sodium, calcium, and magnesium are in units of milliequivalents/liter. For additional detail, see Chapter 12.

Waters with high SARs are less suitable for irrigation and can lead to loss of permeability and infiltration rates in soil, and with this, problems in the production of crops. Desalination can address the salinity, but the SAR requires separate adjustment. Because of high water volumes and the need to manage the concentrate produced, the treatment schemes frequently involve high-recovery processing. Various treatment schemes have been proposed depending on site-specific conditions. Nearly all designs discussed in the literature and in presentations involve high-recovery processing using both RO and thermal desalination steps.

Desalination-based processing is typically cost-effective within the economics of the oil and gas industry, using methods that would, in general, be cost-prohibitive in the municipal and agricultural industries.

> **Example**: The coal seam gas industry in Australia has contracts to supply liquefied natural gas to India and China in the future. Large-scale development of the gas fields has been delayed because of environmental concerns associated with produced water. Because of large-scale past use of evaporation ponds and leakage from unlined ponds affecting groundwater, use of evaporation ponds in Queensland, Australia for long-term disposal of produced water has been outlawed. Short-term storage of water in existing ponds is permitted as an intermediate step in treatment after water in existing ponds is remediated. Existing ponds must be remediated by 2013. Various high-recovery processing schemes for managing the large amounts of produced water in existing ponds and for treating new produced water are being studied. Produced waters range in TDS from 2000 to 15,000 mg/L and are mostly sodium-dominated chloride and bicarbonate waters with a range of metal contaminants. Many of the high-recovery treatment schemes proposed by the various producers include salt recovery (Horn, 2009).

> **Example**: In 2008, produced water from an oil field in Kazakhstan was being considered as feed water for a water treatment plant to supply boiler and other water to the operation, as river water was no longer available. The produced water ranged in TDS from 24,000 to 45,000 mg/L and was highly sodium chloride–dominated. The design requested and produced by a major European engineering firm called for high recovery of the water using RO and thermal evaporators along with the possibility of salt recovery (the author Mike Mickley was a reviewer of the submitted report).

4.3.2 Waters from Agricultural Practices

4.3.2.1 Dryland Salinity

Dryland salinity is a soil condition resulting from a rising water table primarily through removal of deep-rooted native vegetation and replacement with nonnative vegetation with shallow roots. Groundwater high in salinity rises nearer the surface, and can leave salt deposits on the surface by evaporation. The condition limits the types and feasibility of crops that can be cultivated. The situation can be further worsened by excessive irrigation. Waterlogging can occur and result in damage to homes and other structures. In some cases, the waterlogging may be mitigated by removal of the high water table water. This process has occurred in many locations, but most notably in the Murray–Darling River basin of Australia (AAS, 2009).

4.3.2.2 Irrigation Salinity

Irrigation salinity is a soil condition brought about by excessive irrigation and/or inadequate drainage, resulting in a rising water table. Waterlogging may result and salts may accumulate on the surface through evaporation. The situation is best managed by improved irrigation practices but may require some mitigation (desalination) of the groundwater or irrigation water salinity before a feasible condition can be reached. However, desalination is rarely economical for this condition.

4.3.2.3 Overpumping and Irrigation

In some areas, groundwater is pumped excessively to access more irrigation water. This results in a lowered water table. With salinity increasing with depth, the pumps access lower-quality water in the aquifer. In other cases, new and deeper wells accessing lower-quality water may be drilled to provide needed irrigation water. In other situations, excessive pumping of coastal groundwater has resulted in seawater intrusion.

> **Example**: In a region in Punjab, India, new high-yield crops require much more water than natural rainfall can provide, so farmers dig wells and irrigate with groundwater. Although this system has worked well for years, so much groundwater has been used that the water table is dropping dramatically, as much as 3 ft per year. Farmers dig deeper to find groundwater and encounter higher salinity water. Use of the higher salinity water results in salt deposits appearing on the soil. This is not necessarily a widespread problem, but is an example of what can occur (Zwerdling, 2009). Desalination is likely not economically feasible.

4.3.2.4 Agricultural Drainage Water

Irrigation water increases in salinity because of evaporation and accumulation of minerals from percolation through soils as it works its way to the water table. Efficient irrigation practices include installation of a drainage system to intercept the percolating water and limit its effect on groundwater quality and to prevent a rising water table. In many instances, the recovered water may be reused for irrigation of more salt-tolerant crops. Eventually the drainage water becomes too saline for irrigation and must be managed.

> **Example**: The highly productive farmlands in the arid San Joaquin Valley of California require large volumes of irrigation. In the 1960s, irrigation and drainage practices resulted in rising water tables of increasing salinity that began to harm crops. In 1971, the Bureau of Reclamation completed the 134-km Kesterson Drain and the Kesterson Reservoir system of 12 evaporation ponds to convey and receive drainage water from the valley. Land in the valley has high levels of naturally occurring selenium, and in 1982, a study to determine the cause for declining reservoir waterfowl and wildlife found elevated selenium concentrations (FAO, 1997). As a result of a 2002 court settlement, the U.S. government was forced to develop and implement a solution to the San Joaquin Valley irrigation drainage water problem. Many possible solutions were studied, and currently the Bureau of Reclamation is planning on implementing a system of four separate treatment facilities ranging in capacity from 0.84 to 15.9 mgd. Drainage water will be collected, reused, collected again, and treated by RO. Salinity of the drainage water ranges from 6000 to 14,000 mg/L. Product water will be suitable for irrigation. The concentrate is further treated biologically to reduce the level of selenium prior to discharge to newly constructed evaporation ponds. Operation of a demonstration plant is scheduled for late 2012 (Bureau of Reclamation, 2008).

4.3.2.5 Agricultural Water Summary

Improvements in irrigation and drainage practices can reduce the incidence and severity of problems with saline water in agriculture. Eventually, however, drainage water will be the water management challenge.

In all of the preceding conditions, saline water may be managed by sending it to evaporation ponds, location and climate permitting. This, however, represents lost water, requires significant land, and can result in environmental problems. Desalination provides a means of recovering water for reuse and thus offers a solution to the challenges, as long as the concentrate produced can be adequately disposed of. Desalination, however, is frequently not cost-effective for agricultural water remediation in developed countries and certainly not in developing countries.

In irrigated agriculture, water salinity does not usually reach the high levels found in many produced waters. Water composition is typically that of the original irrigation water concentrated by evaporation and supplemented by minerals leached from the soil.

4.3.3 Dewatering

Dewatering is the temporary lowering of the water table for the purpose of construction, compaction, or drainage. The water typically requires disposal and, depending on the volume involved, may require desalination prior to disposal. The waters in these situations may be produced only during a period of need. In other cases, pumping may be an ongoing requirement. In coastal areas, where shallow aquifers may have been affected by salt water intrusion, the water salinity can be very high.

> **Example:** The City of Masdar in Abu Dhabi, United Arab Emirates, is planned to be the first zero carbon city in the world. Impressive and inspiring plans in 2006 for the 50,000-person city called for pushing the limits on environmental sustainability. This included potable water from desalination, 80% recycled water, minimization of concentrate waste through high-recovery processing, and possibly salt recovery. Some of the desalination challenges included treating salinized groundwater with 95,000 mg/L TDS and water from construction dewatering with 277,000 mg/L TDS. Both waters are extreme, but are real examples of high-salinity waters for which treatment is being sought. The desalination portion of the project has been on hold since mid-2009. (Personal communication, Dr. Arakel, 2009)

4.3.4 Mining Waters

Mining waters are of three types: groundwater found along with the mined material, surface mining runoff water, and water from the processing of the mined material. Although the waters are typically not as high in salinity as produced waters, the chemistry can be much more complex (primarily because of the chemical processing of the mined material). These waters are typically stored in ponds. Pond salinity and composition can be highly variable because of runoff, particularly in the case of surface mining. The ponds may need to be remediated because of environmental problems or mine closure requirements. Desalination processes are often involved in the remediation of waters derived from mining operations.

> **Example:** In recent years there have been several lawsuits against various coal mining companies in West Virginia over water discharge violations. A recent Order

for Compliance (December 2009) required Consol (Consolidated Coal Company) to submit draft engineering details for its chosen wastewater treatment technology for achieving compliance. A single 5-mgd regional treatment system was proposed that consisted of a high-recovery desalination system to take the 10,000-mg/L sodium-, sulfate-, bicarbonate-, and chloride-dominated mining water to solids for disposal at an on-site dedicated monofill. Pretreatment is required for aluminum, iron, and manganese, and removal consisted of lime, oxidation, and advanced clarification and filtration technologies. Further treatment consisted of RO, thermal brine concentrators, and crystallizers. (CONSOL, 2010)

Example: In 2008, a large South African coal mining operation was forced by tightening discharge regulations to find a solution for treating acid mine drainage water. The water had a TDS of 6200 mg/L and was highly sodium sulfate–dominated, with very high iron levels. Multiple proposals for pilot studies were requested, with the stipulation that all include a means of recovering salt from the water. All proposals received involved high-recovery processing to solids. (Author's personal experience)

4.4 Key Differences from Municipal Concentrate

Several observations may be made from comparison of U.S. municipal desalination with applications of desalination in other industries. These observations include identification of the following:

- different salinity and composition of waters being treated
- greater use of high-recovery processing in other industries
- greater use of salt recovery in other countries

Each of these areas is discussed in the following sections.

4.4.1 Observations: Salinity and Composition

In industries other than municipal desalination, the feed water may be higher in salinity and have significantly different amounts and types of contaminants. The various waters treated show wide ranges of salinity, major ions (composition), and contaminants.

4.4.1.1 Salinity and Major Ions

Concentrate management challenges are dependent on concentrate characteristics including volume, salinity, and composition. A recent study (Mickley, 2008) has shown that salinity, composition, and process size can all have significant effects on unit costs for high-recovery processing. Because these are important variables, the look at global desalination practices included consideration of water qualities. The global range of water qualities encountered is large.

Seven major ions typically constitute more than 95% of the total dissolved solids in natural waters and most wastewater. These are

- cations: Ca, Mg, K, Na
- anions: HCO_3, Cl, SO_4

Although geochemistry texts present various ways to categorize and represent varying water qualities, there have been two efforts that the author is aware of to categorize water qualities with CM in mind. The first was developed by Geo-Processors Pty Limited (GEO-PROCESSORS, 2011) and is included in their patents. Figure 4.1 categorizes inorganic saline waters according to seven basic compositional types. These types were determined from analysis of a large number of global waters. They provide insight into both treatment approaches and salts that can be practically obtained from the different waters. The types are dependent on levels of salinity and the ratios of Cl/SO_4 and Cl/HCO_3. Note that beside each type of water is a short listing of global waters of that type.

The second approach is called percent difference from balance (PDFB) (Mickley, 2000). Although originally developed as a predictive indicator for major ion toxicity in groundwater-based concentrates, the parameter also serves to characterize the composition of waters relative to seawater. From a physiological perspective, seawater and more specifically the relative major ion composition of seawater at any salinity is considered "balanced" water. Freshwater and marine organisms are least challenged by major ion concentrations that are balanced at a salinity appropriate for the particular organism. The PDFB parameter compares a water composition to that of seawater diluted or concentrated to the same salinity. Thus it eliminates salinity as a variable and reflects the composition of the water relative to seawater. A water having a relatively greater amount of a major ion than seawater at the same salinity has a positive PDFB for that ion. Similarly, a water having a relatively lesser amount of a major ion than seawater at the same salinity has a negative PDFB for that ion. Seawater by definition has PDFB values of 0% for each species.

The variability in PDFB values for the Australian, U.S. (municipal concentrate portion), and global data sets by ion is given in Table 4.1. From Table 4.1, it can be seen that the largest variability is in the HCO_3 values, followed by Ca and then SO_4 for all data sets.

Important points for the present discussion are as follows:

- Globally, concentrates and other waters for treatment vary widely in salinity and composition.
- U.S. municipal concentrates appear to be of lower salinity than many global waters.
- On a standardized salinity basis, as in Table 4.1, U.S. municipal waters have smaller ranges of major ions than are found in Australian and global waters—many of which are nonmunicipal waters.
- Because of the wide range of water qualities, care should be applied in generalizing the results from site-specific studies concerning CM.

4.4.1.2 Contaminants

A distinguishing characteristic of the waters to be treated in nonmunicipal industries is that they frequently have a wider range of contaminants. This is because of the specific nature of different waters, such as produced water and mining water, but also because of more frequent contamination of surface and groundwater by wastewaters (particularly in developing countries).

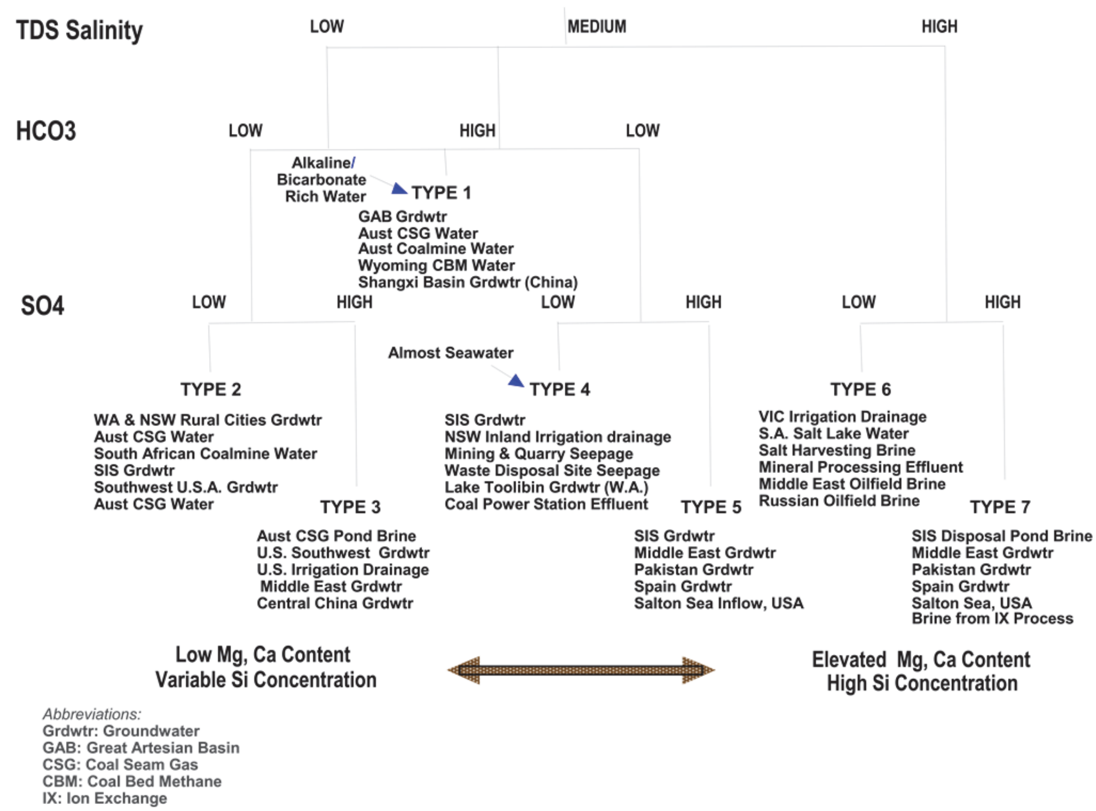


Figure 4.1. Classification of saline waters (Arakel, personal communication, 2010)

Regarding feed water to various desalination applications:

- Municipal feed water worldwide is from the best available sources.
- There is a distinct difference in municipal feed water quality between developed and developing countries (where sources are frequently contaminated with wastewater).
- Feed water to U.S. municipal desalination facilities may be of higher quality in terms of lower salinity and lower amounts of natural contaminants.
- Feed water to U.S. municipal WTP and WWTP desalination processes may be of lower quality in terms of emerging, manmade contaminants than in other developed countries.
- Feed water to nonmunicipal desalination systems is typically more complex in chemistry and has contaminants not normally found in municipal feed water.

Table 4.1. Variability in PDFB Values for Different Data Sets

	Na	Cl	Mg	SO_4	Ca	HCO_3
Australia	-93 to 22	-92 to 39	-99 to 383	-100 to 908	-100 to 1056	-98 to 17,803
United States	-81 to 0	-99 to -2	-91 to 130	-100 to 642	-33 to 988	144 to 18,070
Global	-93 to 39	-99 to 39	-100 to 383	-100 to 908	-100 to 1223	-99 to 18,070

4.4.2 Observations: Use of High-Recovery Processing

Desalination feed water in other industries is frequently of higher salinity. Consequently, there is a greater need for and consideration of HR processing. Water recovery from higher salinity feed water via membrane processes is limited, and thus thermal evaporative technologies more suited to treating higher salinity feed water are used. Most industries have products valued higher than water and can justify application of higher cost, high-recovery technologies. As a result, high-recovery processing (including ZLD) is much more widely considered in nonmunicipal industries.

The application of high-recovery processing (including ZLD) is driven by several factors:

- need for more efficient water resource use
- need to solve environmental challenges (driven by regulations)
- lack of CM options for lower recovery concentrate
- reduced time for obtaining permits (in the case of ZLD processing)

In general, the treatment technologies used in other industries are those that would be used in high-recovery processing in municipal water treatment.

4.4.3 Observations: Use of Salt Recovery

Salt recovery is more widely considered in other industries and in other countries (Ahmed et al., 2001, 2003; Alberti et al., 2008; Arakel and Mickley, 2007; Horn, 2009). This appears to be because of the better funding capabilities of nonmunicipal industries, the need to import salt in many countries (such as the Middle East), and the positive impact on costs that can result from production of commercial salts.

4.4.4 Observations: Technologies Used

In general, there are no new or different technologies or CM solutions used for industrial applications that have not been considered for municipal treatment. There is widespread use of RO, evaporators, and, where possible, evaporation ponds. Many nonmunicipal industries can afford technologies and treatment that are currently too costly for municipal consideration.

4.4.5 Observations: Benefit of National Policy, Leadership, and Incentives

There has been a substantial focus on policy and financial commitment to solving water problems in various countries, notably Australia and Israel. Although this is in large part due to significant drought and general crisis conditions, it also represents a commitment to defining and addressing long-term needs rather than simply resorting to crisis management.

One result of this is a much shorter time interval from identifying a need to building, permitting, and operating municipal desalination plants in some other countries than in the United States.

4.5 Summary

Source waters considered for drinking-water treatment are the highest quality source waters available, and from a broad perspective, they represent an extreme in terms of simplicity of desalination treatment. There are exceptions where high levels of well-known scalants and foulants are found in the source water. Increasingly, source waters are treated that have contaminants such as nitrate, selenium, arsenic, and perchlorate. In the future, treatment may be required to remove emerging contaminants.

Consideration of the broad context of worldwide desalination situations reveals a range of challenges similar to and beyond those facing the U.S. municipal desalination industry. Review of global saline water management challenges and desalination applications has provided information about high-recovery and salt management practices and about treatment challenges associated with higher salinity and more complex feed water. Such information will be of growing importance in municipal desalination as (a) source waters become more impaired, (b) concentrate composition increasingly contains contaminants, and (c) high-recovery processing becomes more frequently considered and implemented.

Chapter 5

Evaluation of Concentrate Management Options

5.1 Introduction

This chapter provides an overview of how the feasibility of CM options for a particular site may be evaluated. More option-specific discussions are provided in following chapters.

5.1.1 General Approach to Evaluation

In general, the feasibility of CM options is evaluated based on the following factors:

- concentrate volume and water quality
- general suitability of the option for the location (terrain, hydrogeological conditions, climate, distance of the management option from the desalination plant)
- ability to get permitted
- cost-effectiveness

Each of these factors is site-specific to some degree. Any one of these factors can lead to a given CM option not being feasible.

This chapter introduces a general two-level approach to evaluating CM options that has been used successfully in many desalination projects. Both evaluation levels are part of the planning phase for the desalination plant and take place prior to final system design.

The screening-level evaluation occurs as part of an initial general feasibility study or conceptual design study for the desalination plant, where the purpose is to develop and evaluate alternative conceptual plans for how a desalination plant might be implemented to meet water-related needs. The conceptual plans include how concentrate can be managed. The goal of the screening-level evaluation is to short-list potentially feasible CM options.

Based on the results of the feasibility study/conceptual design study, projects may move ahead, become stalled, or end. When projects move ahead to the next level of definition, a more exacting evaluation of CM options is required. This is made possible by better definition of raw water quality, site location, process, process performance, and other factors.

This second level of CM option evaluation is referred to here as the preliminary-level evaluation and occurs as part of the preliminary design study.

Evaluation of CM options needs to begin early in the planning phase because of

- the challenges and time it takes to define an implementable CM option
- the time it takes to permit CM options

- the need for reasonable assurance of project feasibility (dependent on finding a permitable and cost-effective CM option) at each of various decision stages during the planning phase

For discussion purposes, the evaluation approach to be described considers an inland brackish groundwater source to be treated by reverse osmosis. Later chapter sections discuss variants of the approach for other membrane technologies and for seawater.

Comments in this chapter are more general in nature. The reader is referred to Chapters 6 through 14 for specific issues involved with evaluating each CM option.

5.1.2 Other Factors to Be Considered in Evaluations

Conveyance of concentrate between the desalination plant and the CM option site can be a determining factor in defining feasibility for each of the options. Pipeline and pumping costs are a function of distance, with the pipeline route based on assumptions of favorable terrain, ease and cost of securing right-of-way for the pipeline, and minimization of available ecological impacts through route selection.

Although most of the feasibility-related factors discussed here are technical, the public plays a role in the approval of permits associated with implementing CM options. Public interaction can range from minor comment to organized efforts to prevent the granting of permits. Although this has been less of an issue with inland desalination than with seawater desalination, it is important to get an early reading of public support or opposition to possible CM options and to continue to take public sentiments into consideration throughout the desalination plant planning stages.

Although regional approaches have been suggested in regard to definition of CM options, and although there are indeed regional trends, site-specific variables most often dictate the determination of CM feasibility. Thus, a consistent approach to determining feasibility is suitable for all regions. Regional trends, however, will give insights into what CM options have generally been feasible in a region.

It is recommended that CM options and the desalination facility in general be evaluated within a watershed context that considers interactions between conservation, reuse, and desalination operations.

5.2 Concentrate Management Option Evaluation Stages

The stages of CM option feasibility evaluation correspond to the different decision-making stages associated with the desalination project. The amount of information and detail available for consideration in the evaluation increases in moving from general feasibility to preliminary design and system design stages.

There are several variants on project delivery methods, on how a desalination plant proceeds from conception to operation, on definition of project levels, and on the accuracy of cost estimates associated with design levels. The various project definition stages are described in the literature by terms such as conceptual, screening, feasibility, preliminary, budget, bid/tender, engineering, 20% design, 50% design, and 90% design. As the project proceeds from the initial planning effort to the final system design,

- the level of project definition goes from 0% to 100%
- the expected cost accuracy (expressed in variation) goes from perhaps +100/-50% to at least +15/-10%
- the preparation effort in design and costing significantly increases.

This framework holds true for evaluation of CM options. For discussion purposes, the simplified desalination plant phases are defined and referred to in Figure 5.1 as

- Planning Phase
  - general feasibility/conceptual design study (1 in Figure 5.1)
    - purpose is to identify and evaluate alternative conceptual plan for how a desalination plant can meet water-related needs
    - the *screening level evaluation of CM options* occurs here
  - preliminary design study
    - arbitrarily this study may be considered to be made up of three parts:
      - prior to pilot plant study (2 in Figure 5.1)
      - pilot study
      - following pilot plant study (3 in Figure 5.1)
    - the study will develop a scope of work for the final design study
    - the *preliminary-level evaluation of CM options* occurs here
  - final system design study (4 in Figure 5.1)
    - this study will develop a bid package containing drawings and specifications
- Construction Phase
- Operation Phase

This framework is reflected in Figure 5.1.

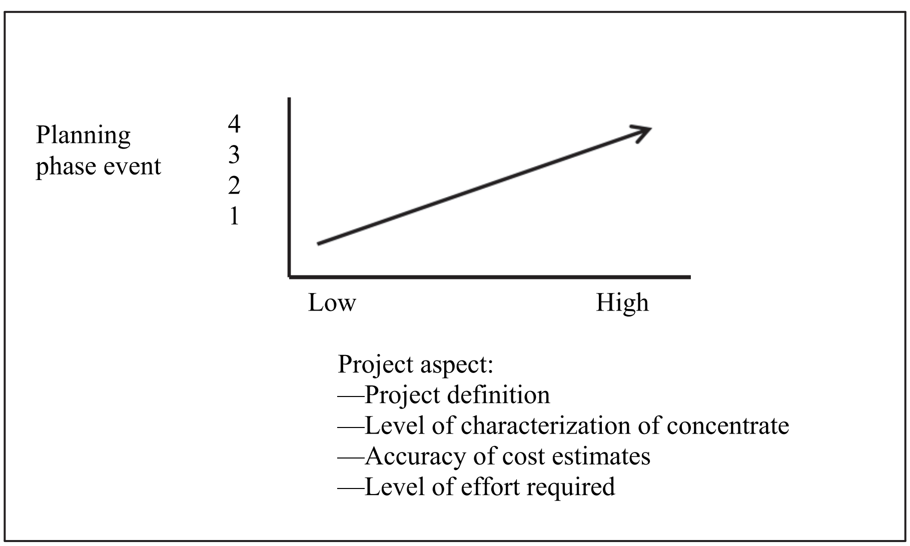


Figure 5.1. Increasing detail of information available as project proceeds.

The *multistep path* to defining a (a) permitable and (b) cost-effective CM option begins early in the planning phase of a desalination plant, with some consideration given to each of the factors discussed in Section 5.1. The screening-level evaluation of CM options needs to provide some degree of assurance that at least one potentially feasible CM option exists for the desalination project to be considered further. At this level of evaluation there is typically a lack of detail on raw water quality, desalination plant location, and desalination process definition, such that only rough estimates of ranges for concentrate water quality and volume may be available. Even so, some CM options can usually be eliminated, based on estimates of water quality, concentrate volume, physical location, regulatory constraints, and initial order-of-magnitude cost estimates. This initial screening-level evaluation results in a short list of options for further consideration.

If the desalination plant proceeds to a more detailed level of consideration, preliminary desalination process designs are developed and evaluated and more data are available to define concentrate characteristics. This allows a more exacting evaluation of short-listed CM options. In this preliminary-level evaluation, a preferred CM option may be defined along with other potentially feasible options.

Before a system design (which follows conceptual and preliminary design in time) can be finalized, several design factors need to be well defined. These include

- factors typically definable prior to pilot testing:
    - raw water quality
    - design specifications
    - desalination plant site
    - desalination technology (currently: RO, NF, or EDR)
    - processing goal (conventional or high-recovery)
- factors typically requiring pilot testing:
    - pretreatment needs (what is required; characterization of residuals produced)
    - cleaning protocol (what is required; characterization of residuals produced)
    - specific membrane(s) to be used
    - technology performance (recovery; permeate quality; system flux)

Ideally, prior to the time of pilot studies, one or two CM options are considered feasible. These options are supported by detailed cost estimates that are based on the best available data. What is lacking is final concentrate definition and any changes that might result from the pilot studies. It is not until after pilot plant studies, necessary to determine desalination process performance, that concentrate characteristics are defined at the level required for most permit applications and detailed cost estimates.

The means of managing concentrate must be established as part of the system design prior to desalination plant construction.

The approach to determination of feasibility of the CM options can deviate from that presented here as follows:

- Some options are less dependent on more exacting concentrate water quality and volume definition than others.

- Some options typically require much less effort to initially screen than others.
- Some options require much less effort after short-listing to conclusively determine feasibility.
- Some options can thus reach a stage of confirmed feasibility more quickly than others.

Consequently, the assignment of efforts and milestones to specific stages in the determination of CM option feasibility, as will be expressed, is only a generalized example of what might happen.

5.2.1 Screening-Level Evaluation—General Aspects

This evaluation is part of a general feasibility study for the desalination facility, where a conceptual design and plan are developed to determine if a desalination plant is worthy of further consideration as a way to meet the water utility's needs. During such a study, CM options are reviewed and evaluated to rule out those not obviously feasible and retain those worth further consideration.

The feasibility of CM options is ultimately constrained by regulatory and cost factors. Before detailed evaluation of these factors is possible, site-specific parameters having to do with plant size (concentrate volume), concentrate salinity and composition, and site-specific conditions (climate, hydrogeological conditions, terrain, distance to potential receiving waters, etc.) may eliminate some options from further consideration. These factors are the main focus for the screening-level evaluation.

At this early stage in the consideration of a desalination plant, many factors affecting feasibility can only be roughly estimated. However, such estimates can be sufficient to eliminate some options from further consideration. Estimates at this stage may be rough because of limited definition of several aspects:

- raw water quality
- product water specifications (volume, salinity, and composition)
- processing approach (type of membrane component and conventional or high-recovery)
- system performance (recovery)
- use of blending to achieve product water goals (size of membrane system required)

5.2.1.1 Estimation of Concentrate Water Quality and Volume

Evaluation of CM options depends on concentrate characteristics, which must be estimated until a pilot study concentrate is available. Until such a time, concentrate characteristics are based on projections made from analysis of raw water characteristics. The details of these projections also evolve with time and may go through several stages where raw water characterization is based on

- historical raw water data from wells in the general vicinity of the planned source water wells
- more extensive analysis (as needed) of current water from some of these wells to provide information about possible contaminants or to supply missing data

- extensive analysis of water from test source water wells

This sequence reflects the challenge of determining a design basis water quality for the desalination plant itself. The final basis is an accurate assessment of raw water characteristics, over time, for the wells supplying the raw water.

As the definition of raw water characteristics evolves, the accuracy of estimates of concentrate characteristics evolves. Concentrate characteristics, however, are also dependent on the membrane system design, which is also evolving. Thus, evaluation of CM options proceeds in stages corresponding to the quality and detail of information available regarding the desalination plant.

At the screening-level evaluation stage, concentrate water quality is typically estimated by assuming different membrane system recoveries applied to an assumed raw water quality or range of raw water qualities, based on available groundwater data. Concentrate volume is based on assuming a range of recoveries that will produce the initial water production volume target. Computer simulation programs may be used to define the likely range of attainable recovery. Both concentrate water quality and volume are thus typically represented in terms of ranges. With rough estimates of concentrate water quality and volume, the general site-specific feasibility of the CM options can be evaluated on a relatively simple basis.

5.2.1.2 Estimation of Costs

At this stage of evaluation, costs are considered only on a general basis. All capital and operating cost factors should be identified and reviewed for each CM option. These factors are listed in succeeding chapters that deal with individual CM options. Key cost factors should be evaluated with the data available at the screening stage. Key unknown parameters should be highlighted for future investigation. Preliminary-level cost models (Mickley, 2006) are available for most of the CM options.

Figure 5.2 represents the general trend of capital costs for the five conventional CM options and for ZLD processing. There are many exceptions to these trends, one reason being they do not take into consideration the site-specific conveyance costs. Figure 5.2 also assumes that all of the CM options shown are otherwise suitable and available for the site in consideration and this is rarely the case.

From Figure 5.2 it may be seen that

- discharge to surface water and to sewers are typically lower-cost CM options
- spray irrigation and evaporation ponds are typically cost-effective only for small volumes of concentrate, as there is a lack of economy of scale
- DWI has economy of scale, but is expensive for small concentrate volumes

The trends of Figure 5.2 may be helpful in understanding some of the issues related to cost for the different CM options. Chapters 6 to 14 discuss individual options, including their feasibility evaluation.

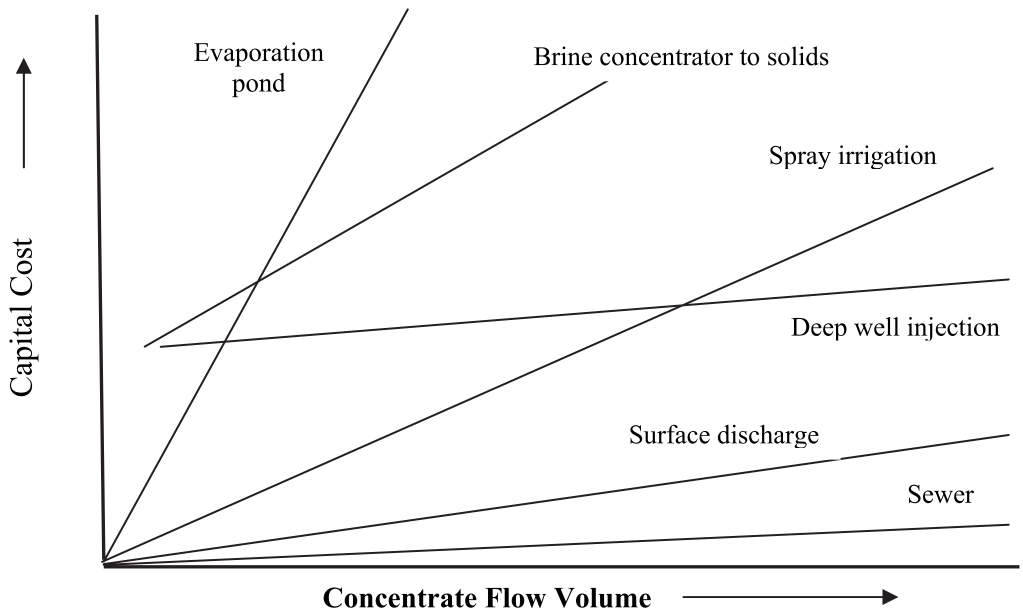


Figure 5.2. Relative capital costs of CM options (not considering conveyance).

5.2.2 Screening Evaluation Stage Efforts

At the screening stage of evaluation the effort may involve

- interaction with regulatory agencies to identify/determine
  - other desalination facilities in the region and their CM methods
  - whether any of the options have been permitted in the region (for municipal and other industries)
  - specific regulatory policy and protocols used to determine permitting feasibility
  - their thoughts as to general feasibility of permitting various CM options (their insights may save evaluators a considerable amount of time)
  - *Note:* this will require interaction with several different divisions or groups within the regulatory agencies as different groups oversee the different CM option permitting
- interaction with regional desalination plants
  - to benefit from their experience with evaluating CM options
- interaction with peripheral groups (as needed)
  - with the local WWTP to determine WWTP capacity, water characteristics, general openness to taking concentrate

    - with industrial landfills to determine locations, requirements, costs, capacity
    - with regional drilling, groundwater services companies to gather general information on hydrogeological conditions
- development of calculations based on available raw water quality analyses to estimate ranges of volume, salinity, and composition of concentrate and possible solids
- review of climate, terrain, classification of land in region of potential desalination plant site(s)
- identification of potential sites for the CM options to estimate distances from the desalination site(s) to the CM option site(s)
- determining the advantages and disadvantages associated with each CM option
- determining a rough estimate of general and relative costs associated with the CM options.

The following less technical items, although important, are generally addressed on a broader front than those focusing on evaluation of CM options:

- getting a reading on public support for various CM options
- taking into account how the CM options might affect the long-range water management plans of the utility

5.2.3 Preliminary-Level Evaluation—General Aspects

As the desalination plant project moves forward beyond the general feasibility stage, several project aspects become more defined. These include

- project requirements
- raw water quality data
- plant location and specific site conditions
- general membrane process definition
- product water specifications
- estimates of membrane process performance
- estimates of pretreatment requirements
- cost-related information (capital cost, operating cost, interest rate, etc.)

This increased definition allows a more complete and comprehensive evaluation of the CM options short-listed in the screening-level evaluation stage. The effort is focused on fewer CM options but conducted at a greater level of detail. Concentrate characteristics (salinity, composition, and volume) are defined more accurately and in more detail. More exacting interactions with regulatory agencies are possible, and more definitive evaluations of feasibility of individual CM options can be undertaken.

Until pilot studies have produced concentrate and a detailed analysis of concentrate composition is available, more detailed consideration of concentrate composition must be based on projections made from a detailed analysis of feed water.

Still missing at this level of description are pilot plant confirmations of membrane system performance including recovery, permeate and concentrate water quality, pretreatment requirements, and operating conditions. These items are necessary for

- final process design
- performance projections
- design documents
- equipment selection
- tighter estimation of capital and operating costs

Some projects may end before pilot tests are conducted. These projects, in effect, will have gone through a feasibility analysis more extensive than that provided by the general feasibility-stage study defined previously. Some larger-scale projects eliminate the general feasibility-stage study and begin with the more extensive evaluation of feasibility at the pre–pilot plant preliminary design stage.

For projects with a strong intent to move to construction/implementation, a pilot plant study is typically required to enable comprehensive final system design. The bullet items provide the basis for the pilot studies. Pilot plant data are usually required for more accurate documentation/estimation of concentrate parameters that are needed for CM permit applications.

At this preliminary stage of consideration, more information is available to evaluate the CM options costs. Each of the cost factors associated with a CM option can be evaluated. The basis of costing may change somewhat from using in-house cost files/experience to obtaining updated estimates for different costs. The long-term viability of each CM option over the life of the desalination plant needs to be considered.

5.3 Some Factors to Consider in Nanofiltration and Electrodialysis Reversal

The consideration of CM options for both NF and EDR is substantially the same as for BWRO. There are, however, some differences.

First, waters considered for NF and EDR treatment are, in general, of lower salinity than those considered for BWRO treatment. This is reflected in Table 3.2, where ranges of typical feed water TDS concentrations are listed. The feed water TDS range is much lower for NF than for EDR, as NF has much lower rejection and removal rates for monovalent ions than does EDR or BWRO. For EDR, the upper range of feed water salinity is limited by high energy costs. For NF, the upper range of salinity is limited because NF is much less efficient at TDS reduction than BWRO.

Second, recoveries typically achievable by EDR and NF are higher than for BWRO. Thus the concentrate volumes for similar feed water would be somewhat less for EDR and NF than for BWRO.

Third, as a result of these two differences, the salinity of concentrate from NF processing is lower than that from EDR and BWRO processes.

Relatively low-salinity NF concentrate is much more suitable for surface water discharge, discharge to sewers, land application, and combining with WWTP effluent for beneficial reuse as irrigation water.

5.4 Evaluation Osmosis Treatment of Concentrate Management Options for Inland Brackish Water Reverse of Surface Water

Inland surface water considered for municipal treatment is generally of relatively low TDS compared to brackish groundwater. Consequently, NF and EDR are more likely to be considered for processing. Concentrate characteristics and CM option considerations are similar to those discussed in previous sections of this chapter.

5.5 Evaluation of Concentrate Management Options for Seawater Reverse Osmosis

Seawater RO concentrate is nearly universally discharged to high-salinity marine waters—i.e.,, back to the sea. Thus, the evaluation effort is typically not focused on which CM option to pursue, but on where and how discharge to the sea might be accomplished. The screening-phase goal is to confirm that sea discharge is potentially feasible, to identify possible approaches and sites for discharge, and to map out a path toward accomplishing the detailed investigations required to obtain a discharge permit.

The primary approaches for sea discharge are

- shore outfall
- co-discharge with effluent from a power plant or WWTP
- beach well discharge
- discharge to a river, canal, or estuary tidally influenced by proximity to the ocean

The amounts of time and effort required to secure a discharge permit, including the amount of interaction with the various regulatory agencies, can be very high. Much of this effort is in baseline monitoring and defining receiving water characteristics and in modeling mixing and dispersion characteristics, both near- and far-field, of concentrate discharge into the receiving water. The baseline monitoring should be done over an extended time period to address stockholder concerns and to demonstrate compliance and lack of impacts when the plant is on line. The modeling work should provide the basis for ensuring that the discharge system will achieve compliance and lack of impact. All this is to ensure minimal/acceptable impact on the marine flora and fauna.

Details of the evaluation effort for ocean discharge are provided in Chapter 8.

5.6 Illustration of How Feasibility Factors Can Become Limiting

Several factors that can be considered at the general feasibility level of evaluation are summarized in Table 5.1. Cells with numbered entries identify factors that can be limiting. Many of these factors can be evaluated and judged to be limiting at the screening level of evaluation. The numbers refer to information provided as to why a given factor might eliminate the CM option from further consideration.

5.7 Summary of Overall Evaluation Process

The CM option evaluation process was presented in terms of two levels, the screening-level evaluation and the preliminary-level evaluation. The goal of the screening evaluation of CM options is to short-list options for further review if the project proceeds to a preliminary design stage. The goals of the preliminary design stage for the desalination plant are to develop information and the scope of work for final system design. Feasibility of the CM option should be as certain as it can be at the conclusion of this stage.

Table 5.1. Explanation of Why Feasibility Factors Can Be Limiting

Major Feasibility Factor	Surface Water Discharge	Discharge to Sewer	Deep Well Injection	Evaporation Pond	Land Application	Landfill
Obtaining a permit						
A—can't meet conditions	1	1	1	1	1	1
B—permit not offered			2			
Cost	3	3	3	3	3	3
Climate				4	5	
Terrain				6	6	
Hydrogeology			7			
Water quality						
A—salinity/salt load	8	8	9	10	11	
B—common ions	12	12	13		14	
C—contaminants	15	15	16	17	18	19
Distance	20	20	20	20	20	20
Volume, amount	21	21	22	23	24	25
Land availability				26	26	

1—For a variety of reasons, concentrate conditions may be such that permitable requirements cannot be met.
2—Class I industrial wells are not allowed in some states.
3—Costs may be prohibitive for any of these options.
4—Climate may not be suitable for evaporation in general or for some seasons.
5—Climate may not be suitable for year-round irrigation.
6—Relatively flat land may not be available.
7—Required hydrogeology may not exist.
8—High salinity and/or high salt load may not be permitable.
9—Blending of concentrate with aquifer water may be a problem.
10—High salinity can reduce evaporation rates.
11—High salinity can eliminate irrigation use unless dilution water is available.
12—Some common ion concentrations may not meet water quality standards for NPDES permits. In the case of discharge to sewer this applies to the WWTP's NPDES permit.
13—Some common ion concentrations may lead to blending problems with aquifer water.
14—Some common ion concentrations may not meet groundwater standards.
15—Contaminants may eliminate discharge option.
16—Contaminants may lead to blending problems.
17—Contaminants may affect wildlife and waterfowl.
18—Contaminants may rule out irrigation use depending on vegetation/crops; may not meet groundwater standards.
19—Contaminants can lead to solids being hazardous and cost-prohibitive to landfill.
20—Distance from desalination plant to CM option may be excessive and conveyance too costly.
21—Volume and/or load (volume times concentration) may be too large for available dilution.
22—Volume may be too great for the aquifer capacity over the life of the desalination plant.
23—Volume of concentrate may require too much land and thus be too costly.
24—Volume of concentrate may require too much irrigation land and thus be too costly.
25—The amount of solids may be too great for an existing landfill.
26—The required amount of land may not be available.

The following phase of final system design will include full project definition, development of specifications, preparation of the bid package, qualification of design groups, and choice of the design and construction team.

This chapter has reviewed the general approach to defining feasibility of CM options prior to the final system design phase. To do this there is a need to understand characteristics, limitations, cost factors, regulatory factors, and the history of each CM option being considered. These feasibility factors are addressed for the various CM options in the following chapters of this report.

Chapter 6

Regulation of Surface Water Discharge

As the most widely used concentrate disposal option, approximately 50% of all municipal desalination plants discharge concentrate to surface water. The time and effort required for determining the feasibility of surface discharge can be significant and beyond that associated with other disposal options, with the exception of DWI.

6.1 General Framework

The national regulatory program, set in motion by the enactment of the Clean Water Act (CWA) in 1972, includes the Effluent Guidelines Program to develop limitations and standards for all facilities that discharge or may discharge directly into waterways of the United States or that indirectly discharge or may discharge into publicly owned treatment works (POTWs). As part of the national regulatory program, the CWA created a National Pollutant Discharge Elimination System (NPDES), under which the administrator of the U.S. EPA may issue permits for the discharge of any pollutant or combination of pollutants upon the condition that such discharge will meet all applicable requirements of the CWA relating to effluent limitation, water quality standards, implementation plans, new source performance standards, toxic and pretreatment effluent standards, inspections, monitoring and entry provisions, and guidelines establishing ocean discharge criteria (U.S. EPA, 1991).

The NPDES program is used by the U.S. EPA or designated state agencies to issue, condition (tailor or modify), and deny permits for the discharge of pollutants from point sources into navigable waters, the coastal zone, and the ocean. Discharges that are required to obtain permits include, among other point sources, municipal and other publicly owned waste treatment works, industries discharging directly to navigable waters, and concentrated animal feeding operations. A permit is not required for discharge to a POTW. The NPDES permitting program has been broadened to include storm runoff as a point source, whereas other nonpoint sources are not regulated by NPDES permits. In this definition, "navigable water" means waters of the United States, including the territorial seas (waters adjacent to U.S. territories). Each discharger must have an NPDES permit specifying, among other things, the required waste quality, as well as stipulations for regular reports that must be submitted to the regulatory agency by the permittee. In this case the permittee is the owner or operator of the desalination facility.

The authority to issue and condition permits or to deny application of discharges covered by the NPDES and by Section 405 of the CWA was delegated to each of the regional administrators of the U.S. EPA. Delegation of authority for the NPDES process has in certain cases been granted at the state level. Currently there are 46 complete state NPDES programs. States that have not been granted complete authority are not excluded from the permitting process, but they generally work very closely with the regional administrator in the application evaluation process. The U.S. EPA must obtain state certification prior to issuing an NPDES permit. This process allows nondelegated states to have a voice in if, when, and where a permittee can discharge to a surface water (U.S. EPA, 2010a).

6.2 Current Guidelines

6.2.1 The U.S. EPA's Technical Support Document

The U.S. EPA's surface toxics control regulation, 54 FR 23868, June 2, 1989, established specific requirements that an integrated, three-pronged approach must be used as a means of protecting aquatic life and human health (U.S. EPA, 1989). The U.S. EPA March 1991 Technical Support Document for Water Quality-based Toxics Control provides states and regions with guidance on procedures for use in the water quality-based control of toxic pollutants (U.S. EPA, 1991). It presents recommendations to regulatory authorities and guidance for each step in the control process from standards development to compliance monitoring.

The document mandates three approaches for protection of the nation's waters:

- chemical standards
- whole effluent toxicity tests
- biological assessments

Each approach has its limitations, and thus, exclusive use of one approach alone cannot ensure the required protection of aquatic life and human health. The chemical-specific approach to aquatic life toxics control relies on numeric water quality criteria in state standards and interpretations of state narrative standards to assess and control specific toxicants individually. Numeric standards are measurable values determined for the pollutant of concern that, if achieved, are expected to result in the attainment of water quality standards in the specific water body. Narrative standards are nonnumeric qualitative guidelines that describe a desired water quality goal.

The whole effluent approach to toxics control involves the use of WET tests to assess and control the aggregate toxicity of the elements. WET tests expose test species to 100% concentrate and various dilutions of concentrate. These tests determine the effects of concentrate on survival (acute toxicity) and on growth and reproduction (chronic toxicity). The effects are quantified in terms of the concentration lethal to 50% of the test organisms, the LC_{50} value, for acute toxicity, and the concentration of no observable effect, the NOEC, for chronic toxicity. Regulation is based on the LC_{50} and NOEC values. Aquatic impacts occur not only from the quantity of a pollutant, but also from the duration and frequency with which criteria are exceeded. Thus the U.S. EPA's recommended aquatic life criteria for both individual toxicants and WET are specified as two numbers: the criterion continuous concentration is applied as a 4-day average concentration, and the criterion maximum concentration is applied as a 1-h average concentration.

Exposure assessment includes analysis of how much of the water body is subject to the exceedance of criteria, for how long, and how frequently. In the assessment and control of discharges, states may allow mixing zones where ambient criteria for control of acute toxicity to aquatic life may be met within a short distance of the outfall.

Biological assessment is an evaluation of the biological condition of a water body using biological survey methods to analyze a representative portion of the resident aquatic community and indicate compliance with biological indicators of water body health. These evaluations address compliance with protection of the designated uses of the water body.

Table 6.1 provides a summary of the three approaches and the roles of the U.S. EPA and the states.

Wasteload allocation is defined as the portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution.

6.2.2 Mixing Zones

U.S. EPA guidelines allow zones of initial dilution (ZIDs) where it is not necessary to meet all water quality criteria within the discharge pipe to protect the integrity of the water body as a whole. Mixing zone allowances will increase allowable concentrations of the pollutant at the end-of-pipe location beyond the applicable surface water quality criterion and decrease treatment requirements. The U.S. EPA position is that sometimes it is appropriate to allow ambient concentrations above the criteria in small areas near outfalls. Because these areas of impact could potentially adversely impact the productivity of the water body, and have unanticipated ecological consequences, they should be carefully evaluated and appropriately limited in size. The CWA allows mixing zones at the discretion of the state. U.S. EPA recommends that states have a definitive statement in their standards as to whether or not mixing zones are allowed (U.S. EPA, 1991). Some states include ZIDs automatically as part of the initial permit feasibility determination for certain water classifications (example: Texas), whereas others grant mixing zones only on a case-by-case basis (example: California). Florida does not in general grant ZIDs for discharge; however, it does grant them for demineralization wastewater (concentrate) for major ion toxicity (see Sections 3.1.2 and B.2.2).

In order not to impair the integrity of the water body, it should be determined that the mixing zone will not cause lethality to passing organisms and, considering likely pathways of exposure, that there are no significant human health risks. One means of achieving these objectives is to limit the size of the area affected by the mixing zones.

Table 6.1 Process for Implementation of Water Quality Standards

Criteria	U.S. EPA Guidance	State Implementation	State Application
Chemical specific	Pollutant-specific numeric criteria	State standards - use designation - numeric criteria - antidegradation	Permit limits monitoring Best management practices Wasteload allocations
Narrative "free froms"	Whole effluent toxicity guidance	Water quality narrative - no toxic amounts translator	Permit limits monitoring Wasteload allocation Best management practices
Biological	Biosurvey minimum requirement guidance	State standards - refined use - narrative/numeric criteria - antidegradation	Permit conditions monitoring Best management practices Wasteload allocation

In the general case, where a state has both acute and chronic aquatic life criteria, as well as human health criteria, independently established mixing zone specifications may apply to each of the three types of criteria. The acute mixing zone may be sized to prevent lethality to passing organisms and the chronic mixing zone to meet the chronic criteria. For any particular pollutant from any particular discharge, the magnitude, duration, frequency, and mixing zone associated with each of the three types of criteria will determine which one most limits the allowable discharge. States have discretion, however, over what effluent parameters may be considered for mixing zones. For instance, Florida does not allow mixing zones for acute toxicity (other than in the case of major ion toxicity).

6.2.3 Impaired Waters and Total Maximum Daily Loads

An impaired water body is any water body that is listed according to Section 303(d) of the CWA. Water bodies are considered impaired as a result of chronic or recurring monitored violations of the applicable numeric and/or narrative water quality standards. Impairment may mean that the ambient concentration in a receiving water is greater than the water quality standard. Standards may be violated because of an individual pollutant, multiple pollutants, thermal pollution, or an unknown cause of impairment.

According to Section 303(d)(1)(A) of the CWA, "Each state shall identify those waters within its boundaries for which the effluent limitations . . . are not stringent enough to implement any water quality standard (WQS) applicable to such waters." The CWA also requires states to establish a priority ranking of water quality limited segments and to establish total maximum daily loads (TMDLs) for such waters. The purpose of a TMDL is to restore and protect the beneficial uses of an impaired water body. A TMDL is defined as the sum of the individual waste load allocations for point sources and load allocations (LAs) for nonpoint sources and natural background. TMDLs must be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge between effluent limitations and water quality. TMDLs also represent a strategy for restoring an impaired water body so the water quality can once again meet the water quality standards (U.S. EPA, 1997).

Thus TMDL development is specific for impaired waters. The TMDL process provides for more stringent water quality-based controls when technology-based controls are inadequate to achieve state water quality standards. The TMDL process also provides a mechanism for integrating the management of point and nonpoint pollution sources that together may contribute to a water body's impairment (U.S. EPA, 1997).

Under the TMDL process,

- States
  - identify specific waters where problems exist or are expected
  - set priorities
  - allocate pollutant loadings among point and nonpoint sources and thus propose TMDLs
- The U.S. EPA
  - approves state actions or acts in lieu of the state if necessary

Point and nonpoint sources then reduce pollutants to achieve the pollutant loadings established by the TMDL through a wide variety of Federal, state, tribal, and local authorities. For programs and initiatives in waters having both point and nonpoint sources, TMDLs may result in greater waste load allocation to point sources through reduction of nonpoint-source loads. Consequently, consideration of TMDLs in a given permitting situation does not necessarily result in more stringent discharge limits—although this is the typical result.

6.2.4 Anti-Degradation

In addition to the NPDES program and TMDL development, the CWA also mandated that each state develop an anti-degradation policy to further protect stream, river, lake, and wetland water quality.

The anti-degradation rule allows four levels of protection: Tiers 1, 2, 2.5, and 3. Tier 3 protection is the highest level of protection and it is applied to "Outstanding National Resource Waters." Tier 3 protected waters cannot be degraded. An example of implementation of the anti-degradation rule is given in the following paragraphs (adapted from Skousen, 2002).

Tier 2.5 protection is given to waters of special concern. Tier 2.5 protected waters are designated as streams that the state determines to be reference streams with a high biological and aquatic life score. No significant degradation of a Tier 2.5 protected stream will be allowed. Significant degradation is defined as reducing the assimilative capacity of the receiving water by more than 10%. New or expanded NPDES permits that discharge into a Tier 2.5 protected stream may be given more stringent water quality–based effluent limits so that no significant degradation of the stream will occur. Public comment will be allowed for those streams that are being considered for the Tier 2.5 protection list.

Tier 2 protection is the default or standard level of protection. These are high-quality waters that meet or exceed the water quality standards established for a given stream. The intended uses of these waters must be protected, and degradation can be allowed up to the numeric criteria for that water use category. However, any significant degradation (>10% of remaining assimilative capacity) of a Tier 2 protected water must undergo an alternatives analysis and socioeconomic review before the degradation activity can be approved.

Tier 1 protection requires that existing uses of the water be maintained and protected. This level of protection is applied at a minimum to all waters. However, this protection level may also be assigned later on a pollutant-by-pollutant basis to other streams that do not currently meet water quality standards. Discharges into Tier 1 protected waters will have water quality–based effluent limits for the pollutants that exceed water quality standards.

New or expanded activities (discharges) will have to undergo an anti-degradation review. The question that will be asked for any new or expanded activity that will discharge water into a stream is, "Will the proposed activity significantly degrade the water segment?" If the answer is yes, then an anti-degradation review must be performed. Existing facilities will have their current effluent limits reviewed when their NPDES permits are renewed, and the effluent limits in the renewed permits may be altered if the original limits are not protective of a stream's use.

6.2.5 General Discharge Restrictions

In general terms and with acknowledgement of exceptions, concentrate discharge restrictions may be summarized as follows. Discharge to a receiving water is regulated by water quality standards (Table 6.1). If mixing zones are not allowed for the constituent/parameter in question, then compliance is end-of-pipe. In this case, an end-of-pipe concentration, for instance, must be equal to or less than the water quality standard. Depending on the antidegradation level of protection for the receiving water, the receiving water may be degraded. That is, the discharge concentration may be higher than the ambient concentration as long as it is lower than the water quality standard. When mixing zones are allowed, the receiving water may be degraded to an even greater extent. In this case the discharge concentration may be greater than the water quality standard value as long as the downstream value at the edge of the mixing zone is less.

6.3 Discharge Permits

States have some latitude in determining how to implement U.S. EPA guidance. Consequently, regulation of surface water discharge may differ from state to state. In general, assigning permit conditions for a given discharge involves consideration of several items that include

- water body information
    - classification of a particular section of the receiving water body (including use, applicable TMDL restrictions, applicable anti-degradation restrictions)
    - historical/statistical flows associated with the receiving water body
    - ambient conditions
- discharge information
    - the particular industry (for those having limitation guidelines—municipal facilities do not have limitation guidelines)
    - effluent parameters and characteristics

Interaction with the appropriate regulatory agency will determine what specific permit application information is required. Permit applications will require some analysis of discharge water quality parameters and may also require WET test results. Depending on the effluent parameter levels relative to the corresponding water quality standards, comparisons/calculations are conducted to determine if discharge water quality parameters are likely to meet allowable limits. The state-defined analysis procedure then assigns discharge limits and monitoring conditions to the permit. Parameters well below the applicable water quality standard may not appear in the permit as parameters having limits and requiring periodic monitoring and reporting.

6.4 Permit Conditions and Compliance

The permit granted to a discharger stipulates discharge requirements in terms of

- numeric limits for end-of-pipe concentrations of regulated constituents' assigned limits and for other parameters (pH, DO, etc.)
- possible WET test numeric limits
- possible bioassessment limits

The permit also contains monitoring and reporting requirements (associated with the chemical constituents and parameters that are assigned limits). Permit compliance is evaluated by the regulatory agency, based on comparison of permit limits with monitoring data.

When permit conditions are not met, there may be various relief possibilities and consequences:

- administrative relief:
    - mixing zone relief—mixing zones may be assigned in the initial permit but also may be assigned later based on changes in discharge conditions and evaluation by the regulatory agency.
    - variances—typically involve a fine and a time period before another fine is imposed
    - waiver—no longer subject to that limit/requirement
    - use modification of the water body
    - apply for watershed-based permitting and site-specific criterion
- consent order—a voluntary agreement to define a course of action to achieve compliance within a defined schedule, when an organization has a permit but is in violation of specific discharge limits
- administrative order—a temporary order if an organization needs time to prepare

The U.S. EPA reviews all mixing zones and variances.

6.5 Implementation of U.S. EPA Strategy and Plans

As reflected in the preceding discussion, the U.S. EPA has developed strategies, plans, and approaches to protect the nation's waters and has given states some leeway in their implementation. Thus states vary in the timing and degree of implementation and in the level of regulation. A current example illustrating this situation is provided by the U.S. EPA’s 1998 National Strategy and Plan to promote state adoption of nutrient water quality standards (which better protect aquatic life and human health). Nutrients as referred to here are nitrogen and phosphorus. As stated in a U.S. EPA evaluation memo (U.S. EPA, 2009):

> EPA's strategy and plan . . . has been ineffective. In 1998, EPA stated that a critical need existed for improved water quality standards, given the number of waters that were impaired from nutrients. In the 11 years since EPA issued its strategy, half the States still had no numeric nutrient standards. States have not been motivated to create these standards because implementing them is costly and often unpopular with various constituencies. EPA has not held the States accountable to committed milestones. The current approach does not assure that States will develop standards that provide adequate protection for downstream waters. Until recently, EPA has not used its Clean Water Act authority to promulgate water quality standards for States.
>
> USEPA cannot rely on the States alone to ensure that numeric nutrient standards are established. EPA should prioritize States/waters significantly

> impacted by excess nutrients and determine if it should set the standards. EPA also needs to establish effective monitoring and measures so that accurate program progress is reported. This will assist EPA management in program decision-making. . . .
>
> EPA's current approach is not working. EPA has relied on the States to develop standards on their own without any meaningful monitoring or control. EPA did not establish priorities, enforceable milestones, or adequate measures to assess progress. States have made minimal progress in developing standards and have not yet considered the impact of their waters on downstream waters. EPA has neither held the States accountable nor used its CWA authorities to promulgate standards. Consequently, EPA is not assured that the States will set numeric nutrient standards or that the standards would provide adequate protection under the CWA for downstream waters.

Numeric nutrient limits are currently being implemented in Florida, as an early USEPA trial. The greatest impact of nutrient limits will be on discharges from WWTPs utilizing desalination. WWTP effluent, in general, has high levels of nutrients, and unless nutrients are removed prior to a desalination step, concentrate can have elevated levels of nutrients. These high levels could prevent concentrate discharge to surface waters.

These paragraphs reflect some of the challenges associated with providing protection to the nation's waters and some of the issues in discharging to surface waters:

- Within a general framework mandated by the U.S. EPA, state regulations vary.
- Various strategies and plans put forth by the U.S. EPA have not been implemented.

6.6 Regulation of Ocean Discharge

The CWA applies to the adjacent ocean as well as to inland waters. Consequently, the discussions of water quality standards, whole effluent toxicity tests, TMDLs, and the antidegradation rule in the preceding sections also apply to ocean discharge. However, TMDLS and antidegradation are not often applied except to bays and estuaries or areas of exceptional pollution (e.g., Santa Monica Bay—TMDL for bacteria). Individual state regulations must be consistent with federal guidelines but may be more stringent. In California, for instance, the Ocean Plan was originated in the 1970s, somewhat before the U.S. EPA enhancements to the NPDES program were enacted. Consequently, some of the California regulations were grandfathered into California NPDES permitting and these are more stringent than the Federal guidelines.

Municipal seawater desalination plants represent only 4% of municipal desalination facilities in the United States. Nearly all of the plants are small facilities constructed and operated more than 10 years ago. The situation is clearly changing. Nearly 75% of the population lives within 50 miles of an ocean coast (Voutchkov, 2006). With growing population, periodic droughts, frequent overdependence on groundwater in coastal regions, and deteriorating quality of groundwater, seawater desalination is a major consideration in coastal water resource management planning.

Because of the relative newness of large-scale seawater desalination to the United States, increasing public environmental concerns, relatively high energy use and costs of seawater desalination, and the troubled initial history of the Tampa Bay desalination facility, seawater desalination has received much scrutiny from public and regulatory agencies alike. Ten years ago relatively little was known about environmental impacts from the many global municipal seawater desalination plants. Since that time, environmental impacts of seawater desalination has received increased attention (Lattemann and Hopner, 2003; Pankratz and Tonner, 2006). Much of the concern has been with concentrate discharge. As a result, there have been extensive environmental impact studies, with detailed modeling and monitoring of receiving water conditions.

6.7 Summary

This chapter has two broad purposes. The first is to describe the regulatory framework for surface water discharge and how its implementation can vary considerably from state to state. The second is to illustrate where changes in regulation that could affect concentrate discharge may be forthcoming.

Surface water discharge is the most widely used concentrate disposal option for municipal desalination concentrate, representing nearly 50% of all CM cases (see Chapter 3). The framework for regulation of surface water discharge is the U.S. EPA's NPDES program. States have some latitude in determining how to implement U.S. EPA guidance. Consequently, regulation of surface water discharge varies significantly from state to state. Examples of where NPDES regulation may vary from state to state include the following:

- automatic inclusion of ZIDs in initial permit feasibility determination (example: Texas) as opposed to mixing zones being granted on a case-by-case basis (example: Florida and California)
- automatic inclusion of WET tests for municipal membrane concentrate (example: Florida) versus a case-by case basis (example: Texas)
- different water quality standards (all must be at least as stringent as the federal guidelines)
- different degrees of implementation of TMDL development

Source water quality improvements have taken place as a result of regulating point source discharges and some of the non–point source discharges. Water quality as measured by the major historical contaminants has improved to a large degree. In spite of these improvements, many of the nation's waters have become increasingly impaired by discharge of wastes. As emerging contaminants are identified, increased regulation to protect the nation's waters is inevitable. One regulator pointed out that NPDES stands for National Pollutant Discharge *Elimination* Program (emphasis added) and that this is what is happening.

The increased regulation ultimately will come in the form of more stringent water quality standards. The specific regulation resulting in tighter water quality standards may be

- increased implementation of existing U.S. EPA policies/guidelines
  - increased implementation of TMDLs (although, to date, CM has not been affected much by TMDLs)
  - increased implementation of WET tests

- tightening chemical standards, TMDLs, WET test criteria, anti-degradation definitions for existing regulated species
- chemical standards for chemicals not currently regulated (such as for emerging contaminants)
- new U.S. EPA or state policies for control mechanisms not currently in place

Chapter 7

Surface Water Discharge—Inland

7.1 Description

Inland surface water discharge is defined as direct discharge of concentrate into a river, creek, canal, ditch, lagoon, lake, or other inland surface water. It also includes discharge into the effluent side of a wastewater treatment plant where effluent is discharged into surface water. In any of these cases, concentrate may be diluted prior to discharge. Note that discharge of inland concentrate to a brine line is covered in Chapter 8, which addresses direct surface water discharge to the ocean, and Chapter 9, which addresses discharge to sewers.

7.2 Historical Use

Surveys have shown that discharge to surface waters is the most widely used CM option, accounting for approximately 50% of the municipal desalination plants in the United States (Mickley, 2006 and present project survey). Currently, 27 of 33 states having municipal desalination plants permit surface discharge of concentrate. As reflected in Figure 3.3, surface discharge is the only one of the five conventional CM options that has been used with plants of all sizes.

7.3 General Feasibility Factors—Site Requirements

Major feasibility factors include

- cost
    - reasonable distance of receiving water from desalination plant
    - suitable terrain for conveyance of concentrate to discharge site
    - ability to obtain right of way for conveyance pipeline
- regulatory
    - suitable receiving water: sufficient year-round flow in the receiving water such that discharge does not significantly impact receiving water standards
    - suitable concentrate water quality: ability to meet water quality standards of the receiving water
- technical
    - acceptable level of any treatment required prior to discharge

An initial evaluation of these and other factors needs to be done at the feasibility/screening stage of evaluation of CM options. This will require estimation of the concentrate water characteristics, which can be obtained from simulation of concentrate, based on raw water quality data. It will also require interaction with the regulatory agency overseeing discharge permits.

More detailed evaluations can take place once specific source waters are defined and after pilot plant data are available to provide more accurate indications of concentrate water quality.

7.4 Major Cost Factors

All phases of a desalination plant (planning, construction, and operation) include labor and costs associated with interactions with regulatory agencies. Capital costs occur mainly during the construction phase. Some capital costs are associated with periodic replacement or upgrading of equipment during operation. Operational and maintenance costs occur after plant start-up. When surface water discharge is a feasible CM option, capital costs are typically much less than those associated with other options.

7.4.1 Planning Phase Costs

Although interactions with regulatory agencies are necessary for all CM options, they are typically more time-consuming with surface water discharge. This is because of the complex nature of surface discharge regulations and the correspondingly more complex evaluation procedures agencies use to determine permit feasibility and conditions. This translates into more time being spent in information gathering and in communication with the regulatory agencies than in other CM options (with the possible exception of DWI).

Sections 7.6 and 7.7 describe recommended interactions with regulatory agencies that are associated with planning-phase (feasibility stage, preliminary design, system design) evaluations of CM option feasibility.

Costs associated with planning phase efforts may include

- labor associated with gathering and communicating information, primarily with the regulatory agency overseeing industrial wastewater NPDES permitting
- sampling and analysis of source waters or representative waters
- computer simulations to define concentrate characteristics (recovery, salinity, composition, etc.)
- toxicity testing
- dispersion modeling

Details of planning-phase efforts are discussed in Sections 7.9 and 7.10.

7.4.2 Capital Costs

Capital costs may be associated with the following:

- Equipment required for treatment of groundwater-based or surface water–based concentrates to remove naturally occurring constituents to meet water quality standards and eliminate toxicity based on WET tests. Concern for corrosion may prompt use of more expensive corrosion-resistant materials. Treatment may include
  - aeration to increase DO (for groundwater-based concentrate)
  - degasification for H_2S, CO_2, NH_3 (for groundwater-based concentrate)
  - pH adjustment

    - dechlorination (if cellulose acetate membranes are used)
    - particulate removal
    - removal of As, Se, and other naturally occurring contaminants
    - dilution to remove major ion toxicity
    - removal of NORMs
- Equipment that may be required to reduce levels of non-naturally occurring constituents in groundwater-based and surface water-based concentrate that do not meet receiving water standards. Currently, only a few concentrates require such major treatment; however, this is an area of increasing concern because of increased occurrence of anthropogenic contamination. Examples of contaminants whose removal may be required include
    - nitrate
    - perchlorate
    - arsenic
    - selenium
    - various emerging pollutants of concern
- Conveyance of concentrate to the receiving water. These costs are dependent on the distance from the desalination plant to the discharge site. Costs factors include
    - pumps
    - pipeline (and possible pipeline protection)
    - fabrication
    - trenching of pipeline
    - costs associated with obtaining right-of-way for piping
- Conveyance from shore line to the outfall structure. Cost factors include
    - pipeline
    - possible underwater fabrication
    - possible dredging/trenching
- Outfall structure. Cost factors include
    - pipe (diffuser)
    - risers
    - ports
    - fabrication
    - possible trenching and armoring

Groundwater-based concentrates routinely require some minor treatment to increase pH and DO before discharge to meet receiving water standards. Treatment to remove contaminants prior to discharge is less frequently needed, but is sometimes required for removal of dissolved gases naturally found in many groundwater. A small, but increasing, number of systems require removal of other contaminants (see Section 7.5.1.1).

Many inland discharge systems have relatively simple outfall designs. The most significant and variable cost factor associated with inland surface water discharge is the piping and pumping requirement. This variable is site-specific and dependent on the distance and terrain between the desalination plant and the discharge site.

7.4.3 Operating Costs

Operating costs associated with inland surface water discharge are usually on the low end of CM options. Operating costs may be associated with

- monitoring and reporting to the regulatory agencies
- routine operation and maintenance
- pumping

7.5 Environmental Concerns

The major environmental concern is degradation of waterways. The anti-degradation rule (discussed in Chapter 6) does not prevent degradation of waterways except for the most pristine waters, which are designated as Tier 3, "Outstanding National Resource Waters" (U.S. EPA, 2010b). All other waters can be degraded up to the point of ambient levels reaching allowable water quality standards for a given water body. The degrading water quality can affect

- flora and fauna
- human health
- downstream uses

7.5.1 Flora and Fauna

The following sections consider the effects on flora and fauna of raw water quality, chemicals added during desalination processing, membrane cleaning, and potential precipitation and sedimentation.

7.5.1.1 Concerns Associated with Raw Water Quality

Low dissolved oxygen levels in groundwater. Groundwater typically has low levels of DO and, unless aeration/oxygenation is part of a pretreatment step, concentrate will also have low levels of oxygen. In these situations, aeration or another means of introducing oxygen is necessary to meet DO water quality standards.

High levels of gases in groundwater. Groundwater may have high levels of dissolved gases, such as H_2S, CO_2, or NH_3, which will then be present in concentrate and require removal prior to discharge.

Ion imbalance in groundwater. Relative concentrations of major ions in groundwater may result in ion imbalance or major ion toxicity when concentrate undergoes WET tests. The toxicity is dependent on the groundwater quality and the test species used. The imbalance is present in the raw water and changed only in a minor way by membrane processing. Toxicity typically is mitigated by mixing the concentrate with three to five volumes of receiving water. Consequently, regulatory relief via mixing zones is sometimes sufficient for remediation (Mickley, 2000).

Natural trace contaminants in raw water. Examples of this are NORMs, as experienced in southwest Florida and parts of Illinois, and arsenic concentrations, such as in a plant in Texas.

> **Example:** *Radium at Geneva Reverse Osmosis Plant, Geneva, IL*. Various northern Illinois facilities have radium issues. At Geneva, radium removal was the reason for RO treatment. Concentrate goes to the WWTP and ends up in the biosolids from the WWTP. (Survey communication, 2010)

> **Example:** *NORMs in Florida*. Several locations in southwest Florida have high levels of NORMs in groundwater. Discharge of concentrate with even higher levels of NORMs to surface water is prohibited. These facilities utilize deep well injection for concentrate disposal. (Survey communication, 2010)

High levels of contaminants in raw water from human activities. Examples include increased levels of nutrients, perchlorate, and selenium (such as from mines), which have potential adverse impacts on aquatic flora and fauna. Although the other concerns mentioned earlier are naturally occurring, this increasing concern is directly related to human activities.

> **Example:** *Perchlorate, West Valley, T, Barton Well Field Drinking Water Treatment Facility*. Concentrate from a 6-mgd EDR facility is treated for perchlorate removal at the WWTP facility, which uses a new patented technology it developed called BioBrox; perchlorate is converted to chloride.

> **Example:** *Nitrate, City of Thornton, CO.* The BWRO portion of a 2002 design for a UF/RO WTP to produce 50 mgd of UF product water and 20 mgd of BWRO product water was never constructed. The only practical CM option for RO concentrate was discharge to the South Platte River. This was prohibited because of high nitrate concentrations. This plant would have been the largest inland desalination plant in the United States at the time.

> **Example:** *Nitrate, City of Brighton, CO.* Several studies in the past decade have looked at alternatives for CM to allow BWRO plant expansion. The existing permit for concentrate discharge to the South Platte River could not be changed to allow a greater volume of discharge. The limitation is nitrate discharge to the South Platte River. After several studies, including consideration of high-recovery processing options, a request for proposal will be issued in late 2010 for denitrification of concentrate prior to discharge.

> **Example:** *Phosphate, ACWWA Water Purification Plant, Arapahoe County, CO.* Concentrate is treated for phosphate removal by adding alum, flocculating, coagulating, and filtering with a MF unit; treated concentrate is then blended 1:1 with WWTP effluent for discharge to a local creek.

> **Example:** *Nutrient Removal Study at North County Reverse Osmosis, Vero Beach, FL*. A closed foam cell mat (Beemats LLC) is used to support aquatic plants. Floating gardens of specially selected grasses and weeds then serve as wetland islands to remove nutrients from RO concentrate. Blending of treated concentrate with WWTP effluent allows meeting nutrient TMDL.

7.5.1.2 Concerns Associated with Chemicals Introduced in Desalination Processing

Residuals/chemicals from pretreatment. The most frequently occurring examples are the use of antiscalants/dispersants and acid added to inhibit precipitation of sparingly soluble salts and silica onto membrane surfaces. The antiscalants/dispersants add synthetic chemicals to the raw water, whereas the acids, typically sulfuric acid or hydrochloric acid (other than impurities present), add only major ions and reduce the pH of the raw water. In cases of pretreatment involving coagulants and/or flocculants, a soluble fraction of the coagulants/flocculants and the resulting complexes may remain in the concentrate. When disinfectants are added to mitigate biofouling, some of the chlorine will be present in the concentrate unless a dechlorination step is also part of the pretreatment process. Where sodium bisulfite is used for dechlorination, as a result of the reaction, only sodium, sulfate, and chloride are added to the concentrate. The primary concerns associated with pretreatment are not added major ions, but rather synthetic chemicals.

Concentrate pH is typically slightly higher than feed pH because of changes in the distribution of carbonate species that result from RO processing. When acid is added during pretreatment, concentrate pH may end up being lower than allowed for discharge. In this case the concentrate may need to be neutralized prior to discharge. Neutralization will also serve to reduce the corrosive nature of concentrate, which may be of concern in pipeline conveyance of concentrate to the discharge site.

ED concentrate may have free chlorine, requiring neutralization prior to discharge.

7.5.1.3 Concerns Associated with Cleaning Chemicals

The cleaning chemicals remove foulants that cause loss of membrane performance. The cleaning residuals include spent cleaning solution and materials removed from the membrane system during cleaning. Many cleaning solutions contain proprietary chemicals to optimize cleaning efficiency. The cleaning solutions may be diluted with rinse water and may contain detergents, surfactants, acid, caustic, or other chemicals. The spent cleaning solution volume is typically a very small percentage of the treated flow (less than 0.1%). Material removed from the membranes and part of the spent cleaning solution may include inorganic salts, metal oxides, silt, silica and silicates, and biofilms and organics (Malmrose, 2004). Because of possible effects on flora and fauna, spent cleaning chemicals are most frequently disposed of by discharge to sewers. In some cases, however, they are combined with concentrate for disposal.

7.5.1.4 Concerns Associated with Potential Precipitation and Siltation

Most concentrates have one or more sparingly soluble salts (or silica) in a supersaturation state allowed by the use of antiscalants/dispersants. The inhibition of precipitation is a kinetic effect and thus temporary. The supersaturated constituent will eventually precipitate. In most cases, concentrate is discharged to a receiving water before the effect wears off. The dilution afforded by the receiving water eliminates the precipitation potential. Unwanted precipitation, however, can happen within storage, conveyance, or other equipment prior to discharge. These solids may then be carried to receiving waters. This may occur because of

- storage over hours/days, in which the inhibitory effect of the antiscalants/dispersants is no longer present and precipitation occurs in the storage container
- conveyance over long distances, where either the conveyance time exceeds the inhibitory time or interaction with the conveyance media adsorbs antiscalant (in both cases precipitation may occur in the conveyance system)
- change (increase) in concentrate pH prior to discharge, which increases the precipitation potential for constituents such as $CaCO_3$, Ca/PO_4 salts, and silica

7.5.2 Human Health

Regulations are developed on the basis of environmental impacts on both human health and flora/fauna. Humans are more sensitive to some contaminants and flora/fauna more sensitive to others. Water quality standards are set to protect the most sensitive species.

Receiving waters are classified according to potential uses. Some classifications include recreation activities. In general, humans can be exposed to contaminants from direct contact and eating of fish and other species from the receiving water. All of these factors are taken into consideration in developing the water quality standards. The same concerns discussed in the previous section apply in this section.

7.5.3 Downstream Use

Discharge of concentrate to receiving water affects water quality at the point of discharge and downstream. As mentioned in the beginning of this section, most receiving water standards (except for certain receiving water classifications) allow degradation of water quality until ambient levels reach standard levels. Consequently, water quality seen downstream is often worsened by upstream discharges. There are increasing concerns with this salt/mineral/contaminant loading of receiving waters, and inland surface water discharge is increasingly globally viewed as a nonsustainable option.

7.5.4 Increasing Environmental Concerns

Environmental concerns have been increasing because of several factors. Municipal desalination plants have been steadily increasing in both numbers and size, resulting in greater volumes of discharged concentrate. At the same time, raw waters providing feed to the municipal desalination plants are experiencing increased levels of contaminants because of human activities. Environmental awareness and concern have increased because of increased visibility and frequency of environmental problems.

Climate change is leading to increasing focus on greenhouse gas (GHG) emissions and energy use. Unless pumping long distances is required, relatively low energy requirements are associated with discharge of concentrate to surface waters. There is a possibility of CO_2 emission from discharge of alkaline concentrate.

7.6 Regulatory Basis

Because of the complexity of regulations for discharges to surface waters, a separate chapter (Chapter 6) was devoted to the subject. In this chapter, only highlights are presented.

Wastewaters are categorized in the CWA as either industrial or domestic. Domestic waste is defined as sewage, and thus municipal desalination membrane concentrate is considered an industrial waste. Regulations are developed based on environmental concerns such as those described previously. Most regulations applicable to discharge of municipal desalination concentrate were developed for industrial wastes other than concentrate. Discharge to surface waters is regulated under the NPDES program.

Suitability of discharge is based on compatibility of discharge with receiving water in terms of salinity, individual constituents, and other parameters. Water quality characteristics of potential discharges are evaluated against water quality standards and policies associated with each receiving water. Receiving waters are classified according to use.

Discharge permits specify allowable discharge characteristics, which may include limits on parameters of concern and monitoring requirements associated with such parameters.

Federal guidelines specify policies and rules to be implemented, giving the states some leeway in both time and specific implementation aspects, as long as minimum requirements are met. Thus, states differ to some extent in terms of discharge regulations.

Determination of the feasibility of surface discharge of concentrate (and of other CM options) is discussed in Chapter 5. In all cases, it is important to initiate interaction with the appropriate regulatory agency early in the planning of municipal desalination plants to assure that definition of a feasible CM option does not delay construction and operation of the plant. The complexities of surface discharge regulations frequently translate into considerable effort and time to secure a discharge permit.

7.7 Impact of Concentrate Volume

The impact of concentrate on receiving water depends on its volume, salinity, and composition. Concentrate volume is not a regulated parameter, but together with salinity and composition, it determines the amounts of total solids and individual constituents discharged to the receiving water. The greater the volume, the greater the potential impact on the receiving water.

7.8 Impact of Concentrate Salinity

The following sections illustrate how concentrate salinity may affect the feasibility of surface water discharge. The same general considerations apply to the individual constituents in the concentrate, discussed in Section 7.9.

7.8.1 Concentrate Salinity

Concentrate salinity is dependent on raw water characteristics, pretreatment processing, membrane system performance, and any treatment and/or blending of the concentrate prior to discharge.

7.8.1.1 Concentrate from Brackish Reverse Osmosis Treatment of Groundwater

Most inland receiving waters are of relatively low salinity compared to concentrate. An exception to low-salinity receiving water is inland terminal lakes such as the Great Salt Lake. Tables 3.3 and 3.4 in Chapter 3 show general characteristics of raw water and of membrane system operation. Considering brackish RO processing, whereas brackish groundwater can have salinity as high as 10,000 mg/L, raw water for municipal desalination plants is frequently less than 3000 mg/L. Recoveries are typically in the range 65%–85%. At 85% recovery, the concentrate from such raw water would be at most 20,000 mg/L. The range is typically from 1500 to 20,000 mg/L.

In high-recovery processing, concentrate salinity can be much higher. For instance, if a feed water of 3000 mg/L is processed with a recovery of 95%, the concentrate salinity will be roughly 60,000 mg/L. Higher salinity concentrate will increasingly occur as high-recovery processing is more frequently used. Salinity increases but volume decreases.

As salinity increases (such as where groundwater characteristics change with time), or as volume increases (such as where a desalination facility expands), the salt load (amount of salt) increases, and at some point, inland surface discharge may not be feasible based on receiving water regulations. Discharge of inland concentrate to the ocean, such as via brine lines (covered in Chapter 8), or discharge of concentrate to terminal lakes such as Great Salt Lake allows a greater salt load.

7.8.1.2 Concentrate from Non-Brackish-Water Reverse Osmosis Groundwater Desalination Facilities

As shown in Figures 3.3 to 3.5, the upper range of NF concentrate salinities (generally less than 10,000 mg/L) is much lower than that for typical BWRO concentrates. BWRO concentrate from treatment of inland surface waters (typically less than 10,000 mg/L) will be of lower salinity than groundwater-based concentrate.

As shown in Tables 3.3 to 3.5, concentrate from treatment of WWTP effluent is similar to NF concentrate. Concentrate is generally less than 10,000 mg/L.

Aside from composition considerations, in each of the three situations, concentrates will be more suitable for surface discharge than BWRO groundwater-based concentrate because of the lower salinities and lower salt load.

7.8.2 Receiving Water Limits

Water quality standards for surface waters vary with receiving water classification. Some receiving waters have TDS (salinity) limitations; others have limitations on sulfate and chloride (which effectively limit TDS). In all classifications except waters designated as "outstanding," receiving water salinity levels may be allowed to increase above ambient levels up to the levels of the water quality standards (see discussion of antidegradation in Section 6.2.4). When mixing zones are granted for TDS, the discharge TDS may be greater than the water quality standard as long as the concentration at the edge of the mixing zone is not greater than the standard. When mixing zones are not possible, discharge feasibility is based on end-of-pipe concentrations. This situation may occur when a TMDL exists for TDS or when for other reasons a mixing zone is not possible for TDS. A feasible discharge then requires the discharge TDS to be less than the water quality standard at end-of-pipe.

The effect of a mixing zone on discharge feasibility may be illustrated. The following mass balance equation, also called the completely mixed dilution equation (U.S. EPA, 1991), is used as a basis for determining downstream concentrations that would result from complete mixing. This calculated concentration is compared to the water quality standard and if it is less than the standard, a mixing zone may be considered further. The equation is also used as the basis for calculating mixing zone dilution requirements.

The downstream salinity is calculated from a mass balance, where

$$C_{ds} = [(Q_d)*(C_d) + (Q_{rw})*(C_{rw})]/(Q_d + Q_{rw}),$$

where C_{ds} = downstream salinity, C_d = discharge salinity, C_{rw} = receiving water salinity, Q_d = discharge flow, and Q_{rw} = receiving water flow.

The receiving water conditions are "worst case" and correspond to a statistically defined low-flow condition for the receiving water condition. The following example illustrates how receiving water with and without a mixing zone can impact discharge feasibility.

> **Example:** Consider receiving water characterized by a low-flow condition of 1000 mgd and an ambient TDS of 500 mg/L. Case 1 is a 5-mgd concentrate of 5000 mg/L and Case 2 is a 1-mgd concentrate of 25,000 mg/L. Case 2 represents a reduced-volume concentrate achieved as a result of high-recovery processing. Assume the water quality standard for TDS is 800 mg/L. The downstream TDS is calculated from a mass balance where:-
>
> $$C_{ds} = [(Q_d)*(C_d) + (Q_{rw})*(C_{rw})]/(Q_d + Q_{rw}).$$
>
> The Case 1 result for the 5-mgd discharge is 714 mg/L TDS; the Case 2 result for the 1-mgd discharge is 743 mg/L, a 14% increase in receiving water TDS. With a mixing zone, the water quality standard of 800 mg/L would need to be met at the edge of the mixing zones. Both Case 1 and Case 2 have blended salinity values less than 800 mg/L and would be considered further as candidates for mixing zones on the basis of salinity.
>
> If the mixing zone were not allowed for salinity, feasibility of discharge would be based on comparison of discharge TDS (5000 mg/L in Case 1 and 25,000 mg/L in Case 2) with the water quality standard of 800 mg/L. Neither discharge would be allowed.
>
> Consider also a discharge of 600 mg/L TDS. In this case the discharge salinity is higher than the ambient salinity but is less than the water quality standard for salinity. No mixing zone would be needed for this discharge to be allowed on the basis of TDS.

This example illustrates several points:

- the effect on discharge of having a mixing zone
- volume reduction of concentrate (reducing volume and increasing salinity) not affecting feasibility of surface water discharge if mixing zones are allowed (the example is oversimplified a bit, but the general implications are correct).
- discharges being allowed to degrade receiving waters up to the point of the water quality standards

A favorable outcome based on the mass balance equation would lead to the possibility of a mixing zone being further considered. The reasons for not automatically granting a mixing zone are that (1) the blending of discharge and receiving water may not be completely mixed (an assumption of the mass balance equation) and (2) there are physical restrictions on the size of mixing zones. These restrictions vary somewhat from state to state. The mass balance equation can be used to calculate the dilution necessary for the mixing zone being granted.

The potential discharger must conduct modeling and other studies to demonstrate that sufficient dilution may be attained within the state-defined physical constraints of a mixing zone.

As illustrated, concentrate discharges of higher salinity (and higher concentrations) are less likely to meet water quality standards.

7.9 Impact of Concentrate Composition

The effect of concentrate composition on CM is dependent on both the concentrate composition and the receiving water limitations. Although the example just considered focused on the effect of salinity on discharge feasibility, the same considerations apply to the effects of individual constituent concentrations. Mixing zones for constituents would follow the same analysis presented in Section 7.8.

Mixing zones may also be given for toxicity indicated by WET tests. Toxicity, in general, increases with concentration. However, toxicity for a given constituent is also a function of salinity (see Appendix B).

With the exception of impaired water having a TMDL for the constituent in question, the discharge concentration of a constituent may be higher than the ambient receiving water level, as long as it is not higher than the water quality standard level. When a mixing zone is allowed, the water quality standard must be met at the edge of the mixing zone. When a mixing zone is not allowed, the water quality standard must be met at the end of the pipe.

In either case, the discharge concentration may be higher than the ambient concentration, with the effect of increasing the ambient level of that constituent in the receiving water, although not necessarily to a significant extent. If this practice is allowed for enough dischargers, it is possible for the ambient level of that constituent to reach the water quality standard. In this case the receiving water would, in theory, be declared an impaired water with respect to the particular constituent (salinity or constituent concentration) and be granted a TMDL, and mixing zones would not be allowed for that constituent.

7.9.1 Concentrate Composition

7.9.1.1 Concentrate from Brackish Reverse Osmosis Treatment of Groundwater

Concentrations of constituents in brackish RO concentrate are dependent on raw water quality, pretreatment processing, membrane system performance, and any additional treatment and/or blending prior to discharge.

Concentrate may be composed of

- constituents found in raw water and present in concentrate at higher concentrations depending on the membrane system performance (rejection and recovery)
- residuals from pretreatment and cleaning, as well as antiscalants

The raw water may contain naturally occurring contaminants (such as NORMs) and contaminants from human activities (such as perchlorate and nitrate) that find their way into surface water and groundwater.

Concentrate emerging from the RO process should have at most only minor amounts of suspended solids other than those concentrated from the feed water. The antiscalant and dispersants added as part of the pretreatment serve to slow the kinetics of formation of the nuclei and colloids from the sparingly soluble salts and silica. Eventually, however, solids may form because of the saturated or supersaturated nature of some sparingly soluble salts and silica. This can contribute to turbidity. If this occurs prior to discharge, upon discharge the turbidity will settle and cover the benthic zone in receiving waters. If this does not occur prior to discharge, it likely will not occur after discharge, because of dilution of the concentrate in the receiving water.

The storage and conveyance times of concentrates before precipitation begins are dependent on concentrate composition, conditions experienced by the concentrate, and antiscalant/dispersant usage. This aspect of concentrate behavior is not well understood.

7.9.1.2 Other Concentrates

NF concentrate from treatment of groundwater or surface water will contain lower levels of monovalent ions and other smaller constituents than concentrate from BWRO treatment of the same water.

BWRO concentrate from treatment of surface water will have higher DO levels and likely lower levels of sparingly soluble salts and silica than BWRO groundwater-based concentrate.

Based on these general considerations, NF concentrate and BWRO surface-water-based concentrate should have similar or fewer challenges in meeting surface discharge regulations than BWRO groundwater-based concentrate.

Table 3.1 gives the general characteristics of WWTP effluent. Depending on pretreatment, WWTP concentrate may have higher levels of nutrients, metals, and organics than concentrate from groundwater-based concentrate. The organics may include emerging contaminants (see Chapter 16).

7.9.2 Receiving Water Limits

Composition limitations vary with receiving water classification and are the primary way of controlling environmental and health impacts of discharges to receiving waters. Thus composition plays a fundamental role in determining feasibility of surface water discharge.

A major concern is the increasing manmade contamination of source water, such as by emerging contaminants, nitrates, and others, because of human activities. These may become a major concern, resulting in both new drinking water standards and new receiving water standards. Drinking water standards for contaminants may increase the demand for desalination treatment. Increasing levels of these and other contaminants in desalination concentrates may result in increased need for treatment of concentrate prior to discharge to meet more stringent receiving water standards.

7.10 Screening-Level Evaluation

7.10.1 Discharge to Inland Surface Water

Important parameters to define at this early general feasibility stage study include

- relative volumes of concentrate and potential receiving waters
- relative salinities of concentrate and potential receiving waters
- relative concentrations of major ions in concentrate and receiving waters
- distance and terrain between desalination plant site to potential receiving waters

These parameters will allow early assessment of the potential feasibility of surface discharge.

It is important to begin interaction with the appropriate regulatory agency early in the planning process. The agency can provide information as to

- any NPDES permits granted to desalination plants in the region
- the classification of potential receiving waters and whether aurface water discharge would be considered for these receiving waters
- what the major limiting parameters are for discharges to these receiving waters
- whether surface discharge might be possible and what receiving waters/segments might be best to consider based on volume, salinity, and major ion estimates of the concentrate
- pertinent regulations and agency screening protocols for evaluating potential discharges

Concentrate water quality composition at this stage may only be estimates of ranges for major ions. Composition of nonmajor constituents and contaminants in the concentrate are also important factors in determining the feasibility of surface water discharge. However, at the general feasibility study stage of consideration, concentrate composition is likely not well-defined, and composition issues other than major ions may be left for later consideration. Concentrate water quality is typically estimated based on computer simulation of membrane performance, given the best available raw water quality data.

The state agency overseeing industrial NPDES permitting should be provided with the best available concentrate water quality and volume estimates. This will allow them to perform screening calculations in order to render an opinion on the possibility of surface water discharge.

It is important, however, to understand and separately perform the same calculations to evaluate the impact of different water qualities and treatments on discharge feasibility.

The calculations range from simple to complex depending on the particular state agency protocols for evaluating potential discharges. In all cases, protocols must be consistent with federal guidelines, but specific approaches vary. For instance, states have a choice as to whether a mixing zone (zone of initial dilution) is automatically included in the protocol calculations (example: Texas) or is considered only on a case-by-case basis (example: Florida). When mixing zones are not included in the initial screening consideration of discharges, the screening calculations may be as simple as comparing an end-of-pipe concentration with the water quality standard for the receiving water segment in question. When mixing zones are included in the calculations, ambient receiving water flow and concentrations may be used to calculate an acceptable end-of-pipe concentration limit. The example in Section 7.2.2 illustrates this calculation in a simplified form. The calculations can be complex in terms of what values to use and how to interpret the results. Interaction with the state's industrial wastewater NPDES permitting group should occur early during feasibility evaluations to obtain and understand the calculation methods and to access data required to make the calculations.

After agency screening protocols are obtained, as well as applicable water quality standards and ambient flow and concentration data for the receiving water in question, calculations can be made to determine if any concentrate constituents are likely to require dilution to meet the discharge limit. Calculation of dilution ratios necessary to meet water quality standards for different concentrate constituents is helpful to determine the major limiting constituents.

A higher salinity, reduced-volume concentrate may have a salt load similar to that of a lower-salinity, higher volume concentrate. The impact on the receiving water, however, will be somewhat greater for the higher salinity, reduced-volume concentrate as a result of less combined volume of the blended water. This is illustrated in the example of Section 7.7.2. The added salt load is similar but the added volume is less—resulting in a greater increase in receiving water salinity.

Other regulatory considerations come into play depending on the classification of the receiving water and can include

- WET testing
- TMDLs
- the anti-degradation rule

These considerations may pose more stringent limitations on a given discharge—including reduced-volume concentrate.

The broader regulatory approach is explained in detail in Chapter 6.

Conveyance costs increase and the feasibility of surface water discharge decreases as the distance between the desalination plant and the receiving water increases. Similarly, conveyance costs increase as the terrain between the desalination plant and the receiving water becomes more difficult. In the screening-level evaluation, the major cost to be estimated may be the conveyance of the concentrate to the site of discharge. Estimates of conveyance costs should be developed at the screening evaluation stage.

7.10.2 Discharge to Brine Line

Brine lines that deliver water to WWTPs, such as the Santa Ana River Interceptor (SARI) line in California, are considered a subcategory of disposal to sewers and are addressed in Chapter 9. Most brine lines deliver water directly to an ocean outfall.

> **Example:** *California SARI line*: The Santa Ana Regional Interceptor (SARI) is a system of conveyance lines that serve the Santa Ana River watershed to carry brine (concentrate) from desalination plants, sewage, and various industrial discharges to the Orange County Sanitation District Plant No. 2 WWTP. Effluent from Plant No. 2 is discharged to the ocean.
>
> **Example:** *California Southern Orange County Water Authority—San Juan Creek Ocean Outfall*: The Southern Orange County Water Authority brine line collects effluent from various WWTPs and water reclamation plants, and concentrate from

the San Juan Capistrano RO plant. The brine is discharged directly to the ocean via the San Juan Creek Ocean Outfall.

Example: *California Calleguas Salinity Management Pipeline System*:
The Calleguas Salinity Management Pipeline will be constructed in nine phases and will ultimately connect the West Simi Valley Desalter with the Hueneme Outfall. The pipeline will eventually connect at least six desalters, five WWTPs/WRPs, and a number of industrial dischargers. The capacity of the pipeline is 20 mgd, which should be sufficient to convey projected brine-concentrate flows to the ocean. However, if future flows exceed the capacity, then some level of brine concentrate volume reduction may be necessary. (Bureau of Reclamation, 2009a)

Evaluating technical feasibility of discharge to a dedicated brine line that takes multiple discharges is relatively simple. Feasibility depends primarily on whether capacity is available and, if so, what costs are involved. Costs are based on volume of concentrate. Other costs may include treatment of concentrate prior to conveyance to the brine line to meet established requirements. These can be for parameters such as pH, total suspended solids (TSS), and some constituents. Another cost can be conveyance of concentrate to the brine line.

During the screening-level evaluation stage, interaction with the brine line operating and permitting groups can determine if, and under what conditions, concentrate can be disposed of to the brine line. This analysis should be based on best available estimates for concentrate volume and water quality.

7.11 Preliminary-Level Evaluation

Evaluation at the preliminary stage is discussed in two sections corresponding to before and after piloting of the desalination process.

7.11.1 Surface Water Discharge—Before Piloting

More definitive consideration of surface water discharge of concentrate requires more accurate and complete characterization of the concentrate. This requires tighter definition of water quality and better estimation of membrane system performance. More accurate groundwater quality data eventually will come from selection of the site for groundwater wells and drilling of a test well or wells. Ideally, this is done prior to the pilot test, but, in some cases, the pilot test might be conducted on source water assumed to be representative of the plant site groundwater. In the case of inland surface water desalination, the challenge of obtaining accurate water quality data is not the site definition but seasonal changes.

Prior to the pilot test, concentrate water quality will be estimated based on computer simulation of membrane treatment system performance. It should be noted that membrane system performance computer simulation programs typically provide estimates of concentrate composition only for major ions. Knowledge of how membrane systems affect other constituents can be used to estimate concentrate levels of other constituents. The progression to more accurate estimates of concentrate makeup will allow more detailed interaction with the applicable regulatory agency representatives.

At this stage,

- concentrate water quality and flows should be well defined

- water quality standards for potential discharge sites should be identified
- regulatory protocols for determining discharge feasibility should be understood and used to independently (from the regulatory agency) estimate discharge feasibility

Further interaction with the regulatory agency is necessary to

- provide more exacting characterization of the concentrate (volume, composition)
- review data and calculations for the regulatory agency's comments
- determine
  - what, if any, water quality parameters might be limiting
  - confirmed estimates of the effect of changes in volume and composition on meeting water quality standards
  - what data is required on the permit application (and thus what data needs to be obtained from the pilot studies)
  - the path and the estimated time to get feedback on the permit applications and to get an approved permit

Cost estimates at this stage should reflect that

- all cost factors have been identified
- all cost factors have been evaluated and assigned costs suitable to the accuracy required for this stage evaluation
- sensitivity of each cost factor to changes in concentrate water quality and volume have been evaluated

In addition, less defined parameters should be identified for future focus.

7.11.2 Surface Water Discharge—After Piloting

Analysis and testing of concentrate from the pilot tests should supply the more exacting data required for a discharge permit application. This should include a more comprehensive water quality analysis of the concentrate and any toxicity test results that may be required.

The concentrate characteristics (volume, composition, other parameters) may be different from those used in previous interactions with the regulatory agency, and these need to be reviewed to determine possible effects on discharge feasibility.

7.11.3 Discharge to Brine Lines

If discharge to a brine line was short-listed, then after desalination piloting, any changes in concentrate characteristics should be reviewed with the brine line permitting agency to confirm feasibility and determine final cost estimates.

7.12 Summary

Surface water discharge is used by approximately 50% of the municipal desalination facilities and in 27 of the 33 states having such facilities. For low-volume, low-salinity concentrate free of major contaminants, determination of the feasibility of concentrate discharge to surface water can be simple. In general, however, feasibility determination can be more complex than feasibility determination associated with other CM options. Part of the complexity has to do with the methodology used to determine receiving water limits. Because of the complexity, Chapter 6 was devoted to discussing surface discharge regulations.

Regulations applying to surface water discharge, namely the NPDES program regulations, are changing more rapidly than regulations for other disposal options. There is growing environmental concern with protecting surface and groundwater sources. Source water quality is deteriorating because of human activity. Some emerging contaminants will likely become regulated in terms of both drinking water standards and source water protection. Tighter drinking water standards may result in the increased application of desalination to remove the growing list of regulated contaminants. Concentrates will have higher levels of these contaminants and may not be able to be discharged to surface water because of more stringent receiving water standards and other restrictions.

The trend is set for increasing challenges to surface discharge of concentrate. More than ever, it is important for utilities to interact with regulatory agencies very early in the planning process to directly address the agencies' positions regarding surface discharge permitability.

Chapter 8

Surface Water Discharge—Coastal

8.1 Background

There are two general situations in which desalination concentrate is discharged to marine/coastal environments. The first is where seawater desalination plants located near the coast discharge concentrate into the ocean, an estuary, a canal, or another body of water adjacent to the ocean that is of similar salinity. The second is where inland brackish desalination plants discharge concentrate to a brine line that carries concentrate to an ocean outfall. This second situation occurs in California, where the terrain allows substantial opportunities for gravity flow. It was discussed in Section 7.10.2 and is further addressed in Sections 8.9 and 8.10.

The desalination plant discharge may be diluted before discharge. The coastal discharge options include

- shore outfall or open ocean discharge to deep water offshore
- co-located outfall (power plant or WWTP)
- beach well (this may be considered a shallow injection well)
- subsurface conveyance and discharge
- discharge to a river, canal, or estuary tidally influenced by proximity to an ocean

There are several differences between management of seawater desalination concentrate and inland desalination concentrate. These include the following:

- Seawater is much more uniform in water quality than inland brackish water.
- There is far less variability in seawater desalination treatment and plant design than in brackish desalination treatment and plant design.
- The only practical CM option for seawater concentrate is discharge to the ocean. Inland CM has more than one option.
- The sea has a much more varied and complex ecology than inland flowing waterways.
- The major feasibility challenge of seawater desalination CM is getting a surface water discharge permit; the major feasibility challenge of inland desalination CM, in many cases, is defining a viable and acceptable CM option.
- Consequently, the planning phase CM evaluation task for SWRO is focused on getting the discharge permit; the planning phase CM evaluation task for brackish desalination is focused on defining a CM option and then getting the permit.

8.2 Historical Use

Only 4% of municipal desalination plants in the United States are seawater plants; all discharge into marine waters (Mickley, 2006 and Appendix A). Most of these plants are old and small. The 25 mgd Tampa Bay desalination plant constructed during the 2000s was a milestone undertaking, being by far the largest SWRO plant in the United States.

Although 75 % of the population is located within 50 mi of an ocean coast and could be supplied with desalinated seawater, less than 1% of this population uses desalinated seawater (Voutchkov, 2006). With periodic drought conditions, as well as growing coastal populations and water needs, several seawater desalination projects have been under consideration in the last 10 years; these are primarily in California, but also in Florida and Texas.

The troubled history of the 25-mgd Tampa Bay desalination plant, along with the recessionary budget constraints since 2008, has put a damper on implementation of many of these projects. It is likely, however, that seawater desalination will play an increasingly important role in providing potable water for coastal urban areas in the future.

> **Example:** *Tampa Bay Water Desalination Plant*: The project was originally a private venture by Poseidon Resources. Project delays resulted from bankruptcy of three of the companies involved and a dispute over ownership and control, which reached the federal courts. Tampa Bay Water was forced to purchase the project from Poseidon in 2002. The project did not meet required performance tests, and in 2004, Tampa Bay Water hired a renovation team, American Water/Acciona Aqua, to bring the plant to its original design. Although the plant was deemed fully operational in 2007, operating problems continued through 2009. The plant opened five years late and at a cost of $158 million, approximately $40 million more than expected (Tampa Bay Water, 2010; Water-Technology, 2010). It should be noted that the extensive environmental monitoring associated with co-discharge of the concentrate has shown no measurable changes in salinity, flora, and fauna in the receiving water.

Historically, discharge of concentrate to the ocean was viewed within the context of discharge of domestic wastewater to the ocean. Some regulations that affect concentrate discharge were originally developed for wastewater discharges. Because domestic wastewater is less dense than seawater, upon discharge it rises to the surface rather than sinking to the bottom of the ocean. Seawater concentrate, however, is denser than seawater, and this different type of ocean discharge has raised concerns as to the potential environmental impact on the sensitive benthic layer at the ocean bottom. With proper outfall siting to deeper waters with sufficient current, and through careful design of high-rate diffusers, risks of benthic habitat effects can be controlled. Such ocean outfalls for concentrate discharge are considered technically feasible. However, stringent regulatory review is required.

In general, seawater desalination plants being considered in the United States are larger than inland desalination plants that have been built.

8.3 General Feasibility Factors—Site Requirements

The major feasibility factors include

- ability to obtain a discharge permit
- addressing public perceptions
- addressing environmental impacts
- cost-effectiveness

The permitting process for seawater desalination concentrate disposal is complicated by the need to interact with multiple governmental agencies. It is further complicated by significant public concern about potential environmental impacts. In part this is because of the large size of SWRO facilities being considered and the related cost and energy requirements. Although desalination treatment costs have decreased significantly, costs remain higher than those for conventional water treatment plants. One outgrowth of the ongoing debate over and questioning of SWRO has been a push toward integrated water resource management, in which the elements of conservation, reuse, and desalination are considered in a balanced watershed context where the benefits and interrelationships of each of the elements is taken into consideration. The lack of a national water policy with cost-effective and streamlined state implementation hampers balanced consideration of desalination based on its benefits.

> **Example:** *Carlsbad, California Seawater Reverse Osmosis*: The Carlsbad Desalination Project is a 50-mgd seawater desalination plant that will supply the San Diego region with approximately 10% of its drinking water needs. The project, being developed by Poseidon Resources Corporation, will be the first large-scale desalination plant on the west coast and the largest of its kind in the western hemisphere. Poseidon has been working with the city of Carlsbad since 1998 on a public–private partnership to construct the plant at the site of the Encina power station. After years of planning and five years in the state's permitting process, the Carlsbad Desalination Plant has now received final approval from every required regulatory and permitting agency in the state, including the California Coastal Commission, State Lands Commission, and Regional Water Quality Control Board. The project could be completed as early as 2013. (City of Carlsbad, 2010)

The Tampa Bay desalination experience and the Carlsbad and other ongoing California stories are strong reflections of this.

There was a historical example of when, during a severe drought crisis, the many regulatory agencies worked together to streamline a path to get a SWRO desalination plant up and running within three years. This was the Santa Barbara plant, built in 1993. This example is by far, the exception compared with the 10+ year time period associated with the Carlsbad site.

8.4 Major Cost Factors

8.4.1 Planning Phase Costs

Planning phase costs are largely associated with permitting. These costs can be significant. This phase may include

- communication with regulatory agencies
- evaluating ocean discharge options
  - direct ocean outfall
  - discharge by coastal shallow wells
  - subsurface conveyance and ocean discharge
  - co-located discharge
- determining concentrate characteristics
- baseline monitoring of receiving water conditions—typically extensive

- modeling of dispersion of the concentrate discharge—typically extensive
- determining treatment needs
- addressing public relations and stakeholder issues

The only practical CM option for SWRO concentrate is discharge to the ocean. There is less variation in the nature of SWRO concentrate than in concentrate from inland brackish and surface water sources. Consequently, the planning phase effort for SWRO CM is focused on evaluating the various means of discharging to the ocean.

8.4.2 Capital Costs

Capital cost factors may include

- concentrate treatment equipment
- conveyance of concentrate to shoreline
  - pump
  - pipeline
  - right of way
  - fabrication
  - trenching of pipeline
- pipe from shore to outfall
  - pipeline
  - possible underwater fabrication
  - dredging/trenching
- outfall structure
  - pipe (diffuser)
  - risers
  - ports
  - fabrication
  - possible trenching
- shallow injection wells
  - drilling
  - casing, tubing, and other well construction costs
- subsurface conveyance and injection
  - drilling of access tunnels
  - piping
  - pumping
  - outfall/discharge structure

With the exception of possible onshore treatment of concentrate, all capital costs are associated with conveying concentrate to the discharge point and the outfall or final discharge structure. Material selection for any processing or conveyance equipment is a major issue with seawater concentrate because of the corrosive nature of SWRO concentrate.

8.4.3 Operating Costs

Operating cost factors may include

- monitoring and reporting
- operating and maintenance associated with conveyance and outfall discharge
- pumping
- routine operation and maintenance of (possible) concentrate injection wells

8.5 Environmental Concerns

8.5.1 General Discussion

Within the past 10 years, many detailed environmental studies have been completed in the United States, Australia, Israel, Spain, and Cyprus. They indicate that environmental risks associated with well-planned, -designed, and -operated SWRO plants are comparable to those associated with conventional water treatment plants.

As stated in a 2004 World Bank report (World Bank, 2004):

> It is important to note that, in the case of seawater desalination plants, the environmental impact of brine discharge is often minimal, especially if there are not sensitive environmental ecosystems near the outfall, if mitigation measures are taken and/or the plant is only small or medium size. However, if there are cumulative impacts from several large plants discharging to a sensitive eco-system in an area without currents and without sufficient mitigation measures, the impacts may be great.

This statement points out some of the critical factors involved in potential environmental impacts from ocean discharger:

- the nature of the local ecosystems
- the extent of mitigation measures taken
- the size of the discharge
- the mixing and flushing conditions of the receiving water
- cumulative impact of multiple discharges

Potential impacts from undiluted concentrate may be from

- constituents present in the raw water
- higher concentrations of these components than in the receiving water, and thus higher salinity
- residual chemicals from the pretreatment process (most pretreatment chemicals are removed as a result of sedimentation and filtering, but residuals remain)
- heavy metals from intermittently used cleaning solutions and from choice of equipment, pipe, and pump materials

- other components from cleaning solutions: acid, base, detergents, complexing agents, enzymes, etc.
- chlorine from disinfection
- dechlorination chemicals such as sodium bisulfite
- lower DO as a result of dechlorination chemical use
- organohalogen compounds formed from interaction of chlorine with naturally occurring organic material
- pH difference from receiving water
- antiscalants
- temperature difference from receiving water
- variations in these with time
- density differences

Although most organisms can adapt to minor changes in salinity (and other conditions) or temporarily manage greater deviations, the continuous discharge of concentrates significantly more saline than seawater can be harmful to marine life. The individual concentrate properties also have potential effects on the marine environment, which may be additive or synergistic.

Most components of concentrate have a limited dispersal range, so environmental effects are restricted to the discharge site (near-field) and its more immediate vicinity (far-field). The environmental fates include chemical changes (e.g., chlorine), transport into sediments (e.g., heavy metals), ingestion/uptake by flora and fauna, and dispersion/dilution. Most chemical concentrations of pretreatment residuals in concentrate are relatively low, but may eventually amount to heavy loads from the large concentrate volumes produced (World Bank, 2004).

A major factor in determining the level of impact is the receiving water condition. From both simulations and measurements of discharges in waters of limited mixing, the concentrate discharge forms a distinct mass characterized as a plume that originates at the discharge outlet and grows and disperses away from the outlet in the direction of net receiving water movement. The concentrate is of higher salinity and higher density and thus negatively buoyant. The plume sinks and spreads along the seafloor, affecting the less mobile benthic organisms. The extent to which this will occur is dependent on the depth of the seafloor relative to the sea surface, the density of the concentrate, and the mixing/dispersion conditions of the receiving water. In a high-energy deep receiving water, impacts will be minimized. In a low-energy shallow receiving water, impacts will be magnified, potentially precluding successful permitting of this option. Residuals can be safely returned to the ocean as long as there is rapid mixing of the residuals with ambient ocean water.

This has successfully been accomplished in two different ways: co-discharge with a discharge from a power plant or WWTP, and use of diffusers at the end of the discharge pipe to provide accelerated mixture of discharge with the ocean water.

8.5.2 Co-Discharge

Co-discharge of concentrate from SWRO with seawater power plant cooling water can significantly reduce the salinity at the outfall. If the power plant is medium-sized to large and the desalination plant is not enormous, the flow of the power plant's cooling water can greatly exceed that of the desalination plant. Consequently, high dilutions of concentrate can be achieved with spent cooling water.

> **Example:** *Tampa Bay Desalination Plant:* Cooling water flow is 1400 mgd and desalination withdrawal from the cooling water is 44 mgd. The water is from Tampa Bay. Thus, the ratio of cooling water to concentrate in the discharge is 1356 to 19 mgd, offering a dilution ratio of more than 70:1. Salinity of the Bay varies by more than 100%. Assuming 50% recovery and a mean salinity of 22.5 ppt, the concentrate after dilution with cooling water would have a salinity of 22.8 ppt or less than 300 mg/L above the average salinity of the receiving water.

Benefits from co-location of discharges include

- use of the same existing outfall structure
- reduction of the salinity of the desalination discharge through mixing and dilution with power plant or WWTP discharge
- possible reduction of the need for treatment of concentrate to reduce the contaminant level resulting from the dilution effect

Co-location has other benefits, such as use of an existing energy source and shared infrastructure. Because of these substantial benefits, co-discharge with a power plant has been the favored approach in seawater plants in the United States and is exemplified by the Tampa Bay desalination plant in Florida and designs for the Carlsbad facility in California.

Although there are logical reasons to locate desalination facilities next to power plants, power plants are under pressure to eliminate their use of “once through” cooling water, which requires large amounts of water intake. The concern is with destruction of marine organisms through “impingement,” which refers to trapping or killing of larger animals on intake screens, and “entrainment,” which refers to passage of smaller organisms through the screens and their subsequent deaths in power plant or desalination systems.

Power plants may be required by the U.S. EPA or state agencies to recirculate cooling water to reduce the amount of seawater intake and fish kill. Some power plants may convert to an air cooling system that uses no water. If these changes take place, it may no longer make sense to locate desalination plants next to power plants (BEACHAPEDIA, 2010). Such changes could end the co-location of desalination plants with power plants.

Co-discharge has also taken place with WWTP ocean discharges. In this case, the independent desalination plant only shares an existing outfall system with the WWTP. Although volumes of WWTP effluent are not as large as cooling water volumes, the low salinity of WWTP effluent results in greater dilution of the desalination concentrate. By a 2008 law, the construction of new ocean outfalls for WWTP effluent is prohibited in the South Florida Water Management District. The law also provides priority funding consideration for projects that implement reuse as a means of eliminating ocean discharge (Florida House of Representatives, 2008).

8.5.3 Outfall Diffusers

Another method of reducing local increase in receiving water salinity is to discharge the concentrate over a very large area, so that there is only a slight increase in salinity in the immediate region. For example, once the pipeline containing the concentrate reaches the seafloor, it can split off into many diffuser branches, each releasing the concentrate gradually along its length through small holes.

Detailed modeling of the discharge into the receiving water is typically done to estimate dispersion and dilution patterns for both the near field (immediate vicinity of the outfall where strong initial mixing occurs) and far field (where receiving water conditions predominate). Programs such as CORMIX (MixZon, Inc., 2010) and PLUMES (PLUMES, 2010) provide 2-dimensional flow modeling. Sophisticated 3-dimensional modeling (i.e.,, computational fluid dynamics modeling) is sometimes used for far-field simulation. Such modeling is particularly necessary for enclosed areas such as bays and estuaries, but is also helpful in determining dispersion patterns in more open coastal areas, where tides and storm activity can influence them.

8.5.4 Shallow Injection Wells and Subsurface Conveyance and Disposal

Another environmental impact from ocean discharge is the laying of pipeline and outfall structures in the ocean, which disturbs the local seabed environment. Surface or shallowly buried pipes can be at risk of storm damage during construction and operation. Some local environments have high visibility, which also creates significant design constraints.

Shallow subsurface disposal of seawater concentrate is an emerging area of development. Although conventional shallow vertical beach wells used for concentrate discharge have shown mixed success, subsurface disposal of seawater concentration holds potential for environmental and cost benefits in eliminating the costly and complex diffuser systems (Voutchkov, 2009).

A possible solution to this challenge has been implemented at the 33-mgd Gold Coast Desalination SWRO project near Brisbane, Australia.

> **Example:** *Gold Coast Desalination Project, Australia:* Lined tunnels of internal diameter 2.8 m were dug and extended about 1.6 km offshore into water depth 20 m. One tunnel was for intake and one for discharge. Twin 10-m-diameter vertical shafts connect the tunnels to the land surface at the plant site. The two independent horizontal tunnels are 2 km (discharge) and 2.2 km (intake) in length. Vertical risers of internal diameter 2 m lead from the end to the horizontal tunnels to the water above. An outlet diffuser manifold consists of a 287-m-long seabed pipeline with 14 outlet nozzles 250 mm in diameter. The diffuser design was validated using computer modeling. The design offers the advantages of minimizing surface works and thus of avoiding disruption and environmental impacts while providing a more sustainable long-term system. This represents the first time this approach has been used in a large-scale SWRO plant. The approach has since been adopted for the Sydney Desalination Project and has been proposed for the Melbourne Desalination Project.

8.5.5 Flora and Fauna

The following sections discuss the environmental concerns associated with source water, chemicals used in desalination treatment, and chemicals used in membrane cleaning—all of which may be present in concentrate and may affect flora and fauna in the receiving water.

8.5.5.1 Concerns Associated with Raw Water Quality

Seawater is much more uniform in salinity and composition than inland brackish water. It is usually less influenced by contaminants from human activities, with the possible exception of ocean discharges of effluent from WWTPs. As a reflection of general concerns with WWTP discharges, in 2011 California will require monitoring of nutrient levels in WWTP ocean discharges. Care must be taken in siting SWRO facilities with regard to relative proximity to pollutant sources because of possible effects on flora and fauna.

8.5.5.2 Concerns Associated with Chemicals Introduced in Desalination Processing

Flora and fauna may be affected by residuals/chemicals added during pretreatment of seawater that may end up in concentrate. These include

- chorine (to mitigate bioactivity)
- coagulation chemicals (such as $FeCl_3$, $Fe_2(SO_4)_3$, or organic polymers)
- acid (to prevent scale formation)
- scale inhibitor (antiscalants/dispersants to prevent scale formation)
- sodium bisulfate (for dechlorination)

Chemicals from pretreatment typically include antiscalants/dispersants added to inhibit precipitation of sparingly soluble salts and silica onto membrane surfaces. Acid may be used to reduce the potential for carbonate scaling. The antiscalants/dispersants add synthetic chemicals to the raw water whereas the acids, typically sulfuric acid or hydrochloric acid, other than impurities present, add only major ions and reduce the pH of the raw water. In cases of pretreatment involving coagulants and/or flocculants, a soluble fraction of the coagulants/flocculants, and the resulting complexes, may remain in the concentrate. When disinfectants are added to mitigate biofouling, some of the chlorine will be present in the concentrate unless a dechlorination step is also part of the pretreatment process. For instance, where sodium bisulfite is used for dechlorination, aside from impurities, only sodium, sulfate, and chloride will be added to the concentrate. The primary concerns are not with added major ions, but with synthetic chemicals and residuals remaining after filtration of the effluent from the coagulation/flocculation step.

Because of the distribution of carbonate species as a result of reverse osmosis processing, concentrate pH is typically slightly higher than feed pH. When acid is added during pretreatment, concentrate pH may still end up being lower than required for discharge. In this case the concentrate may need to be neutralized prior to discharge. Neutralization will also serve to reduce the corrosive nature of concentrate, which may be of concern in pipeline conveyance of concentrate to the discharge site.

8.5.5.3 Concerns Associated with Cleaning Chemicals

Most frequently, spent cleaning chemicals are disposed by discharge to sewers. In some cases, however, they are combined with concentrate for disposal. The cleaning chemicals remove foulants that cause loss of membrane performance. The cleaning residuals include the spent cleaning solution and the materials removed from the membrane system during cleaning. Many cleaning solutions contain proprietary chemicals to optimize cleaning efficiency. The cleaning solutions may be diluted with rinse water and may contain detergents, surfactants, acid, caustic, or other chemicals. The spent cleaning solution volume is typically a very small percentage of the treated flow (less than 0.1%). Material removed from the membranes and part of the spent cleaning solution may include inorganic salts, metal oxides, silt, silica and silicates, and biofilms and organics (Malmrose, 2004).

Spent cleaning solutions may have to be handled separately from concentrate.

8.5.6 Human Health

Regulations have been developed considering environmental impacts on both human health and flora/fauna. Humans are more sensitive to some contaminants and flora/fauna to other contaminants. Water quality standards are set to protect the most sensitive species.

Receiving waters are classified according to potential uses; some classifications include recreation activities. In general, humans can be exposed to contaminants through direct contact and also by eating fish and other water species from the receiving water. All of these factors are taken into consideration in developing water quality standards. The same concerns discussed in the previous section apply in this section.

8.5.7 General Comments

Discharges from SWRO plants with beach well intakes may need to be aerated to increase the level of DO prior to discharge. Similarly, DO in SWRO concentrate may be low because of use of dechlorination chemicals and require aeration. Co-discharge may serve to raise DO levels, as the other discharges may have addressed the DO requirement in a way sufficient to result in an adequate co-discharge DO level.

8.6 Regulatory Basis

The CWA federal framework for discharge to the ocean is the same as that for discharge to inland waterways. States may choose to implement guidelines in different ways and to have more stringent regulations. In California, discharge to open ocean is subject to different regulations than discharge to inland waterways, estuaries, and bays. In Florida, discharge to ocean and estuaries is under the same regulation.

The same general concerns and regulatory constraints, however, apply to both inland and ocean discharges and include

- regulation based on compatibility of concentrate with receiving water (salinity and individual constituents)
- receiving water standards based on its use classification
- discharge standards as defined by
  - numeric limits for specific constituents and parameters
  - whole effluent toxicity test requirements
  - meeting biological diversity parameters
  - TMDLs
  - anti-degradation rule

Regulation of large-volume seawater desalination concentrate to the ocean is a relatively new challenge to the U.S. EPA and the states. The large plant sizes and the potential impact on coastal areas make projects more visible and of greater public concern than with inland desalination plants. Although the primary environmental concern originally was with concentrate discharge, it has more recently shifted to the effects of water intake systems on sea life.

8.7 Impact of Concentrate Salinity

Concentrate salinity and concentration of constituents are dependent on raw water quality, pretreatment processing, membrane system performance, and any additional treatment and/or blending prior to discharge. With some exceptions, recovery from seawater RO systems ranges from 30 to 60%. Thus, for instance, for feed water of 35,000 mg/L the concentrate would range from 50,000 to 88,000 mg/L. Consequently, SWRO concentrate salinity is generally greater than inland concentrate salinity, except for inland cases where high-recovery processing might be applied.

The impact of concentrate discharge salinity to the receiving water is an important consideration. Marine species differ in their mobility and ability to move away from discharge regions. Seafloor benthic organisms are the most vulnerable. Marine life can adapt over time to changes in salinity. In estuaries, flora and fauna have adapted not only to large seasonal variations in salinity, but also daily tidal conditions. Higher salinity concentrates are typically discharged close to the receiving water salinity.

Salinity limits account only for the salt content (TDS) of the concentrate and salinity tolerances are specific to the particular organisms in the area of discharge. Federal and state laws in the United States regulate concentrate salinity indirectly through establishing site-specific/project-specific acute and chronic WET standards. WET is a comprehensive measure of the environmental impact of the discharge as it accounts for synergistic impacts of salinity and composition of the concentrate and thus WET limits are arguably more appropriate for regulating salinity than general salinity limits.

8.8 Impact of Concentrate Composition

Concentrate composition is dependent on raw water quality, pretreatment processing, membrane system performance, and any additional treatment and/or blending prior to discharge.

As mentioned in Section 8.5.6, concentrate may be composed of

- constituents found in raw water; at higher concentrations depending on the membrane system performance
- trace elements peculiar to the site-specific feed water (this is generally a minor consideration for seawater)
- residuals from pretreatment, cleaning, antiscalants, As, Se, heavy metals, weak acids, detergents, and un-reacted chemicals from pretreatment

The relative concentrations of constituents of seawater are fairly uniform. Similarly the relative concentrations of raw water constituents in concentrate are fairly uniform with concentrations depending on system recovery. Variation in constituents is mostly due to added chemicals such as antiscalant, cleaning chemicals, and residuals from pretreatment steps. As with inland surface water discharge, care must be taken to minimize that the effect of added chemicals on the receiving water.

Typically, the composition of seawater-based concentrate varies less than that of inland concentrate because of significantly less variability in the feed water composition and in the processing steps. As previously discussed, the environmental impact of seawater concentrate on the receiving water depends not only on the composition of the concentrate, but also on the receiving water conditions and the specific means of discharge. The effect of concentrate composition on discharge feasibility may be less significant than for these other factors.

8.9 Screening-Level Evaluation

8.9.1 Discharge to Ocean

Feasibility of ocean discharge may be less of an issue with concentrate salinity and composition than it is with the location of the SWRO facility. An exception is when source waters warrant special attention, such as with elevated concentrations of B, Br, and Fe. These species affect pretreatment and treatment choices, but may also cause increased concern with ocean discharge. The location affects the co-discharge options, the classification of the immediate ocean region, the general nature or activity of the receiving water (water turnover, tidal effects, etc.), and the relative probability of presence of sensitive aquatic species or habitats.

Important parameters to define at the screening-level evaluation stage to allow assessment of the potential feasibility of ocean discharge include

- location-specific chemistry of raw water
- projected composition of concentrate discharge
- concentrate volume
- general plant location
- possible co-discharges
- possible outfall sites
- possible subsurface conveyance and discharge sites
- presence of fauna and flora that are given higher levels of environmental protection by regulatory agencies

For SWRO plants, there can be several agencies involved in permitting the desalination facility in general, and in permitting various aspects of concentrate discharge. It is important to identify and begin interactions with the appropriate regulatory agencies early in the planning process. Relative to the agency granting NPDES permits, the agency can provide information as to

- any NPDES permits granted to desalination plants in the region
- the classification of potential receiving waters and whether a surface water discharge would be considered for these receiving waters
- what the major limiting parameters are for discharges to these receiving waters

- based on volume, salinity, and major ion estimates of the concentrate, whether surface discharge might be possible and what receiving waters/segments might be best to consider
- pertinent regulations and agency screening protocols for evaluating potential discharges
- all regulatory issues associated with getting concentrate from the desalination plant to a discharge point in the ocean

The state agency overseeing industrial NPDES permitting should be provided with the best available concentrate water quality and volume estimates and asked to perform screening calculations to render an opinion as to the possibility of surface water discharge.

It is important at the screening stage of evaluation to fully understand how the state determines discharge feasibility, to separately perform the same calculations to be able to evaluate the impact of different water qualities and treatments on discharge feasibility, and to obtain initial indications of discharge feasibility, based on limited concentrate characterization from the NPDES permitting agency.

8.9.2 Discharge to Brine Lines—Inland Concentrate

Evaluating feasibility of discharge of an inland concentrate to a brine line that takes multiple discharges is relatively simple. Feasibility depends primarily on whether capacity is available and if so, what costs are involved. The primary cost is based on volume of concentrate. Other costs may include treatment of concentrate prior to conveyance to the brine line to meet requirements established for the brine line. These can be for parameters such as pH, TSS, and some constituents. Another cost can be conveyance of concentrate to the brine line.

During the screening-level evaluation stage, interaction with the brine line operating and permitting groups can determine if (and under what conditions) concentrate can be disposed of to the brine line. This analysis should be based on the best available estimates for concentrate volume and water quality.

8.10 Planning Phase—Preliminary-Level Evaluation

Of all the concentrate disposal options, discharge of SWRO to the ocean requires the most information collection during the early stages of the planning phase. Information required includes oceanographic information: tides, currents, bathymetric survey, and marine biological survey. Much of this information is used in dispersion modeling of the discharge and receiving water interaction. There is a particular concern with discharge to enclosed waters (bays and estuaries) where there is a greater chance for constituents to accumulate.

Once a discharge site has been selected with sufficient certainty, it is important to begin extensive and detailed baseline monitoring of the receiving water conditions. This will provide the basis for demonstrating compliance and lack of impacts when the desalination plant is operating. These data are also required for detailed dispersion modeling of the proposed discharge that will support definition of an appropriate discharge system to achieve lack of impacts. Together the baseline monitoring and modeling effort will also be the basis for addressing stockholder concerns.

Example: *Tampa Bay Desalination Modeling Effort*: The 25-mgd Tampa Bay SWRO desalination co-discharges concentrate along with TECO Bid Bend Station power plant discharge into Tampa Bay. Extensive modeling of the circulation and dispersion in the bay was conducted to estimate biological impacts of the proposed discharge. Dr. Mark Luther of the University of South Florida conducted farfield circulation to determine flushing of the bay. Mote Marine Laboratory and the Danish Hydraulic Institute performed salinity studies based on actual salinity obtained during the 2000–2001 drought. Factors considered included bathymetry (water depth measurement), freshwater inflow, rainfall, evaporation, salinity, wind, tides, and recirculation. These, coupled with worst-case scenario data for power plant operations, were used to estimate potential long-term changes in salinity. Hillsborough County funded its own independent, similar study. The results of the studies suggested that the marine ecology of areas of major biological concern would not be affected by the desalination facility operations (Tampa Bay Water, 2003). Based on these studies and other information provided to the FDEP, an NPDES permit was eventually granted. Because of the lack of U.S. experience and data on environmental effects of SWRO discharges, the permit included a major monitoring program. A 2009 report (PBSJ, 2009) analyzing hydrobiological monitoring data from 2005–2008 concluded that "the data collected to-date suggest that the desalination facility's effects on salinity in the Bay are consistent with those predicted in the initial design and permitting process, and no adverse impacts to biological communities have been documented."

8.10.1 Surface Water Discharge—Before Piloting

At this stage of consideration,

- concentrate water quality and flows should be well-defined
- water quality standards for potential discharge sites should be identified
- regulatory protocols for determining discharge feasibility should be understood and used to independently (from the regulatory agency) estimate discharge challenges

Further interaction with the regulatory agency is necessary to

- provide more exacting characterization of the concentrate (volume, composition)
- review data and calculations with the regulatory agency for their comment
- determine
  - what, if any, water quality parameters might be limiting
  - confirmed estimates of the effect of changes in volume and composition on meeting water quality standards
  - what data are required on the permit application (and thus what data need to be obtained from the pilot studies)
  - the path and the estimated time it will take to get feedback on the permit applications and to get an approved permit
  - the presence of highly protected ecological communities, threatened and endangered species, and cultural or archeological resources to avoid during siting evaluations

Further interaction with other agencies having a say in the implementation of surface discharge is necessary to make sure all permitting issues have been identified and addressed. This includes identifying and addressing environmental issues associated with construction of possible conveyance and discharge systems.

Cost estimates at this stage should reflect that

- all cost factors have been identified
- all cost factors have been evaluated and have been assigned costs suitable to the accuracy required for this stage evaluation
- sensitivity of each cost factor to changes in concentrate water quality and volume are evaluated
- less defined parameters are identified for future focus

8.10.2 Surface Water Discharge—After Piloting

Analysis and testing of concentrate from the pilot tests should provide the more accurate and precise data required to for a discharge permit application. This includes a more comprehensive water quality analysis of the concentrate and any toxicity test results that may be required.

The concentrate characteristics (volume, composition, other parameters) may be different from those used in previous interactions with the regulatory agency, and these need to be reviewed to determine possible effects on discharge feasibility.

8.10.3 Discharge to Brine Lines—Inland Concentrate

If discharge of inland concentrate to a brine line was short-listed, then after desalination piloting, any changes in concentrate characteristics should be reviewed with the brine line permitting agency to confirm feasibility and determine final cost estimates.

8.11 Summary

There are several examples from Florida and California of the many challenges associated with discharge of SWRO concentrate to the ocean. There can be several different agencies having jurisdiction over various aspects of getting concentrate from the desalination plant and into the ocean. The examples reflect the cautionary approach being taken with large-scale SWRO plants, which are relatively new to the United States. Extensive fluid flow and dispersion modeling efforts to support discharge have been conducted at both the Tampa Bay and the Carlsbad sites. A significant amount of monitoring at the Tampa site was required as part of the discharge permit.

As with all the CM options, it is important to begin interaction with regulatory agencies very early in the consideration of discharge of SWRO concentrate to the ocean. Lack of agency staff familiarity with SWRO amplifies the need for early coordination efforts.

Chapter 9

Discharge to Sewers

9.1 Description

Discharge of concentrate to a sewer means that concentrate will be processed along with other wastewater influent to the municipal WWTP. The CM option includes

- discharge to an existing sewer line (shared with other discharges)
- discharge to a dedicated sewer line (direct line to WWTP)
- discharge to a brine line (a dedicated pipeline that conveys inland wastewater first to a WWTP for eventual discharge to the ocean)

Although most brine lines convey wastewater directly to an ocean outfall, some convey wastewater to a coastal WWTP prior to ocean discharge.

9.2 Historical Use

About 24% of municipal desalination plants in the United States discharge concentrate to sewers (Mickley, 2006 and present project survey). Currently, 27 of 33 states having municipal desalination plants utilize this option. Use of this CM option decreases significantly as the volume of concentrate increases because of impacts of concentrate on the WWTP.

Brine lines have been in existence in California for several years. Much of their flow is by gravity, taking advantage of the natural topography. The use of shared conveyance and outfalls represents a significant savings in cost relative to a dedicated pipeline and outfall.

9.3 General Feasibility Factors—Site Requirements

Feasibility of discharge to a sewer depends on whether the WWTP can handle the impact of volume and salinity/composition on its operation. The impact increases as the volume and salinity of concentrate increases and the capacity of the WWTP decreases. Specific factors to consider include

- for discharge to an inland WWTP:
  - reasonable proximity of discharge point to the desalination plant
  - sufficient WWTP capacity relative to concentrate volume to minimize impact of concentrate on WWTP
  - permission/agreement with the WWTP to discharge to the sewer
  - (possible) treatment of concentrate prior to discharge.
- for discharge to a coastal WWTP via a brine line:
  - reasonable proximity to brine line or feeder line
  - sufficient line capacity

- contract with the entity operating the brine line
- (possible) treatment of concentrate prior to discharge

As with discharge to surface water, feasibility depends on the compatibility of the concentrate with the WWTP influent in terms of salinity, concentration of constituents (i.e.,, nitrogen), and volume. Although concentrate composition is also important, it is usually not well-defined at the general feasibility study stage. If discharge to a sewer becomes short-listed as a potential CM option, the composition compatibility of the concentrate with the WWTP operation can be addressed then. More detailed consideration of the impact of concentrate on the WWTP is given in Section 9.5.

Details of how to evaluate the feasibility of discharge to a sewer are discussed in Sections 9.9 and 9.10.

9.4 Major Cost Factors

9.4.1 Planning Phase Costs

As with all CM options, there is a cost associated with the effort to determine feasibility. Efforts at this level include

- characterization of the concentrate volume, salinity, and composition
- initial estimation of possible effects of volume and salinity on the WWTP inflow, outflow, and treatment processes
- interaction with the local WWTP to determine receptiveness to further consideration of the option and a path to further evaluate its feasibility
- more detailed evaluation of feasibility if discharge to the sewer is short-listed as a possible option (see Sections 9.9 and 9.10)

In the case of discharge to a brine line, the efforts may include

- characterization of the concentrate volume, salinity, and composition
- interaction with the owner/organization regulating and controlling discharge to the brine line to determine if discharge is a possibility
- more detailed evaluation of feasibility if discharge to the sewer is short-listed as a possible option (see Sections 9.9 and 9.10).

9.4.2 Capital Costs

Capital costs may include

- piping and pumping costs to the sewer or brine line, a function of the distance of the sewer line (or WWTP) or brine line from the desalination plant
- a possible one-time fee for purchasing capacity at the WWTP or brine line
- possible costs associated with treatment of concentrate to meet discharge requirements

9.4.3 Operating Costs

Operating costs may include

- a monthly charge based on characteristics of the concentrate (such as volume, salinity, organic load, level of suspended solids)
- energy costs associated conveyance of the concentrate to the sewer, WWTP, or brine line
- operation and maintenance costs associated with treatment of the concentrate prior to discharge

Discussion of design factors and preliminary-level cost models for discharge to the sewer is available (Mickley, 2006).

9.5 Effects of Concentrate on Wastewater Treatment Plant Operation

Discharge of concentrate to a sewer can affect WWTP operation and WWTP discharge. Only the second effect represents a health and environmental impact.

Desalination concentrate can affect salinity and composition of the feed flow to the WWTP depending on both the volume and the composition of the concentrate relative to that of other influents to the WWTP. Typically, concentrate represents a higher salinity sewer discharge. Increased salinity and changing composition of influent to the WWTP can affect the state of microorganisms in the digestion and activated sludge process steps. Microorganisms can adapt to modest changes in salinity over time and, if concentrate disposal to the sewer is otherwise a feasible option, gradually raising the influent pH over a period of time can facilitate implementation of this option. More specifically (Rimer et al., 2008), the higher salinity and different composition of concentrate can

- inhibit the biological treatment process
- affect settling by changing wastewater density
- aggravate corrosion in the collection system piping and treatment plant process equipment

Increased salinity and composition can also affect the effluent salinity and composition from the WWTP and thus their NPDES discharge permit. In this case, discharge to the sewer represents an indirect discharge to surface water and raises the same environmental concerns associated with direct discharge to surface water (see Chapter 7). According to Rimer et al. (2008), higher salinity and different composition of concentrate can

- increase aquatic toxicity (which may limit the options for surface discharge or reuse)
- result in the effluent being out of compliance with the WWTP's NPDES permit

Higher salinity discharges to a sewer can also impact the suitability and cost of treating the WWTP effluent for reuse. Contaminants in concentrates could also limit biosolids land application.

No concentrate discharge permit is required, but the discharge must be agreed to by the WWTP. U.S. EPA has developed guidelines for establishing local ordinances including those for industrial users that include municipal desalination facilities. Each WWTP must set local limits based on site-specific conditions that include the efficiency of the treatment process, history of compliance with their NPDES permit, the water quality standards applicable to the receiving water and biosolids handling (U.S. EPA, 2005). Concentrate must meet the WWTP's pretreatment requirements.

9.6 Regulatory Basis

Municipal desalination concentrate is classified as an industrial waste under the CWA, and under the U.S. EPA Pretreatment Program it may be required to meet WWTP standards for sewer discharge. Concentrate affects the wastewater treatment effluent and thus the plant NPDES discharge permit, if it discharges to a surface water. Generally, no desalination plant permit is required for discharge to a sewer, but permission is needed from the wastewater treatment plant, and it may enforce treatment requirements under the Pretreatment Program.

Feasibility of discharge to the sewer comes down to a decision on the part of the WWTP on whether to accept the discharge. Discussion of more specific regulations is provided in Rimer et al. (2008).

9.7 Impact of Concentrate Salinity

Concentrate from BWRO and EDR systems typically have salinities greater, and sometimes much greater, than the WWTP influent flow. The potential impact of salinity (described in Section 9.5) depends on the volume of concentrate relative to that of the other inflows to the WWTP.

Concentrate from NF processes has lower salinities than BWRO concentrate. NF concentrate may be sent directly to the WWTP or it may be combined with WWTP effluent and used for irrigation. High salinity concentrate from SWRO processes are generally too high a volume for consideration to discharge to the WWTP.

9.8 Impact of Concentrate Composition

9.8.1 Concentrate from Brackish Reverse Osmosis or Electrodialysis Reversal Systems

Concentrates typically have low levels of organics because of low feed water levels, feed waterwhich are required to limit organic fouling of membranes. Concentrate can have high levels of nutrients, particularly where desalination is used to reduce nitrate levels. As with any industrial discharge to sewers, the discharge water quality should be carefully examined for possible effects on the WWTP operation, including how the concentrate composition may affect the WWTP's effluent NPDES permit. A good reference for these considerations is Rimer et al. (2008).

Concentrate discharge to a sewer may have positive benefits where concentrate and other influents offer dilution of each water's content. There may be other benefits.

> **Example:** *Waynesboro, Pennsylvania small 0.36 NF plant:* The NF treatment is for hardness, with the concentrate discharged to the sewer without treatment. The concentrate buffers other water incoming to the WWTP, which is soft; this allows better pH control.

9.8.2 Concentrate from Other Treatment Processes

The same considerations apply to NF concentrate. The volume of high-salinity concentrate from SWRO processes is generally too great for consideration of discharge to a WWTP.

9.9 Screening-Level Evaluation

9.9.1 Discharge to Inland Wastewater Treatment Plant

Feasibility factors that can be addressed at the early general-feasibility stage are discussed in this section. The primary factors include

- relative volumes of concentrate and WWTP capacity
- relative salinities of concentrate and WWTP influent water
- composition of concentrate
- whether the WWTP has or is planning reuse of effluent
- distance and terrain between desalination plant site and discharge site

It is helpful to begin a dialogue with the local WWTP early in the planning process to determine if the WWTP is open to consideration of taking concentrate. Because this CM option is handled by the local WWTP, as opposed to a state or regional regulatory group that may have already handled similar applications, the WWTP's process may be less defined than those of regulatory groups. The decision to accept concentrate may be based on a more qualitative evaluation of the perceived effect on WWTP operation. There have been cases where a WWTP has set an impossibly high disposal fee to discourage further consideration of this CM option, presumably as a means of avoiding political and legal issues regarding other potential dischargers. In cases where the WWTP is owned by the same entity as the proposed desalination plant, this negotiation and option is simpler to evaluate and may have been reviewed at a very early stage in water management planning.

The most obvious potential limitation is the capacity of the existing WWTP. Limited capacity may rule out discharge of concentrate to a sewer. Other possible limitations have to do with concentrate composition and other parameters such as pH.

Other issues to be evaluated include the effect of the discharge on the WWTP treatment operation and the effect on the WWTP's NPDES permit (assuming WWTP effluent is being discharged to surface water, the most common situation).

The WWTP's criteria for industrial discharges should be obtained to provide a starting point for evaluation. Concentrate characteristics (including salinity, composition, and pH) provide data for consideration by the WWTP. At this stage of evaluation, concentrate characteristics may be defined only in a limited way, without identification and concentrations of pollutants of concern. Thus, a more detailed evaluation of feasibility will need to wait until a more extensive concentrate water quality estimate or data are available.

In most cases, discharge of concentrate to the WWTP will increase salinity, and this and composition changes can affect the WWTP's NPDES permit. The concentrate discharge can also impact the suitability of the effluent for reuse.

As with surface water discharge, the distance and terrain between the desalination plant and the sewer discharge site become conveyance cost issues.

Concentrate resulting from high-recovery processing may be less suitable for sewer discharge. Although the reduced volume will have less impact on the capacity of the WWTP, the salt load is approximately the same as with a lower-recovery concentrate. The net effect is to have a slightly greater impact on the salinity and composition of the WWTP influent, and thus a greater impact on the WWTP system in general.

Cost factors are listed in Section 9.4. The major cost factors for consideration at the screening-level evaluation stage are the conveyance of concentrate to the site of discharge, the possible treatment of concentrate required for discharge (dictated by the WWTP), and a possible capacity/treatment fee imposed by the WWTP. Typically, costs are less and securing of the management option is simpler when the desalination plant and the WWTP are owned by the same entity.

9.9.2 Discharge to Coastal Wastewater Treatment Plant via a Brine Line

Brine lines convey inland effluent to coastal water. Several brine lines exist in California, where advantage can be taken of gravity flow from the higher inland elevations to the coast. Brine lines can take a range of effluents including desalination concentrate, domestic and commercial wastewater, and ion exchange regenerant.

Unless brine lines take domestic wastewater, most discharge directly to the ocean (see Section 7.10.2). The lower reaches of the SARI line, operated by the Santa Ana Watershed Project Authority, collect sewage and the entire flow goes through Orange County Sanitation District Plant II prior to being discharged to the ocean. The same situation occurs with the upper basin brine discharges to the Non-Reclaimable Water System (NRWS) brine lines, NRWS (N) and NRWS(S), operated by the Inland Empire Utilities Agency. The NRWS(S) line joins the SARI line; the NRWS(N) line becomes a trunk line to the Carson JWPCP WWTP prior to ocean discharge.

Interaction with the brine line owner/operator/regulators needs to take place early in the planning effort to determine if the line has the capacity for additional discharge and, if so, what capacity and operating and maintenance costs are involved and what the discharge requirements are.

Costs may include

- capacity buy-in costs (one-time)
- various operating costs per mgd discharged for
  - flow
  - BOD
  - TSS
  - others
- pipeline maintenance

Brine line requirements for BOD (biological oxygen demand), TSS, pH, and other concentrate characteristics may need to be met by treatment of the concentrate prior to discharge.

9.10 Preliminary-Level Evaluation

9.10.1 Discharge to Inland Wastewater Treatment Plant

If discharge to the sewer or brine line has been short-listed, it likely means that concentrate volume (more correctly, the WWTP capacity or brine line capacity) is not an issue. The next level of evaluation will require a more detailed consideration of pollutants of concern. This information likely is not available at the screening-level stage of evaluation. WWTP experience with the regulation of membrane concentrates, backwash water, and waste chemical cleaning ages is still very limited (Rimer et al., 2008) and permit limits can vary widely. Where possible, the concentrate impact on WWTP effluent can be estimated in terms of TDS increase and increases in individual constituents. Results of the hypothetical blended waters can then be compared to existing NPDES permit limits. Other limits may be imposed because of their effects on WWTP operation; limits may focus on the corrosiveness of RO concentrate, high and low pH, high salinity, heavy metals, and possibly high nutrients (specifically nitrogen).

At this stage, all information required by the WWTP for a decision should be provided and an agreed-upon path and schedule for reaching a decision should be mapped out.

Concentrate composition prior to the pilot plant results will be based on a detailed analysis of raw water. As discussed in Chapter 4, accurate characterization of raw water evolves with the project phase. Thus, the accuracy of the concentrate characteristics that can be provided to the WWTP for consideration also evolves with time. The most accurate information available at any time should be provided to the WWTP to get as much of an evaluation as possible. It may be possible for the WWTP to render a decision based on information available before the pilot plant stage.

At this stage of consideration, disposal fees based on the volume and chemical parameters of the concentrate can be used, along with the best estimates of concentrate parameters to estimate costs.

9.10.2 Discharge to Coastal Wastewater Treatment Plant via a Brine Line

Formal agreements for discharge to a brine line, including any treatment requirements and all costs, should be settled prior to the construction phase. In addition, final plans for meeting conveyance needs to get concentrate to the brine line or a feeder line should be settled, including right-of-way issues, general pipeline and pump design, and capital and operating and maintenance costs.

9.11 Summary

Discharge of concentrate to a WWTP may be by sewer or by a dedicated pipeline or brine line to the WWTP. The major limitations are the possible impact of the concentrate volume, salinity, and composition on WWTP capacity and operation. The impact can be considerable, and therefore this CM option has been used mostly for smaller-volume concentrates. It has been used historically for approximately 25% of -municipal desalination concentrates in the United States. The discharge of concentrate can limit reuse possibilities of WWTP effluent and biosolids.

Chapter 10

Subsurface Injection

10.1 Description

Subsurface injection wells include both deep wells (used for inland concentrate) and shallow wells (such as beach wells used for seawater desalination concentrate). The vast majority of injection sites for municipal desalination concentrate disposal are inland deep wells.

Deep injection wells are a disposal option in which liquid wastes are injected into porous subsurface rock formations. The aquifer/rock formation receiving the waste must possess the natural ability to contain and isolate it.

Paramount in the design and operation of an injection well is the ability to prevent movement of wastes into or between underground sources of drinking water. Injection wells may be considered a storage method rather than a disposal method; the wastes remain there indefinitely if the injection program has been properly planned and carried out.

Because of their ability to isolate hazardous wastes from the environment, injection wells have evolved as the predominant form of liquid hazardous waste disposal in the United States (U.S. EPA, 2010c). Industrial deep injection wells in the United States are used for injection of hazardous and nonhazardous wastes. Although RO concentrate is rarely classified as hazardous, injection wells are widely used for domestic wastewater and concentrate disposal in the state of Florida.

Depths of wells typically range from 1000 to 8000 ft. Injection of concentrate represents permanent loss of potential water and mineral resources (unless accessed in future when appropriate technologies permit).

10.2 Historical Use

As of 2010, about 16% of municipal desalination plants in the United States disposed of concentrate to deep wells (Mickley, 2006 and present survey). Although other states are increasingly exploring the use of DWI for municipal desalination concentrate, as of 2010, only Florida, California, Texas, Colorado, and Kansas have such wells. Florida is the only state having more than one well. The preponderance of wells in Florida is due to a confluence of factors including population growth, dependence on groundwater, proliferation of municipal desalination plants, near-ideal hydrogeological conditions for DWI, historical use of DWI for disposal of WWTP effluent, and the presence of NORMs (rendering the concentrate hazardous) in some southwestern Florida locations.

Because of significant front-end feasibility determination costs, DWI is not usually cost-effective for small plants. DWI use increases significantly with plant size.

Until recently, the classification of municipal desalination concentrate as an industrial waste restricted concentrate disposal to Class I deep wells, the same classification that applies to injection of hazardous waste. Class I wells have design requirements beyond those of other well classifications. The design includes concrete covering of all well casing down to the injection zone, as well as a tubing and packer arrangement for monitoring for well leaks from the injection tubing. An annular space between the innermost casing and the injection tubing is filled with fluid, whose conductivity is monitored for indication of leakage from the injection tubing. The packer is the means of isolating the annular fluid from the injection fluid at the bottom of the casing string.

There are fewer than 50 Class I wells in the United States that are used for municipal CM. As of 2006, the U.S. EPA Well Inventory lists 549 Class I wells in the 50 states for all Class I injections (hazardous, nonhazardous, and municipal wastewater)—see Table 10.1. Municipal concentrate is included in the nonhazardous category. The municipal wastewater wells are in Florida, and the well designs do not require a tubing and packer arrangement. The successful operating history of large municipal disposal wells in Florida, together with some of the best geological conditions in the country and the need for economical disposal options for large quantities of membrane concentrate, prompted Florida utilities to seek permission to use municipal wells for disposal of concentrate (Mickley et al., 1993). Because of the significant difference in the types of water being injected, the regional U.S. EPA required either that concentrate be sent to the headworks of the WWTP or that the injection well be built to Class I standards. The additional well construction cost associated with the tubing and packer arrangement has been an ongoing issue between utilities and regulating agencies.

Reasons for states having no Class I wells include Class I wells not being permitted and Class I wells not having been applied for (in some cases this is because suitable hydrogeological conditions have not been found).

The less restrictive well designs associated with Class II and Class V wells have prompted desalination facilities to seek injection into these wells. Texas allows discharge of municipal desalination concentrate to Class II wells (oil and gas wells) and Class V wells (wells not included in the more restrictive Class I to IV categories) if specific conditions are met. Similarly, in Florida the specific conditions for injection of concentrate into Class V wells include meeting primary federal standards and Florida secondary standards and not degrading the receiving water TDS level. A large concern and challenge in Florida is meeting the gross alpha primary standard. To date, only one inland facility (the KBH Desalination Facility in El Paso) has sought and received a Class V permit for injection of municipal desalination concentrate. To minimize risk, however, the well was built to Class I standards.

Table 10.1. 2006 U.S. EPA Injection Well Inventory (U.S. EPA, 2010d)

Category	Number
Class I hazardous wells	119
Class I nonhazardous and municipal wells	430
Class II wells	143,951
Class V wells	402,020
Number of states having no Class I wells	36

10.3 General Feasibility Factors—Site Requirements

The major feasibility factors for deep well injection include

- adequate aquifer characteristics
- adequate well design
- cost effectiveness
- disposal permit under the UIC program
- permit for an alternative CM option for times of periodic well integrity checks
- for Class V wells, concentrate salinity and composition restrictions
- public acceptance

Desired aquifer characteristics include structural isolation from overlying drinking water aquifers (for Class I wells), sufficient capacity to accept concentrate over the lifetime of the desalination plant (all class wells), and sufficient permeability and porosity for an acceptable individual well injection rate, yet low enough permeability and porosity to avoid excessive migration (all class wells).

Such aquifer characteristics are not often found. Unlike other CM options, DWI requires significant front-end capital and other costs to determine its feasibility. Because of these high costs, deep wells are most cost-effective for large concentrate volumes. The effort to determine feasibility can include

- evaluation of available hydrogeological data
- drilling of test wells
- conducting tests and modeling to determine capacity, permeability, porosity, and the general feasibility of injecting concentrate into the aquifer

> **Example:** *San Antonio Water System:* In 2009, a potential DWI wellfield was determined to have less capacity than needed to dispose of concentrate from a planned desalination system. Options identified were either to cut back on desalination capacity or to utilize HR processing to the extent needed to reduce the volume of concentrate to match wellfield capacity.

Well design requirements are dictated by regulations that differ according to well classification. Injection of industrial wastes other than produced waters from oil and gas drilling operations is restricted to Class I wells—the same well classification used for injection of hazardous wastes.

Permitting is overseen by the UIC Program. Many states are fully delegated to oversee the UIC program. In other states, the responsibility may be shared with the U.S. EPA or carried by the U.S. EPA.

Deep wells periodically undergo integrity testing, during which time the concentrate must be stored or disposed of by another CM option. The means of meeting this requirement must be defined as part of the UIC permit.

The public increasingly plays a role in determining policy and permit approvals. The association of deep wells with hazardous wastes constitutes a public perception issue when deep wells are considered for CM.

10.4 Major Cost Factors

10.4.1 Planning Phase Costs

As mentioned, costs associated with determining the feasibility of DWI can be very high. In the screening-level evaluation, the effort is primarily in gathering historical data from DWI injection and other drilling activity in the region. Once DWI has been short-listed in the screening-level evaluation of CM options, significant additional costs are associated with drilling a test well and conducting hydrogeological tests. Modeling groundwater flow dynamics is also needed to determine capacity, permeability, porosity, and the general feasibility of injecting concentrate into the aquifer.

Efforts include interaction with the regulatory agency overseeing the UIC program and developing contracts with groundwater services companies to conduct hydrogeological investigations and studies.

10.4.2 Capital Costs

Capital costs can occur during the preliminary-level evaluation associated with drilling and testing of test wells. Other capital costs are associated with implementing DWI as the CM option. Capital cost factors include:

- possible pretreatment of concentrate (pH change, addition of anticorrosion inhibitors, etc.)
- land purchase and easements
- piping and pumping from the desalination plant to the injection field
- land preparation
- mobilization
- logging, testing, and survey
- drilling and reaming
- well construction (casing, grouting, injection tubing, packer)
- demobilization
- backup disposal system for use during system integrity tests (periodic)
- monitoring wells

Class I wells undergo integrity tests every five years, and during this time a backup means of managing concentrate is required.

A cost-saving alternative to drilling new wells may be reworking abandoned wells, such as those associated with oil and gas drilling.

A preliminary-level capital cost model for DWI is available from Mickley (2006).

10.4.3 Operating Costs

Operating cost factors are associated with

- monitoring
- periodic integrity testing
- pumping
- general operation and maintenance

10.5 Environmental Concerns

The two major concerns associated with DWI are leakage and migration of injected fluid from the well and plugging of the aquifer. The second may be considered more of an operational concern.

10.5.1 Leakage and Migration of Waste

Injection of waste can be considered safe if the waste never migrates out of the well and out of the injection zone into other aquifers. There are at least five ways a waste material may migrate and contaminate potable groundwater (Strycker and Collins, 1987). Wastes may

- escape through the well bore into an underground source of drinking water because of insufficient casing or failure of the injection well casing because of corrosion or excessive injection pressure
- escape vertically outside the well casing from the injection zone into an underground source of drinking water (USDW) aquifer
- escape vertically from the injection zone through confining beds that are inadequate because of high primary permeability, solution channels, joints, faults, or induced fractures
- escape vertically from the injection zone through nearby wells that are improperly cemented or plugged, or that have inadequate or leaky casing
- contaminate groundwater directly by lateral travel of the injected wastewater from a region of saline water to a region of fresh water in the same aquifer

A study prepared for the Underground Injection Practices Council showed that relatively few injection well malfunctions have resulted in contamination of water supplies (Strycker and Collins, 1987). However, other studies document instances of injection well failure resulting in contamination of drinking water supplies and groundwater resources (Gordon 1984). Similar concerns are associated with injection in earthquake-sensitive regions and with overpressure causing fracture and earthquakes. Fracture of the confining layers that isolate the injection aquifer from over-lying aquifers can lead to leakage and contamination of the shallower aquifers. Injection pressures need to be less than fracturing pressures.

Concerns and risks may be addressed and minimized through:

- detailed aquifer and hydrogeological modeling and other studies during feasibility phase studies
- well construction methods/requirements

- low pressure injection—much lower than reservoir fracture pressures
- monitoring of well performance

10.5.2 Reducing Aquifer Permeability/Porosity

Aquifers are mostly sandstone and other formations having connected void spaces that provide permeability and porosity characteristics. Precipitation of species in the blended concentrate and aquifer water have potential to plug formation passages and thus to reduce aquifer permeability/porosity characteristics. This can lead to reduced injection rates and significantly compromise well operation.

Precipitation can occur in two ways:

- As a result of blending concentrate with aquifer water, where contributions from each water result in one or more salts becoming supersaturated in the blend. The possibility of precipitation is dependent on the composition of both the concentrate and the receiving (aquifer) water. The mixing effects need to be studied as part of the planning phase. Effects of temperature and pressure also need to be included.
- From the precipitation of species present in the concentrate at levels in excess of solubility limits. Concentrates typically have one or more species at concentrations in excess of solubility limits, made possible through the use of antiscalants and dispersants. The antiscalants/dispersants have a limited effective life in slowing the precipitation kinetics. The effective life of antiscalants can also be reduced by adsorption of antiscalants onto aquifer media.

Downhole precipitation in concentrate injections is largely an unstudied area, as concentrates with some constituents close to solubility limits differ from most deep-well-injected fluids.

Study and mitigation of these concerns may include

- modeling studies simulating blending results
- wellhead injection of acid and/or antiscalant

10.6 Regulatory Basis

The UIC Program (U.S. EPA, 2010c), like the NPDES for surface water discharge and the Pre-treatment Program for nondomestic discharge to the WWTPs, are is a federal program whose primary regulatory responsibility can be delegated to individual states. Currently, 33 states have primacy and oversee the UIC program, 7 states share responsibility with the U.S. EPA depending on the well class, and the U.S. EPA has primacy in 10 states.

The UIC Program prevents contamination of USDWs by regulating injection activities. The UIC regulations address activities throughout the life of an injection well, including siting, construction, operation and monitoring, and closure. These requirements are designed to prevent contaminants from moving into drinking water sources. There are UIC requirements specific to each class of well to address the uses of the wells and the potential threats to USDWs each may pose (Mickley et al., 1993; U.S. EPA, 2010c).

Some states do not permit Class I wells. The first step in consideration of DWI is to find out whether the state (1) permits Class I wells and (2) has permitted any Class I wells. The first point would close any further consideration of DWI. The second point may indicate the nature of the challenge ahead in defining DWI feasibility, as in part, gathering of hydrogeological information necessary for feasibility determination is facilitated by the existence of other Class I wells in the area.

Typically, consideration and implementation of DWI is a multistep process involving test wells prior to the full-scale well. As permits are required for drilling test wells, the regulations include requirements for test wells for hydrogeological testing as well as injection wells. Permit applications for injection wells require information obtained from testing of test wells.

In sum, regulations apply to

- well design and construction requirements
- construction requirements based on well type (Class I wells in the United States)
- testing requirements prior to well operation
- periodic well integrity test requirements
- requirement for a permitted second disposal option for use during periodic integrity tests

Some states are exploring discharge to other well classes. In Texas, desalination concentrate may be discharged to a Class I well, to a Class II well for the purpose of enhanced oil recovery, or to a Class V well where (1) salinity is less than 10,000 mg/L and (2) concentrate meets primary water quality standards. Discussions with the regulatory agency can determine the state's position on discharge to other class wells.

10.7 Impact of Concentrate Volume

Injection wells have high economies of scale. In part, this is because of the substantial capital cost associated with determining the feasibility of DWI. The unit volume capital cost ($/mgd) decreases as this cost is spread out over a larger volume. The economies of scale are also due to reduced per-volume cost of transporting larger volumes of water through increasing diameters of pipe, or in this case of injecting larger volumes of water through tubing. The economies of scale are reflected in Figure 5.2. Deep well injection has not been used much for small-volume concentrates because of the high feasibility-determination costs. The increased use of DWI with high-volume concentrate is reflected in Figure 3.3.

10.8 Impact of Concentrate Salinity

Class I wells require injection below the USDW zone (below aquifers with TDS of less than 10,000 mg/L). Otherwise there is no restriction relative to injection salinity.

Injection via Class V wells into USDW aquifers requires the injection fluid to have a water quality comparable to or better than the USDW aquifer receiving water. Class II deep wells for produced water from oil and gas drilling operations are not subject to injection below the USDW zone. Historically, concentrate with water quality better than what is injected into many Class II wells has been restricted from injection into Class II wells.

Recently, Texas has allowed injection into Class II (oil and gas) wells for the purpose of maintaining production pressure and into Class V wells where TDS is less than the aquifer TDS and where concentrate meets primary water standards.

Restrictions on injection of concentrate into Class II and Class V wells exist in other states. They (1) limit opportunities for injection of concentrate and (2) limit opportunities to decrease injection costs of DWI for concentrates.

Frequently, high salinity goes hand in hand with high chloride levels and thus increased material corrosion concerns. Injection of higher salinity concentrate may more frequently give rise to corrosion problems (SJRWMD, 2008)
.

> **Example:** *Some Florida deep wells have had corrosion problems:* The Plantation WTP in Plantation, Florida, solved tubing corrosion by using polyvinyl chloride (PVC) liners. Marco Island RO Plant had to do more frequent maintenance/replacement on pumps and valve.; T. Mabry Carlton EDR Facility experienced packer failure and replaced packer and casing with duplex stainless pipe. West Palm Beach WTP #3 had to replace tubing and packer.

High-recovery processing may result in brines of substantially higher salinity than those from conventional recovery operations. The greater difference between salinity of injected water and aquifer water may pose additional challenges. There is little experience with injection of substantially higher salinity concentrate into aquifers of lower salinity.

10.9 Impact of Concentrate Composition

The primary concern is with precipitation of species resulting from the injection of concentrate. The means of precipitation were discussed in Section 10.5.2.

For Class I wells there is no restriction on concentrate composition. If the concentrate were hazardous, Class I wells would be required. Class I hazardous wells require additional aquifer structural studies and additional well design constraints.

The general concern associated with HR concentrate is increased probability of aquifer plugging. This is largely an unstudied area. HR processing can result in salts being nearer to or past solubility limits. HR processing can also result in higher levels of total suspended solids. Supersaturation and high suspended solids may both require some form of treatment (wellhead addition of antiscalants, filtering, etc.) prior to injection. Higher recovery can also increase chloride levels and result in increased concerns with corrosion of well components.

10.10 Screening-Level Evaluation

Factors that can be addressed at the screening level evaluation include

- volume of concentrate
- initial estimates of concentrate chemistry
- state regulatory position toward Class I, II, and V injection wells
- existence of Class I wells in the region
- existence of Class II and Class V wells in the region
- possible well retrofitting opportunities

- amount of hydrogeological data available for the general region
- locations where DWI might be considered
- distance between the desalination plant and possible injection sites
- general cost evaluation

Volume of concentrate is an important parameter in determining whether DWI will be cost-effective. The major costs associated with determining the technical feasibility of DWI can be cost-prohibitive for small plants. This was reflected in Figure 5.2. DWI costs increase with the number of wells required, and this is strongly dependent on location. The largest Class I well in Florida for the disposal of any waste is near 22 mgd. The largest Class I wells in other states are much smaller, as shown in Table 10.2.

Currently, 36 states do not have any Class I wells. Early determination of state DWI activity will influence whether further consideration is given to DWI. The presence of Class I wells in the general region indicates that the DWI option is likely possible and may provide hydrogeological information helpful for further evaluation of DWI feasibility.

Regulation of DWI comes under the UIC Program and requires a UIC permit. Currently, 33 states are delegated to oversee the UIC Program. In the other states, responsibility is either shared with the regional U.S. EPA or assigned to the regional U.S. EPA. Contact should be made with the appropriate responsible agency.

The Groundwater Protection Council (GWPC, 2010) and the U.S. EPA are sources for information about existing wells and can be used to determine the existence of Class I and other wells in the region, and to some extent, information about the wells. There may be clear reasons that DWI is not feasible for the location in question, such as being in a state where Class I wells are not allowed; having a small-volume concentrate that would likely make DWI cost-prohibitive; being in an earthquake risk area; or being in an area where there have been no previous considerations of DWI and thus where no data are available for consideration. In this latter case, the risk associated with several unknowns and the high cost of converting them to knowns may be deemed cost-prohibitive.

Table 10.2 Largest Class I Wells by State[a]

State	Capacity (mgd)
Florida	22.0
Texas	3.0
North Dakota	0.9
Oklahoma	0.7
Illinois	0.6
Wyoming	0.5
Louisiana	0.43
Michigan	0.36
Kansas	0.3

[a]For disposal of any waste.

If, however, there appears to be some historical evidence to support consideration, or the risk is otherwise determined to be worth undertaking, then a more definitive evaluation is needed and a groundwater services company can be engaged. It can help define the level of existing hydrogeological data available and do a feasibility level review. If the general feasibility is promising, it can also provide an estimate of the steps, schedule, and cost necessary to develop the information for establishing feasibility.

In parts of Florida where DWI is widely used, the screening-level evaluation is simply "yes." In most other parts of the United States, more effort is required to determine the general feasibility of DWI.

Although disposal of concentrate to Class II (oil and gas) wells or Class V wells (where salinity is less than 10,000 mg/L and the discharge meets primary drinking water standards) are not generally considered options for concentrate disposal, these possibilities have been explored in recent years in Texas and Florida. Discussion with the appropriate regulating agency will determine whether Class II or Class V DWI might be options to consider further.

DWI costs are somewhat different from the costs of other CM options. This is reflected in Figure 5.2. Determination of the feasibility of DWI typically requires significant expenditures for hydrogeological evaluations, test wells, and aquifer water characterization. Moreover, the result of the investment may be that the option is not feasible. With the possible exception of ocean discharge from a seawater RO facility, these front-end costs are much higher than those associated with other CM options. Most of these costs occur after DWI has been short-listed for screening-level evaluation.

In screening-level evaluation, a ballpark figure for the cost of a well (assuming, optimistically, that DWI is feasible and only a few wells can accommodate the concentrate) can be assumed to provide a number for comparison with the estimated ballpark costs of other CM options. Frequently, this cost is much higher than for other options and thus eliminates DWI from further consideration. Conveyance of concentrate to the disposal site can also be a major cost factor.

10.11 Preliminary-Level Evaluation

As previously mentioned, costs associated with determination of DWI feasibility are typically much higher than those associated with other CM options. Costs involved with continued consideration of DWI escalate following the screening-level evaluation stage of consideration.

The decision to continue consideration of DWI should be made in light of other short-listed CM options. If one or more CM options are considered more likely to be feasible, strong consideration should be given to not undertaking expensive field work and testing required to determine DWI feasibility. The reason is the many unknowns associated with DWI feasibility.

If the decision is made to continue consideration of DWI, a groundwater/consulting company can be engaged to develop a proposal for drilling a test well and conducting tests and modeling efforts to determine capacity, permeability, porosity, and the general feasibility of injecting concentrate into the aquifer. The sizable costs involved with the proposed effort will be visible at this time.

As the project moves forward, evaluations can be made on the suitability of the aquifer to meet CM requirements. The aquifer needs to have an acceptable capacity for the concentrate volume over the lifetime of the desalination plant; if capacity is less but other conditions are acceptable, further volume reduction of concentrate can be considered and included in the pilot tests. The aquifer characteristics should also allow acceptable injection rates such that the number of injection wells and the size of the injection wellfield is not excessively large.

Interactions should continue the regulatory group overseeing the UIC program and, if warranted, with the appropriate state group overseeing Class II oil and gas wells.

Modeling and possibly bench-scale testing need to be conducted to anticipate such challenges associated with blending injection water with aquifer water.

> **Example:** *KBH Desalination Plant, El Paso*: DWI at this facility represented the first major municipal desalination DWI outside of Florida. Extensive investigations and studies were undertaken to address the concern of loss of injection well efficiency from borehole scaling or formation damage. The investigations and studies included
>
> - *Characterization of reservoir water*. Accurate reservoir conditions of temperature, pressure, and water quality were required as input data for computer simulations of blending.
> - *Evaluation of the thermodynamic potential for minerals to precipitate* from solution during pipeline transport, in wells during injection, and after injection into the receiving formation. The evaluation was done through the use of geochemical modeling software. From the analysis of saturation conditions, it was recommended that acid pretreatment of the concentrate to eliminate calcite formation be considered along with exclusion of oxygen to eliminate the potential for ferric hydroxide precipitation (GTC, 2007).
> - *Adsorption tests to determine the fate of antiscalant.* From the results, it was assumed that inhibitor would absorb onto the host rock (dolomite) almost immediately and should not be depended on to reduce precipitation potential in the formation.
> - *Identification and evaluation of analogous DWI sites* including characterization of scaling experiences at those sites. Computer simulations of scaling potential at these sites were shown to correctly predict the scaling results observed at these sites (GTC, 2006).

Salinity and composition can affect material choices for injection tubing and downhole chemistry. Material choices affect cost but are relatively straightforward to deal with. Once feasibility conditions are defined, a detailed cost analysis of DWI can be developed.

10.12 Shallow Wells

A few municipal desalination plants that discharge concentrate via shallow coastal wells. Discharge is into the coastal water table of seawater salinity.

> **Example:** *Florida shallow injection wells*: The Marathon (1-mgd SWRO) and Stock Island (2-mgd SWRO) municipal desalination plants are emergency facilities owned by the Florida Keys Authority. They both discharge into shallow injection wells. Manalapan, FL has a 1.7-mgd BWRO municipal desalination facility that conveys concentrate to a nearby island for shallow well injection (personal communications as part of the present survey).

10.13 Summary

DWI holds some promise for increased use with both conventional and high-recovery processing. It has been widely used for municipal concentrate only in Florida. Other states (especially Texas) are considering its more widespread use. DWI is, however, expensive in part because of the substantial effort and costs associated with determining whether or not its use is feasible. Feasibility depends on finding an injection aquifer having suitable hydrogeological characteristics and having aquifer/concentrate compatibility. The risk and cost associated with determining whether or not these requirements can be met often rule out further consideration of DWI at the screening-level evaluation stage.

Chapter 11

Evaporation Ponds

11.1 Description

Evaporation ponds are impoundments for which solar energy is the driving force for evaporation of water in the concentrate to the atmosphere. The ponds are designed to have a sufficient evaporative surface area for evaporation to balance incoming water flow. Ponds require a net evaporation rate (evaporation rate minus precipitation rate) over the course of a year and preferably each month; therefore evaporation ponds are most suitable for areas with high net evaporation rates. Thus, ponds are found more extensively in warmer climates.

Although net evaporation rates decrease slightly with increasing pond depth, there is only a 4% reduction in net evaporation rate as depth is increased from 1 to 40 inches (Mickley et al., 1993). Pond depths of water (not including settled solids) are typically 40 inches or more.

Ponds are constructed with pond liners (synthetic or earthen) to protect against groundwater contamination and may, depending on state regulations, require various degrees of monitoring for pond leaks. This can take the forms of leak detection between liners in a double-liner setup and shallow monitoring wells adjacent to the pond.

As concentration of dissolved solids increases as a result of evaporation, solids accumulate as precipitates, gradually consuming pond volume. Depending on the rate of solids accumulation, periodic removal and drying of solids for subsequent landfill may be necessary for longer-term use of the site; an alternative is to retire and cover ponds and replace them with new ponds.

11.2 Historical Use

In 2010, about 4% of municipal desalination plants in the United States discharged concentrate to evaporation ponds. Only 3 of 33 states having municipal desalination plants utilized this CM option. Even in warmer and drier climates in the United States, average net evaporation rates are rarely greater than 3 gpm per acre. As a result, most evaporation pond use has been for small-volume concentrates.

11.3 General Feasibility Factors—Site Requirements

Major feasibility factors include

- availability of level land
- location of land away from long-term flood recurrence areas
- sufficient land to provide the required evaporative surface area
- limited distance and workable terrain between desalination plant site and pond site
- high annual net evaporation rate (unless concentrate volume is very small)
- cost effectiveness

Evaporation ponds are land-intensive and best suited to areas where large amounts of low-cost, level land are available, in climates with year-round high net evaporation rates. These conditions are not frequently found other than in arid areas of the United States. Per-acre construction costs can be high and with very little economy of scale. Evaporation ponds are usually not cost-effective except for small volumes of concentrate.

11.4 Major Cost Factors

11.4.1 Planning Phase Costs

The effort during the planning phase is directed at determining feasibility. With an estimate of the concentrate volume, screening-level evaluations are made of yearly net evaporation rate, land requirements, design requirements with respect to liners and leakage monitoring, land availability and costs, and other related design and cost issues. If the evaporation pond option is short-listed, more detailed design and costing are done as the volume and water quality become better defined and monthly net evaporation data are considered. Planning-phase costs are all effort-related.

11.4.2 Capital Costs

Capital cost factors include

- land
- land clearing and preparation
- pond liner(s)—synthetic or clay liner
- fencing
- roadway
- piping and pumping system—dependent on distance from desalination plant
- (possible) distribution system with associated valving and control for larger pond areas
- seepage monitoring system

The cost of land can range from very low to very high. Liner costs can be significant, particularly when double liners with an inner liner leak detection system are required. Recent per-acre pond costs have ranged from \$60,000 to \$600,000. Any savings related to larger size are offset by the need for a more complex distribution and pumping system, resulting in limited economies of scale.

Detailed design factors and a preliminary-level cost model for evaporation ponds may be found in Mickley (2006).

11.4.3 Operating Costs

Operating cost factors include

- routine pond maintenance (minimal cost)

- pumping
- pond clean-out and disposal of sludge (possible periodic cost)
- (possible) cleanup of contaminated soil if pond leakage occurs
- pond closure at end of useful pond life

Operating costs for evaporating ponds are generally low.

11.5 Environmental Concerns

Environmental concerns associated with evaporation ponds include

- leakage from the pond affecting groundwater
- composition of the pond affecting wildlife
- pollution impact on surrounding areas of salt spray
- leakage/runoff from improperly closed ponds

The risk of leakage from the pond is addressed by the use of pond liners. Liner requirements are specified in the state regulations dealing with pond construction. Liners may be natural, such as clay and other earthen materials, or synthetic, such as an HDPE geomembrane. Double liners with an intervening leak collection and recovery system are state-of-the-art. Recovered leakage is pumped back to the evaporation pond. Synthetic liners can be checked for leakage and repaired prior to pond operation.

Salinity and trace elements in ponds can have negative impacts on breeding and migrating birds, as evidenced by the well-known Kesterson reservoir incident (NRC, 2008). Birds may use ponds for resting, nesting, and feeding. They can be poisoned by coming into contact with hazardous constituents in a pond. This situation creates a liability under the Migratory Bird Treaty Act (U.S. Congress, 1976). Ponds may be constructed with bird netting over areas as large as 300' by 600'. The netting spacing of 2" prevents pond access by waterfowl (Golder Associates, 2008).

> **Example:** The highly productive farmlands in the San Joaquin Valley of California require large amounts of irrigation water. In the 1960s, irrigation and drainage practices resulted in rising water tables of increasing salinity that began to harm crops. In 1971, the Bureau of Reclamation completed the 134-km Kesterson Drain and the Kesterson Reservoir system of 12 evaporation ponds to convey and receive drainage water from the valley. Land in the valley has high levels of naturally occurring selenium, and in 1982, a study to determine the cause for declining reservoir waterfowl and wildlife found elevated selenium concentrations. As a result of a 2002 court settlement, the U.S. government was forced to develop and implement a solution to the San Joaquin Valley irrigation drainage water problem. Many possible solutions were studied, and currently the Bureau of Reclamation is planning on implementing a system of four separate treatment facilities ranging from 0.84 to 15.9 mgd. Drainage water will be collected, reused, collected again, and treated by RO. Salinity of the drainage water ranges from 6000 to 14,000 mg/L. Product water will be suitable for irrigation. The concentrate will be further treated to biologically reduce the level of selenium prior to discharge to newly constructed evaporation ponds. Operation of a demonstration plant is scheduled for late 2012. (Bureau of Reclamation, 2008)

Pollution of surrounding areas by drift of accumulated salts can be a problem if the pond is allowed to dry out or if the pond, full of solids, has not been dredged or covered. Overflow runoff and salt spray from active ponds can be prevented by pond construction of a berm at the pond perimeter to shield surrounding areas.

Highly alkaline waters can increase CO_2 emission when pH change occurs from precipitation. Odors can also become a problem if ponds become anaerobic because of high sulfate levels. The problem can be mitigated by installing some form of aeration device.

> **Example:** *Chandler, AZ:* operation of a 2.4-mgd plant begun in 1996, with concentrate going to five evaporation ponds. Each pond is about 7 acres. The ponds were constructed before local housing development started in 2003. As homes were built nearer and nearer to the ponds, complaints increased about H_2S resulting from a pond becoming anaerobic. The problem was solved by putting bubblers in the ponds.

11.6 Regulatory Basis

Permits for evaporation ponds are not covered under Federal NPDES or UIC programs. They are typically part of a state groundwater protection program. The overseeing state agency varies by state. State regulations typically include pond design and testing requirements, as well as monitoring requirements and pond closure procedures.

11.7 Impact of Concentrate Volume

As reflected in Figure 5.2, evaporation ponds can have high per-acre capital costs. With limited economies of scale, evaporation ponds have been used primarily with small-volume concentrate (see Figure 3.3). Consequently, the feasibility of using evaporation ponds is strongly dependent on concentrate volume.

11.8 Impact of Concentrate Salinity

Dissolved salt in water results in a lower saturation vapor pressure because of the decreased chemical potential of the water. This results in a lower evaporation rate. Up to a 30% reduction in evaporation rates due to salinity buildup has been cited over the life of a pond (Mickley et al., 1993). For water saturated with sodium chloride (26.4%), the evaporation rate is generally about 70% of the rate for fresh water (OSW, 1971). The initial evaporation rate of a higher salinity concentrate, such as 60,000 mg/l, may be 10% less than that of a 4000-mg/L concentrate.

The rate of solids accumulation is dependent on the feed water salinity as well as the evaporation rate. Doubling the feed water salinity will, other factors being constant, fill up the pond twice as fast. The rate of solids accumulation determines how often the pond needs to be cleaned out. Ponds with relatively low feed water salinity may never need to be cleaned out during the life of the desalination facility. Ponds with high feed water salinity may need to be cleaned out several times over the same time period.

11.9 Impact of Concentrate Composition on Evaporation

Theoretically, composition of concentrate should have some effect on evaporation rates through the effect of composition on water vapor pressure. However, although the effects may be significant when vapor pressures of a solution of one salt are compared with those for a solution of another salt, the variation in composition of concentrates does not generally have a significant impact on evaporation rates.

11.10 Screening-Level Evaluation

The primary feasibility factors that can be addressed at an early stage of consideration include

- climate
- net evaporation
- area required (volume)
- availability of suitable land
- distance and terrain between desalination plant site and suitable land

A regional net evaporation rate can be determined from readily available evaporation and precipitation data. Net evaporation rates can be expressed as inches/year or volume per year per area (such as gpm per acre). Most net evaporation rates are in the range of 0-3 gpm per acre. This range of rates can be used to estimate the range of evaporation area required for the concentrate volume (expressed as gpm). This simple calculation will illustrate the high land intensity characteristic of evaporation ponds. A 1-mgd concentrate in a region of high net evaporation (such as 3.0 gpm/acre) would require 247 acres of evaporation area.

A monthly positive net evaporation rate is needed; otherwise excessive pond storage capacity will be required. Cold climates may limit the use of evaporation ponds to warmer months. In this case, either concentrate would need to be stored during the low-evaporation months, or an alternative CM option would be needed.

Even at the lower cost of $60,000/acre, 247 acres would cost more than $14.8M. Enhanced evaporation techniques, discussed in Section 11.12, can significantly reduce the land evaporation area required, but also result in increased per-acre capital and operating costs. Thus, although the techniques offer cost savings, the savings may be less than 50%, with the result that evaporation ponds for large-volume concentrates may still be a costly CM option.

If evaporation ponds are still considered a CM option, land availability and distance and terrain between the desalination site and the possible evaporation pond site become important considerations.

Evaporation ponds may be a CM option for reduced-volume, higher salinity concentrates resulting from high recovery. Tradeoffs that would need to be evaluated include somewhat lower evaporation rates, possible more frequent pond cleanouts, and elevated concentrations of trace elements that may cause harm to wildlife interacting with the pond. Considerations of salinity and composition are evaluated at later stages.

11.11 Preliminary-Level Evaluation

If evaporation ponds have been short-listed, additional tasks include more accurate determination of land requirements through use of monthly net evaporation rates, addressing land acquisition issues, and developing more detailed cost estimates based on evaporation area required, pond design requirements, conveyance terrain and distance, land costs, anticipated frequency of pond cleanouts, etc.

A detailed water quality analysis/estimate of concentrate is necessary to ensure that the concentrate and pond contents will be safe for wildlife. Prior to the pilot study of the desalination system concentrate composition can be estimated using a detailed raw water analysis, estimates of the effect of pretreatment steps on the raw water composition, computer simulation to determine major ion concentrate levels, and estimates of membrane separation on other feed water components. Following pilot studies, a detailed chemical analysis of concentrate generated during the pilot runs can be used to check and refine, as necessary, estimates of concentrate composition.

11.12 Enhanced Evaporation Methods

Several different means have been studied to increase evaporation rate through increasing the effective surface area of water exposed to air. Enhanced evaporation systems hold the promise for reducing the amount of land required for evaporation and thus the amount of pond liner required, both significant cost factors for evaporation ponds.

The methods include

- using spray irrigation nozzles to spray water into the air
- using snow-making equipment to spray water into the air
- dripping water from elevated tubing so that water falls through the air
- wicking water onto a vertical thin absorbent material that is exposed to the air

> **Example:** *Hargesheimer WTP, Abilene, Texas:* A 3-mgd BWRO plant typically running at 1.2 mgd discharges untreated concentrate to evaporation ponds equipped with misting evaporators.

Problems associated with some of the technologies have included salt damage to soil/vegetation surrounding the pond and nozzle/delivery system clogging due to salt deposits left as a result of evaporation (Bureau of Reclamation, 2000).

The most successful system appears to be the commercial wind-aided intensive evaporation system developed in Israel (LESICO, 2010). Evaporation rates may be increased by a factor of 5 or more, which reduces the acreage required and thus the acreage-related capital cost. The additional equipment required for the enhanced evaporation results in higher per-acre capital costs than for conventional evaporation ponds. Energy and other operating costs are higher than for conventional evaporation ponds. The net effect is a lowering of annual costs (amortized capital plus operating cost) by a factor of 2 and possibly more.

Such systems can make evaporation ponds less costly and applicable to somewhat larger volumes of concentrate. The limitations, however, for U.S. municipal CM are that (1) evaporation ponds are restricted by climate to certain regions, and (2) land requirements and costs can still be significant for larger concentrate volumes.

11.13 Summary

Evaporation ponds are best suited to small-volume concentrates in regions of high net evaporation rates and where inexpensive level land is available. These conditions are not met with at most locations outside of the arid southwestern United States. Even at high net evaporation rates, the amount of evaporation per acre is limited, with a high value being 3 gpm. Consequently, land requirements can be excessive, and per-acre costs can lead to very high costs for large-volume concentrates. Enhanced evaporation methods can reduce evaporation pond costs, but the costs can still be high for most municipal settings.

Chapter 12

Land Application

12.1 Description

There are two categories of land application for CM: irrigation and percolation ponds (or rapid infiltration basins).

Irrigation is a beneficial use of concentrate, and the irrigation application far exceeds that of percolation ponds. Most land application of concentrate has been without subsurface drainage systems and thus represents a final fate disposal solution for concentrate.

Concentrate is most often used to irrigate lawns, parks, and golf courses. Frequently, dilution of the concentrate is required to meet groundwater standards and/or to match irrigation water salinity tolerance thresholds of vegetation. Use of salt-tolerant plants may increase applicability of irrigation in some areas. Irrigation is land-intensive and the need for dilution water increases concentrate volume and may increase land requirements. Consequently, land irrigation is determined by the hydraulic, nutrient, and salt loading rates, as well as the climate and the vegetation used. Irrigation can be more land-intensive than evaporation ponds, as loading rates for irrigation are generally lower than net evaporation rates, which determine the area required for evaporation ponds (Mickley, 2006).

Land application also includes disposal of concentrate via percolation ponds or rapid infiltration basins. With this application, there are higher hydraulic loading rates, and a much greater portion of the concentrate percolates to the groundwater than with irrigation. There is little or no consumption by plants and there is less evaporation because of a reduced surface area. Use of ponds typically requires high-permeability soil and underlying groundwater with higher salinity. With adequate control over discharge salinity and composition, percolation ponds (and rapid infiltration basins) allow concentrate to percolate through the soil and eventually reach the groundwater without contaminating the groundwater. Percolation ponds can be used to recharge surficial aquifers. Typically, these applications have liners along the sides of the ponds to prevent horizontal movement of the concentrates (Mickley et al., 1993). Potential advantages of percolation ponds over crop irrigation are (1) that greater volumes of concentrate (likely diluted) may be disposed of with less land area, (2) that systems do not have any special seasonal constraints, and (3) that they have been successfully operated throughout the winter months in the northern United States and southern Canada, and salt accumulation in vadose zones is not a plant salt-tolerance issue.

Sometimes, in cases of both irrigation and percolation, recovery of the applied water may be required and accomplished using underdrains. Although this situation represents a beneficial use of the concentrate, it is not a final fate solution, and disposition of drainage discharge must be determined.

12.2 Historical Use

About 7% of municipal desalination plants in the United States dispose of concentrate by land application. Currently, only 3 states of the 33 having municipal desalination plants utilize land application of concentrate (present survey).

Historically, percolation ponds (or rapid-infiltration basins) were used extensively for land treatment and disposal of primary and secondary WWTP effluent. Treatment, including filtration, adsorption, ion exchange, precipitation, and microbial action, occurs as the wastewater moves through the soil matrix. Phosphorus and most metals are retained in the soil, whereas toxic organics are degraded or adsorbed. As wastewater percolates through the soil, it can be collected, or it can flow to native surface water or groundwater aquifers. Where the groundwater table is relatively shallow, the use of underdrains allows control of groundwater mounding and recovery of the renovated water. In areas with deeper groundwater, wells are used to recover the renovated water. This recovered water can be used for irrigating crops or for industrial uses. Water that is not recovered can recharge groundwater aquifers. More stringent groundwater protection laws have decreased the use of rapid-infiltration basins for WWTP effluent and for CM.

12.3 General Feasibility Factors—Site Requirements

For most of the discussion that follows, it is assumed that irrigation or percolation ponds for CM do not include a drainage system. Otherwise irrigation/percolation is not a final fate solution for CM.

Major feasibility factors include

- compatibility with vegetation, soil, and groundwater
- relatively level land
- favorable climate
- application site reasonably close to desalination site
- availability of dilution water

Groundwater protection regulations typically set upper limits on salinity discharge and for various constituents in the discharged water. With the possible exception of NF concentrate, concentrate is usually higher in salinity than the groundwater it may affect. Dilution of concentrate is a means of resolving this and also meeting constituent-based limits. In addition, for irrigation, concentrate must be of suitable salinity and composition for the vegetation being irrigated.

The land requirement is based on the concentrate (likely diluted) volume and the irrigation or percolation loading rate. Level land will eliminate the need for berms for percolation ponds to prevent runoff; otherwise runoff may require an NPDES permit. A backup disposal or storage method may be needed for climates where year-round irrigation/percolation is not possible (Malmrose, 2004) or where irrigation or percolation during seasonal rains may not be possible.

As with all CM options, feasibility is dependent on the distance from the desalination plant to the irrigation or percolation site. The distance and terrain both affect capital and operational costs associated with conveyance.

12.4 Major Cost Factors

12.4.1 Planning Phase Costs

Planning phase efforts include interaction with the appropriate regulatory agency, defining dilution water needs, determining possible sources of dilution water, and determining land requirements. Concentrate volume and composition initially will be based on the best available raw water quality estimates and computer simulation of concentrate volume and composition. If land application is short-listed as a CM option at the screening-level evaluation, subsequent consideration of land application will be based on more extensive desalination plant performance estimates and data.

12.4.2 Capital Costs

Possible capital costs include

- land
- land clearing and preparation
- pumping and conveyance of dilution water
- equipment associated with blending, modifying, or treating concentrate prior to use
- pipeline to the site of irrigation or percolation
- pump
- distribution systems (header, submain header, laterals, sprinklers, valves)
- storage tank for rain days
- underdrain (possible)
- monitoring wells
- surface runoff control system

There are few economies of scale associated with land application systems, as larger operations require more extensive distribution and control systems.

12.4.3 Operating Costs

The primary operating cost is the energy associated with conveying concentrate to the land application site and then distributing the concentrate to the land. Other operation costs are associated with monitoring and standard operation and maintenance associated with treatment, conveyance, distribution, and application. The possibility of selling the concentrate to agricultural interests can be investigated.

12.5 Environmental Concerns

The primary concerns are impacts on

- groundwater
- surface water
- soil and vegetation

Groundwater concerns are addressed by meeting associated regulatory standards. This typically requires concentrate to be diluted. There are increasing concerns associated with trace contaminants (Mohamed et al., 2005; Rao et al., 1990). A drainage system can be used to avoid contamination of groundwater and, in general, its use is a recommended practice. In such a situation, use of concentrate represents a beneficial use but not final disposal.

Surface runoff can lead to downstream impacts. This can be mitigated by a surface drainage system and a berm around the irrigation/percolation area, and through other management tools.

Potential environmental impacts also include uptake of contaminants by plants or leaching of these contaminants into the soils or groundwater (NRC, 2008; WHO, 2007; Xu et al., 2009). Plant uptake of water is not a significant sink in the overall mass balance. Thus for irrigation, if evaporation from soil and plant surfaces plus transpiration from vegetation exceeds precipitation and irrigation to the soil, salts will accumulate in the soil over time (NRC, 2008). Irrigation design typically includes construction of a "leaching fraction," which is the excess irrigation water applied to ensure that salts do not accumulate in the root zone.

12.6 Regulatory Basis

Permitting of evaporation ponds and percolation ponds is overseen by state regulatory agencies. Typically regulation is based on concentrate characteristics and groundwater standards are based on land use classification. These can vary considerably among states. In some states, feasibility is based on a direct comparison of the concentrate water quality with groundwater quality standards. In other states, no degradation of existing groundwater conditions may be permitted. The point of compliance can also make a difference—monitoring well in the field versus at the edge of the field.

> **Example:** *Colorado groundwater standards*: Discharge of concentrate to land is regulated by groundwater standards based on land use classification. The applicable standards are the most stringent of human health, drinking water, and agricultural standards. Comparison of appropriate groundwater standards with concentrate water quality will define limiting constituents that will dictate concentrate dilution requirements. (CDPHE, 2010)

> **Example:** *Texas groundwater regulation*: There are no groundwater standards or classification of land. Regulation is through limiting flow according to the crop and evapotranspiration rates. Flow is limited in this way so that it cannot reach groundwater. If flow reaches groundwater this brings the UIC (Underground Injection Control) regulations into consideration. (TAC, 2010)

12.7 Impact of Concentrate Volume

For a given irrigation or percolation crop/soil and application rate, increased concentrate volume requires more land. The size of pumps and conveyance pipeline may also increase. Small economies of scale and a high unit capital cost ($/mgd), along with the land requirement, have resulted in land application being used only for small-volume concentrates (see Figure 3.3).

12.8 Impact of Concentrate Salinity

Increased salinity can result in greater incompatibility of the concentrate with plants, soils, and underlying groundwater. Because there is no equivalent of a mixing zone for groundwater discharge (irrigation and percolation), the regulation described in Section 12.6 applies, and as the salinity of the concentrate increases, more dilution water will be needed to meet groundwater limits.

Increasing concentrate salinity may eliminate feasibility of land application of concentrate because of the large volume of dilution water required for crop tolerance and groundwater protection and the resulting large land area required.

Land application of high-recovery, high-salinity concentrate would require increased amounts of dilution water, and would not generally be considered a CM option. Land application of NF concentrate is more frequently possible because of its lower salinity.

Although, strictly speaking, discharge of concentrate to an irrigation canal is a surface water disposal option, the canal water may offer sufficient dilution for subsequent irrigation use. Irrigation canals have less restrictive water quality standards than other receiving waters and thus may become a viable CM option, particularly for concentrates with nitrate levels that prohibit discharge to other surface waters. However, this may be a seasonal option only.

> **Example:** *East Cherry Creek Valley, Colorado*: A planned 7-mgd BWRO plant is presently in the bid phase. Planned concentrate discharge is to an irrigation canal during the growing season. Some discharge may be possible during the winter season; otherwise concentrate will go to a storage pond. (Personal communication—survey)

12.9 Impact of Concentrate Composition

The composition of concentrate can be critical in determining whether land application of concentrate is feasible. Specific issues of concern include the following:

- Major ions in concentrate may not meet groundwater standards (e.g., chloride limit).
- TDS in concentrate may not meet groundwater standards.
- Salinity of concentrate may be too high for various vegetation/crops.
- The SAR (see Section 4.3.1) may not be compatible with vegetation and soil conditions.
- Contaminants and trace elements may not be compatible with groundwater standards or vegetation.

To determine potential impacts, concentrations of major and minor constituents in the concentrate need to be compared with groundwater standards, with SAR ratios for the vegetation being considered for irrigation, and with other requirements for irrigating specific vegetation (see www.salinitymanagement.org for additional information; also Tanji and Kielen, 2002).

Data on toxicity levels of water constituents to vegetation and crops are well known, and it is important to access this information if land application becomes a short-listed CM option. The sensitivity of plants, fruit trees, and grasses to various natural water constituents can vary significantly.

> **Example:** Boron, for example, is essential to plant growth, with the optimal level for many plants being in the few tenths mg/L range. However, citrus fruit trees are sensitive at 1 mg/L levels, and most grasses are relatively tolerant at 2.0 to 10.0 mg/L. (Rowe and Abdul-Magic, 1995)
>
> **Example:** Selenium (Se) could potentially be toxic to some plants in concentrations as low as 0.025 mg/L (Ayers and Westcot, 1985). Therefore the recommended the maximum irrigation water concentration for Se is 0.02 mg/L. It is not an essential element for plants, but is an essential element for animals. The difference between required and toxic levels for animals is small. Excessive levels of Se in soil or irrigation water may lead to excessive Se uptake by plants, which may lead to toxicity issues for domestic animals or wildlife eating the plants. Drainage water from some areas such as the Central Valley of California often contains problematic levels of Se as a result of the region's geology, regardless of the quality of irrigation water applied.
>
> Selenium uptake by plants is significantly inhibited by sulfate, and higher maximum irrigation water Se may be acceptable if soil or irrigation water sulfate levels are high (Pratt and Suarez, 1996). As an example, alfalfa is known as a relatively high-risk crop in terms of uptake and crop use (Tanji and Kielen, 2002). With high levels of sulfate, and a substantive leaching fraction (i.e.,, 20% excess irrigation to maintain relatively constant salinity in the root zone), crop levels of Se would not exceed animal thresholds for toxicity at an irrigation water concentration of 0.1 mg/L. Therefore the 0.02 mg/L irrigation threshold is a conservative screening level, and higher rates may be acceptable depending on other aspects of irrigation water quality, soil conditions, the crop, and the intended use of the crop.

12.10 Screening-Level Evaluation

A primary concern with both irrigation and percolation ponds is possible contamination of groundwater. Thus, use of concentrate for these applications is limited by groundwater protection regulations based on the classification of the underlying groundwater. Although it is possible to install drainage and collection systems, these are not widely required practices for concentrate land application.

Another primary concern in using concentrate for irrigation is compatibility with the vegetation or crops being irrigated.

The primary feasibility factors that can be addressed at the early screening level evaluation include

- climate
- volume of concentrate
- sufficient land
- effect of concentrate salinity and composition on underlying groundwater
- need for and availability of dilution water
- permitability
- effect of concentrate salinity and composition on vegetation or crops
- distance and terrain between desalination plant site and suitable land

Concentrate volume and composition may not be well defined at the beginning of the screening level evaluation. Initial estimates may be based on the best available raw water quality information and the results of computer simulations to predict concentrate conditions. As better water quality information becomes available, evaluations should be reviewed and updated as necessary.

As with evaporation ponds, cold climates may limit irrigation and percolation to the warmer seasons. During the colder months, concentrate may need to be stored or an alternative CM option may be needed. Land application may also require storage for periods of heavy rainfall.

Interaction with the state regulatory agency will provide salinity and constituent limits based on groundwater protection regulations. Comparison of concentrate salinity and composition (estimates) with groundwater limits can provide an indication of whether and how much dilution water might be needed (this requires identification of an available dilution water). Dilution ratios for individual constituents can be calculated to determine what constituent is dictating the dilution water need.

When the total volume of concentrate (possibly diluted) and loading rates for the type of landscape or crops (or soil for percolation) are known, the required land area may be estimated.

Frequently, the amount of dilution water needed, the volume of concentrate, the land required, and/or the climate-related feasibility of year-round land application will eliminate it from further consideration.

As reflected in Figure 5.2, land application costs are typically less than evaporation pond costs, as the land may not need to be purchased and expensive liners are not needed. Most typically, the land application cost estimates are delayed until a later evaluation phase. The costs are primarily conveyance and distribution costs.

12.11 Preliminary-Level Evaluation

If land application has been short-listed, a more detailed analysis is required to ensure the feasibility of the option. This analysis will be based on better estimates of concentrate composition and volume. Concentrate concentrations and groundwater water quality standards will determine what level of dilution of concentrate might be required. A source of dilution water and its water quality needs to be defined and availability ensured. Water uptake/loading of the particular crop or landscape vegetation needs to be taken into consideration in determining the irrigation land requirement. Similarly, for percolation ponds, the soil permeability and loading rates are used to estimate the land requirement. If the land application cannot proceed every day, as might be the case during heavy rains, a means of storage or an alternative CM option may be needed. Similarly, if land application is seasonal, an alternative CM option for the off season will be necessary. All of these aspects should have been considered in more general terms at the screening-level evaluation stage in order for land application to have been short-listed. At the preliminary level of consideration, the analysis is conducted at a more detailed level. Final details of land availability, crop/vegetation/soil specifics, need for and source of dilution water, design requirements for the conveyance and distribution system, and need for and identification of possible storage and back-up CM options all need to be well defined and costed.

Any estimates and evaluations based on estimates of concentrate water quality and volume prior to pilot tests may need to be checked and refined following pilot tests.

12.12 Summary

Land application for irrigation is the only potential beneficial use option among the five conventional concentrate disposal options. When irrigation or percolation ponds are used with drainage systems, the challenge of managing concentrate becomes the challenge of managing drainage water. Land application in this case does not represent final disposal.

Environmental concerns are associated with the compatibility of the concentrate with underlying groundwater and soil (for both irrigation and percolation ponds) and with vegetation (for irrigation).

Dilution of the concentrate may be necessary to address these concerns and to meet regulatory limits. The amount of dilution required can be many times the volume of concentrate, such that the need for dilution water and the greatly increased volume can be limiting factors in the feasibility of land application of concentrate.

As a result, land application is the least frequently used option for CM, and its use is usually restricted to small-volume and low-salinity concentrates.

Chapter 13
Landfill

13.1 Description

Wastes from municipal desalination plants are classified as industrial wastes. Residual solids from various CM options may be placed in an industrial landfill, a municipal landfill designed to take industrial wastes, or a dedicated landfill built to industrial landfill standards. Solids from municipal desalination facilities (which may be in the form of slurries prior to dewatering) may be from

- pretreatment processing
  - solids resulting from filter backwash, etc.
  - solids resulting from coagulation and precipitation steps
- solids removed from evaporation ponds
- final solids from high-recovery ZLD processing crystallization ponds or thermal crystallization steps

When used for landfill, solids from pretreatment processing usually require dewatering to minimize transportation costs and to meet landfill site disposal requirements. Solids from evaporation ponds and from crystallization (or spray dryers) typically do not require dewatering prior to disposal.

The total mass of solids can vary significantly. The amount of solids from a large ZLD process (from a crystallizer or from an evaporation pond) may be too great for disposal in existing landfills and may require construction of a dedicated monofill.

13.1.1 Solids from Pretreatment Steps

Membrane systems have screens, strainers, and cartridge filters to remove larger raw water debris/particles. Filtration may be needed to reduce turbidity and suspended solids levels to acceptable feed water levels. The concentration of TSS in surface water is usually much higher than that in groundwater. Thus surface water pretreatment systems typically contain filtration systems. Seawater-fed systems sometimes include more extensive pretreatment in the form of conventional chemical clarification or in-line coagulation followed by filtration. Pretreatment steps beyond particle/solids removal are dependent on source water quality.

Although antiscalants/dispersants are used to slow precipitation reactions, some raw waters may require a pretreatment step specific for removal of potential scalants. This is frequently in the form of a variant of lime softening or (for iron and manganese) air oxidation and filtration.

In general terms (there are exceptions),

- Membrane systems typically use some antiscalant/dispersant.
- Seawater systems have solids from filter backwash and from some form of coagulation and filtration.

- Inland surface water systems have solids from filter backwash.
- Inland brackish water systems typically use cartridge filtration and do not have pretreatment beyond addition of antiscalant/dispersant and possibly acid.

Solid wastes from pretreatment steps have been a standard part of many municipal desalination systems. The connection with CM is present when the solids are associated with additional processing of concentrate (e.g., removal of contaminants or removal of scalants and foulants).

Although solid waste from precipitation steps such as lime softening may go to landfill, they are more typically disposed of or used in other ways (Rodgers, 2011; SCSC, 2010), including

- lagooning (settling ponds where supernatant may be send back to the treatment plant and solids eventually taken to a landfill)
- land application to soils needing calcium enhancement
- neutralizing acid water (such as acid mine waters)
- disposal to sewers (for small volumes)
- soil amendment (mixing of solids with other soils/wastes to provide engineered fill material
- cement production
- dust control

Wastes may require dewatering prior to disposal or use.

13.1.2 Solids from Evaporation Ponds

Depending on the salinity influent to the evaporation pond, the ponds may fill up with solids during the lifetime of the desalination plant and require solids removal to extend the life of the pond. Solids would go to a suitable landfill or a dedicated monofill. In some cases, ponds filled with solids may be covered and retired from use and new ponds may be built. Solids removed from evaporation ponds for landfill typically do not require further dewatering.

13.1.3 Solids from Additional Concentrate Processing Steps

Solid waste from additional treatment steps associated with high-recovery processing is a new option for municipal desalination plants. Solid waste may result from additional chemical coagulation and precipitation steps (discussed in Section 13.1.1) and/or from processing the concentrate all the way to solids (mixed salts).

Mixed salts have been produced in high-recovery ZLD schemes in many industries. Mixed salts produced by thermal crystallizers are routinely landfilled. When the mixed salts are heavily dominated by a single salt, they may find some use. These salts do not require dewatering because of the low water content.

13.2 Historical Use

Very few municipal desalination concentrates have produced solids needing to be landfilled. This is due to the low occurrence of generated solids. The use of evaporation ponds is low, there are no ZLD facilities directly processing of concentrate to solids, and pretreatment solids, such as lime softening solids rarely go to landfill but instead are used in some manner. Landfill of solids, however, is likely to be a growing occurrence with the increased application of high-recovery ZLD processing schemes and associated increased use of small-evaporation ponds and, to a lesser extent, increased direct processing to solids by crystallizers and spray dryers.

13.3 General Feasibility Factors

Major feasibility factors include

- distance between desalination plant and landfill
- nonhazardous nature of solids that meet landfill requirements (i.e.,, moisture content)
- amount of solids produced

The distance between the desalination site and the landfill determines hauling costs. Solids must meet landfill requirements, which depend on the nature of the solids, the appropriate landfill class, and state-dependent regulations. Requirements for landfilling include demonstrating a degree of solidification sufficient to pass a "paint filter" test (U.S. EPA, 2010e). If the solids prove to be hazardous, disposal costs are likely prohibitive for municipal desalination plants. To be designated as nonhazardous, solids must pass a toxicity characteristic leaching procedure test (or a state-required similar test) to meet contaminant-dependent allowable leaching levels (U.S. EPA, 2010f).

The amount of solids from a large ZLD process may be too high for disposal to an existing industrial landfill and thus may require a dedicated monofill. Solids removed from pretreatment of water/wastewater (e.g., lime softening) usually represent a small portion of the total solids present, and such solids may find a use and avoid the need for being landfilled. When, however, water/wastewater is processed to solids, such as via evaporation ponds or thermal evaporation, the amount of solids can be large. As an example, a 1-mgd concentrate of 4000-mg/L TDS contains 16.7 tons (per day) of dry solids.

13.4 Major Cost Factors

13.4.1 Planning Phase Costs

Planning phase costs are related to design efforts. Planning phase tasks include characterizing the nature and amount of solids associated with desalination processing. The nonhazardous nature of the solids needs to be confirmed. The landfill disposal cost of hazardous solids is very high, and if such solids are present in anything but small amounts, the high disposal cost may limit the feasibility of the desalination plant. The need for solids dewatering should also be defined at this stage. Suitable landfill sites and disposal requirements need to be identified and an early judgment made as to whether landfill disposal is possible. This is dependent on solids volume, hauling distances, and disposal requirements. If disposal to an existing landfill is not possible, issues associated with developing a dedicated monofill need to be examined. Cost estimates need to be developed for the landfill or monofill scenarios. During the initial screening level of evaluation, solids characteristics will be based on estimates of feed water qualities to various processing steps. As the level of design advances, estimates can become more exacting.

13.4.2 Capital Costs

Capital costs include costs associated with dewatering and storage of solids. The higher salinity of concentrate, resulting from SWRO or high-recovery processing in the case of inland desalination, requires suitable construction materials to avoid corrosion. Capital costs may also include costs related to construction and eventual closure of a dedicated monofill.

Costs associated with construction of a monofill can best be estimated by communicating with a landfill construction service company.

13.4.3 Operating Costs

Operating costs include

- costs associated with dewatering operations
- hauling costs from desalination site to an existing industrial landfill or a dedicated monofill
- disposal fees at the industrial landfill
- (possible) monitoring and other costs associated with maintaining and operating a dedicated monofill

13.5 Environmental Concerns

The primary concern associated with landfills is leakage and migration of wastes, such that the landfill can become a point source of contamination. For disposal of nonhazardous waste to existing landfills, the liability is the responsibility of the landfill owner. The concerns can be the responsibility of the municipality in the case of construction and use of dedicated monofills. Another concern is the carbon footprint associated with transport.

13.6 Regulatory Basis

Landfill regulations are overseen by state agencies, except for the case of hazardous waste, where the Resource Conservation and Recovery Act has jurisdiction. State regulations determine the design and disposal requirements for all nonhazardous landfills and monofills. Solids delivered to suitable landfills need to meet paint filter test standards that determine the level of liquid leakage. Some landfills offer a solidification service to enable brines/slurries to pass a paint filter test.

13.7 Impact of Feed water Volume on Solids

The amount of solids in concentrate is proportional to the volume of concentrate.

13.8 Impact of Feed water Salinity on Solids

Simply stated, higher salinity source waters result in the production of a larger mass of solids for landfill disposal. The amount of solids produced at each processing step depends on salinity and composition. For pretreatment, such as lime softening, the amount of solids generated per feed volume depends on hardness, alkalinity, and the extent of removal attained.

In ZLD processing, typically some of the solids in the original feed water are removed in various pretreatment/treatment steps. This usually represents a relatively small percentage of the solids in the original feed. Thus, the amount of solids going to either an evaporation pond or a crystallization (or spray dryer) step at the end of a ZLD process is dependent on the volume and salinity of the original feed water. Two mgd of a 4000 mg/L feed water will, except for solids removed in pretreatment/treatment steps, contain twice as great an amount of solids as 2 mgd of 2000 mg/L original feed water. The amount of solids going to an evaporation pond or to a landfill thus depends on the salinity of the original feed water.

Continuing with this example, an evaporation pond will fill with solids approximately twice as fast in the 4000 mg/L case as in the 2000 mg/L case. Original feed water salinity influences when and how often evaporation ponds need to be dredged or covered over and retired.

13.9 Impact of Feed water Composition on Solids

Feed water composition effects on solids processing include the following effects:

- Dewatering of solids solutions is highly dependent on the solution composition. This can impact solids dewatering costs and final solids volume and thus disposal cost.
- Contaminants determine whether or not the solids are hazardous.

Although various precipitation steps are chosen to remove specific potential scalants, foulants, and/or contaminants, many also remove varying amounts of other constituents. Composition of solids removed in pretreatment/treatment steps is thus somewhat dependent on the general composition of feed water to those steps.

Similarly, in the case of ZLD processing, the composition of the final brine going to either an evaporation pond or a crystallization (or spray dryer) step is dependent on the feed water to that step. Feed waterComposition of feed water to each step is influenced by the original process feed water composition and the effect on composition from pretreatment/treatment steps.

13.10 Screening-Level Evaluation

Solids can result from pretreatment and from high-recovery processing, where potential scalants are removed to allow higher recovery levels. Solids can also result where mixed solids are the end byproduct from high-recovery ZLD processing.

Management concerns are twofold. First, the amount of solid material can be significant, depending on the size of the proposed desalination plant. The amount can be too large (see Section 13.3) for disposal at existing landfills, in which case a local dedicated monofill must be constructed. Second, the solids may be hazardous, in which case the cost of disposal may be prohibitive. It is important to get an early indication of whether solids disposal might be a feasibility-limiting concern.

In the screening stage, the amount of solids generated from processing can be roughly estimated once a conceptual design is defined. The design, based on the raw water quality and product water goals, will define whether high-recovery processing will be used and whether any solids removal/pretreatment steps may be needed. Estimates of solids from any pretreatment steps will be based on the nature of the steps, according to standard design practices for those steps. The maximum amount of solids will occur if high-recovery ZLD processing is considered. In this case, an initial conservative estimate of solids that may result can be based on assuming that all solids present in the feed water end up as final solids. This will give a dry solids amount. The volume of solids from a thermal crystallizer or a spray dryer can be estimated by assuming solids to be in equilibrium with ambient moisture. This is frequently assumed to be 10 to 15% water by volume.

Determination of whether solids are hazardous or not requires a comprehensive raw water quality analysis that includes trace metals, organics, and NORMs—any materials that could render solids hazardous. A detailed water quality analysis may not be undertaken until the preliminary design phase of the desalination plant—thus, after the project moves ahead based on a favorable feasibility study. During the screening-level evaluation stage, discussions with regulatory agencies can be helpful in identifying any natural background contaminant levels that are associated with regional source water.

Travel distances and the general possibility of utilizing existing landfills can also be determined. Hauling costs can be estimated. Existing landfills may be too small or too far away, in which case construction of a dedicated monofill for storing solids can be considered.

13.11 Preliminary-Level Evaluation

A more comprehensive analysis of feed water to any pretreatment steps and of concentrate for solids coming from possible high-recovery processing is needed to define solids composition and determine whether any solids from the desalination process may be hazardous. At some point in the preliminary stage of design, the processing approach(s) will be well defined and processing steps that generate solids will be known. The amount of solids estimated from standard design principles can be more exact.

Evaluation of possible solids from NF- and EDR-based desalination processes follows these same considerations, as does the evaluation of solids produced by treating surface water.

13.12 Summary

Disposal of solids is a relatively straightforward CM option. Solids are either nonhazardous or hazardous. Disposal of hazardous solids related to desalination processing is, in general, cost-prohibitive to municipal facilities. Some solids require dewatering and some do not. As with concentrate, solids associated with municipal desalination plants are considered industrial waste, and disposal must be to a landfill that can accept industrial waste. Costs of disposal are dependent on the distance between the desalination plant and landfill, as well as on the volume of solids to be disposed of. In some cases, disposal volume or hauling cost may require construction and operation of a dedicated monofill. Regulation of landfills for nonhazardous waste is overseen by a state agency. Disposal requirements include passing a paint filter test to demonstrate the nonliquid nature of the solid.

Chapter 14

Beneficial Uses

14.1 Description

Concentrate represents a potential resource in terms of the water and minerals it contains, and if a beneficial use can be found, it could enhance the feasibility of some desalination projects. Beneficial and nontraditional uses of concentrate have been described and evaluated previously in detail (Jordahl, 2006). The materials in this chapter summarize and update the previous report. Beneficial uses are defined here as any applications where a flow of concentrate or individual salts contained within the concentrate are utilized to support or supply some other process that results in some economic, social, or environmental advantage. In most cases, these potential beneficial uses do not represent a final disposal of salts in the concentrate. These potential options are listed in Table 14.1 (same as Table 3.9)**.**

Issues associated with beneficial use options (not included in other chapters) are described in the following sections. In general, the beneficial use options are primarily theoretical or potential applications that have either not been tested or have not yet been implemented at full scale.

14.2 Oil Well Field Injection

14.2.1 Historical Use

There is no known case where concentrate has been used for oil recovery, but the issue has been examined in some detail in Texas. Dwindling supplies of domestic sources of oil are increasing interest in finding ways to extract additional oil, and concentrate could potentially be used to provide additional makeup water to facilitate this extraction. Additional details and references can be found in Jordahl (2006).

14.2.2 General Feasibility

The key factors that would likely determine the general feasibility of this approach include the following:

- beneficial use arising from opportunity to pressurize oil reservoirs to extract additional oil
- need for isolation of the receiving formation from drinking water aquifers
- potential for formation damage as a result of the chemistry of the concentrate or other factors, resulting in reduced permeability (e.g., scale, precipitates, deflocculation/migration of clays)
- injectivity—the capacity of the formation to receive water must be sufficient and sustainable
- potentially applicable to Texas, Oklahoma, Kansas, and California (i.e.,, states with extensive oil and gas fields)

- need for water utilities to establish acceptable long-term agreements with oil and gas field operators

- Finite nature of receiving oil and gas reservoirs and possible downtime associated with oil and gas operations outside the water utility's control would necessitate necessitating additional short short-term and long long-term CM options.

Table 14.1. Summary of Potential Beneficial Uses of Concentrate

Beneficial Use Concept	Description
Oil well field injection	Make-up water can be used to pressurize oil reservoirs to extract additional oil.
Energy generation (solar ponds, etc.)	Feedstock and make-up water in solar ponds can capture solar energy and heat water.
Land application/irrigation (discussed in Chapter 12)	Low-salinity concentrates can be used to irrigate salt-tolerant crops.
Aquaculture	Feedstock can be used for marine (salt water) aquaculture (production of fish for food under controlled conditions).
Wetland creation/restoration	Brackish or salt marsh wetlands can be created or restored.
Treatment wetlands	Constructed treatment wetlands can be used to remove nutrients, metals, and organic compounds; reduce discharge volume; support subsequent reuse for environmental benefit; and allow discharges that would otherwise not be possible.
Stormwater/wastewater blending	Where low-salinity discharges are problematic, such as to estuaries, concentrate could provide a source of soluble salts. In addition, concentrate could be used to dilute wastewater, reducing the concentration of certain compounds in wastewater (i.e.,, BOD, ammonia-N). Nitrate-rich concentrate may reduce air requirements for wastewater facilities that do not have total nitrogen limits in their NPDES permits.
Feedstock for sodium hypochlorite generation	Concentrate could provide a source of chloride.
Cooling water	Could be a source of additional makeup water.
Dust control and de-icing	Salts such as calcium chloride could be separated and applied for these uses.
Cement manufacture	Proprietary processes (e.g., Calera, 2010) can utilize alkalinity obtained from salt solutions to precipitate carbonate compounds, which in turn may be useful cements for construction materials.
Greenhouse gas sequestration/air pollution scrubbing	Proprietary processes (e.g., Calera, 2010) provide the potential to sequester CO_2, SO_2, and concentrate as a potential feedstock.
Separation of individual salts from concentrate (introduced in Chapter 3 and discussed in detail in Chapter 15)	Potential exists for industrial or other reuse.

14.2.3 Major Cost Factors

14.2.3.1 Planning Phase Costs

Planning phase costs are not well defined for most of the potential beneficial use options, including oil wellfield injection. Planning phase costs would likely be generally similar to ordinary DWI, but potentially even more costly, given the lack of a track record for this approach. Planning phase costs would likely include

- developing estimates of concentrate volume and composition
- initial permitting efforts
- evaluation of hydrogeological conditions in the area
- discussions with oil and gas extraction companies, and eventual development of contracts
- evaluating alternative short-term and long-term CM options
- assessment of compatibility of concentrate with aquifer materials
- installation and operation of test wells
- modeling groundwater flow dynamics and chemistry

14.2.3.2 Capital

A number of major capital cost considerations for oil wellfield injection would be very similar to those for DWI (Section 10.4.2). Additional capital cost components for this approach would likely include the following:

- Injection well classification—Class I industrial waste (which may or may not be considered "hazardous") injection wells would be more expensive than Class II (used for produced water injection at oil and gas sites). The applicability of Class II standards for concentrate injection is not fully established, but appears possible.
- Development of short-term and long-term options for CM when oil/gas wellfield injection is offline or capacity is exhausted.

14.2.3.3 Operating

Operating costs would be very similar to ordinary DWI (Section 10.4.3), and would include

- monitoring
- periodic integrity testing
- pumping
- coordination with oil/gas firms
- pretreatment costs to maintain compatibility with aquifer, including chemicals and associated equipment, including maintaining equipment
- corrosion issues

14.2.4 Environmental Concerns

Leakage and migration of concentrate would dominate environmental concerns. No impacts to flora, fauna, or human health would be expected unless leaks, spills, or unanticipated groundwater discharges to the surface occurred, or there were leakage to a drinking water supply aquifer or surface water. If concentrate could be used to replace higher quality makeup water, an argument could be made that there would be an environmental benefit in terms of water supply.

14.2.5 Regulatory Issues

Regulatory issues for oil/gas wellfield injection would primarily be driven by state-level interpretations of U.S. EPA rules on DWI (see Chapter 10).

14.2.6 Impact of Concentrate Salinity and Composition

Similarly to ordinary DWI, the impact of concentrate salinity on chemical compatibility with the receiving aquifer would have to be considered, as well as the potential for formation damage as a result of the chemistry of the concentrate or other factors, resulting in reduced permeability (e.g., scale, precipitates, deflocculation/migration of clays).

14.3 Proprietary Processes (e.g., Calera's MAP and ABLE)

A proprietary process has been developed to capture carbon dioxide from industrial sources such as power plants, and convert it to carbonate solids that could potentially be used in building materials as cement, or for injection of carbonates in solution into underground reservoirs, capturing the carbon. The process is being tested as part of a 100 MW natural gas plant in Moss Landing, CA (Calera, 2010). No full-scale or long-term applications are known. Concentrate may be used as a feedstock for the process.

14.4 Solar Ponds

14.4.1 Historical Use

The management issues associated with solar ponds for energy generation have been explored in considerable detail through testing in El Paso, TX (Lu et al., 2001, 2004; UTEP, 2005). No literature is known describing an actual solar pond constructed and operated with concentrate (Hou, 2004); however, the Israelis have been investigating solar pond technology for more than 30 years (Morales and Smith, 2004). Current investigations include those by the University of Nevada—Reno, examining low-cost solar ponds coupled with a patented membrane distillation system (Science Daily, 2010).

14.4.2 General Feasibility

The general feasibility of the solar pond approach would include evaluation of the following process and climatic factors:

- For start-up, the lower zone of the pond needs to be >200,000 mg/L TDS. Therefore a source of high-salinity brine or evaporation of most concentrates would be required before use.

- Applicable to areas with consistent high levels of solar radiation (e.g., U.S. southwest).
- Less applicable to areas subject to seasonal stormy weather (e.g., U.S. Gulf Coast), as strong winds would disrupt the required layers in the pond.
- A number of months are required to establish the needed layers and gradients of salinity/temperature within the pond.
- Maintenance of the different salinity/temperature layers that are required is a management challenge.
- Periodic wasting and disposal of accumulated salts from the pond would eventually be required (i.e., a solar pond does not constitute a final disposal option for concentrate).

14.4.3 Major Cost Factors

14.4.3.1 Capital

One estimate of capital costs as a function of solar pond size based on research in Texas is provided in Table 14.2, but it should be noted that the capital costs shown are probably underestimates for a system that includes leak detection, liner, and land costs. Although full-scale examples for which to assess capital costs are not available, the following considerations would likely be applicable:

- Economies of scale are likely to be considerable.
- As compared to evaporation ponds, water depths are greater, and berms are larger.
- Other components include heat exchange piping and monitoring equipment, and requirements to generate a very high-salinity brine for the bottom layer (a significant increase in concentration for most concentrates).
- Major factors include liner, leak detection, heat exchanger, and land costs.
- Solar ponds are currently being investigated as a source of energy to drive thermal desalination processes, which could impact both capital and operating cost considerations (Science Daily, 2010).

14.4.3.2 Operating and Maintenance

An initial estimate of operating and maintenance (O&M) costs is provided in Table 14.2. Some key factors that would likely influence these costs include the following:

- The value of energy generated would be an important factor offsetting construction and operating costs
- Periodic disposal of accumulated salts
- Monitoring and maintenance of zones of salinity in the pond
- Corrosion control

14.4.4 Environmental Concerns

Environmental concerns for solar ponds are essentially the same as described for evaporation ponds (Chapter 11). No downstream uses for water or salts from the pond are likely feasible, unless individual salts can be separated from solar pond residuals. Increasing energy costs and GHG concerns are increasing interest in sources of alternative energy, which could renew interest in the technology.

Table 14.2. Summary of Estimated Costs for Solar Pond Coupled Reverse Osmosis Plants

RO plant capacity	1 MGD	10 MGD
Solar pond size (ac)	52	469
Total capital costs	$4,722,000	$31,899,000
Total annual O&M	$933,000	$6,594,000

Source: Lu et al. (2002).

14.4.5 Regulatory Issues

Regulatory issues for solar ponds are not well established, but would likely be very similar to those for evaporation ponds (Chapter 11).

14.4.6 Impact of Concentrate Salinity and Composition

Most concentrates are too dilute to use for system start-up, but would be adequate for makeup water. Further concentration steps may be problematic in terms of precipitation, with some constituents already at or beyond saturation. The presence of organics in the solar pond (e.g., from algae) may impact saturation indices for various salts.

14.5 Aquaculture

14.5.1 Historical Use

No specific research is known that examines concentrate use in an aquaculture system, although aquaculture has been investigated as a beneficial use for saline groundwater in the Murray–Darling region of Australia (Flowers and Hutchison, 2004).

14.5.2 General Feasibility

Production would be limited to fish species adapted to brackish water up to seawater concentrations. *Mariculture* is a term for saltwater aquaculture (Goldberg et al., 2001). Shrimp, salmon, clams, and oysters are species of commercial importance for marine and brackish waters (Goldberg et al., 2001). Tilapia are technically freshwater fish, but are very tolerant of salinity, and have rapidly increasing importance (SRAC, 1999).

Other factors that would need to be considered in the evaluation of aquaculture as a beneficial use include the following:

- Although a considerable fraction of current aquaculture production is conducted in pens in larger water bodies, it is assumed that aquaculture using concentrate would need to be in constructed impoundments.
- Volumes of concentrate required will generally be low, as recirculating systems are increasingly common in aquaculture.

- Warm climate (for most commercially important salt-tolerant fish), flat topography, low-cost land, access to markets for fish, and options for final effluent disposal are needed.
- Potential exists for toxic constituents and ion imbalance issues. Ion imbalance would be especially important if egg/larval stages were included in the process, as these stages are most susceptible to these effects.
- Membrane cleaning solutions would likely be problematic, and would likely need to be treated or disposed of separately.
- Final effluent may be more problematic to dispose of than original concentrate because of increased salinity from evaporation, increased BOD, nutrients, TSS, etc.
- New marine aquaculture facilities are increasingly placed in open-ocean environments rather than as constructed lagoons. These are often submerged to reduce visibility, the impact of severe weather, and shipping (FTAI, 2010).

Vegetative systems have been integrated with aquaculture, known as aquaponics, as a means of creating more sustainable food production systems through a symbiosis of plant needs for nutrients and the need for clean water for fish production (Diver, 2006). This approach has not been investigated with concentrate.

14.5.3 Major Cost Factors

14.5.3.1 Capital

Capital costs may be roughly similar to evaporation pond costs (Chapter 11), but no actual data are available for a system based on concentrate. Costs in addition to typical evaporation pond costs include recirculation piping and pumps, provisions for effluent disposal, and potentially larger berms to accommodate greater water depths. Additional costs are likely because of the need to be able to routinely harvest the cultured fish/invertebrates either through netting or via pond drainage/harvest/refilling cycles. Short-term storage may be required if these waters are to be reused rather than discharged.

14.5.3.2 Operating and Maintenance

Operating costs for an aquaculture disposal option would include

- culture and purchase of juvenile fish, nutrients, food, chemical additions, marketing and shipping costs, and maintenance of pumps and piping
- effluent disposal
- value of fish produced can help to offset operating costs, but margins are low
- routine testing to confirm food safety
- corrosion control

14.5.4 Environmental Concerns

There would be a number of environmental concerns associated with an aquaculture beneficial use. One major issue would be the increase in nutrients, TSS, and salinity in the effluent from the system as compared to the concentrate. Effluent discharges could potentially be recovered for reuse, depending on final salinity and salinity tolerance of the crop to be irrigated. The enrichment in nutrients could be beneficial. Filtration would likely be needed prior to irrigation, with the extent of filtration needed a function of the design of the application system.

Other environmental concerns for aquaculture as a potential beneficial use include the following:

- Toxicity from concentrate to fish being produced and to incidental species such as birds that may visit the site.
- Bioaccumulation within the fish of constituents in the concentrate (e.g., arsenic, mercury, selenium), which could become an issue for both incidental wildlife species and human consumption of the fish produced.
- If the concentrate is derived from wastewater, endocrine disruptors and other potential compounds of emerging concern will be found at increased levels in concentrate, and use for aquaculture will likely result in further bioconcentration in the fish and health concerns for consumers of the fish.
- Fish farm workers will have higher exposure to potential toxicants. “Aquaponics” (described previously) could potentially provide a means of producing higher quality discharges.
- Decreasing stocks of fish in oceans are increasing reliance on aquaculture for human food consumption, which could potentially increase interest in alternative methods of producing salt water fish.

14.5.5 Regulatory Issues

Regulatory issues for aquaculture as a beneficial use would be largely driven by effluent water quality concerns, potential groundwater impacts, food standards for fish produced, and various state and local concerns. Surface water and groundwater permit requirements (CWA, state standards, etc.) are discussed in Chapters 6–8. USDA food standards would apply to the fish produced. Local and state permit requirements would impact zoning, aesthetics, odor, land use, and other issues.

14.5.6 Impact of Concentrate Salinity and Composition

Considerations regarding concentrate salinity and composition would include the following:

- Production would be limited to fish species adapted to brackish water up to sea water concentrations.
- USDA food standards on fish produced could lead to concerns over bioaccumulation, which may be proportional to salinity.
- There is a potential for toxic constituents and ion imbalance issues.

Membrane cleaning solutions would likely be problematic, and would likely need to be treated or disposed of separately.

14.6 Wetland Creation/Restoration

14.6.1 Historical Use

The only known case as of concentrate discharge being used in association with marsh creation/restoration is the Spoonbill Marsh in Florida (http://www.dep.state.fl.us/secretary/post/2008/0222_1.htm). This concept has also been considered in a coastal application at Oxnard, CA, for restoration of the Ormond Beach wetlands system (Jordahl, 2006; Kepke et al., 2009).

14.6.2 General Feasibility

The general concept is that brackish or salt marsh wetlands could be created, or that existing wetland systems could potentially be enhanced using concentrate. A number of issues would influence the feasibility of this concept, including but not limited to the following:

- Flows required to wetlands may be small relative to concentrate flow, and discharges may need to be periodic, thus requiring other disposal options during these periods.
- Concentrate chemistry relative to ecotoxicological thresholds, other pertinent water quality criteria, and potential accumulation of constituents is a concern.
- Discharges to existing wetlands would require broad regulatory review, and would also receive considerable scrutiny by many stakeholders.
- The concept could potentially also apply to inland or coastal systems. Inland salt marshes are most common in arid to semiarid regions, but are also found in many other areas.

14.6.3 Major Cost Factors

14.6.3.1 Capital

Capital cost considerations for a brackish or salt marsh creation or augmentation project may include land, special vegetation issues, and various structures to control or convey concentrate flows.

- For inland salt marshes, the cost of land is typically very low compared to that for coastal applications, but still could be a significant line item in capital costs.
- Purchase and planting of vegetation in nonstandard environments/climates could increase risks of the need to provide plant management/replanting.
- Structures could include conveyance, conveyance termination, possible outfall structure, and possible concentrate storage facilities to allow variable flows to the wetland.

14.6.3.2 Operating and Maintenance

The components of operating costs would be similar to those for other types of monitored wetland restoration projects, but the relative magnitude could vary considerably. Major components would include

- water level management and control

- vector (pest) control
- monitoring
- pump, conveyance, and distribution system maintenance
- plant species management
- corrosion control

14.6.4 Environmental Concerns

Environmental concerns for wetland creation/restoration are somewhat similar to those for evaporation ponds (Chapter 11), including the potential for toxins to accumulate and impact wildlife, and the potential for groundwater impacts to occur if there are leaks. If effluent from the wetland is discharged to surface water, then considerations for surface water discharge (Chapters 6–8) will apply. Other specific factors to consider for concentrate-fed created or restored wetlands would include the following:

- Direct toxicity or bioaccumulation are potential risks (note that appropriately designed treatment wetlands upstream (Section 14.7) could be used to reduce risks to downstream wetlands).
- Human health issues generally are not significant, assuming the site is well maintained and vectors are controlled.
- The potential for downstream uses would depend on the climate, hydraulic loading rate, hydrology of the wetland area, and chemical characteristics of the concentrate discharged to the wetland.
- Increased populations of insect vectors may emerge in areas where no habitat existed previously.

14.6.5 Regulatory Issues

Discharges to existing inland salt marshes would likely be significantly more difficult and costly to permit than if the discharge were to a newly created salt marsh. Existing inland salt marshes likely already have special protections. Extensive site investigations and potentially extensive mitigation projects could be required for discharges to existing salt marshes. The case could potentially be made for an environmental benefit (beneficial use) for a newly created marsh as an amenity, a beneficial reuse of an otherwise unused property or undesirable site condition, etc.

14.6.6 Impact of Concentrate Salinity

Vegetated wetland systems exist across a wide range of salinities, including freshwater, brackish, and estuarine, up to and in some cases exceeding seawater concentrations. The vegetative system would have to be matched with the range in concentrate salinity and evaluated in terms of long-term site water and salt balance.

14.6.7 Impact of Concentrate Composition

Direct toxicity or bioaccumulation are potential risks that must be considered. Note that reductions in toxicity were noted with wetlands treatment in the Oxnard, CA pilot study (Jordahl , 2006). Constituent concentrations must not jeopardize the surviva of created/restored wetland either in the short term or in the long term. Adverse impacts on normal wetland plant and microbial communities would need to be evaluated.

14.7 Treatment Wetlands

14.7.1 Historical Use

Treatment wetlands for concentrate have been pilot tested in Oxnard, CA (Jordahl, 2006) and Brisbane, Australia (Kepke et al., 2009), and a pilot system is currently being tested in Goodyear, AZ (Kepke et al., 2009).

14.7.2 General Feasibility

The key factors to be considered in a feasibility assessment for treatment wetlands include the following:

- Wetland purpose—constructed treatment wetlands could be used to reduce mass or concentrations of specific constituents problematic for surface water discharge (e.g., nutrients, selenium), reduce overall toxicity, and provide temperature reduction (TMDLs have been issued for temperature in some states such as Oregon) and/or volume reduction through evaporation.
- Climatic conditions—applicable to broad range of climates, but more temperate climates will result in better year-round performance, and there is more opportunity for volume reduction in arid climates.
- Sufficient land area must be available.
- An available discharge option downstream from the treatment wetlands is required. Depending on climatic conditions, evaporation may lead to increases in salinity of the final discharge.

14.7.3 Major Cost Factors

14.7.3.1 Capital

Capital cost considerations for a treatment wetland project include the following:

- Major physical components include land, site investigation and system design, earthwork, liners, media, plants, water control structures and piping, site preparation, fencing, access roads, and human use facilities (Kadlec and Wallace, 2009).
- Type of wetland needed for specific constituents will have large impact on costs per unit area. Free water surface, emergent marsh wetlands are relatively low cost compared to vertical or horizontal subsurface flow (e.g., gravel bed or peat bed) systems.
- Kadlec and Wallace (2009) provide a regression based on data from 84 surface flow wetlands (Capital Cost (\$1000s) = $194 \times \text{Area}^{0.69}$, where area is in hectares). Area requirements are a function of type of wetland, flows, and treatment requirements. Wetlands for CM would likely have a higher cost based on piping, number of cells, and possible use of engineered media for growing beds or treatment.

14.7.3.2 Operating and Maintenance

Low O&M costs tend to be a major advantage of wetland treatment systems as compared to conventional wastewater treatment technologies. Specific factors that impact O&M costs include the following:

- Regulatory-driven, research-type continued monitoring can have a large impact on costs.
- For surface flow systems, O&M cost components include pumping energy, compliance monitoring, berm maintenance, pump and piping maintenance, and nuisance species controls (Kadlec and Wallace, 2009).
- Annual costs typically range from $5000 to $50,000/year for smaller systems (Kadlec and Wallace, 2009). These costs do not include any possible increased maintenance costs specific to higher salinity influents. Initial pilot studies have suggested a typical design life of a decade or more. Some types of systems, depending on loading, could require removal and replacement of soil or other media, as is currently anticipated as good practice for subsurface flow wetlands receiving conventional wastewaters. The cost of periodic replacement of media could be annualized as an operational cost. The frequency of media replacement would be determined based upon monitoring results.
- Corrosion control.

14.7.4 Environmental Concerns

Environmental concerns for treatment wetlands are very similar to those described in the previous section on wetland creation/restoration**.** Specific concerns that have emerged from pilot studies using concentrate, and other long-term treatment wetland projects addressing other wastewaters, include the following:

- Direct toxicity and bioaccumulation are potential risks that must be considered. Note that reductions in toxicity were observed with wetlands treatment in the Oxnard, CA pilot study (Jordahl, 2006). Subsurface flow and vertical flow designs can be used to reduce exposure in initial cells.
- Permitting of surface discharge from a treatment wetland can be challenging. Recently, permitting a discharge from a treatment wetland has been difficult in Florida, because of concerns regarding TDS impacts on freshwater receiving waters.
- Constituents must not jeopardize the effectiveness of the treatment system either in the short term or in the long term.
- Water management and periodic sediment and/or plant removal from initial cells can be used to manage risks.
- Human health issues generally are not significant, assuming the site is well maintained and vectors are controlled.
- Surface and groundwater (infiltration) discharges would be available for other uses downstream. Limited available data suggests that overall toxicity would be reduced, mass and concentration of nutrients and some metals would be reduced, and TDS in discharge relative to inflows will depend on climatic conditions (balance of evapotranspiration, hydraulic loading, and infiltration). In lower-rainfall areas, preliminary data suggest reductions in TDS mass, but increases in concentration.
- Blending with other water sources prior to discharge may be needed for some sites.

- Microconstituents such as endocrine disruptors are an increasing concern, and evidence is emerging that treatment wetlands can reduce concentrations of many of these compounds (Gray and Sedlak, 2004).
- Increased populations of insect vectors may emerge in areas where no habitat existed previously.

14.7.5 Regulatory Issues

Regulatory issues for the effluent from treatment wetlands are essentially the same as for other surface water discharges, and are therefore primarily driven by NPDES permits at state and federal levels. Additional information on these regulatory issues is provided in Chapters 6–8. Compliance with groundwater protection regulations is also important in the design. The potential for protected species to reside in or visit the wetland, and potential exposure risks associated with contaminants such as selenium, would require consultation with state or federal wildlife agencies.

14.7.6 Impact of Concentrate Salinity

Vegetated wetland systems exist across a wide range of salinities, including freshwater, brackish, estuarine, and up to and in some cases exceeding seawater concentrations. The vegetative system would have to be matched with the range in concentrate salinity and evaluated in terms of long-term site water and salt balance. Pilot treatment wetland systems have been successfully tested with concentrates of 11,000 mg/L TDS, and somewhat higher concentrations may be possible (Kepke et al., 2009).

14.7.7 Impact of Concentrate Composition

Direct toxicity and bioaccumulation are potential risks that must be considered. Note that reductions in toxicity were noted with wetlands treatment in the Oxnard, CA pilot study (Jordahl, 2006). Constituent concentrations must not jeopardize the effectiveness of the created/restored wetland or wetland treatment system either in the short term or in the long term. Adverse impacts on normal wetland plant and microbial communities need to be evaluated.

14.8 Others

Various other potential beneficial uses for concentrate have been mentioned in the literature, and are briefly discussed as follows:

- *Stormwater or Wastewater Blending*: Theoretically, concentrate could be beneficial as a blending solution in areas such as estuaries where the lack of salinity in existing discharges results in some negative effects. Lack of a precedent, regulatory roadblocks, and blending and storage issues would all need to be resolved. Depending upon concentrate quality, wastewater blending may be beneficial for reducing concentration of certain compounds in wastewater (i.e.,, BOD, ammonia-N). Concentrate may contain high concentrations of nitrate, which can be used as an alternative electron acceptor for oxygen. This can reduce aeration demand for facilities that do not have total nitrogen requirements in their NPDES permits.
- *Subsurface Storage*: Subsurface storage of concentrates less than 10,000 mg/L TDS for later recovery and reuse has been considered where local geological conditions

will allow, but has not been tested. Technological advances may allow recovery of water in the concentrate to be more economical at some point in the future.

- *Feedstock for Sodium Hypochlorite Generation* (which would be mainly limited to concentrate from seawater and perhaps brackish water treatment, but would not be applicable to reuse concentrates): Concentrate could potentially provide a source of chloride to allow generation of sodium hypochlorite for disinfection or other industrial uses. In general, the use of concentrate for hypochlorite generation is not likely to be economically viable for anything other than on-site use by seawater desalination facilities. Because of the potential to form bromates, recent trends are moving away from using seawater as a feedstock.
- *Cooling Tower Water*: Concentrate could potentially be used to supplement cooling water supplies. A major limiting factor is that cooling tower operation is already limited by accumulation of salts leading to scaling, and concentrate would enter the system already high in salts, and sometimes likely already supersaturated. Concentrate blended with wastewater has been used as a cooling water supply for the Palo Verde nuclear power generation station at Winterset, AZ (CASS, 2005). The number of total cycles possible with concentrate would be limited as compared to that for lower-salinity sources of water.
- *Dust Control and De-icing* (which would be mainly limited to BWRO and SWRO concentrates): Some salts in concentrates could be useful in dust control and de-icing, but the mixed salt nature of most concentrates, environmental restrictions, and large volumes generated relative to areas of application make it highly unlikely that concentrate could be successfully used without modification. If pure salts such as $CaCl_2$ or $MgCl_2$ could be separated from the concentrate (Chapter 15), dust control and de-icing would be potential beneficial uses. These hygroscopic salts retain moisture in the surface layers of soils, preventing the formation of dust.

14.9 Summary

A number of potentially beneficial nontraditional uses of concentrate have been identified. Most beneficial uses do not necessarily provide a final discharge for salts and other concentrate constituents, but some of these might contribute to improved water quality, making some form of blending and discharge more viable. Alternatively, some might result in volume reduction, making subsequent disposal options more feasible to implement. It may be possible to develop creative local options for beneficial use. A combination of methods such as linking more conventional options with beneficial nontraditional uses may provide redundancy, reliability, and potentially some ancillary benefits.

Because many of the beneficial use options for concentrate are not well tested, typical planning phase costs are not well defined. However, it is likely that to gain regulatory/environmental approval for some of the candidate beneficial uses, substantive planning-level studies, modeling, or other demonstrations of technology feasibility will be required prior to moving on to detailed design and implementation steps. The level of detail required for such investigations and demonstrations will clearly be highly variable, depending on the state or national review criteria applicable to a given prospective beneficial use project application.

Convergence of the increasing need for desalination with existing and likely future constraints on concentrate disposal by conventional methods suggests that all possible disposal options must be considered to meet water resources needs of the future.

Beneficial nontraditional options for CM tend to have numerous and critically important site-specific considerations that must be considered prior to implementation, including climate, markets, regulatory issues, and ecological risk concerns. Additional investigation appears to be especially warranted for beneficial uses that provide volume reduction, oil well field injection, GHG and other air pollutant sequestration, halophyte irrigation, treatment wetlands to address reductions in the mass or toxicity of specific constituents, and recovery of separated salts.

Chapter 15

Solids Management and Recovery of Values from Concentrate

15.1 Description

Solids that may result from municipal membrane-desalination processing with conventional recovery include

- wastes (which may be slurries prior to dewatering)
  - from treatment steps preceding membrane processing
    - solids from filter backwash
    - solids from coagulation and precipitation steps
  - solids removed from evaporation ponds

Additional solids including separated salts and more complex compounds with potential commercial value may result from high-recovery processing (in most cases from additional treatment of concentrate). These include

- wastes
  - final solids (mixed salts) from
    - high-recovery processing crystallization ponds
    - thermal crystallization
    - spray dryer steps
- separated salts and other compounds with potential commercial value
  - salt products (ionic compounds; i.e.,, Na_2SO_4, $CaCl_2$, $CaCO_3$, $Mg(OH)_2$, etc.)
  - products resulting from additional treatment of concentrate or products from concentrate

Example: There is potential for recovery of struvite ($NH_4MgPO_4{\cdot}6H_2O$), a valuable agricultural fertilizer, by reacting magnesium containing RO-derived brines with ammonia- and phosphorus-rich effluent from the sludge dewatering process of a close-by wastewater treatment plant, where the two plants are co-located or are nearby. (Dr. A. Arakel, personal communication)

More traditional desalination concentrate processing that does not involve specific product recovery steps may also produce salts that can find a use (see Section 13.1.1.). For instance, most lime softening solids are not landfilled but find various applications (ISU, 2006; Rodgers, 2011; SCSC, 2010) that include

- soil amendment
- construction fill
- road fill
- wastewater conditioning

Generally, however, there are few uses and little commercial value of salts not produced to commercial specification, and most go to landfills that accept industrial waste. The reader is referred to Chapter 13 for discussion of solids disposal at landfills.

Separated salts and other products with potential commercial value and mixed salt waste from high-recovery processes are new considerations for municipal desalination.

Discussion in this chapter focuses on recovery of salt products of value, including those listed in Table 15.1. It is possible, for instance, to add salts of lesser value to tailor and force precipitation of salts of higher value. In this way, product recovery does not have to depend on reducing the volume of concentrate to force precipitation of a commercially valuable product. This approach is particularly relevant to mildly saline and alkaline groundwaters, which are prevalent in the southwestern United States. In this case, the reaction of such water with a calcium ion source results in preferential precipitation of fine-grain calcium carbonate at the expense of calcium sulfate. According to Geo-Processors, conventional countercurrent washing the $CaCO_3$ precipitate followed by dewatering enables efficient removal of impurities for producing commercial grade precipitated calcium carbonate (Dr. A. Arakel, personal communication). Multiple products may be recovered in a sequential fashion by alternating product recovery and solution concentration steps. It is simple to cause precipitation of products by pushing a given salt to and beyond its saturation limit. However, production of a given salt of a desired commercial grade and size also requires control of a number of factors including reagent dosing rate, reaction pH and temperature, degree of saturation of salt in concentrate, degree of product washing and thickening, and level of impurities in the final products. Processing sequences for salt recovery include steps specifically designed to meet commercial grade product requirements, an approach very similar to that in the mining/mineral processing industry, where the prime objective is the recovery of valuable carbonates and hydroxides from alkaline or acidic waste streams.

The level of contaminants present in concentrate can dictate the grade of product that can be recovered. Contaminants may be removed up front by precipitation/flocculation or the concentration may be controlled in the product, depending on product quality requirements. Ideally, the bulk of contaminants should be removed in initial treatment steps (i.e.,, before countercurrent washing), and this may include an initial partial precipitation step aimed at co-precipitation/removal of ionic contaminants. In some cases where concentrations are well below the reporting level of a product for a specific use, the contaminant may be left to the end solid phase (i.e.,, encapsulated by the end product).

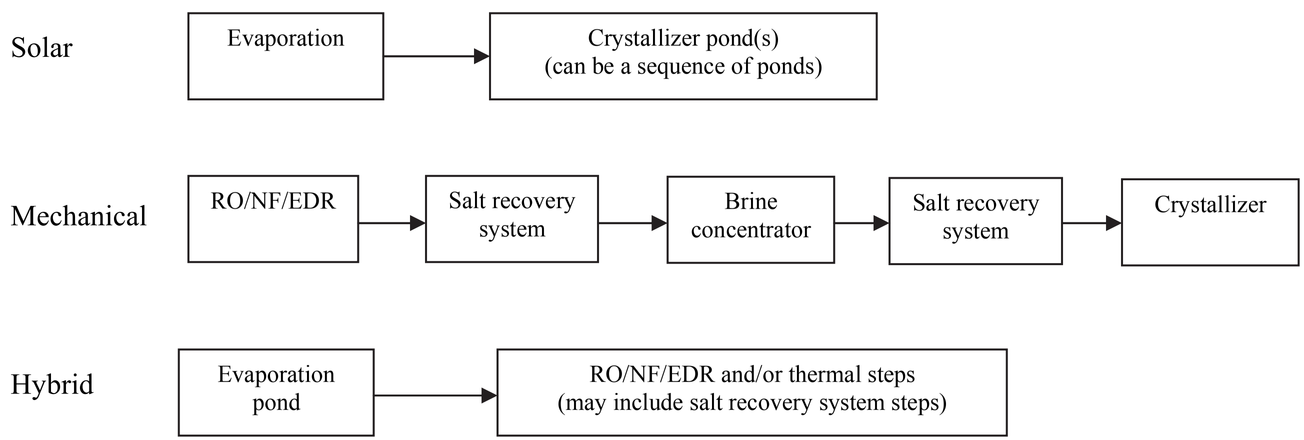
As with high-recovery processing in general, salt and product recovery is a topic of increasing interest within the U.S. municipal desalination community. This is reflected by the amount of research (AWI, 2008; Balliew and Fahy, 2011; CASS, 2006; Howe, 2011; Mickley, 2008, 2009, 2010; Mohammadesmaeili, 2009; WRRF, 2011) and the number of presentations and published articles devoted to salt recovery, as well as the increasing frequency of consideration of salt recovery at desalination plant planning stages (BC, 2005; MWH, 2006; EMWD, 2008).

Table 15.1. Salts Recoverable from Concentrate (from Mickley, 2009)

Chemical Formula	Name	Some Application Areas
$CaCO_3$	Calcium carbonate	Paper coating pigment//Filler for plastics and rubbers, special inks, paints, and sealants
$CaSO_4 \cdot 2H_2O$	Gypsum	Remediation of sodic soils//Manufacture of building products
$CaSO_4 \cdot 2H_2O+Mg(OH)_2$ slurry	Gypsum Magnesium hydroxide	Wastewater treatment//pH buffering//Soil conditioner for sodic soil
$CaCl_2$ (liquor)	Calcium chloride	Dust suppression//Road base stabilization//Sodic soil remediation//Cement/concrete stabilizer//Construction industry
$KNaSO_4$	Glacerite	Potassium fertilizer
$Mg(OH)_2$ slurry	Magnesium hydroxide	Water/wastewater treatment//Environmental//Animal stock feed//Feedstock for magnesium metal production//Fire retardant & refractories//Acid neutralization
$x MgCO_3 \cdot y Mg(OH)_2 \cdot z H_2O$	Magnesium carbonate light	Fire retardant//Feedstock for magnesium metal production//Filler for paper manufacturing, rubber, & paint
NaOH	Caustic soda	Many applications industrially: manufacture of aluminum from bauxite, basic feedstock for other chemical processes, pH adjustment, etc.
NaCl	Halite	Food and industrial processes//Chlor-alkali production//Many industries require bulk salt supply
Na_2CO_3	Soda ash	Water treatment, chemical industry, etc.
Na_2SO_4	Thenardite	Surfactants manufacture//Detergents manufacture//Glass manufacture//Remediation of calcareous soil
NaOCl	Sodium hypochlorite	Disinfection//Chemical industries//Pool chlorine
$NaClO_4$	Sodium chlorate	Paper bleaching//Chemical industries

15.2 Historical Use and Study

Most historical salt recovery operations have source waters dominant in one salt, or end use of the salt product does not demand high purity. Selective recovery of salts from more complex waters is a relatively new approach that is increasingly being considered for incorporation into various high-recovery desalination design schemes (see Chapter 4).
In locations outside the United States, where salts need to be imported, or where the water is highly dominated by one salt, both solar and mechanical (equipment-based) processing may be used to produce salts from desalination concentrate that can be reused (Alberti et al., 2008). Figure 15.1 shows the solar, mechanical, and hybrid general processing schemes, along with how they vary according to physical and energy footprint, quality of salt produced, water production, and equipment cost. Note that all of the processing systems depicted are ZLD systems. The mechanical equipment includes RO/NF/EDR steps, as well as brine concentrator and crystallizer steps. In areas of high solar radiation and relatively inexpensive and level land, the solar approach is the most economical choice. The quality of salt produced, however, is not as high as with the other technical approaches. Variants of the mechanical system (not shown) can include salt recovery steps both before and after a membrane step, multiple membrane steps, and the absence of one or both of the thermal steps. This appears to be the approach followed by Geo-Processors Pty Limited in their patents, presentations, and practice, as reflected in their website (GEO-PROCESSORS, 2011).



Parameter	Solar	Mechanical	Hybrid
Footprint	high	low	high
Energy	low	high	high
Salt quality	lower	high	high
Water production	No	yes (MAX)	Yes
Equipment capital cost	lower	highest	medium

Figure 15.1. Salt recovery systems.

Although recovery of products of value from concentrate is a subject of growing discussion and consideration in the United States, to date there has been no piloting/demonstration of the related technologies at a scale that produces sufficient product to permit verification of product quality and markets by an independent third party. Thus, questions of technical and economic feasibility remain, despite international piloting/demonstration success.

Desktop studies indicate that that recovery of products from concentrate of municipal desalination process can be cost-effective, and this efficacy would improve significantly with an increase in the flow/size of treatment and TDS salinity of the concentrate (CASS, 2006).

Potential benefits of salt recovery include

- reducing the amount of solid waste going to landfill and thus landfill costs
- improving treatment of volume reduction steps that may follow product recovery steps
- reducing operating costs from sale of product (where income from salt sale more than offsets the cost of producing the salt)

Reasons that production of salt and other valuable products has not been part of U.S. municipal desalination processing and CM include the following:

- lack of pilot/demonstration projects (previously mentioned) where control of factors including reagent dosing rate, reaction pH and temperature, degree of saturation of in concentrate, degree of product washing and thickening, and the level of impurities in the final products is demonstrated.
- high costs of implementing high-recovery processing as additional treatment steps relative to conventional recovery processing, and lack of full consideration of the benefits of the product recovery.
- unknowns related to marketing of products, which face a challenge in addressing them in that adequately answering marketing questions require relatively large-scale pilot plants to produce a couple of tons of products to enable a realistic product quality assessment, which would then make it feasible for a third party to verify the market potential of the example products.
- less strong environmental and cost drivers in the United States (such as stronger limitations for surface water discharge, landfilling of waste, etc.) than in some other countries (Dr. A. Arakel, personal communication) that would encourage water districts to seriously consider product recovery from concentrate as part of risk management.

In the past several years, however, selective salt recovery has been increasingly considered at the screening level of evaluation of processing alternatives for U.S. municipal desalination facilities (BC, 2005; EMWD, 2008; MWH, 2006).

Participants in developing and encouraging efforts in salt recovery include Gerry Grott of Superior Salt, Inc. of Phoenix, Arizona, Dr. Tom Davis of both ZDD, Inc. and the University of Texas at El Paso, and Dr. Aharon Arakel of Geo-Processors Pty Limited, Sydney, Australia and Los Angeles, California.

For several decades, Gerry Grott has championed the use of common salt products from natural brines for soil remediation and other uses and has mined and provided certain salts from natural brines for various applications. More recently, he has encouraged the use of salts derived from concentrate for various applications (Grott, 2011).

Dr. Tom Davis has patented a process involving electrodialysis metathesis for the recovery of various salts and slurries of value from seawater and other waters (Davis, 2006; Davis and Raymon, 2008). The processing concept is owned by ZDD, Inc. and has been licensed to Veolia for commercial development of the technology.

The primary source of information on the recovery of products of value from a wide range of waters, including concentrate, is Geo-Processors, Pty Limited via various publications, presentations, and patents. Their patents and commercial processes have been piloted and demonstrated outside the United States (GEO-PROCESSORS, 2011; Rodgers, 2002; Svenson, 2005).

15.3 General Feasibility Factors

Major feasibility factors include

- technology to manufacture (from concentrate) a salt that meets commercial specifications (including purity and grain size)
- local market feasibility
    - presence of potential users
    - price of salt product
    - proximity and cost to transport salt to the market
    - competition for the salt market
- large enough operation to achieve economy of scale and produce enough product to penetrate market
- cost effectiveness
- separate entity management structure to broker materials (i.e., through offtake contract)

Salts of lower commercial value can frequently and relatively easily be obtained as by-products when (a) feed water composition is less complex and dominated by an individual salt or (b) pretreatment/coagulation steps result in a treated water composition dominated by one salt. Product quality in these situations may be sufficient to meet low-value applications not requiring high purity or a specific grain size. It is considerably more difficult (i.e., a more sophisticated process and knowledge of product market requirements are needed) to produce salt to meet higher value product specifications. The technology exists to produce high-purity, higher value products and has been demonstrated by various, mainly international, efforts.

Without a market, there is no incentive to recover salts. It is important, early in a project, to establish a market for salts that may be recovered. This may be done through a market study, preferably independent of the technology provider, to enable independent quality assessment and market valuation of the products. The availability of local markets will minimize transportation costs for salt products. The potential salt recovery operation should be large enough to benefit from economies of scale and from attracting market clients and brokers. Ideally, a concentrate treatment system that achieves both waste minimization and product recovery objectives can help to boost the economics and hence implementation of salt recovery significantly as part of a total desalination and CM solution. Such an approach should be appealing in regions where regulatory or drought conditions limit surface discharge. Salt recovery can result in a concentrate disposal solution that reduces the risks and liabilities associated with landfill disposal.

A cost/benefit analysis is necessary for feasibility determination. This analysis includes consideration of the salt products that can be produced, the market value of the products, and the capital and operating costs involved with the desalination/salt recovery operation. The cost effectiveness should be compared with that of a desalination plant where concentrate is managed without salt recovery.

15.4 Major Cost Factors

15.4.1 Planning Phase Costs

Initial planning phase efforts include

- modeling studies based on source water quality to determine possible salt products and alternative processing schemes
- conceptual design of integrated desalination and salt recovery process
- bench-scale study to confirm ability to meet salt product specifications and define operating conditions
- market feasibility study
- salt product management study

As with all planning-phase tasks, initial considerations begin with rough or incomplete source water quality projections and estimates of plant size. Conceptual design can be undertaken with limited information and be updated and firmed up when more quantitative information becomes available. Processing variables include

- temperature and pH
- residence time
- addition of inexpensive salts to facilitate recovery of more valuable salts
- alternative processing pathways involving multiple desalination, salt recovery, and thermal volume reduction steps to achieve both waste minimization and product recovery objectives

Initial design alternatives are assigned advantages and disadvantages, including rough estimated costs. Salt recovery steps can also serve as pretreatment steps in allowing additional, more efficient water recovery in the desalination steps that follow. In general, salt recovery steps can come before or after desalination steps. The water recovery achieved in desalination steps preceding salt recovery steps needs to be appropriate for recovering salt in the following salt recovery steps. Consequently, the design of the processing system must consider the interaction between salt removal and desalination steps.

Lab-scale tests are helpful in defining/confirming salt recovery operating conditions, chemical needs, and amounts of salt product obtained under given conditions. These tests typically would take place after the initial screening level, in which salt recovery possibilities and preferred processing scenarios are defined.

In parallel with the initial feasibility screening study and prior to possible preliminary design, a market feasibility study needs to be undertaken to determine the size of the local market, the local value of the product, and possible purchasers of the salt and more generally that salt recovery is economically viable and that there are no significant impediments (technical, political, or social).

Pilot studies would be required following an initial positive outcome planning phase to demonstrate salt recovery on a continuous basis and confirm assumptions about salt product yield, quality, costs, and applicability issues.

15.4.2 Capital Costs

As reflected in Figure 15.1, there are two general types of processes necessary for a selective salt recovery system:

- desalination equipment (or crystallization ponds)
- reactors, tanks, thickeners, filter presses, etc. similar to those used in mineral, chemical, and food processing operations

Capital costs vary according to the size and type of equipment or pond used.

There may be waste products from some processing steps, including pretreatment and final processing steps (ponds or mechanical equipment). Capital costs may include storage tanks, waste treatment (such as dewatering), and final waste disposal (such as landfill costs) for residual concentrate components.

The marketing of salt products should be done by a separate entity that purchases the salt product and performs final packaging, marketing, and selling. This separates the marketing and product commodity business from the municipality.

Some of the capital and operating costs might be shared with the desalination facility, as high-recovery processing and salt recovery can improve desalination system performance, aside from providing a means for waste management.

15.4.3 Operating Costs

Operating costs may include

- chemicals
- energy
- possible treatment and transport of process waste products
- possible income from product sales

Operating costs are also associated with the selling of the products. Income from product sales can offset other operating costs and in some cases result in a net operating income (GEO-PROCESSORS, 2011). Each case needs to be assessed by its own set of conditions and commercial criteria.

15.5 Environmental Concerns

The high-recovery processing associated with selective salt recovery may result in brine and solids requiring disposal:

- concentrate/brine
- pretreatment solids
- mixed final salts from crystallization pond or thermal crystallizer
- possible small-volume purge stream from a thermal crystallizer or final bitters from a crystallizer pond

Previous chapters addressed environmental concerns associated with management of the first three of these materials. Concentrate or brine would likely go to evaporation ponds; solids would likely go to landfill. The only new twist may be the management of very high-salinity brines of highly soluble salts from a thermal crystallizer or crystallizer pond. If these brines contain suspended solids, the solids may need to go to a decantation pond prior to conveyance to an evaporation pond to prevent solids from settling/precipitating in the pipeline. Typically, these brines go to an evaporation pond or, if the volume is small enough, to a spray dryer. One of the benefits of salt recovery is reducing the production of wastes and thus reducing the environmental concerns associated with waste disposal.

15.6 Regulatory Basis

Selective salt recovery is a processing approach. Aside from the salt products produced, the byproducts/waste streams associated with the approach are the same as or similar to those discussed in previous chapters. The regulations that come into play with the concentrate and solids are those associated with evaporation ponds (Chapter 11) and landfill (Chapter 13). Salts/solids for use do not generally require governmental permits. The products need to meet application specifications.

15.7 Impact of Feed Water Salinity

Removal of an individual salt by precipitation occurs when solubility limits are reached. Solubility is a function of ion concentrations, concentration of other constituents, pH, and temperature. Most often, manipulation of ion concentrations is used to reach solubility limits and recover separated salts. This may be through concentration of the feed water via a desalination step and/or by adding less expensive salts having an ion in common with the salt to be removed. Salinity, in general, has no relationship to how close a given salt is to its solubility limit.

15.8 Impact of Feed Water Composition

The ionic makeup of the feed water will determine the relative amounts of various salts that can be produced through

- further concentration of the feed water (volume reduction)
- addition of salts (manipulation of the chemical balance)
- temperature and/or pH change

Volume reduction will concentrate ions and eventually bring salts to their solubility limit. After precipitation of the first salt, additional volume reduction will bring another salt to its solubility limit. The sequence of salts coming out of solution defines the solution's precipitation path.

The precipitation path sequence can be changed by addition of ions that change the chemical balance and bring a desired salt closer to its solubility limit.

The solubility of salts is a function of temperature and in some cases pH. The dependence of solubility on temperature varies with each salt in terms of whether solubility increases or decreases and how sensitive solubility is to temperature change. Thus temperature may also be used to influence precipitation pathways. Temperature also can be used to affect the kinetics of precipitation.

Impurities or contaminants in the feed water may affect salt recovery processing. Some contaminants in feed water may be removed along with the desired salt in the salt recovery process steps. This may or may not be a problem in regard to salt products meeting application requirements. The contaminants may be present in the salt product in such small quantities/concentrations that they are of no consequence. In some cases it is possible to remove contaminants in an initial, limited salt recovery step. Solids from this step may be disposed of as solid waste (Dr. A. Arakel, personal communication).

15.9 Evaluation of Feasibility

In addition to technical feasibility issues associated with producing salts of commercial value, both technical and marketing issues need to be evaluated. Various feasibility efforts include

- modeling studies based on source water quality to determine possible salt products and alternative processing schemes, including dealing with contaminants
- conceptual design of integrated desalination and salt recovery processes for the various processing alternatives
- cost analysis of the processing and salt recovery alternatives
- bench-scale study to confirm ability to meet product specifications and define operating conditions
- market feasibility study to establish market possibilities for selling produced salts
- marketing approach study to identify separate entity possibilities for salt product management—it is assumed that a separate entity would purchase the salt product and assume the marketing risks, such as those associated with changes in demand and price

These steps are represented in Figure 15.2 to show the interrelationships between the various feasibility efforts (adapted from Geo-Processors literature; personal communication). This feasibility stage evaluation, if positive, would be followed by a pilot study to demonstrate continuous salt recovery and confirm feasibility level assumptions.

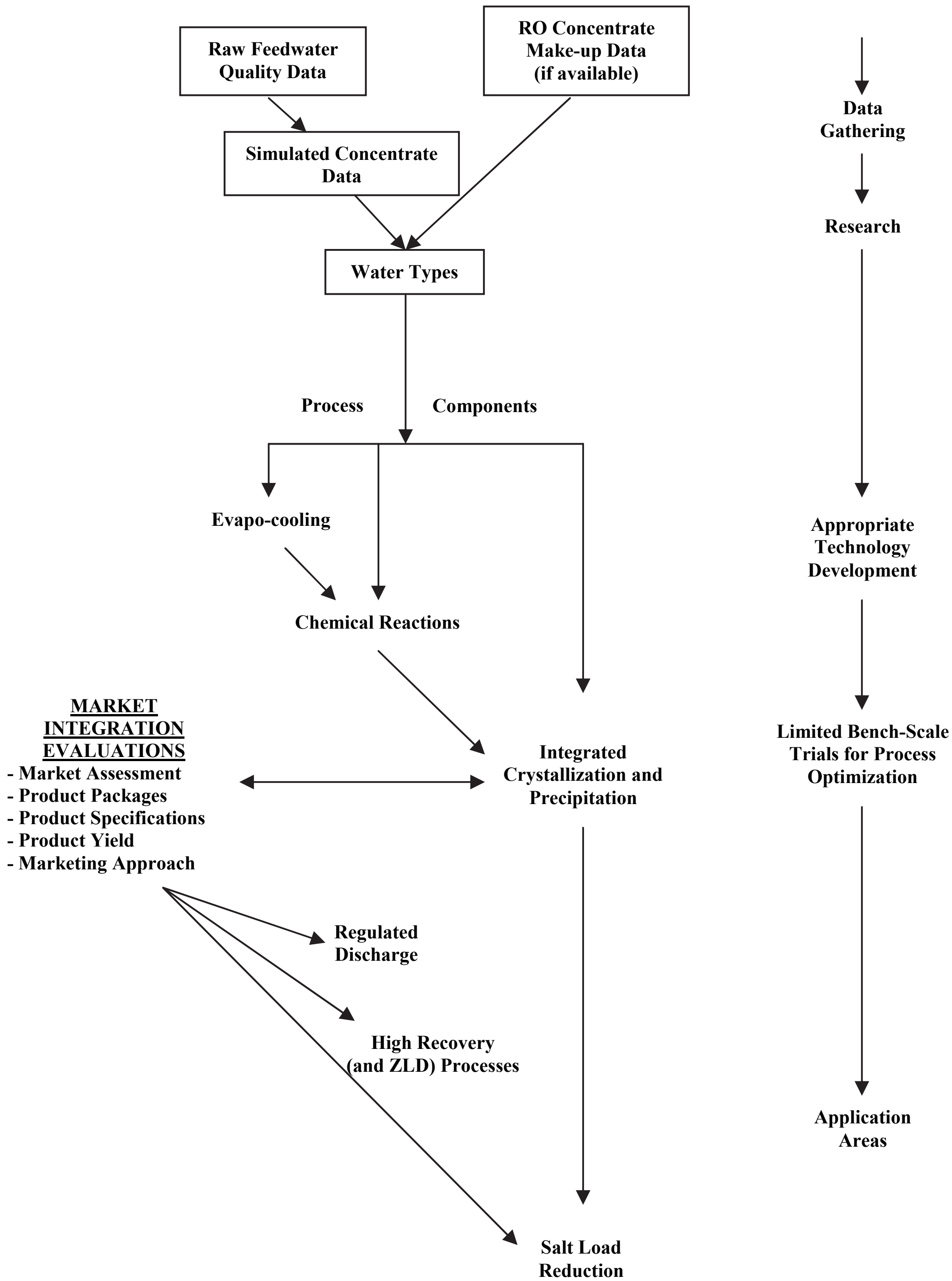


Figure 15.2. Representation of salt recovery feasibility efforts.

15.10 Summary

Selective salt recovery is a variant of high-recovery processing. It presents a potential means for creating beneficial products that increase the sustainability of CM. Depending on the types of salts present in the concentrate and their concentration, salt recovery also offer the opportunity to reduce CM costs. The technologies, chemistry and process understanding, and equipment exist for removal of salts from a wide range of waters. However, for various reasons, there has not been a pilot/demonstration study done on the scale required to demonstrate the feasibility and benefits of selective salt recovery from municipal desalination concentrate.

Some of the challenges associated with selective salt recovery have to do with marketing of the salt and separation of salt recovery and marketing from utility operations. The marketing of products of value should be undertaken by a third party entity that purchases the products as recovered by the desalination facility. It is possible that salts produced by one or more desalination sites may saturate the local market. Ultimately, recovered salts may need to be transformed into value-added products such as building materials that can be used locally.

An unexplored but related topic is the recovery of trace minerals and other low concentration constituents of value from concentrate. This area also could contribute to reducing CM costs.

Few references discuss selective salt recovery in general terms. For more detailed information the reader is referred to Mickley (2008, 2009, 2010) and GEO-PROCESSORS (2011).

Chapter 16

Emerging Issues

16.1 Introduction

In Chapter 1 a CM issue was defined as any constraint (environmental, social, economic, technical) that affects CM options. Many issues were identified in the previous chapters, including some that may be considered emerging issues. In this chapter, we highlight issues that will likely bring about changes in CM.

16.2 Concerns for Source Water Quality

U.S. waterways have become cleaner because of pollution controls on the discharge of many long-recognized pollutants/contaminants. However, extensive water quality problems remain.

The growing concern for water quality is reflected in

- revisions and extension of U.S. EPA regulatory guidelines
- increasingly stringent state regulations for both drinking water standards and water quality standards for receiving waters
- increased detection of contaminants in surface water, groundwater, and treated wastewater effluent
- increased occurrence of contaminants found in membrane concentrate (perchlorate, nitrate, arsenic are examples)
- increased number of waters considered by the U.S. EPA to be impaired

The causes of surface and groundwater deterioration are severalfold. In some cases, the U.S. EPA framework for the states to address protection of the nation's waters has not been fully implemented. The U.S. EPA has not held the states accountable nor used its CWA authority to promulgate standards. States vary considerably in how stringent their regulations are. In other cases, for known contaminants, the framework put forth and implemented by the states has been inadequate to protect the nation's waters.

To some extent the growing concern is an outgrowth of the increasing sophistication of measurement devices. This is particularly true in the case of emerging contaminants, many of which are present in ppb or lower levels and were not measurable or definable in the past.

Emerging contaminants represent chemicals that have not yet been routinely monitored or regulated. The growing presence of such chemicals has been documented in many source waters, yet the impact of these chemicals on marine life and human health has not yet been fully assessed.

Desalination may be increasingly needed to meet more stringent drinking water standards and to remove emerging contaminants from source water and eventually from WWTP effluent. Removal of the contaminants using desalination technologies will result in higher contaminant levels in concentrate. The number of situations where concentrate requires treatment prior to discharge or other disposal will likely increase.

The following sections briefly discuss growing concerns for water quality.

16.2.1 Nutrient Standards

Household wastewater usually contains both nitrogen and phosphorus, as both are readily found in many foods, and thus WWTP effluent usually contains high levels of nutrients compared with background levels in receiving waters. Fertilizers appear to be the leading cause of nitrate pollution in California groundwater. The Department of Water Resources says high nitrate levels have forced more wells to shut down than any other contaminant, and experts with the Pacific Institute have estimated that at least 1 million Californians have dangerous levels of nitrate in their domestic wells (*San Jose Mercury News*, 2010).

As explained in Chapter 6, although the U.S. EPA developed a 1998 national strategy and plan to promote state adoption of nutrient water quality standards, nearly half of the states still have no numerical nutrient standards. Consequently, in a 2009 U.S. EPA evaluation memo (USEPA, 2009), it was stated that "USEPA's strategy and plan . . . has been ineffective." Numerical nutrient limits (limits on nitrogen and phosphorus) are currently being implemented in Florida as an early U.S. EPA trial.

Enforcement of receiving water nutrient limits will pose a major challenge for WWTP effluent discharges. One regulator described numerical nutrient limits as an erupting issue as opposed to an emerging issue. Another regulator said that if he were a WWTP manager, he would be terrified of numerical nutrient limits. The concern relative to municipal desalination plants is on two fronts. First, an increasing number of water reuse facilities use desalination to treat WWTP effluent. The concentrates with high levels of nutrients increase the difficulty of discharge to surface water. Second, the same situation will occur with the increasing number of WTPs using desalination to remove nitrate.

16.2.2 California Ocean Discharge

The California State Board Ocean Group is planning to issue, likely in the summer of 2011, a monitoring policy for emerging contaminants in WWTP discharges to the ocean (Stuber, 2010). Some California coastal desalination plants are waiting for changes in mixing zone requirements forthcoming in the updated Ocean Plan to see how it may affect their discharge considerations (personal communications with California utilities).

16.2.3 Salt Buildup

Farmers in California have been complaining of increasing TDS from WWTP effluent. This has been due in part to use of home softening units whose regenerant solution has been discharged to the sewer. Various communities are banning the use of home softeners.

Central Valley farmers have complained of increasing salinity in both imported water and groundwater. Contributing factors include evaporation from lengthy canals that supply much of the water. Other factors include deep percolation of excess irrigation water and subsequent reuse of drainage water. Similar salinity concerns are associated with the Central Arizona Project (CAP) canal water from the Colorado River (CASS, 2003).

16.2.4 Emerging Contaminants

Emerging contaminants are pollutants that are currently not included in routine monitoring programs and that may be candidates for future regulation. Regulation will depend on research into their toxicity, on potential health effects, on public perception, and on monitoring data regarding their occurrence in the various environmental settings. The U.S. EPA uses the term “pollutant” as defined in the CWA. Emerging pollutants are not necessarily new chemicals or known biologicals. They include pollutants that have often been present in the environment, but whose presence and significance are only now being elucidated (Bureau of Reclamation, 2009b; Deshmukh et al., 2003; Gray et al., 2007; NWRI, 2009; U.S. EPA, 2006; WEF, 2007).

The list of emerging contaminants changes with time. The names and categories of emerging contaminants also vary. The following listings are not mutually exclusive and include alternative terminology for various emerging contaminants:

- pharmaceuticals and personal care products
- endocrine-disrupting chemicals (EDCs)
- organic wastewater contaminants
- persistent organic pollutants
- contaminants of emerging concern
- microconstituents
- nanomaterials
- anticancer drugs
- bacteriocides
- disinfection byproducts
- fluorescent brighteners
- organotins
- polybrominated diphenyl ethers
- perfluorinated organic acids
- prions

As an example, consider the emerging problem of endocrine disrupting compounds (EDCs). This group of compounds includes cancer treatment drugs, mood stabilizers, sex hormones, antibiotics, and a whole range of modern health, beauty, and medical compounds. These chemicals can have deleterious, but as yet poorly understood, effects on the endocrine and reproductive systems of humans and other organisms. There are known effects on some life-forms and much research has been done on their effects on humans. Modern WWTPs were not designed for and are not capable of treating these types of ultra-low-level contaminants. Their eventual collective effect on human health is potentially staggering (Maxwell, 2010).

Emerging contaminants enter groundwater via septic tanks, leach fields, and surface waters through discharge of WWTP effluent.

Treatment technologies having some capability for removing emerging contaminants include membrane bioreactors, advanced oxidation methods, and desalination. When desalination is used, the resulting concentrate will have elevated levels of the contaminants. If and when some of these contaminants are regulated, concentrate may need to be treated to permit subsequent discharge to receiving waters (surface water, sewer, groundwater).

16.2.5 Organic Contaminants in Recycled Water

As mentioned in the discussion of emerging contaminants, these and other organic contaminants can be found at elevated levels in concentrate from WWTP desalination processes. This is a growing concern in Australia, where various states have mandated increased levels of reuse water from WWTPs. Section 16.2.3 mentioned that in 2011 the California State Water Board will issue a monitoring policy for WWTP discharges to the ocean. The levels of these constituents in concentrate from WWTP facilities could be higher by a factor of 4 to 10 than that of those found in WWTP effluent. This will become a growing concern in the United States.

16.2.6 Boron and Use of Reclaimed Water for Irrigation

Boron is essential to plant growth, with optimum yields for many plants being at a few tenths mg/L in nutrient solutions, but is also a potential toxicant. Citrus fruits, for example, are sensitive at 1 mg/L, whereas most grasses are relatively tolerant at 2.0 to 10 mg/L (Rowe and Abdul-Magid, 1995). WWTP effluent can contain boron levels sufficiently high for concentrate from reuse desalination processes to contain levels detrimental to crop and landscape irrigation. Consequently,

- Levels of boron can restrict the direct use of WWTP effluent from irrigation, and thus require desalination or some other form of removal prior to irrigation use.
- If desalination is used to treat WWTP effluent, the resulting concentrate can have elevated levels of boron, and these levels may complicate discharge to receiving waters.

16.2.7 Total Maximum Daily Loads and Number of Impaired Water Bodies

As explained in Chapter 3, TMDLs are a regulatory tool and approach used to define discharge limits to receiving waters considered impaired. TMDLs take into consideration non-point-source as well as point-source discharges and provide more stringent water-quality-based control. To date, TMDLs have not been defined for all impaired waters. This is an ongoing program with increasing implementation of TMDLs by states. TMDLs are granted for a number of different parameters, and in many cases may become an additional limiting factor for surface water discharge. With the ongoing program, the number of impaired water bodies and number of TMDLs will increase and may result in instances where TMDLs can limit concentrate discharge.

16.3 Changing Regulations

Concerns for maintaining and improving the quality of drinking water and of the nation's waterways are resulting in changing drinking water regulations and regulations for protecting surface water and groundwater.

The change in drinking water regulations may lead to greater use of desalination, whereas the changes in regulations protecting waterways may make disposal via surface water discharge, irrigation, and discharge to sewers more difficult.

16.4 Integrated Water Resource Management

Integrated water resource management includes the balanced application of conservation, reuse, and desalination within a watershed. There is little question that all are important tools to apply in providing a sensible water management program. At some level of implementation, however, each practice affects source water quality and quantity as well as receiving water quality and quantity to a degree that affects the implementation of the other practices. The question is, what is the optimal implementation strategy that takes into account the interrelations among the three tools?

There have been several studies considering integrated water resource management that have resulted in management plans and recommendations for management (City of San Diego, 2007; Durham et al., 2003; EBMUD, 2009; MWD, 2010; SEQ, 2010; SNWA, 2009; Water Corp, 2009).

A brief discussion follows on how implementation of water reuse and conservation might affect desalination and CM practices.

16.4.1 Increased Water Reuse and Aquifer Recharge

Increased water reuse is assumed here to mean the reuse of WWTP effluent primarily for irrigation and nonpotable industrial use. Increased water reuse may have the following results:

- *Stream flows of lower volume and higher salinity:* Less discharge to surface water from WWTPs will result in lower stream flows. The salinity and constituent concentrations may change because of higher impact of runoff into the lower-flow streams. Irrigation discharges may be of higher salinity because of use of higher salinity irrigation water (reuse water instead of stream water, groundwater, or potable water).
- *Higher salinity groundwater:* Use of higher salinity irrigation water will result in higher salinity groundwater or drainage water (through soil percolation).
- *Reduced need for new water resources (e.g., desalination):* Less use of potable water from WTPs for nonpotable needs will free up treated water for potable use, resulting in less need for new water resources (e.g., desalination). This also reduces the need for increasing WTP capacity.

Although this suggests less need for desalination to produce potable water, the increased reuse may require desalination to treat WWTP effluents (those of higher salinity), in order to meet nonpotable agricultural and industrial water needs.

16.4.2 Increased Water Conservation

Conservation at the residential level (along with reductions in water losses from distribution systems) has resulted in a growing trend to less use per capita. Increased water conservation may have the following effects:

- *Lower discharge flow to the sewer and to the WWTP* as residential and commercial wastewater volumes decrease.
- *Higher waste concentrations influent to the WWTP* as the concentration of wastes in the discharge likely are greater. This assumes that less water use to perform certain tasks will provide less dilution water for the wastes generated.
- *Higher concentration may require increased use of desalination of water reuse.*
- *Lower need for new water resources (desalination)* as less residential and commercial use of potable water will result in less need for new water resources (desalination); conservation can lessen the need for increasing WTP capacity.

16.4.3 Net Effect on Desalination and Concentrate Management

Maintaining/protecting raw water quality is becoming more important not only for source water protection, but also to minimize current and future CM issues. This is an "emerging" issue for integrated water resource management that can impact options for drinking water, wastewater, and reclaimed water and is difficult to address because of myriads of uncoordinated regulatory agencies and requirements.

Although these effects may take place, it is impossible at this stage to estimate which effects will be predominant. Dominant effects may depend on the watershed in question.

In Section 16.1 the deteriorating quality of surface and groundwater sources was discussed. With this in mind, in addition to the preceding analysis, desalination provides a new water resource and achieves higher quality treatment of water (which is why desalination can provide a new water resource in treating lower-quality water).

The preceding review of effects suggests (a) that desalination might be used less in the future to provide a new water resource and (b) that it will be used more in the future to treat higher salinity and more contaminated source water. This second factor may occur at both WTP and WWTP applications.

This analysis ignores other benefits of desalination as a means of providing potable water, namely (a) a drought-proof source of water and (b) the higher quality treatment of water that conventional water treatment cannot achieve.

The analysis also suggests that feed water to both WTPs and water reuse facilities in the future may be of higher salinity and higher contaminant content. Hence, the resulting concentrate will also have higher levels of contaminants. At the same recovery levels, the salinity would be higher. Discharge of concentrate to surface water or to sewers may be less feasible because of the lower flows and thus have a greater impact on the receiving waters.

At best, this analysis can only suggest possible effects. It cannot predict their extent. If the result of lower receiving water flows is correct, it will be an additive effect on top of possible decreased stream flows because of climate change.

In summary, water resource management tools of reuse, conservation, and desalination are interactive, and the interaction can affect CM practices.

16.5 Volume Reduction of Concentrate—High-Recovery Processing

There is a trend toward researching and considering volume reduction of concentrate (in effect amounting to high-recovery processing of the original feed water). The effort stems from the perceptions that it will (1) increase the use of the water resource and (2) provide a solution to CM challenges. The first consideration is true, the second one, not necessarily.

To a good approximation, volume reduction increases the salinity and concentrations of constituents in the same ratio; halving the volume increases the concentrations by a factor of close to 2. The exception has to do with scalants and foulants. In most situations, some form of pretreatment will be required to permit a second membrane-processing step for volume reduction (high recovery). The pretreatment is required to reduce/remove recovery limitations imposed by scalants and foulants. The recovery of volume-reduced concentrate may itself be limited by scalants and foulants or in some cases by osmotic pressure. Various contaminants may or may not be eliminated by the pretreatment step used to reduce scalants and foulants. This depends on the particular contaminant and the particular pretreatment process(es) used.

The question to be addressed is, how does volume reduction affect the feasibility of the various CM options?

16.5.1 Effects of Volume Reduction on Inland Surface Water Discharge

As discussed in Chapter 6, the regulatory approach includes consideration of water quality standards, whole effluent toxicity tests, mixing zones, TMDLs, and antidegradation rules. Within this approach, the feasibility of discharge for a volume-reduced concentrate depends on two issues: granting of a mixing zone and toxicity.

In states where a ZID (see Chapter 7) is not allowed and where granting of a mixing zone is not allowed, water quality standards must be met at end-of-pipe. Decreasing concentrate volume and increasing salinity and concentrations makes meeting all end-of-pipe water quality standards less likely.

When an end-of-pipe concentration is greater than the water quality standard and when a ZID or mixing zone may be possible, feasibility of discharge depends on whether sufficient dilution is possible, given the relative volumes and concentrations of the two flows. The example of Section 7.8.2 describes how this is determined. As the salinity and constituent concentrations increase, the likelihood of having sufficient dilution decreases.

The granting of mixing zones is done on a case-by-case basis and there is no guarantee that a mixing zone will be granted.

The second issue has to do with the toxicity of volume-reduced concentrate. As explained in Appendix B, toxicity of individual constituents may decrease at higher salinities. The occurrence of toxic levels of constituents in higher salinity, HR concentrates has received little study. Data from Mickley (2000) on toxicity of major ions suggest that the toxicity of Ca, K, Mg, and HCO_3 decreases somewhat with increasing salinity, whereas the toxicity of B_4O_7 and F increases somewhat with increasing salinity. The net effect of increasing both the concentration and the salinity of the concentrate depends on the toxicant. It is likely, however, that the toxicity of some constituents will increase as recovery increases. It is also likely that as recovery increases and the concentration of all constituents increases, more constituents may be present at toxic levels.

16.5.2 Effects of Volume Reduction on Ocean Surface Water Discharge

It is generally acknowledged that concentrates discharged to the ocean should have a salinity relatively close to that of the receiving water salinity (see Section 16.5.2). The increased salinity of volume-reduced concentrate, such as that from seawater facilities (possibly employing new desalination processes in the future), would require greater dilution of concentrate prior to discharge and/or improved methods of dispersing concentrate at the outfall.

16.5.3 Effects of Volume Reduction on Other Concentrate Management Options

16.5.3.1 Effect on Discharge to Sewers

Feasibility of discharge to a sewers can be limited by high volume and high salinity. The volume may be too high for the WWTP capacity, and the salt load (volume times salinity) may have too great an impact on the WWTP process and on WWTP effluent. The likelihood of this occurring depends on the impact of the concentrate on the system's overall and constituent mass balances. Volume reduction of concentrate lessens the volume limitation. The salt load, however, remains approximately the same. Because of the lower-volume concentrate, the added salt load is distributed over less total volume than when the same salt load comes from a higher volume concentrate. This factor, however, can be relatively minor.

16.5.3.2 Effect on Land Application

Feasibility of land application, either through irrigation or via a percolation pond, may lessen as concentrate salinity increases. With the exception of some relatively low-TDS NF concentrates, most concentrates require dilution prior to land application. Dilution of concentrate increases its volume and may increase the land requirement. Availability and amount of dilution water can themselves be limiting.

16.5.3.3 Effect on Deep Well Injection

Feasibility of DWI depends on what happens when injected concentrate is mixed with aquifer water. The primary concern is with formation of precipitates. Sparingly soluble salts and/or silica may be supersaturated in the concentrate but kept from precipitation through use of antiscalants/dispersants and possibly acid. Antiscalants have a limited effective lifetime. Eventually precipitates will form in the concentrate. How mixing concentrate with reservoir water affects this is dependent on the two water qualities. Mixing can cause precipitation to occur or possibly delay or even eliminate precipitation. Ideally, if precipitation occurs, it will not happen before the concentrate is injected into the aquifer rock and will take place well away from the wellbore–aquifer interface, where plugging could significantly reduce injection rates. This same concern exists with concentrate from conventional recovery processes; it is not unique to volume-reduced concentrate. It is likely, however, that high-recovery concentrate will have more scalants of concern than conventional-recovery concentrate, because of the higher concentration of some species in high-recovery concentrate.

The salinity of Class I injection aquifers must be greater than 10,000 mg/L. There is no other salinity requirement. Injection of high-recovery concentrate will likely result in greater salinity differences between concentrate and aquifer water. The effects of higher salinity injections are not well documented.

Thus, injection of HR concentrate raises additional concerns that have not been well studied.

16.5.3.4 Effect on Evaporation Ponds

The effect of higher salinity concentrate on evaporation ponds is twofold. First, evaporation rates decrease with increasing salinity. The effect can be as much as a 20% reduction in evaporation rate, going from fresh water to highly saturated solutions (Mickley, 2006). Second, and more important, evaporation ponds will fill up with solids faster with higher salinity concentrate. For identical concentrate volumes, the amount of solids in 50,000-mg/L concentrate is 10 times that of 5000-mg/L concentrate and the pond will fill up with solids approximately 10 times faster. Solids will then need to be removed from the pond more often, or the pond taken out of service, covered over, and replaced with a new pond more often. This can be a considerable expense over the life of the desalination plant.

16.6 Salt Recovery

Salt recovery was discussed in Chapter 4 in conjunction with saline water management in other industries and countries, and in Chapter 15 with regard to salt management. Salt recovery has been used to

- replace imported salts in the local market
- reduce the quantity of concentrate waste
- avoid regulatory limits on concentrate waste disposal
- offset the costs of concentrate disposal
- provide a CM option when no others exist

The technology used in salt recovery can range from solar evaporation and crystallization ponds to a mechanical high-recovery desalination system. The general application of salt recovery to municipal concentrate in the United States would involve high-recovery processing.

Although the costs of high-recovery processing are high, interest in salt recovery has increased in the United States as a possible solution to growing CM challenges. Various research studies have explored this topic, along with other topics for municipal application (SCSC, 2010; SNWA, 2006).

16.7 New Desalination Technologies

Both membrane distillation and forward osmosis were briefly discussed in Chapter 3. There are other technologies that will likely become commercial in the next decade and will affect desalination performance and costs. The impact of the technologies will be in reducing the capital and operating costs of desalination. They may avoid the performance limitations of current technologies, one example being the osmotic pressure limitation of current RO systems. They may make HR processing of both seawater and brackish water more cost-effective.

Each of these technologies will produce a concentrate/brine or solids. It is unlikely that any new CM option will be defined, because the existing options are the ones used for all different kinds of liquids and solids other than those from municipal desalination concentrate. In other words, the universe of options has been well defined for many years. A trend for general wastes has been to recycle them or convert them into useful products. Chapter 15 discusses selective salt recovery, a potentially promising path toward addressing CM challenges and sustainability. In most situations, selective salt recovery requires high-recovery processing to get to salinities close to the solubility limits of salts of interest. Perhaps new beneficial uses of concentrate will be found, but it is unlikely that they will be widely available.

New desalination technologies that reduce capital and operating costs for high recovery may hasten wider consideration of salt recovery.

16.8 Climate Change

Climate change has the potential to affect the hydrologic cycle, rainfall patterns, and general water resource availability in numerous and complex ways, as well as affecting agricultural productivity and food supplies. It will complicate an already dire water situation (Maxwell, 2010).

Surface water flows could decrease in some regions, affecting use of the water both as a source and as a receiving water for concentrate. Surface water discharge calculations that take low-flow conditions into consideration would be affected. Surface water ambient concentrations could increase because of evaporation. Together, these changes would affect mixing zone calculations and TMDL calculations, and likely increase the number of waters designated as impaired, as well as decreasing the number of allowable mixing zones. For states and situations where mixing zones are not granted, higher salinity in the receiving waters would reduce the feasibility of discharge.

Increased evaporation from canals such as the CAP and the California aqueduct will reduce their volume and increase their salinity, affecting locations dependent on these waters. Thus, both source water and receiving water could see an increase in salinity and composition. There will likely be increasing demand for water and increasing use of desalination to provide drought-proof sources of water. Along with this would be a corresponding increase in concentrate needing to be managed.

Although these may be predominant trends in the southwestern United States, weather pattern changes can result in increased intensity of rain events in other regions. Runoff from these events can increase the occurrence of contaminants in public drinking water sources and supplies. This may result in a greater need for desalination and a concomitant need for CM. Increase in salinity at WWTPs could also result in greater use of desalination in water reuse treatment.

16.9 Carbon Footprint—Greenhouse Gases

Climate change, carbon footprint, GHG, and related issues are the subject of intense interest, controversy, and rapid change worldwide. The GHG of primary interest are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These are the six gases covered by the Kyoto Protocol, an international agreement associated with the United Nations Framework Convention on

Climate Change, which commits industrialized countries to reducing GHG emissions. The increase in atmospheric concentrations of these gases and associated adverse impacts is largely attributed to human activities (IPCC, 2007).

The U.S. is just beginning to implement GHG emission regulations nationally, as a result of a Supreme Court ruling (April 2, 2007, in Massachusetts v. EPA, 549 U.S. 497) that found that GHGs are air pollutants covered by the Clean Air Act (CAA). Subsequently, the U.S. EPA administrator issued endangerment and cause/contribute findings that provide a legal basis for regulation. A key initial action by the U.S. EPA has been development of a mandatory emissions annual reporting rule for any facility with direct emissions greater than or equal to 25,000 metric tons/year of CO_2e (carbon dioxide equivalent basis). There are also reporting requirements for all facilities from certain industry sectors regardless of size. Global warming potential factors are used to convert the more "potent" gases to CO_2e. Monitoring and recordkeeping requirements began January 1, 2010, and the first report was due March 31, 2011.

In this initial effort, the U.S. EPA is focused on major emitters such as power plants and refineries. The U.S. EPA has also begun to regulate GHG emissions for large emitters through the Prevention of Significant Deterioration (PSD) and Title V air permitting provisions of the CAA under a regulation called the Tailoring Rule. The rule "tailors" the CAA permitting thresholds, which are typically very low, to higher levels that are more manageable for capturing larger sources of GHGs. For the first six months of 2011, facilities that are already subject to Title V will need to incorporate GHG emissions into their permits. From July 1, 2011 to June 30, 2013, facilities that have the potential to emit more than 100,000 tons/year CO_2e will be subject to PSD and Title V requirements. Although the U.S. EPA is still determining the requirements that will begin on July 1, 2013, the agency has guaranteed that no sources emitting less than 50,000 tons/year CO_2e will be subject to CAA requirements for GHG before 2016.

California is taking a considerably more aggressive approach than the U.S. EPA, and has a goal of reducing GHG emissions to 1990 levels by the year 2020, and an 80% reduction from 1990 levels by 2050. California's regulations include mandatory reporting for facilities that emit more than 10,000 MT CO_2e, and an enforceable cap-and-trade program for facilities that emit 25,000 MT CO_2e or more. California, Washington, Oregon, Arizona, New Mexico, Utah, Montana, and several Canadian provinces are working together to coordinate these types of programs through the Western Climate Initiative (http://www.westernclimateinitiative.org).

In general, CM is not an industry sector that regulators are focused on, unless emissions are 25,000 MT CO_2e or greater, though some wastewater facilities may trigger the thresholds if they have large combustion sources such as internal combustion engines. Regardless of U.S. EPA, state, or regional initiatives or requirements, the first step that an increasing number of water and wastewater utilities are taking is to conduct a comprehensive inventory of GHG emissions. These inventories typically include both direct (Scope 1) emissions from mobile and stationary combustion sources and indirect (Scope 2) emissions from electricity purchases.

Recent references considering the effect of climate change on water issues include Huxley et al. (2009), Kenway et al. (2008), NRC (2009), and Schnoor (2010).

Three distinct categories have been introduced to help describe direct and indirect emission sources from desalination technology (Pankaj and Ranganathan, 2004). These are

1. Direct GHG emissions (emissions from combustion in process equipment or emissions generated from process equipment)
2. GHG emissions due to purchased electrical power (emissions from the generation of electricity consumed by the facility)
3. Other indirect GHG emissions (an optional reporting category that allows for the treatment of all other indirect emissions)

Trzcinski et al. (2010) have recently examined the carbon footprint of a hypothetical BWRO facility using this approach. The analysis generally fell under the second category with some Category 1 exceptions (the decarbonator). The GHG tallies were mainly from energy consumption.

The study looked at alternative design criteria that included different

- numbers of RO trains
- RO configurations
- membranes
- pressure-rated strainers
- flow-rated cartridge filters
- pressure vessel port sizes
- piping scenarios

as well as the use of

- energy recovery
- on-site power generation
- decarbonator

Improvements/modifications that were considered in an optimal design to reduce GHG emissions included

- furnishing all major pumps with variable-flow drives
- use of energy recovery devices
- use of waste heat
- increasing pipe diameters to allow flow conveyance via gravity

In comparing the two designs, a more nearly optimal design resulted in a 32% reduction in GHG emissions. Specific results depend on the assumptions made. The study suggests that each of these factors can contribute to GHG emissions and that design engineers can reduce emissions by selecting design criteria that meet their operational objectives while minimizing environmental impacts.

As stated by the authors, "a careful evaluation is required to fairly evaluate the benefits of reducing GHG emissions versus the cost of changing design criteria to realize these benefits"

(Trzcinski et al., 2010). Major GHG contributions come from direct energy requirements of equipment. These can be influenced by relatively simple design decisions, such as the pipe diameter and resulting flow velocity, factors that influence pumping energy requirements. Two GHG issues possibly associated with each CM option are (a) treatment of concentrate prior to conveyance and (b) conveyance of concentrate to the site of the CM option. Treatment examples include pH adjustment, aeration, and filtering.

As an example of pretreatment, it is possible in high-recovery processing that a final concentrate/brine may have high levels of suspended solids that would require filtering prior to discharge or other means of disposal (such as DWI). The filtering operation itself may entail significant backwash water that requires conveyance to a discharge site.
Although the Trzcinski study focused on desalination rather than CM, it provides a framework for identifying GHG considerations associated with CM options.

A potential major GHG consideration is associated with conveyance of concentrate to the CM site. Other than energy associated with this, the equipment/processing and associated energy requirements for CM options are relatively simple and include

- surface discharge:
  - (possible) additional energy to overcome resistance of flow through a diffuser system
- DWI
  - energy requirements associated with injecting concentrate into deep wells
  - possible energy requirements associated with distribution of concentrate at CM option site for multiple deep wells
- evaporation ponds
  - possible energy requirements associated with distribution of concentrate at CM option site for multiple evaporation ponds
  - possible energy requirements associated with enhancement of evaporation rates via use of misters
- land application
  - possible energy requirements associated with distribution of concentrate at CM option site for larger irrigation systems
- landfill
  - hauling of solids to landfill/monofill sites
- beneficial options depending on the specific situation

- volume reduction/high recovery (including ZLD) treatment processes

16.10 Improvements in Concentrate Management Options

As mentioned in previous chapters, there have been improvements and efforts toward improvements in some of the conventional disposal options. These include

- *subsurface conveyance and injection* with the potential to avoid ocean discharge impacts and costs (see Chapter 8)
- *DWI* using PVC liners to avoid corrosion problems (see Chapter 10)
- *enhanced evaporation from evaporation ponds,* which can (1) reduce area requirements, resulting in greater consideration of evaporation ponds, and (2) reduce capital costs, increase operating costs, but reduce annualized cost (see Chapter 11)
- *self-sealing evaporation ponds,* which have the potential to lower pond costs through replacement of expensive synthetic liners (see Chapter 11)

The potential for beneficial use of high-salinity-tolerant plants to remove contaminants in wetlands has been studied (see Chapter 14).

In general, the relatively simple equipment and simple nature of the management options does not lend itself to cost breakthroughs.

16.11 Energy Recovery from Brackish Water Concentrate

Although energy recovery from concentrate is more of a desalination issue, it affects the cost and thus the general feasibility of desalination. Consequently it can contribute to the number of desalination plants (discharging concentrate) that will be built.

A recent study (Martin and Eisberg, 2010) examined the potential energy recovery from BWRO systems. Significant energy savings have been realized by applying various energy recovery devices (ERDs) to SWRO systems. The high concentrate pressure and concentrate flow (relative to feed flow) in these systems makes energy recovery easily justified on the basis of operating cost savings. The application of ERDs in BWRO systems is less common. This is primarily because of the relatively low feed pressure and flow rate of the concentrate stream. The results of the study included the following:

- ERDs would be economically justified in most brackish systems where feed pressures are greater than 150 psi.
- High-recovery (relative to SWRO systems) BWRO systems typically require two stages, using an interstage booster pump between the first and second stages to keep the recovery roughly equal between the two stages (to balance the fluxes).
- There are advantages to inserting an ERD between stages rather than in front of the first stage, including smaller device size and replacement of an interstage booster pump.
- The device, however, must be custom designed for the specific application in order not to upset the flux balance between stages.
- Thus in contrast to SWRO applications, where ERDs can be retrofitted into systems, the successful application of ERDs to brackish systems requires a detailed analysis of the entire RO system.

Incorporation of ERDs into BWRO systems can reduce operating costs for both conventional recovery systems and HR processing systems.

16.12 Need for True Valuing of Water, National Water Policy, Leadership

There is a need for big-picture, long-term planning that includes a national water policy and the true valuing of water. The present state of water resource protection and management is not sustainable and is reaching a critical situation in the United States. Other countries have reached this stage already, including Israel and Australia. Both countries have clearly defined national water policies and plans for meeting their water crises. Plans include a mix of conservation, reuse, and desalination. Large desalination plants are being planned and built in short time periods, unlike the situation in the United States. The lack of a federal water policy in the United States results in a lack of clarity, leadership, funding, and incentives for addressing the critical water-related challenges.

At the same time, many large corporations in the United States have understood the benefits of efficient water management and have instituted very efficient and cost-effective programs that have drastically decreased their water use (Senge et al., 2008). The same is true of hotels on the Las Vegas Strip. Although Strip water use looks wasteful, the hotels make efficient use of conservation and water reuse (Glennon, 2009). In some cases, such as Las Vegas, strong mandates with penalties provided a strong driving force, but in Las Vegas and other locations industries have learned that efficient water management practices can save money.

Water is a valuable, exhaustible resource, yet we treat it as valueless and inexhaustible. The pricing of water is inconsistent with the critical nature of the water crisis. As long as this remains unchanged, inefficient use, substantial waste , and nonoptimal use of water resources will continue. Although conservation and reuse primarily affect water quantity issues, desalination addresses both water quantity and water quality issues. Only desalination can augment water supply when conventional water supply options become limited. Optimal water management will likely include increased application of conservation, reuse, and desalination.

16.13 Sustainability

Sustainability is an issue of growing importance to nearly every aspect of life on the planet. The term has been increasingly used in the literature and in presentations concerning desalination and CM. How sustainability can be made a part of desalination and CM will involve considerations of

- energy footprint
- water footprint
- physical footprint
- social, environmental, and economic factors
- increased water recovery and salt recovery

It will also be within the context of balancing water resource management considerations of conservation, reuse, and desalination.

16.14 Summary

Emerging issues presented in this chapter are meant to provide the reader with a better understanding of factors that may affect CM in the coming years. Some of the issues are more location-specific (changes in state regulations, consideration of high-recovery processing, etc.), whereas others are more general (integrated water resource management, climate change, etc.). The issues should be followed, updated, and considered in making long-range plans.

Chapter 17

Summary of Issues

17.1 Introduction

An issue may be defined as any constraint (environmental, social, economic, technical) that affects CM, or more specifically affects the feasibility, implementation, and operation of CM (CM) options, current or future.

Previous report chapters dealing with individual CM options discussed issues under the headings of

- general feasibility factors
- major cost factors
- environmental concerns
- regulatory basis
- impact of concentrate salinity
- impact of concentrate composition

The chapters then discussed how the feasibility of CM options may be evaluated at both a screening level (in order to develop a short list of CM options) and a preliminary level (in order to conclusively determine feasibility of screened options).

From a broad perspective, issues may be categorized in various ways, such as

- by type:
  - technical
  - economic
  - environmental/public health
  - political/public
- by project stage:
  - planning
  - construction
  - operation
  - future

Some issues are common to all CM options, and other, more specific issues pertain to specific CM options. Some issues are more specific to drinking water plants and others to wastewater treatment plants. Issues may be somewhat different for different desalination processes, such as BWRO, SWRO, NF, and EDR. Issues may be regional. Issues may also be current or emerging and future issues.

This chapter looks at issues discussed in previous chapters from this broad perspective. The reader is referred to previous chapters addressing specific issues for each CM option.

17.2 Overview of Concentrate Management Issues By Type

In this section CM issues are considered by the following types or categories:

- technical
- economic
- environmental/public health/regulatory
- public/political

17.2.1 Concentrate Management Technical Issues

Technical issues include the design and resulting performance of CM options—"performance" meaning how well the CM option meets the various site-specific environmental/regulatory and other requirements. Meeting these requirements is dependent on concentrate characteristics, which are defined by the desalination process and its size and performance.

In this sense terrain, climate, and climate change affect performance or suitability of CM options and from this perspective are technical issues.

The design and performance of CM options need to address several issues, including

- land area required
- land area available
- applicability to large flows
- need for treatment of concentrate
- climate limitation
- geological requirements

17.2.2 Concentrate Management Economic Issues

Economic issues include cost issues, which are dependent on the CM option and site-specific factors, such as distance from the desalination plant to the site of the CM option. Costs include capital cost and operating and maintenance costs (including energy use and labor requirements).

A broad economic issue is the fact that water is not valued at its true value, thus restricting the municipal industry's ability to implement various high-performance technologies that are frequently used in other industries to solve water quantity and quality challenges, including challenges related to CM.

17.2.3 Concentrate Management Environmental/Public Health/Regulatory Issues

Impacts of CM options on the environment and public health are anticipated and addressed through federal and state regulations. Permits or approval (in the case of discharge to a sewer) must be obtained, and compliance with permit conditions is evaluated based on submitted monitoring data as required by the permit. Mitigation of potential impacts is a design/implementation issue and thus a technical issue. Issues include

- potential environmental and public health impact
- complexity of the regulation
- time, effort, and cost of seeking and obtaining a permit (or approval)

17.2.4 Political/Public Issues

The primary political/public issue is public perceptions and the public response to a particular CM option. Many permitting situations allow public view of and response to permit applications, and through this process public opinion can complicate and in some cases block permit approval.

It is possible that political issues may influence decision-making concerning CM options. However, this is beyond the scope of the project.

17.3 Concentrate Management Issues by Project Stage

The project stages are considered to be

- planning
- construction
- operation
- future

Most of the issues discussed in this report need to be dealt with at the planning stage of a desalination facility. They include technical, economic, environmental/public health/regulatory, and public/political issues.

Construction issues, such as environmental impacts associated with implementing a CM option, should be anticipated during the planning stage.

Operation issues include operation and maintenance of the equipment associated with the CM option as well as ongoing monitoring, reporting, and other compliance matters that may be associated with regulation of the CM option.

Future issues for existing municipal desalination facilities include

- whether the desalination plant can be expanded and retain its permit
- whether the permit can be renewed because of regulatory policy changes

17.4 Concentrate Management Issues by Location or Region

The following information is based on the updated survey (see Appendix A) conducted for the project. There are a few obvious patterns in the location of municipal desalination plants and the use of the five conventional concentrate disposal options.

17.4.1 Number of Municipal Desalination Facilities

Three states, Florida, Texas, and California, account for 241 (77%) of the 314 U.S. municipal desalination facilities (Florida—49%; California—16%, and Texas—12%). The other 73 plants are spread out over 30 states.

Florida, Texas, and California are three of the top four states in population and have had the greatest growth in residents since 2000 (MSNBC, 2010). They have thus experienced the greatest growth in potable water needs. These three states may be considered as distinct regions because of the number of plants and the resulting awareness of the regulatory agencies and the public to desalination and CM issues. They are also the centers of interest and activity for large-scale SWRO considerations.

17.4.2 Frequency of Use of Concentrate Disposal Options

The most obvious region-related CM issue is the limited-location use of the five conventional disposal options.

- Thirty-three states have municipal desalination plants.
- Florida and Texas use all five concentrate disposal options (surface water discharge, discharge to sewers, subsurface injection, evaporation ponds, land application) for municipal desalination plants.
- California uses all options but evaporation ponds.
- DWI has been used in only five states (Florida, Texas, California, Colorado, and Kansas).
- All but 4 of the 48 DWI sites are in Florida.
- Evaporation ponds have been used in only three states (Florida, Texas, and Arizona).
- Land application has been used in only three states (Florida, Texas, and California).
- Eighteen of 21 land application sites are in Florida.
- Surface water discharge and discharge to sewers are used at 71% of the facilities.

As a result, 27 of the 33 states with municipal desalination plants use only surface water discharge or discharge to sewers. From this viewpoint, two distinct regions for CM issues might be defined as the 27 states relying only on surface water discharge or discharge to sewers, and the other five states (which include Florida, California, and Texas).

Reasons that 27 states have relied on surface water discharge and discharge to sewers include the following:

- Many of the desalination plants in these states, and particularly the older plants, are relatively small.
- Many of the plants are in regions with sufficient rainfall to maintain rivers offering substantial dilution; this is particularly true in comparison to rivers in the arid southwestern United States.

The frequency of use of the various concentrate disposal options also reflects regional differences in climate and shows that the warmer southern states are most suitable for year-round evaporation ponds and land application use.

17.4.3 Southwestern Arid Region of the United States

Included in this region are parts or all of the following states:

- Arizona
- California
- Colorado
- Nevada
- New Mexico
- Texas
- Utah

This area is characterized by relatively small amounts of rainfall and relatively high temperatures. Consequently, the area has few rivers of substantial flow. There have been several feasibility studies conducted for municipal desalination plants in this region that resulted in the plants not being built. The common reason was that cost-effective CM solutions could not be identified. As mentioned in previous chapters, much of the interest in high-recovery processing in the past decade has been driven by the lack of options in this region.

17.4.4 Regions Suitable for Deep Well Injection

Table 10.1 shows the dramatic difference in the sizes of individual Class I injection wells found in various states. The large wells in Florida are likely not possible in other states because of the unusual hydrogeological conditions found in parts of Florida. Thus, in relation to DWI, Florida may be considered a region separate from all other states.

17.5 Water Treatment Versus Wastewater Treatment Concentrate Management Issues

Historically, municipal desalination has been used to produce potable water. Production of high-quality reuse water is a rapidly growing application. The different aspects of feed water and concentrate associated with WTP desalination versus production of high-quality reuse water from WWTP effluent were reviewed in Tables 3.4 and 3.5.

The primary differences between the municipal desalination applications at WWTPs and at WTPs are

- lower feed water TDS (typically less than 1,000 mg/L)
- more complex feed water composition (more organics, higher level of nutrients, higher TSS level)
- lower concentrate TDS

From past surveys and the present survey, 16 WWTP facilities have been identified as using desalination treatment. Twelve of these are in California (with one plant each in Arizona, Florida, Pennsylvania, and Texas). Nine facilities recycle concentrate to the front end of the WWTP (equivalent to discharge to a sewer) and six facilities discharge concentrate to surface water.

An impending issue for WWTP concentrates is the regulation of nutrient levels in discharge to surface waters. Increasing levels of nutrients in source waters are being found in several states. The U.S. EPA has begun a process to implement numerical nutrient standards in Florida. More stringent nutrient standards could limit discharge of WWTP concentrates to surface water.

17.6 Emerging Issues

Emerging issues that may affect CM were presented in Chapter 16. They were identified and discussed under the headings of

- source water quality
- changing regulations
- integrated water resource management
- high recovery
- salt recovery
- new desalination technologies
- climate change
- GHG
- improvements in CM options
- energy recovery
- need for true valuing of water, leadership, national policy
- sustainability

The emerging issues may be recast into a set of unknown impacts of various broad issues, such as the following:

- *Impact of technology advances in reducing desalination costs:* All desalination technologies produce concentrate. Lower desalination treatment costs and increases in energy recovery can lead to greater application of desalination and more concentrates needing to be managed. On the other hand, technology advances may also lower the cost of high-recovery processing so that desalination processing will make more efficient use of water resources and more concentrates will be of higher salinity. It may be more cost-effective for some existing facilities to implement high-recovery processing than to expand the size of conventional recovery facilities. Lower high-recovery processing costs may also result in more processing to solids (providing disposal costs are not prohibitive) and in greater application of salt recovery as part of high-recovery processing (providing markets for recovered salts are available).

- *Impact of beneficial use of concentrate and concentrate products:* From the current perspective, it is difficult to see beneficial use of concentrate as having a large impact on municipal desalination CM. However, given the challenges of CM, it is important that efforts in this direction continue. As with other wastes, it is unlikely that there will be any new disposal options identified. The trend, with wastes in general, is to waste recycling or conversion of wastes into useable products. Although new beneficial uses of concentrate may be found, it is more likely that concentrate will need to be further treated to provide salt products of value.
- *Impact of changing regulations:* Discharge and other regulations that affect concentrate disposal will continue to become more stringent and thus make concentrate disposal more difficult. The need to treat concentrate to meet regulations will continue to increase. This trend appears inevitable. The question is how significant changes will be, and how soon they will happen.
- *Impact of integrated water resource management:* The interaction of reuse, conservation, and desalination is not well defined, including how the interaction will affect desalination and thus CM.
- *Impact of climate change and regulation of CO_2 emissions:* Specific impacts on desalination and CM are not well defined, although some general effects appear likely. Climate models project increasing water supply issues for the arid southwest and government regulation will likely affect CO_2 emissions. This is reflected by the U.S. EPA's intent to regulate CO_2 under the CAA and California's Rules on Emissions.
- *Impact of low-value water and lack of a national water policy:* How long will the undervaluing of water, coupled with the lack of a national water policy, continue to hamper the protection of source waters and delivery of water to meet growing water quantity and quality needs? Given the deteriorating quality of water sources, tightening regulations, and the increasing identification and regulation of contaminants, it is likely that municipal desalination plants will increasingly be required to meet the growing needs for higher quality drinking water and reuse water.

17.7 Chapter Summary

This chapter overview presents a broad framework of issues. For details, the reader is referred to previous chapters addressing each specific CM option. However, to bring the overview back into the context of each concentrate disposal option, Table 17.1 and Figure 17.1, both from Chapter 5, along with Table 17.2, summarize the challenges and issues that limit the use of the options. Both tables list various potentially limiting issues for the five conventional disposal options. Table 17.1 lists different factors that can limit the feasibility of concentrate disposal options. Table 17.2 is somewhat similar and was adapted from a table published in 2008 (NRC, 2008). Although Table 17.1 is more specific as to why a given factor may be limiting for a disposal option, Table 17.2 ranks different factors as to the level of challenge they typically present to a disposal option. Together, they provide a more detailed and accurate summary than either table alone.

Figure 17.1 brings into consideration an additional perspective, that of the relative capital costs of the disposal options compared with one another. It also shows that both evaporation ponds and land application may be cost-effective for small-volume concentrates—something that the capital cost column of Table 17.2 does not imply.

The general status of CM and its many issues may be summed up rather simply. Although "management" is the broader and more politically correct term, nearly all concentrates are disposed of and will continue to be disposed of, at least in the short term. There are no new disposal options, and beneficial use of concentrate, brine, and mixed solids produced from taking concentrate to solids is not typically feasible. Thus CM options are limited. The primary challenge of CM is to find a cost-effective and environmentally sustainable option. The time and effort required to find a CM solution, in large part defined by the regulatory framework and permitting process, are increasing in most locations. For the first time, within the past 10 years some municipal desalination facilities have not been built because of this challenge. The major emerging issue is that increased regulations for protecting source water will pose additional challenges to CM options that affect source water, which currently represent 80% of the municipal facilities.

Table 17.1. Explanation of Why Feasibility Factors Can Be Limiting

Major Feasibility Factor	Surface Water Discharge	Discharge to Sewer	Deep Well Injection	Evaporation Pond	Land Application	Landfill
Obtaining a permit						
Can't meet conditions	1	1	1	1	1	1
Permit not offered			2			
Cost	3	3	3	3	3	3
Climate				4	5	
Terrain				6	6	
Hydrogeology			7			
Water quality						
Salinity/salt load	8	8	9	10	11	
Common ions	12	12	13		14	
Contaminants	15	15	16	17	18	19
Distance	20	20	20	20	20	20
Volume, amount	21	21	22	23	24	25
Land availability				26	26	

1—For a variety of reasons, concentrate conditions may be such that permitable requirements cannot be met.
2—Class I industrial wells are not allowed in some states.
3—Costs may be prohibitive for any of these options.
4—Climate may not be suitable for evaporation in general or for some seasons.
5—Climate may not be suitable for year-round irrigation.
6—Relatively flat land may not be available.
7—Required hydrogeology may not exist.
8—High salinity and/or high salt load may not be permitable.
9—Blending of concentrate with aquifer water may be a problem.
10—High salinity can reduce evaporation rates.
11—High salinity can eliminate irrigation use unless dilution water is available.
12—Some common ion concentrations may not meet water quality standards for NPDES permits. In the case of discharge to sewer this applies to the WWTP's NPDES permit.
13—Some common ion concentrations may lead to blending problems with aquifer water.
14—Some common ion concentrations may not meet groundwater standards.
15—Contaminants may eliminate discharge option.
16—Contaminants may lead to blending problems.

17—Contaminants may affect wildlife and waterfowl.
18—Contaminants may rule out irrigation use depending on vegetation/crops; may not meet groundwater standards.
19—Contaminants can lead to solids being hazardous and cost-prohibitive to landfill.
20—Distance from desalination plant to CM option may be excessive and conveyance too costly.
21—Volume and/or load (volume times concentration) may be too large for available dilution.
22—Volume may be too great for the aquifer capacity over the life of the desalination plant.
23—Volume of concentrate may require too much land and thus be too costly.
24—Volume of concentrate may require too much irrigation land and thus be too costly.
25—The amount of solids may be too great for an existing landfill.
26—The required amount of land may not be available.

Table 17.2. Concentrate Disposal Challenges and Limits (adapted from NRC, 2008)

Method	Issue Type											
	Technical					Cost				Environment/Regulatory		Public
	Land Area Required	Applicability for Large Conc. Flows	Possible Treatment Needs	Climate Limitation	Special Geological Requirements	Unit Capital Costs ($/mgd)	Unit O&M Costs ($/kgal)[c]	Labor Needs and Skill Level (for Operation)	Energy Use	Permitting Complexity	Potential Environmental Impact	Public Perception Concerns
Surface water discharge	—	Y	M	Maybe[d]	N	L[a]	L[a]	L	L[b]	H	M	H
Sewer discharge	—	N	L	N	N	L[a]	L[a]	L	L[b]	M	M	L
Deep well injection	L	Maybe	L	N	Y	H[a]	M[a]	L	M[b]	M[e]	L	L-M
Evaporation pond	H	N	L	Y	Y	H[a]	L[a]	L	L[b]	M	M	H
Land application	H	N	L	Y	Y	M[a]	L[a]	L	L[b]	M	M-H	H
Thermal evaporation to solids	L	N	L	N	N	H[a]	H[a]	H	H[b]	Ld	Ld	L

Notes: L = low; M = medium; H = high; Y = yes; N = no; dashes indicate not applicable. Water quality of the concentrate and composition of landfill solids can eliminate feasibility of each of the disposal options due to presence of toxins, precipitation of solids upon blending, or presence of hazardous levels of contaminants.
[a]Costs are highly site-specific; general trends in relative costs are indicated; capital cost for all options can be higher if distance from the desalination facility to the disposal site is large, necessitating long pipelines and possibly pumping stations or hauling.
[b]Energy use for each option can be higher because of distance from desalination plant to option site; also if land application area is large and a distribution system is required.
[c]Unit O&M costs increase with the amount of monitoring and analytical lab support required.
[d]Climate can affect amount of rainfall and surface water available for dilution.
[e]Class I deep wells are not permitted in some states.

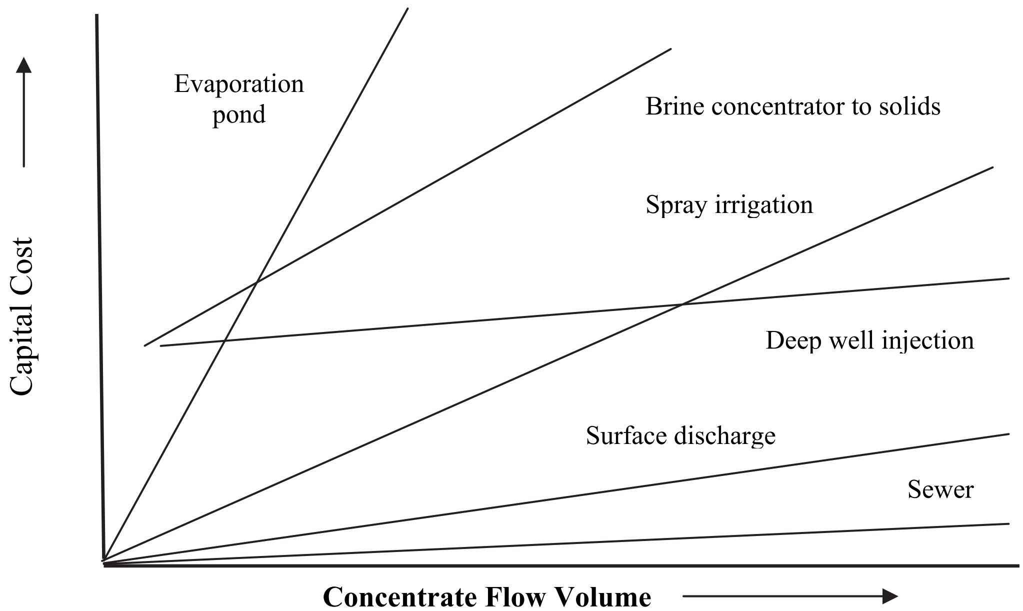


Figure 17.1. Relative capital costs of CM options (not considering conveyance). Mickley, 2004

Chapter 18

Conclusions and Recommendations

18.1 General Project Effort

The two project objectives were

- to gather, analyze, and synthesize information concerning CM and render it into a form suitable for a background or reference document
- based on the analysis, to recommend an approach and technical content of a guidance manual for CM

The objectives were met using a multifaceted effort involving a survey of more than150 municipal desalination plants, telephone interviews with regulators, participation in workshops defining CM needs, and a review of global literature.

The report contains a substantial amount of information about CM to be used as a reference or background document to support future development of a guidance manual for CM. The report's level of detail should be useful for a broad audience including utilities, academics, regulators, consultants, and equipment and engineering companies.

Recommendations for development of a guidance manual are provided in Chapter 19 and should be seen in the context of a two-document tool: the present report as a background and reference document for the guidance manual, and the future guidance manual.

Beyond supporting the development of a guidance manual, the report provides updated statistics regarding U.S. municipal desalination and CM operations. The information can help to educate the industry, so that efforts on many fronts are based on accurate understanding of practices and issues. Knowledge of CM practices and trends is useful in defining research needs and prioritizing research funding. The report also can be helpful in providing an accurate characterization of municipal desalination facilities and CM practices for use as background information in papers, reports, and presentations.

18.2 Project Findings

The extensive project survey of U.S. municipal desalination facilities complements previous surveys (Mickley, 2001, 2006; Mickley et al., 1993) and allows analysis of statistics and trends concerning CM practices. The facility interviews provided clear indications of the utility perspective on CM issues. The other project efforts provided useful information about CM issues from other perspectives, including those of regulators, equipment and system manufacturers, consultants, and academics. In the following two sections, selected project findings are presented.

18.2.1 Survey Findings

Findings from the survey of municipal desalination plants include the following:

- The number of plants being built continues to increase steadily.
- U.S. municipal desalination plants (e.g., BWRO, NF, and EDR facilities) remain mostly inland, at 96% by number.
- As in past surveys, more than 98% of municipal desalination plants utilize one of the five conventional disposal options (surface water discharge, discharge to sewers, DWI, evaporation ponds, and land application).
- An increased number of plants are treating source water to remove contaminants as well as for salinity reduction.
- An increased number of plants have concentrate containing contaminants that restrict CM options or require treatment to remove the contaminants prior to disposal.
- High recovery of concentrate is more frequently being considered during the planning phase of plants.
- Some plants now incorporate high-recovery processing: there is one ZLD plant, and a few high-recovery NF plants.
- Three states (Florida, California, Texas) account for 77% of the municipal desalination plants; the other 23% are scattered over 29 other states.
- A greater percentage of plants are being built outside of the three states where most desalination plants and overall capacity are found (Florida, California, Texas):
  - In 2003, only 19% of plants were built in other states.
  - Between 2003 and 2010, 39% of the plants built were in other states.
- The percentage of plants discharging to surface water or to sewers is unchanged (73%) from the previous 2003 survey.
- More recent data show a greater percentage of plants using DWI and a smaller percentage of plants using evaporation ponds or land application for concentrate disposal.

18.2.2 Findings from Other Project Efforts

Other findings from the various information-gathering efforts include the following:

- CM is increasingly considered in the context of watershed water resource management.
- The concept/term *integrated water resource management* has come into greater use, where conservation, reuse, and desalination are evaluated in a balanced manner appropriate to the watershed in question.
- The deteriorating source water quality of both surface and groundwater makes a case for the increased need for desalination-based treatment.
- At the same time, it has become more difficult to dispose of concentrate via options that may affect surface and groundwater (surface water discharge, discharge to sewers, land application).
- Discharge/disposal regulations are likely to become more stringent because of nutrients, emerging contaminants, and other contaminants being considered for

regulation; as one regulator pointed out with regard to surface water discharge and NPDES permits, "NPDES stands for national pollutant discharge ELIMINATION system and this is what is happening."

- There will be an increased need for treatment of concentrate to remove contaminants prior to discharge.
- Because of these and other CM challenges, there has been increased interest in high-recovery processing, usually under the label of volume reduction or concentrate/brine minimization.
- Similarly, there has been increased interest in salt recovery from concentrate.
- With more stringent drinking water standards and new contaminants being regulated, desalination treatment processing will become more complex and will produce concentrate that will increasingly require additional treatment for some CM options.
- Treatment of more complex feed composition/chemistry is practiced in many nonmunicipal industries, along with high-recovery processing and salt recovery.
- Although technology and understanding both exist to support future municipal feed water and concentrate processing, municipalities have a greater financial challenge in using higher cost technologies than other industries, because water is not being valued at its true value.
- CM challenges will be felt most (1) in states with high desalination usage, where the need for desalination indicates general water resource challenges, and (2) in the arid Southwest, where some plants have not been built because of the lack of cost-effective CM options.
- The planned regulation of nutrient discharges through the setting of numerical nutrient standards can have a profound effect on WWTP discharges in general and particularly on discharge of concentrate from WWTPs that produce higher quality reuse water via desalination processing.

18.3 Broad Conclusions

Because of various water resource management challenges, there is an increased focus on alternative water supply approaches. Desalination treatment of lower-quality water to fresh water/potable standards is the only practical new source of water. Although conservation and water reuse are key strategies for meeting increasing demands with minimal raw water supply impacts, desalination can achieve the higher quality treatment increasingly demanded by contaminant-compromised waters, offer a droughtproof source of water, and position utilities to meet future changes in drinking water standards.

Concentrate produced by desalination processes requires management. Historically and to this day, management has amounted to disposal. Unfortunately, most disposal options can impact source waters. The same environmental and health concerns that have led to the demand for higher quality treatment and increased use of desalination have also led to increased protection of source waters. As a result, it has become more difficult to find a cost-effective and environmentally acceptable concentrate disposal option, and in some cases desalination plants have not been built because of concentrate disposal issues.

More than 96% of the municipal desalination facilities in the United States are inland facilities. For these, and for seawater desalination plants, CM has become a major factor in determining the feasibility of desalination plants. Moreover, it has increasingly become a significant cost factor.

A recent study of desalination by the National Resource Council (NRC, 2008) stated that "Few, if any, cost-effective environmentally sustainable concentrate management options exist for inland desalination facilities."

The challenges and needs associated with CM are reflected in the increased attention given to CM at membrane conferences and the increased amount of research money spent on CM topics.

There is a need to bring clarity to this rapidly growing concern through the development of an information source, a knowledge base, defining the issues surrounding CM, and providing support material for understanding the issues.

The present report is an effort to meet this need.

18.4 Recommendations

The report recommendations are as follows:

- The report should be used as the basis for development of a guidance manual with the approach and content discussed in Chapter 19.
- The report should be used as a general reference document for the industry in educating various groups as to CM issues and practices.
- The two-phase approach to the development of a guidance manual where the initial phase results in a background document, such as this report, should be considered as an effective approach in developing guidance manuals in various desalination-related topics.

Chapter 19

Technical Approach for Development of a Guidance Manual for Concentrate Management

19.1 Introduction

Although extensive information on many issues associated with CM is provided in this report, there remains a need in the industry for a comprehensive guidance document. A recommended approach to development of a future guidance manual is provided in this chapter.

19.2 Approach

Central to the approach would be to build upon this report, providing water utility managers and others with detailed information focused on analysis of concentrates and solids derived from concentrates, criteria and methods for feasibility assessment, evaluation of regulatory/environmental acceptability of alternative concentrate/salt management strategies, and monitoring of effects of concentrate discharge and disposal of solids derived from concentrates. The Guidance Manual will use the present report as a reference document. Because viable CM options are typically limited, the focus of the guidance document will be on providing a resource to support the feasibility assessment phase rather than on providing specific design procedures for each CM option. Design approaches for the predominant CM alternatives are well established. However, processes for feasibility assessment of CM alternatives are not. Case studies would be incorporated throughout the text as exhibit boxes, rather than as appendices, to help illustrate concepts and procedures. Costs for specific case studies, where available, could be provided in appendices, but detailed cost models would not be part of the main guidance manual. The target audience, scope, schedule, and validation approach are described in the following sections.

19.2.1 Target Audience

- Primary—municipal desalination plant managers, operators, and their consultants
- Secondary—regulators
- Tertiary—industrial dischargers of concentrate and others

19.2.2 Scope

- Tentative draft outline (see attachment)
- Designed to complement and build on materials in this report effort and the recent WRF (AwwaRF) guidance document on desalination facilities (Stratus Consulting, 2010)
- Focus on feasibility assessment rather than design guidance

19.2.3 Schedule

Proposed duration of two years (project award to issuance of final draft manual). It is assumed that approximately one year would be required to develop a draft manual, and an additional year would be required to conduct and respond to reviews.

19.2.4 Validation

The guidance manual will require a thorough review from a range of perspectives to be as useful and accepted as possible. This validation process is envisioned as including

- the WateReuse Research Foundation (WRRF)
- Project Advisory Committee (PAC) members
- work-in-kind (WIK) contributors
- regulators (Florida, California, Texas at minimum)
- internal reviews (project team, WRRF, PAC)
  - initial draft
  - revised draft
- external reviews (selected members of academia, regulatory groups, consultants, plant managers)
  - initial draft
  - revised draft

DRAFT OUTLINE—GUIDANCE MANUAL

Executive Summary
Introduction (Including Objectives, Target Audience, etc.)

SECTION 1: BACKGROUND INFORMATION
NOTE: This section will contain a brief summary of the information presented in this knowledge base report, along with additional information not in the knowledge base report.

THE GROWING DEMAND FOR DESALINATION AND THE TROUBLE WITH SALT

Growing Demand for Desalination

- Population growth
- Climate change
- Declining source water quality
- More stringent drinking water standards
- Technology changes in desalination

Salinity Management

- Groundwater quality
- Surface water quality
- Soil quality
- Seawater intrusion

CONCENTRATE, BRINE, AND SOLIDS SOURCES AND CHARACTERIZATION

Generation, Quantity, and Characterization

- Concentrate from brackish water desalination treatment plants
- Concentrate from seawater desalination treatment plants
- Concentrate from water reclamation plants using desalination
- Concentrate from groundwater recovery desalination plants
- Brine from high-recovery desalination treatment plants
- Solids from high-recovery desalination treatment plants

OVERVIEW OF CONCENTRATE MANAGEMENT ALTERNATIVES

NOTE: The concentrate management alternatives below cover concentrate/brine of any salinity; they include low-recovery, high-recovery, and ZLD processing; they include the processing for recovery of separated salts.

Characterization of Management Alternatives

- Discharge of concentrate and brine to surface waters
    - Direct ocean outfall
    - Shore outfall
    - Discharge to river, canal, lake
    - Co-located outfall (power plant or WWTP outfall)

- Discharge to sewers
  - Disposal to sewer line
  - Direct line to WWTP
  - Via brine line
- Subsurface injection
  - Deep well injection
  - Shallow well (beach well)
- Evaporation ponds
  - Conventional ponds
  - Ponds incorporating enhanced evaporation techniques
- Land application
  - Percolation ponds/rapid infiltration basins over brackish aquifers
  - Irrigation
- Landfill disposal of salt solids
- Beneficial uses (besides irrigation)
  - Of concentrate
  - Of mixed solids
  - Of individual salts
- Regional concentrate management

The information for each concentrate management option would include

- Description
- Historical use
- General feasibility factors—site- and project-specific requirements
- Design basis
- Major cost factors
- Environmental and health concerns
- Regulatory basis
- Review of regulatory history
- Possible treatment requirements and technologies
- Impact of volume
- Impact of salinity
- Impact of composition
- Trends in use, practices, regulation
- Energy requirements
- GHG contributions

SECTION 2: GUIDELINES FOR CONCENTRATE MANAGEMENT OPTIONS

DISCHARGE OF CONCENTRATE AND BRINE TO SURFACE WATERS

The following three-section outline is to be used for each of the following discharge suboptions:

- Direct ocean outfall
- Shore outfall
- Discharge to river, canal, lake
- Co-located outfall (power plant or WWTP outfall)

1. **Permitting Overview and Procedures**
   - NPDES, other state, federal, and local considerations
   - Coastal permitting issues
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Whole effluent toxicity determination
   - Assessment of potential impact on aquatic life
3. **Monitoring of Discharge Impacts**
   - Water quality monitoring guidelines
   - Aquatic life impact monitoring guidelines

DISCHARGE TO SANITARY SEWERS

The following four-section outline is to be used for each of the following discharge suboptions:

- Disposal to sewer line
- Direct line to WWTP
- Via brine line

1. **Permitting Overview and Procedures**
   - Local POTW permit constraints and ordinances
   - WWTP's NPDES permit
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Compatibility with industrial pretreatment requirements
3. **Criteria and Methods for Feasibility Assessment**
   - Effect on sanitary sewer operations
   - Effect on WWTP operations
   - Effect on water reuse
   - Effect on WWTP effluent permit
   - Treatment requirements and technologies

4. **Monitoring of Concentrate Discharge Impacts**
   - Water quality monitoring guidelines
   - Wastewater treatment process monitoring guidelines
   - Wastewater discharge monitoring guidelines

DEEP WELL INJECTION

The following four-section outline is to be used for each of the following suboptions:

- Deep well injection
- Shallow beach wells

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Assessment of impact on aquifer quality and conditions
3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Concentrate Injection Impacts**

LAND APPLICATION

The following four-section outline is to be used to each of the following suboptions:

- Irrigation
- Percolation ponds

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Assessment of impact on groundwater quality and use
3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Concentrate Discharge Impacts**
   - Water quality monitoring guidelines
   - Wastewater treatment process monitoring guidelines
   - Wastewater discharge monitoring guidelines
   - Crop or irrigated vegetative community monitoring guidelines

EVAPORATION PONDS

The following four-section outline is to be used to each of the following suboptions:

- Conventional evaporation ponds
- Enhanced evaporation ponds

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Assessment of impact on groundwater quality and surrounding land

3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Concentrate Discharge Effects on Shallow Aquifer (If Ponds Are Unlined)**

LANDFILL DISPOSAL OF SALT SOLIDS

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Solids**
   - Solids quality characterization
   - Assessment of impact on groundwater quality and use
   - Leachability testing (i.e.,, Toxicity Characteristic Leaching Procedure (TCLP))
3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Landfill Leachate for Concentrate Constituents**

HIGH-RECOVERY CONCENTRATE DISPOSAL

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Assessment of impact on groundwater quality and use

1. **Criteria and Methods for Feasibility Assessment**
2. **Monitoring of Concentrate Discharge Impacts**

SOLIDS MANAGEMENT AND RECOVERY OF SEPARATED SALTS AND OTHER PRODUCTS OF VALUE

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
   - Water quality characterization
   - Definition of salt recovery possibilities
   - Assessment of impact on groundwater quality and use
3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Salt Recovery Process Impacts**
   - Energy requirements
   - Quality/quantity of recovered salts
   - Quality/quantity of residual liquids and solids

OTHER BENEFICIAL USES

The following four-section outline is to be used for each of the following discharge options:

- Oil well <u>field injection</u>
- <u>Treatment wetlands</u>
- Other emerging options (Cement manufacture, GHG sequestration/air pollution scrubbing)

1. **Permitting Overview and Procedures**
2. **Guidelines for Analysis of Concentrate**
    - Water quality characterization
    - Assessment of impact on groundwater quality and use
3. **Criteria and Methods for Feasibility Assessment**
4. **Monitoring of Concentrate Discharge Impacts**

Previously discussed beneficial uses such as solar ponds, wetland creation/restoration, sodium hypochlorite feedstock, aquaculture, and dust control etc. will be described in this section but not in great detail. Major limitations for these options will be included.

SECTION 3: GUIDELINES FOR ADDRESSING OTHER RELATED TOPICS

EMERGING ISSUES

- Increasingly stringent water quality standards (TMDLs, numeric standards, CA ocean mixing zones)
- Microconstituents/emerging contaminants
- Climate change
- Energy use/carbon footprint
- Sustainability
- Decreasing source water quality
- New desalination technologies
- Improvements in conventional concentrate management options
- Volume reduction and high-recovery processing
- Integrated water resource management (conservation, reuse, desalination)

REGIONAL CONCENTRATE MANAGEMENT

- Brine line evaluation and development

GUIDELINES FOR MANAGEMENT OF OTHER DESALINATION PLANT WASTE STREAMS

- Cleaning solutions
- Feed water pretreatment (coagulants, antiscalants/dispersants, acids, disinfectants, etc.)

REFERENCES

APPENDICES

- Supporting specific design information for at least some CM alternatives

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Appendix A

Survey of U.S. Municipal Desalination Plants

The survey was conducted to document CM practices and issues through direct contact with desalination facilities. Previous surveys (Mickley, 2001, 2006; Mickley et al., 1993;) were limited to plants operating prior to 2003. Consequently, an emphasis was on identifying and obtaining information on more recent facilities. The survey methodology is discussed in Chapter 2.

Information was obtained on more than 150 desalination plants listed in Table A.1. Data in Table A.1 are listed by state. Chapter 3 contains several tables based on analysis of the data, including comparisons with data from previous surveys.

Nomenclature used in Table A.1 includes the following:

For plant type:

- DW = drinking water
- WWTP = wastewater treatment plant
- reuse = reuse plant
- recharge = groundwater recharge facility

For process:

- BWRO = brackish water reverse osmosis
- SWRO = seawater reverse osmosis
- EDR = electrodialysis reversal
- NF = nanofiltration

For source water:

- GW = groundwater
- surface = surface water
- WWTP = WWTP effluent

For disposal method:

- surface = surface water discharge
- sewer = discharge to sewer
- EP = evaporation pond
- LA = land application
- DWI = deep well injection
- recycle = recycle to front of process
- reuse = reuse

Table A.1. Basic Data Obtained from Municipal Desalination Facilities

Plant Name	City	State	Start Date	Design Capacity (mgd)	Plant Type	Process	Source Water	Disposal Method
Chandler RO	Chandler	AZ	1996	2.4	Recharge	BWRO	Industrial effluent	EP
Gila Bend	Gila Bend	AZ	2003	0.7	DW	BWRO	GW	EP
Goodyear—Bullard Water Campus RO	Goodyear	AZ	2006	6.5	DW	BWRO	GW	Sewer
Goodyear Well Site 12	Goodyear	AZ	2007	1	DW	BWRO	GW	Sewer
Metrowater—Tucson	Tucson	AZ	pilot	0.03	DW	BWRO		LA
Scottsdale Water Campus	Scottsdale	AZ	1998	12	WWTP	BWRO	WWTP	Sewer
Arcadia WTP	Santa Monica	CA	Final testing	10	DW	BWRO	GW	Sewer
Arlington Desalter	Riverside	CA	1990	8	DW	BWRO	GW	Sewer
Bending Station 1 Desalter—Oxnard	Oxnard	CA	2008	7.5	DW	BWRO	GW	Sewer
Beverly Hills WTP	Beverly Hills	CA	2003	1.1	DW	BWRO	GW	Sewer
Cache Creek Desalination Facility	Brooks	CA	2009	0.3	DW	EDR	GW	Surface
Carmel Area WWTP	Carmel	CA	2008	1	reuse	BWRO	WWTP	Surface
Chino 1 Desalter	Chino	CA	2000	14.2		BWRO	GW	Sewer
City of Long Beach CA	Long Beach	CA	2006	0.2	DW	SWRO	Surface	Surface
Irvine—Deep Aquifer TX System (DATS)	Irvine	CA	2002	8	DW	NF	GW	Sewer
Irvine Desalter	Irvine	CA	2007	3.5	DW	BWRO	GW	Surface
Mocho GW Demineralization Plant	Livermore	CA	2009	6.1	DW	BWRO	GW	Surface
RARE—EBMUD	Oakland	CA	2010	3.5	Reuse	BWRO	WWTP	Surface
San Juan Capistrano RO WTP	San Juan Capistrano	CA	2005	5	DW	BWRO	GW	Surface
San Pasqual TDDF Project	San Pasqual	CA	Demo 2009			NF/RO/RO	GW	
Santa Cruz Water District 2—CA	Santa Cruz	CA	Design/EIR	2.5	DW	SWRO	Surface	Surface
South Orange County Desalination Plant	Fountain Valley	CA	Pilot		DW	SWRO	Surface	Surface
Sweetwater Authority	Chula Vista	CA	1999	4	DW	BWRO	GW	Surface
Terminal Island Reclamation TP	Terminal Island	CA	2004	5	WWTP	BWRO	WWTP	Recycle
West Basin Water Management—CA	Carson City	CA	1995	17	Reuse	BWRO	WWTP	Reuse
Yucaipa Regional WFF	Yucaipa	CA	2007	6	DW	NF	GW	LA
Arapahoe County ACWWA WPP	Centennial	CO	2010	9	DW	BWRO	GW	Surface
Brighton WTP	Brighton	CO	1993	6.6	DW	BWRO	GW	Surface
ECCV RO Plant	East Cherry Creek	CO	Bid phase	7	DW	BWRO	GW	Surface
Julesberg	Julesberg	CO	2001	1	DW	BWRO	GW	Sewer
La Junta WTP	La Junta	CO	2005	6.5	DW	BWRO	GW	Surface
Sterling WTF	Sterling	CO	Going to bid	8.5	DW	BWRO	GW	DWI

Todd Creek—Brighton	Brighton	CO	2007	0.7	DW	BWRO	GW	Surface
Ave Maria NF Plant	Ave Maria	FL	2007	1.67	DW	NF	GW	Sewer
Boca Raton Membrane Softening Plant	Boca Raton	FL	2004	40	DW	NF	GW	Surface
Bonita Springs RO Plant	Bonita Springs	FL	2003	12	DW	BWRO	GW	DWI
Burnt Store WTP	Punta Gorda	FL	2010	3.25	DW	BWRO	GW	DWI
Cape Coral—North	Cape Coral	FL	2010	12	DW	BWRO	GW	DWI
City of Fort Myers	Fort Myers	FL	1990	12	DW	BWRO	GW	DWI
City of Hollywood	Hollywood	FL		18	DW	NF & BWRO	GW	Surface
City of Palm Coast WTP #2	Palm Coast	FL	1992	4.8	DW	NF	GW	Surface
City of Palm Coast WTP #3	Palm Coast	FL	2008	2.25	DW	NF	GW	Surface
City of Port Saint Lucie	Port St. Lucie	FL	2005	22.5	DW	RO	GW	DWI
City of Sarasota	Sarasota	FL		12	DW	BWRO		
City of Venice	Venice	FL	1975	4.5	DW	BWRO	GW	Surface
Clearwater RO WTP	Clearwater	FL	2003	3	DW	BWRO	GW	Sewer
Clewiston	Clewiston	FL	2007	3	DW	BWRO	GW	DWI
Dunes	Dunes Community	FL	2007	0.65	DW	BWRO	GW	Surface
FL City RO—Marathon	Marathon	FL	2000	1	DW	SWRO	Surface	DWI
Florida Key Aqueduct Authority FL	Stock Island	FL	2000	2	DW	SWRO	Surface	DWI
Hallandale Beach RO WTP	Hallandale Beach	FL	2008	6	DW	NF	GW	DWI
Henry Gahn WTP	Fort Pierce	FL	2003	7.9	DW	BWRO	GW	DWI
Hialeah RO WTP	Hialeah	FL	Bid phase	10	DW	BWRO	GW	DWI
Highland Beach RO WTP	Highland Beach	FL	2005	3	DW	BWRO	GW	DWI
Holliday Pines—Ft. Pierce County	Fort Pierce	FL		0.25	DW	BWRO	GW	Sewer
J. Robert Dean—Fl Aqueduct	Florida City	FL	2009	6	DW	BWRO	GW	DWI
Jensen Beach—Martin County	Jensen Beach	FL	1992	5.61	DW	BWRO	GW	DWI
Jupiter WTP	Jupiter	FL	1990	13	DW	BWRO	GW	Surface
Lee County North	Fort Myers	FL	2006	6	DW	BWRO	GW	DWI
Lee County Pinewood—NF	Fort Myers	FL	1990	2.3	DW	NF	GW	Sewer
Lee County Pinewood—RO	Fort Myers	FL	2009	3	DW	BWRO	GW	DWI
Marco Island RO Plant	Marco Island	FL	1991	6	DW	BWRO	GW	DWI
Martin County—Jensen Beach North		FL	1992	5.6	DW	BWRO	GW	DWI
Martin County—Tropical Farms	Stuart	FL	2008	8	DW	BWRO	GW	DWI
Miami Dade WRP	Miami	FL	pilot	21	Recycle	BWRO	WWTP	DWI
North County RO Potable WTP- IRCUD	Vero Beach	FL	1998	10	DW	BWRO	GW	Surface
Norwood Oeffler WTP	North Miami Beach	FL	2007	15	DW	BWRO & NF	GW	DWI
Oldsmar ROWTP	Oldsmar	FL	Construction	2.6	DW	BWRO	GW	DWI
Palm Beach County WTP #11	West Palm Beach	FL	1995	24		NF		DWI

Palm Beach County WTP #3	Belle Glade	FL	2008	28	DW	NF	GW	Sewer
Palm Beach County WTP #9	West Palm Beach	FL				NF		DWI
Peele-Dixie WTP	Fort Lauderdale	FL	2007	12	DW	NF	GW	DWI
Plantation WTP	Plantation	FL	1997	12	DW		GW	DWI
Plantation WTP	Plantation	FL	1991	12	DW	NF	GW	DWI
Pompano Beach	Pompano Beach	FL	2002	10	DW	NF	GW	DWI
Riverbend Motorcoach Resort	La Belle	FL	2002	0.04	DW	NF	Surface	Queensland Water Commission
South County RO Potable WTP—IRCUD	Vero Beach	FL	1983	10	DW	BWRO	GW	Surface
South Regional—Palm Bay	Palm Bay	FL	2006	4	DW	BWRO	GW	DWI
St. Augustine RO WTP	St. Augustine	FL	2008	2	DW	BWRO	GW	Sewer
St. Lucie West—James G Anderson	Port St. Lucie	FL	2005	3.4	DW	BWRO	GW	DWI
Tampa Bay Desalination	Tampa	FL	2002	25	DW	SWRO	Surface	Surface
T. Mabry Carlton Jr. EDR Facility	Venice	FL	1995	20	DW	EDR	GW	DWI
Tarpon Springs WTP	Tarpon Springs	FL	2010	3.1	DW	BWRO	GW	Surface
Toutman WTP	Palm Bay	FL	2001	1.5	DW	BWRO	GW	Sewer
Town of Manalapan FL	Manalapan	FL	2006	1.7	DW	BWRO	GW	Well
Tropical Farms—Martin County		FL	2008	8	DW	BWRO	GW	DWI
Vero Beach RO WTP	Vero Beach	FL	1992	2	DW	BWRO	GW	Surface
Village Golf FL	Golf	FL	2002	0.86	DW	NF	GW	Sewer
West WTP—Deerfield—NF	Deerfield	FL	2004	10.5	DW	NF	GW	DWI
West WTP—Deerfield—RO	Deerfield	FL	2010	3	DW	BWRO	GW	DWI
Council Bluffs	Council Bluffs	IA	Construction	5	DW	BWRO	GW	Surface
Tama WTP	Tama	IA	1998	0.4	DW	BWRO	GW	Surface
Winterset Water Works	Winterset	IA	2008	0.8	DW	BWRO	Surface	Surface
Geneva RO Plant	Geneva	IL	2008	6.1	DW	BWRO	GW	Sewer
Ottawa WTP	Ottawa	IL	2002	1	DW	BWRO	GW	Surface
Wheatland	Scott City	KS	2003	5	DW	BWRO	GW	DWI
Swansea Water District MA	Swansea	MA	2010	4	DW	SWRO	Surface	Surface
Taunton River Desalination	Taunton	MA	2007	5	DW	BWRO	Surface	Surface
Clara City RO TF	Clara City	MN	2002	0.45	DW	BWRO	GW	Sewer
Madison RO TF	Madison	MN	1998	0.3	DW	BWRO	GW	Surface
O'Fallon RO WTP	St. Charles	MO	2003	3	DW	BWRO	GW	Surface
Belhaven Well Field DWTF	Belhaven	NC	2003	0.5	DW	NF	GW	Surface
Camden County		NC	2002	0.7	DW	BWRO	GW	Surface
Cape Hatteras	Frisco	NC	2000	1.4	DW	BWRO	GW	Surface
Currituck WTP	Maple	NC	2009	2.9	DW	BWRO	GW	Surface
Dare County North RO Plant	Kill Devil Hills	NC	1989	3	DW	BWRO	GW	Surface

Nano GW TP	Cape Fear	NC	2009	6	DW	NF	GW	Surface
Rodanath—Joe. Midgett WRF	Rodanth	NC	1996	1	DW	BWRO	GW	Surface
Stumpy Point RO WTP	Stumpy Point	NC	2002	0.06	DW	BWRO	GW	Surface
Haverstraw RO Water Supply Project	Haverstraw	NY	pilot	7.5	DW	BWRO	Surface	Sewer
Victory—Schuylerville	Victory Mills	NY	2006	0.65	DW	BWRO	GW	Surface
City of Bowling Green	Bowling Green	OH	Construction	3	DW	BWRO	Surface	Surface
City of Lancaster	Lancaster	OH	2004	8	DW	NF	GW	Sewer
Freedom Crossing RO WTP	Moscow	OH	2009	2	DW	BWRO	GW	Surface
West Jefferson OH	West Jefferson	OH	2008	0.67	DW	BWRO	GW	Sewer
Altus RO Plant	Altus	OK	2005	4.9	DW	BWRO	GW	Sewer
State College Recycling Facility	State College	PA	2003	1	Recycle	BWRO	WWTP	Recycle
Waynesboro WFP	Waynesboro	PA	2009	0.35	DW	NF	GW	Sewer
Hilton Head RO Plant	Hilton Head	SC	2009	3	DW	BWRO	GW	Surface
Tone WTP	Wakonda	SD	2006	0.5	DW	BWRO	GW	Surface
Brownsville	Brownsville	TX	2004	7.5	DW	BWRO	GW	Surface
City of Brady	Brady	TX	2005	1.5	DW	BWRO	GW	EP
Cypress RO WTP	Wichita Falls	TX	2009	12	DW	BWRO	Surface	Surface
Doolittle RO #1	Doolittle	TX	2008	3.3	DW	BWRO	GW	Surface
KBH Desalination Plant	El Paso	TX	2007	27.5	DW	BWRO	GW	DWI
Fort Stockton	Fort Stockton	TX	1996	3	DW	BWRO	GW	LA
Hargesheimer WTP	Abilene	TX	2003	3	DW	BWRO	Surface	EP
LaSara	LaSara	TX	2005	1.2	DW	BWRO	GW	Surface
North Cameron Reg. WA (NCRWA)	North Cameron	TX	2007	2.2	DW	BWRO	GW	Surface
Owassa	Owassa	TX	2008	3.3	DW	BWRO	GW	Surface
Seminole	Seminole	TX	Pilot				GW	Sewer
Southmost Reg. WA (SRWA)		TX	2004	7.5	DW	BWRO	GW	Surface
Valley Municipal UD #2		TX	2001	0.5	DW	BWRO	GW	Surface
Windermere Water System	Pflugerville	TX	2003	1	DW	BWRO	GW	Sewer
Barton Well Field DW TF	West Valley	UT	2008	6	DW	EDR	GW	Sewer
Jordan Valley Water District	West Jordan	UT	Construction	7	DW	BWRO	GW	Surface
Five Forks WTF	James City	VA	2005	3.8	DW	BWRO	GW	Surface
Gloucester County WTP	Gloucester	VA	2003	2	DW	BWRO	GW	Surface
NW River WTP	Chesapeake	VA	1998	10	DW	BWRO	Surface and GW	Surface
Waupun WTF	Waupun	WI	2007	2.2	DW	BWRO	GW	Sewer
Moundsville WTP	Moundsville	WV	2008	3	DW	BWRO	GW	Surface

Appendix B

High-Recovery Processing

This Appendix supplements material contained in Chapter 3 with additional information about high-recovery processing and its effect on CM.

B.1 Approaches to High-Recovery Processing

The major treatment challenge in desalination systems is that at certain levels of volume reduction (concentration of feed water), solubility limits of sparingly soluble salts, silica, silica complexes, and metals (at high pH) will be reached and precipitation will occur. The precipitation can scale membranes and heat transfer tubes and significantly compromise performance. The salts and metals from groundwater of most typical concern include

- $CaCO_3$
- $BaCO_3$
- $MgCO_3$
- $CaSO_4$
- $BaSO_4$
- $SrSO_4$
- SiO_2
- $Mg(OH)_2$
- CaF_2
- Ca/PO_4 salts
- Fe
- Mn
- Al

BWRO and EDR systems typically use antiscalants and dispersants to allow greater recovery than otherwise possible by interfering with (slowing) the kinetics of precipitate formation. Frequently, acid is also used to increase recovery for systems otherwise limited by the precipitation potential for $CaCO_3$ and/or Ca/PO_4 salts.

For brackish water systems, recovery in the initial membrane step is typically limited by one or more of the possible scalants. As a result of antiscalant use, concentrate contains one or more of the scalants in a supersaturated condition. The effect of the antiscalant is temporary and unless the concentrate produced is diluted or processed in some way, precipitation of the supersaturated scalant will eventually occur somewhere downstream.

There are three approaches to addressing this precipitation/scaling potential in a second high-recovery desalination step (Figure B.1):

- Precipitates are allowed to form within the desalination equipment.
- Unique processing sequences allow high recovery by other means.
- Precipitating species are removed before the desalination steps.

B.1.1 Precipitates within Desalination Equipment

In these processes, volume reduction takes place after the point where precipitation of some species occurs. The precipitates are kept from scaling membranes or heat transfer surfaces by (a) precipitation on a circulating slurry such as $CaSO_4$ solids (SPARRO, seeded slurry brine concentrators), (b) high velocities and shear rates (VSEP, VACOM, FBHX), or (c) proprietary surfaces that inhibit attachment under flow conditions (ALTELARAIN).

Although many precipitating solids adsorb onto the circulating slurry, some do not. Thus in seeded slurry processes such as a brine concentrator with a $CaSO_4$ slurry, performance can be limited by $BaSO_4$ precipitate, by glauberite, $Na_2Ca(SO_4)_2$, and eventually by Na_2SO_4, and NaCl.

Information about specific technologies may be found in the following sources:

- SPARRO seeded RO (Juby and Schutte, 2000)
- Seeded ($CaSO_4$) thermal brine concentrator (GE-Ionics-RCC, 2010)
- New Logic Research VSEP (Mickley, 2008; NLR, 2010)
- VACOM high turbulent MVR evaporator (212resources, 2010)
- WaterVap (FBHX) fluidized bed heat exchanger evaporator (WaterVap, 2010)
- Altela Inc's ALTELARAIN low temperature evaporation system (Altela, Inc., 2010)

B.1.2 Unique Processing Sequences

Some approaches (ARROW, HEEPM) use unusual sequences of treatment steps to achieve high recovery. ARROW uses chemical precipitation following two membrane steps and recycles the treated water back to between the two membrane steps. ARROW also has an option to use ion-exchange softening as an integral step. HEEPM runs both a patented ED process and a standard RO process using a common feed tank. The high-salinity ED waste is removed from the system, with the product water returning to the feed tank. The RO product water is the system product water and the RO concentrate is returned to the feed tank. The Tandem RO approach uses improved antiscalants and pH manipulation between two membrane steps to achieve high recovery. RORO is an approach to increasing recovery by sensing incipient precipitation and reversing the feed flow to the membrane system. HERO may utilize ion exchange and chemical precipitation in addition to high pH operation of the RO step. The ZDD process recovers salts for use or sale and uses a unique form of ED called electrodialysis metathesis.

Information about specific technologies may be found in the following sources:

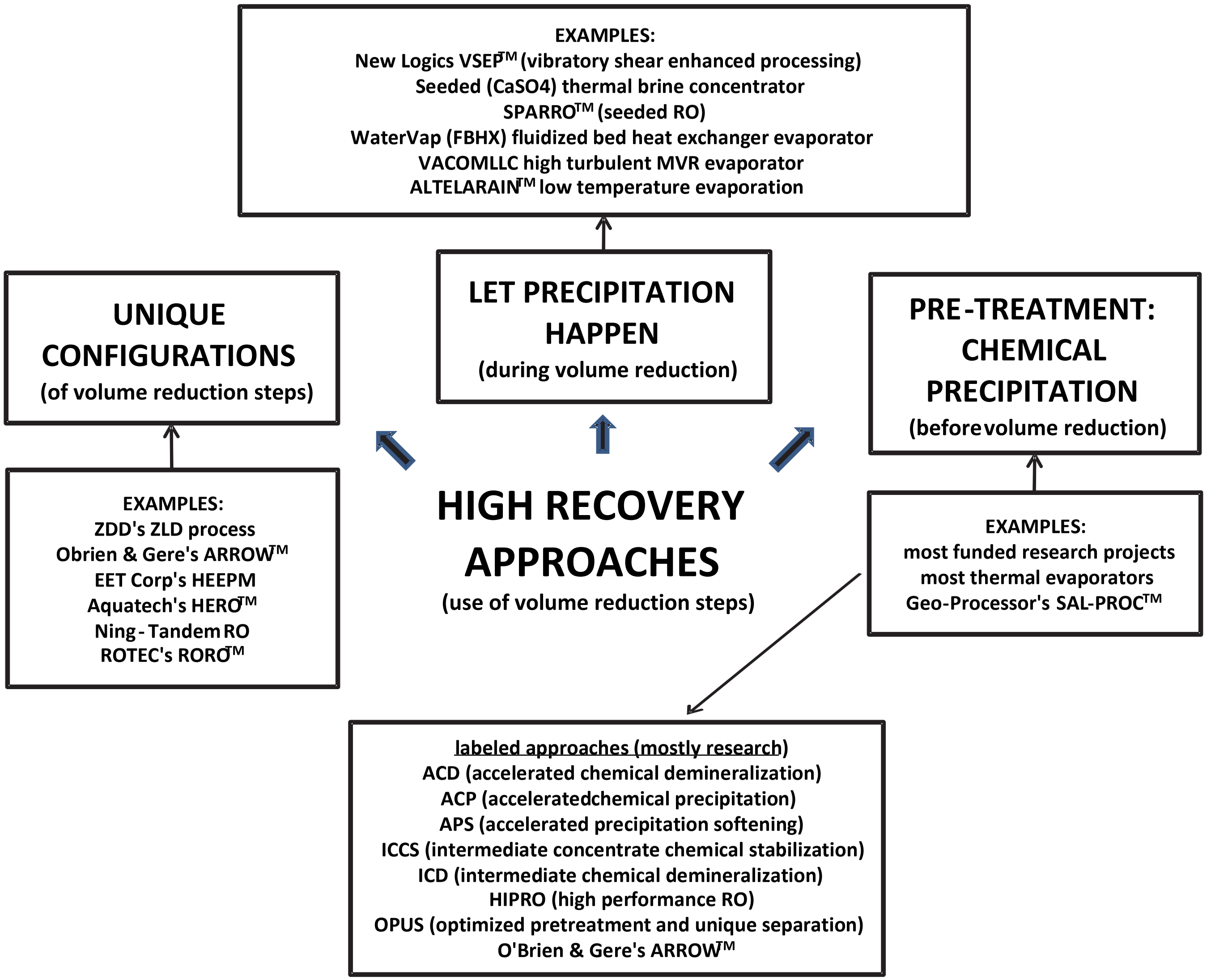

Figure B.1. Representation of high-recovery approaches (Mickley, 2010).

- ZDD's ZLD process (Davis, 2005, 2008)
- O'Brien & Gere's ARROW (Mickley, 2008)
- EET Corp's HEEPT (EET Corporation, 2010; Mickley, 2008)
- Aquatech's HERO (Aquatech International Corporation, 2010)
- Tandem RO (Ning and Tarquin, 2010)
- RORO (ROTEC, 2010)

B.1.3 Precipitation before Desalination Steps

This is the most typical approach to high recovery, where chemical treatment steps before or after desalination steps are used to reduce concentrations of species that might otherwise precipitate upon concentration of the solution. There are many versions of this, with different groups giving their own names to essentially similar processing schemes (some of the names/labels are shown in Figure B.1). A variant of this approach selective removal of commercial grade salts for use or market (GEO-PROCESSORS, 2011). Also included in this group are nonseeded evaporators, for which there are many manufacturers.

Information about specific technologies may be found in the following references:

- Geo-Processors (GEO-PROCESSORS, 2011)
- ACD (Cohen, 2008)
- ACP (Rahardianto et al., 2005)
- APS (Cohen, 2008)
- ICCS (He et al., 2010)
- ICD (Gabelich et al., 2007)
- HIPRO (Keyplan, 2010)
- OPUS (OPUS, 2010).

There have been many funded research studies since 2002 looking at how to achieve high recovery. These studies confirmed for municipal concentrate what has been known in other industries: that high recovery is not a technical problem but a technology constrained by cost. In addition to the Geo-Processors approach, more recently funded studies have concentrated on reducing high recovery costs (He, 2010). Perhaps some these approaches will prove to have cost advantages for municipal application.

B.2 Disposal of Final High-Recovery Concentrate or Solids

The final concentrate from a high-recovery process needs to be managed. When viewed as volume reduction of a concentrate, although the volume is reduced, the salinity and various concentrations are increased. The question is how this affects disposal of the high-recovery concentrate.

There are situations where disposal of the volume-reduced high-recovery concentrate may not represent any greater disposal challenge. These include the following:

- disposal in California, where inland concentrate may be discharged into a brine line leading to an ocean outfall
- disposal in Florida (and other locations), where DWI is possible
- disposal in locations where evaporation ponds are possible

- disposal in Texas, where some facilities discharge into drainage ditches that ultimately discharge into the ocean
- disposal in nanofiltration processes where the high-recovery salinity is still relatively low and thus disposal of concentrate may be similar to disposal of a conventional-recovery BWRO concentrate

In other situations, disposal of high-recovery concentrate may be more challenging. The following sections examine how higher salinity and constituent concentrations may affect disposal by the five conventional disposal options and disposal of solids and brine from a crystallizer.

B.2.1 General Characteristics of High-Recovery Concentrate

Volume reduction of concentrate changes the concentrate discharge characteristics. Salinity will be higher and the concentrations of most constituents will also be higher. However, some constituents in the concentrate prior to volume reduction may have been reduced in concentration because of the treatment that allows volume reduction to occur. This is the case when chemical precipitation pretreatment of concentrate occurs before volume reduction.

The higher concentrations encountered in high-recovery processing can bring other, more soluble salts closer to saturation limits, and these salts may limit recovery in the volume reduction process. As a result, relative to concentrate prior to volume reduction, concentrate from high-recovery processing will have higher concentrations of many constituents and may have similar or different salts near or at saturation limits.

This discussion is with respect to BWRO concentrate. In contrast, high-recovery NF concentrate is of relatively low salinity and as a result will have fewer concerns associated with its disposal.

B.2.2 Discharge of-High Recovery Concentrate to Surface Water

Municipal desalination plants discharging to surface water are required to meet discharge limits for various concentrate parameters. Depending on concentrate characteristics, on the particular discharge regulations that apply (which vary considerably state to state), and on the particular receiving water in question, the discharge permit may be based on end-of-pipe concentrations. When the volume of concentrate is reduced, some end-of-pipe concentrations may be increased to the point of being higher than the permit limits. Depending on the state regulatory policy, mixing zones may be a possible form of relief for the constituent(s) in question. Granting of a mixing zone is dependent on receiving water conditions affording sufficient dilution.

If the receiving water has TMDL limits for a constituent present in concentrate, a mixing zone is not possible for that constituent. However, discharge may still be possible dependent on meeting the concentration-based end-of-pipe water quality standards and meeting the TMDL load (mass-based) standard.

The key issue is whether the discharge meets applicable water quality standards of the receiving water. In many states, the discharge must meet toxicity standards as dictated by limits on WET test results. Because of the higher concentrations in the volume-reduced concentrate, the WET tests results will be different from those for a standard concentrate. Mixing zones may be possible for various toxicity conditions. In Florida, for example, mixing zones may be granted for chronic toxicity but not, in general, for acute toxicity. An exception, however, is made for municipal desalination concentrate having major ion toxicity (ion imbalance). In cases where mixing zones may be possible, the granting of mixing zones depends on demonstration of sufficient receiving water dilution within the physical limits allowed for mixing zones.

The effect of increasing recovery on toxicity depends on how the toxicity of a given constituent changes with salinity. For instance, reducing the volume of concentrate may increase the concentration of a potential toxicant by a factor of 2, but the toxicity of that constituent at the higher salinity may be less than one-half that at the lower salinity.

The literature shows that the effect of salinity on toxicity is dependent on the organism tested and the age of the organism. Most, but not all, heavy metal toxicity decreases with increasing salinity. Exceptions in some studies include lead and mercury. There have been indications of pesticide toxicity (dependent on the pesticide) increasing with salinity.

The results from one study include the following: "The toxicity of most metals such as cadmium, chromium, copper, mercury, nickel, and zinc was reported to increase with decreasing salinity. This finding is likely related to the greater bioavailability of the free metal ion (toxic form) under lower salinity conditions. There was generally no consistent trend for the toxicity of most organic chemicals with salinity. The one exception to this was reported with organophosphate insecticides, the toxicity of which appeared to increase with increasing salinity" (Hall and Anderson, 1995).

Major ion toxicity reflects toxicity of common ions. Mickley (2000) looked at the toxicity of major ions and fluoride at salinities of 10, 20, and 30 ppt. The major ions studied included Ca, K, Mg, HCO_3, B_4O_7, SO_4, and F. The test organism for all major ions except F was the mysid shrimp, commonly used in Florida in WET tests for discharges into brackish waters. The toxicity of these ions decreased with salinity. The toxicity of fluoride was studied using several different organisms, including mysid shrimp, a sea urchin (*Arbacia punctulata*), a red macro alga (*Champia parvula*), and *Menidia beryllina*. The mysid shrimp proved to be the most sensitive organism tested, with fluoride toxicity increasing with salinity.

In summary, for some heavy metals, pesticides, and fluoride, toxicity appears to increase with salinity. For other constituents, toxicity may be relatively constant or decrease with salinity. Changes in toxicity with volume reduction, however, where both concentration and salinity increase, are difficult to predict. With toxicity increasing with concentration, volume-reduced concentrate is likely to have more constituents contributing to toxicity. Combined, however, with a full range of possibilities of toxicity change with salinity, the net effect of volume reduction on toxicity is dependent on the constituent in question.

Further, not all states require WET tests for municipal desalination concentrate, and few states use the very sensitive mysid shrimp used in Florida. Thus, it is difficult to generalize on the likelihood of increased WET test failure with volume-reduced concentrate.

As surface water discharge requirements continue to become more stringent, surface water discharge, in general, will be more difficult to permit—regardless of the salinity of concentrate. The feasibility of surface discharge of a high-recovery concentrate must be determined from site-specific information.

Although the same considerations apply to high-recovery NF concentrate, in general they will be less restrictive because of the lower salinity of the NF concentrate.

See Chapter 8 for a full discussion of surface water discharge.

B.2.3 Discharge of High-Recovery Concentrate to Sewers

As mentioned in the previous section, the mass (volume times concentration) of most constituents is unchanged by volume reduction. The blended volume (concentrate with other WWTP influent) will be somewhat less because of the smaller volume of the concentrate. Thus the resulting blended concentration (amount of constituent divided by blended volume) will be higher, but likely not significantly higher (see example in Section 7.8.2).

Discharge to sewers has been used mostly for low rates of discharge of concentrates. Where such discharge has been used in the past, volume reduction may, in most cases, still be acceptable to the WWTP.

See Chapter 9 for a detailed discussion of discharge to sewers.

B.2.4 Disposal of High-Recovery Concentrate by Deep Well Injection

DWI is not widely used in municipal desalination CM because, in some locations, of the lack of identified suitable receiving aquifers and of regulatory constraints, and in other locations of the applicability of DWI not being investigated.

Higher salinity concentrate raises some issues with feasibility of DWI related to the difference between concentrate salinity and composition and receiving water aquifer salinity and composition. Injection of lower-salinity, lower-density concentrate into higher salinity aquifers may increase the possibility of migration of aquifer water to overlying aquifers. In this case, injection of higher salinity concentrate may be an advantage.

> **Example:** *Cape Coral North:* The newly operated plant discharges concentrate to a deep well. The permit obtained is for a dual-use well that would allow future discharge of WWTP effluent along with the concentrate. A concern is that co-injection with the lower-salinity WWTP effluent may increase the possibility of upward migration of the injected fluid. First-year operation of the well with concentrate-only injection is being closely monitored to provide additional data on the risk of migration.

The Boulder zone receiving aquifer in Florida is high-salinity, and injection of high-salinity concentrate from high-recovery processing may not be a concern. Receiving water aquifers at similar depths in other states are likely of lower salinity, and injection of higher salinity concentrate may be an advantage in these locations also.

Blending concentrate with aquifer water may result in the formation of precipitates within the well bore or close to the injection point because of the resulting levels of sparingly soluble salt ion concentration. This situation may occur with any concentrate. Because of the higher concentrations of constituents, the high-recovery concentrate may have more constituents (salt, metals, silica) at or above supersaturation than the standard concentrate and thus may be more susceptible to precipitation upon blending.

The occurrence of precipitation is dependent on several factors, including

- amounts of antiscalant and dispersant present in the concentrate
- blending effects (temperature, pH, chemistry)
- adsorption of antiscalants and dispersants by aquifer media
- elapsed time since addition of antiscalants/dispersants to the membrane system feed water

There is little information available on DWI of higher salinity desalination concentrates, and care must be taken to anticipate, study, and guard against unwanted results.

Chapter 10 discusses DWI of concentrate in detail.

B.2.5 Disposal of High-Recovery Concentrate by Land Application

Land application includes irrigation and the use of percolation ponds. Both are seldom used for concentrate. Concentrate is typically of higher salinity than groundwater and requires dilution water to make irrigation feasible. The dilution water increases the volume to be disposed of and may increase the amount of land required. Factors limiting irrigation most frequently include concentrate salinity and volume, concentration of specific constituents such as Na, Cl, and B, and the need for sufficient and relatively level land.

High-recovery processing results in a reduced-volume and higher salinity concentrate. The salt load (concentration times volume) is roughly the same (some salts may be removed, such as by chemical precipitation), but a slightly greater amount of dilution water would be required for the volume-reduced concentrate. This may be shown by the following example. Consider two concentrates: a 1-mgd concentrate of 2,000 mg/L and a 0.2-mgd volume-reduced concentrate of 10,000 mg/L. Assume that both concentrates are required to be diluted to 1,000 mg/L and that available dilution water is 500 mg/L. The 1-mgd conventional recovery concentrate will require 3 mgd of dilution water, whereas the volume-reduced concentrate will require 3.8 mgd of dilution water.

Percolation ponds are possible only in situations where underlying groundwater is of compatible salinity. The higher salinity concentrate from high-recovery processing makes the possibility of this occurrence less likely.

Disposal by land application is discussed in Chapter 12.

B.2.6 Disposal of High-Recovery Concentrate by Evaporation Ponds

As with DWI, evaporation ponds have been used in only a few southern states in the United States for disposal of municipal desalination concentrate. Evaporation ponds are climate-dependent and land-intensive, lack economy of scale, require flat land, and thus are only feasible where the right conditions of these factors may occur.

Higher salinity and reduced-volume concentrate affects evaporation pond feasibility by

- reducing the amount of land required, but not in exact proportion to the volume reduction (as the decreased evaporation rate of higher salinity water results in more land required per unit volume of concentrate)
- more quickly filling up ponds with salts, such that the life of the pond is decreased; this may mean that the pond would need to be (a) cleaned out during the life of the

desalination plant (with salts being sent to a landfill) or (b) covered over and retired (in which case new pond area would need to be provided)

Both of these factors increase the cost per unit volume of disposal to evaporation ponds.

Disposal to evaporation ponds is discussed in Chapter 11.

B.2.7 Disposal of Solids from Additional Treatment of High-Recovery Brine

When thermal crystallizers (or spray dryers for smaller volumes) are used to produce solids from brine, the resulting solids are usually of a mixed nature. Given that there are few uses for mixed solids, the solids are typically sent to a landfill. As with evaporation ponds, the amount of solids can be high and may be high enough to require a dedicated monofill to be built for disposal of the solids. Landfill costs can be significant, whether for hauling costs to an existing landfill or for construction of a dedicated monofill.

By calculating the solids composition of feed water taken all the way to solids (without consideration of treatment effects), a worst-case chemical composition of the final solids can be estimated (Mickley, 2009). If the solids composition resulting from this calculation is not classified as hazardous (because of metals, NORMS, arsenic, etc.), then the feed water is likely a candidate for processing all the way to solids.

If the solids contain constituents that would cause them to be classified as hazardous, then landfill disposal costs will be greatly elevated and likely prohibitively high for municipal situations.

B.2.8 Final Residual Brine from Crystallizers

Depending on the presence of highly soluble salts ($MgCl_2$, $CaCl_2$), thermal crystallizers may have a final brine that cannot be solidified, in which case there is a blowdown or purge stream from the crystallizer. The purge stream typically goes to a small evaporation pond or a small spray dryer.

Disposal of final residuals from high-recovery processing—whether brine or solids—can be costly. In industries where high-recovery processing is widely used, it is for reasons other than to reduce disposal costs, usually to provide an acceptable solution—from an environmental and thus regulatory standpoint, to reduce the time to achieve a permit, and to reduce outside water requirements for the industrial facility by providing recycle water. Disposal of these waste streams from a municipal high-recovery process can be a major cost impediment.

B.3 Effects of Salinity and Composition on High-Recovery Costs

A recent WRRF study (Mickley, 2008) investigated the effects of salinity and composition on several high-recovery processing schemes operating as ZLD systems. Eight concentrates, some actual and some projected from raw water quality, were used as the basis for comparing performance and costs of five different commercially used ZLD approaches. In order to uncouple effects of salinity and composition, both of which varied among the concentrates, concentrate salinities (which varied from about 4000 to 11,000 mg/L) were normalized to 8000 mg/L. Each constituent was ratioed in the same manner to provide the 8000-mg/L composition. This approach eliminated salinity as a variable, allowing focus on the effect of composition alone. The five most widely used high-recovery commercial approaches considered are shown in Table B.1. The commercial salt recovery process, due to (GEO-PROCESSORS, 2011), was not included in the same analysis but was evaluated and discussed separately. In addition, five cases explored the effects of concentrate volume and salinity using a single relative composition.

Individual process step performance, system performance, and costs were evaluated as a function of processing scheme, salinity, composition, and plant size. The choice of variable conditions allowed independent study of these effects. Although high costs of high-recovery processing are evident in all the situations studied, the results illustrate a wide range of costs.

For nearly every case, use of crystallizers resulted in higher costs (note, however, that use of crystallizers may be necessary to achieve a solution in some situations—such as where evaporation ponds are not possible). The highest cost processing scheme in nearly every case was 1A (BC >> EP). Use of second-stage RO prior to brine concentrators is nearly always beneficial in terms of cost. The lowest cost ZLD approach is usually 2A, but not always. This illustrates an important point, that the lowest cost (in terms of unit annualized cost) processing scheme is a function of salinity and composition.

ZLD systems are made up of several processing steps. The performance and cost of each step are dependent in different ways on salinity and composition. Because of this complex interaction between processing steps, simple rule-of-thumb predictions of performance and cost can be misleading and inaccurate.

Perhaps the most important point from the study is that it is risky to generalize results from a single case, whether a desktop study or a pilot test, as results are highly dependent on salinity, composition, and concentrate volume.

Table B.1. Commercial ZLD Process Schemes Chosen for Evaluation

Scheme	Processing Step Sequence
1A	Conc.→ BC → EP
1B	Conc. → BC→ Cryst. → EP & LF
2A	Conc. → LS → RO2 → BC → EP & LF
2B	Conc.→ LS→ RO2 → BC → Cryst. → EP & LF
3	Conc. → LS → RO2 → EP & LF

Note: Conc. = Concentrate; BC = brine concentrator; EP = evaporation pond; Cryst. = crystallizer; LF = landfill; LS = lime softener; RO2 = second stage RO.

Appendix C

Workshop Report

MEETING SUMMARY

Concentrate Management Workshop Summary

ATTENDEES: Rob Huehmer/WDC
Bob Bergman/GNV
Juan Gomez/SAN
Brian Fuerst/DFW
(~17 other attendees)

FROM: Jim Jordahl/DMS

DATE: July 16, 2009

As a component of the WateReuse Research Foundation project "Development of an Information Clearinghouse on Concentrate and Salt Management Processes," a workshop on concentrate management was held at the AMTA conference in Austin, TX July 15, 2009. The intent was to hold a regionally-focused workshop, to gather input on key concentrate management issues and content and format of a future guidance manual on CM.

Approximately 17 people in addition to the presenters (Jordahl, Bergman, Huehmer, Fuerst, and Gomez) attended the workshop. The count is approximate as not all attendees attended the entire workshop—a few came late, a few left early, and a few left early but came back. There were no utility representatives at the workshop.

A combination of reasons likely contributed to the lack of utility attendance, including low utility attendance at conferences generally in 2009 due to funding issues, competition with a social hour with food and drink, the additional cost of the workshop on top of conference fees, and what may have been perceived overlap of content with two technical sessions. Attendees included a number of consultants, a representative of the Texas Water Development Board, and Jeff Mosher from NWRI.

Jordahl moderated, and provided an overview of workshop format and objectives, an overview of concentrate management and disposal issues, and a summary of the goals of the WRRF project. Bergman and Huehmer gave presentations on concentrate volume reduction technologies, other constituents in concentrate such as antiscalants, and CM practices and drivers around the world. Gomez and Fuerst presented case studies on how specific utilities in Texas and Florida have dealt with concentrate treatment and disposal issues. An open discussion with panel members and attendees followed the presentations.

Summary

The workshop went well, and there was good engagement by participants in the roundtable segment of the workshop. Major points made about which there appeared to be broad agreement were:

- There is a great need for a standard guidance document that has input and agreement from at least the key states where CM is an important issue. The major purpose of the document would be for regulator education and communication among regulators more so than as a tool for utility design and planning. The "10 States Standards" (Recommended Standards for Water Works) would be a good guide for length and format. The Interstate Regulatory Technology Commission (ITRC) was suggested as a possible consortium of regulatory, industry, and consulting resources that could work together to gain consensus on a document that would facilitate consistent and informed regulatory decisions.
- There is a great need for a central national repository of information on CM, and that something akin to the Wikipedia on the internet, based on key word searches, would be a good model. The repository should also contain good examples of approved permits, laboratory studies, modeling results, etc., possibly in the form of an interactive database. There is a lot of "reinventing the wheel" and regulator education that is required due to the lack of information sharing. The NWRI is one possible group that could help to host such a database.
- The project should consider adapting the survey to include regulators as well as utilities to broaden the perspective. The section on key issues in planning, design, operation, and future issues could be separated from treatment process/capacity sections of the survey.

Specific Discussion Points

Searchable Database Comments

An effort should be made to obtain funding to develop a key word-based collection/retrieval of research database on CM. A continuous process of expanding upon the database is needed.

Refractory compounds, radionuclides, trace elements (arsenic, selenium, etc.) are constituents utilities are dealing with in addition to TDS. The database needs to facilitate collection of data others have compiled on these issues.

The database should separate CM technologies that have a good body of knowledge from emerging technologies.

Utilities may need to lead the drive to develop this database?

Case studies need to be included. (Even the not so successful cases have a lot of value. It is almost like a lessons learned. It is a way to communicate to others things that have not worked for a given utility/project and provide some explanation of why they did not work.)

The database should also include permits to show what has been done/can be done.

Development of a Concentrate Management Guidance Document

The document should parallel the "10 States Standards" (Recommended Standards for Water Works). It needs to be concise. A consensus-building process is needed in the development process by circulating draft copies among states. Content would also be built in this way. It should incorporate case studies. The NSF method for establishing guidelines should be used, such as Standard 60/61.

Regulator Education

There was considerable agreement on the need for better education of the regulatory community. This needs to be industry wide, not project specific to avoid conflicts of interest and maintain credibility. AWWA or AMTA could play a role in this.

A key problem is that regulators don't have budget to attend technical conferences. Workshops need to be done specifically for regulators to help them better understand the issues and the technology.

This can be accomplished through Live Meeting type of events in addition to specific in-person meetings with key regulatory agencies.

Other Comments

Florida statute allows concentrate that meets toxicity protocol (major ion toxicity) to get a discharge permit even if it fails (conventional?) toxicity tests. The major ion toxicity approach has helped "get things done".

In the Southwest, TDS is by far the most important parameter determining disposal options. TDS is typically the major issue in most locations as well, but there are exceptions in certain regions, where issues like Se, As, or other constituents play a major role.

One attendee felt very strongly that the "industrial waste" categorization of concentrate was a critical issue that needs to be changed. A database should be gathered to support changing this, and should be shown to politicians. Other attendees noted that the role of the industrial waste categorization in limiting CM options was more of a factor in Florida than elsewhere.

A greater understanding of chemistry is needed by the water treatment industry. Engineering needs to be better balanced with science. This perspective is especially held by regulators. The gap in understanding between what is known in science to what is applied in engineering is growing.

Water quality offsets may be one approach that could be used to expand CM options as opposed to rigid standards. A utility in one location may "overtreat" where it is feasible to do so, to allow another utility to treat to a lower standard where there are technical or other constraints limiting treatment.

Are there economies of scale in CM? Should regional facilities be considered?

Utilities hesitate to use brine crystallizers and other high-tech processes due to difficulties in operation. They are also very energy intensive and as a consequence very costly in a life cycle type of comparison. However, if there are no other options, ZLD might be the way to go.

Advancing the Science of Water Reuse and Desalination

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