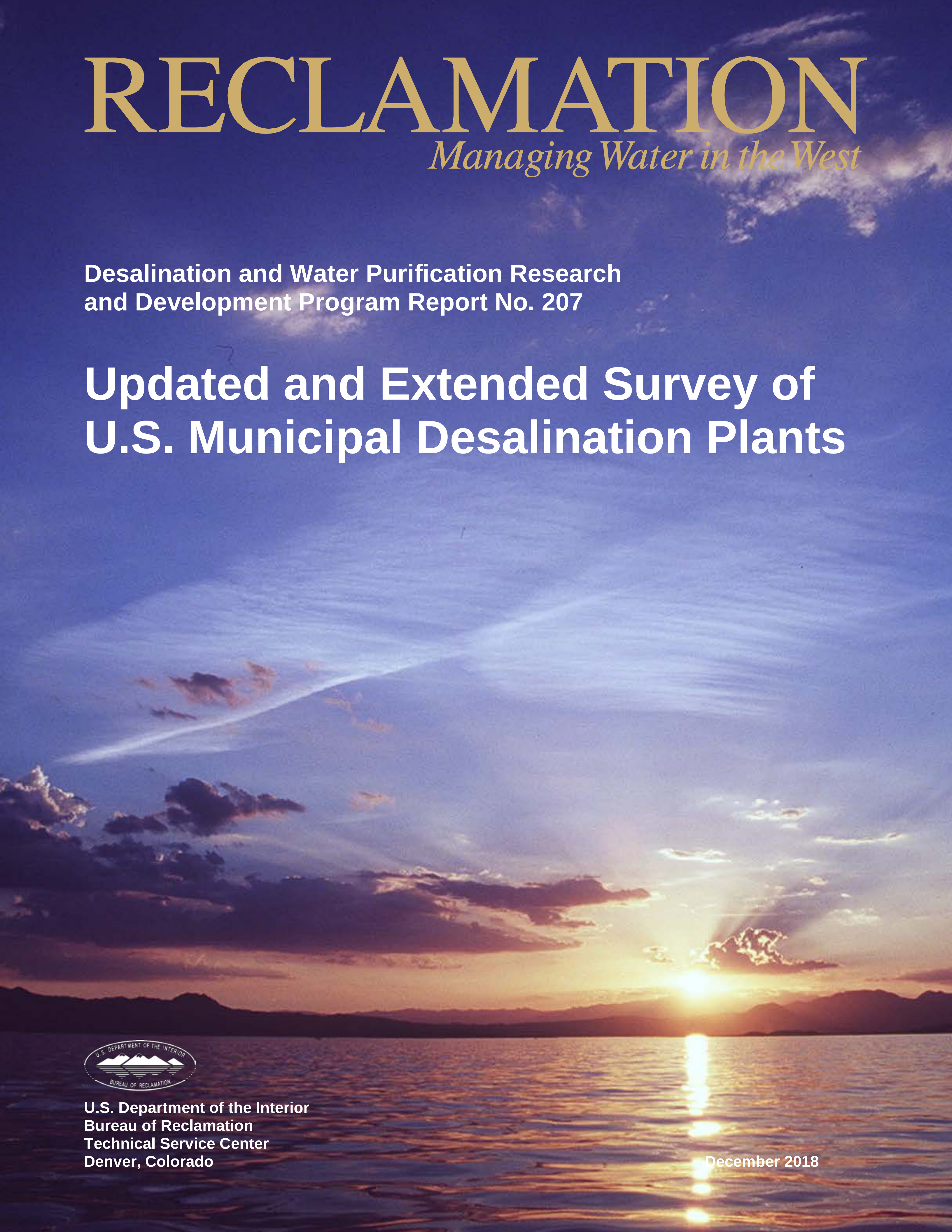
RECLAMATION

Managing Water in the West

Desalination and Water Purification Research and Development Program Report No. 207

Updated and Extended Survey of U.S. Municipal Desalination Plants



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14. ABSTRACT The project survey provides a record of municipal desalination facilities of size 25,000 gpd and greater in the 50 states built from 2010 - 2017. This is the fourth such survey since 1990 and together with the previous surveys the project results show trends in numbers, capacities, size, location, and various performance and practice parameters of these facilities.			
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Prepared for the Bureau of Reclamation Under Agreement No. R16AC00119

by

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acronyms and Abbreviations

AACE	American Association of Cost Engineers
ASR	aquifer storage and recovery
BWRO	brackish water reverse osmosis
CA	California
CAPEX	capital expenditures
CM	concentrate management
DRIP	Desalination Research and Innovation Partnership
DWI	deep well injection
DWPR	Desalination Water Purification Research Program
EDR	electrodialysis reversal
EP	evaporation pond
Fe	iron
FL	Florida
GAC	granulated activated carbon
GW	groundwater
GWI	Global Water Intelligence
HAAs	haloacetic acids
IDA	International Desalination Association
IX	ion exchange
LA	land application
MAX	maximum
MBR	membrane bioreactor
MEDRC	Middle East Desalination Research Center
MF	microfiltration
MLD	minimal liquid discharge
Mn	manganese
MVC	mechanical vapor compression
MWH	Montgomery Watson & Harza
NF	nanofiltration
O&M	operating and maintenance
OCSD	Orange County Sanitation District
OPEX	operating expenses
RO	reverse osmosis
SUD	special utility district
SWRO	seawater reverse osmosis
TDS	total dissolved solids
THM	trihalomethane
TOC	total organic carbon
TX	Texas
UF	ultrafiltration
U.S.	United States
USBR	United States Bureau of Reclamation
UV	ultraviolet
VSEP	vibratory sheer enhanced process
WPP	water purification plant
WRF	Water Research Foundation
WRRF	Water Reuse Research Foundation
WTF	water treatment facility
WTP	water treatment plant
WWTP	wastewater treatment plant
yr	year
ZLD	zero liquid discharge

Measurements

°F	degree Fahrenheit
%	percent
µ	micro
µg/L	microgram per liter
µS/cm	microSiemans per centimeter
bgd	gallons per day
cm	centimeter
gpd	gallons per day
gpm	gallons per minute
kWh	kilowatt hours
m^3/d	cubic meters per day
mg/l	milligrams per liter
mgd	million gallons per day
pH	numeric scale to measure acidity or basicity (alkalinity) of an aqueous solution
psi	pounds per square inch

Contents

Appendices

Executive Summary

This survey project gathered and analyzed information from U.S. municipal desalination facilities built from 2010 to 2017. We identified 86 facilities and gathered information about the characteristics and operation of the facilities. The survey represents the fourth such survey conducted since 1990. The project information along with information from previous surveys are presented in a series of tables and figures that provide detailed picture of the characteristics and trends over time for the 406 facilities built since 1969.

In addition, the project survey gathered some information detailing the facility treatment process and operating conditions that had not been gathered in previous surveys.

Cost information was not gathered due to many challenges associated with gathering meaningful cost data and to the project size. However, a cost-related task identified and discussed challenges associated with gathering and working with cost data providing information that may be helpful in future cost-gathering efforts.

The data gathered from the 86 facilities are provided in a master spreadsheet and separately in a summary page for each facility.

1. Introduction and Project Background

The objective of this project was to gather and analyze information for municipal desalination facilities built in the 50 United States from 2010 through 2017. While the term "survey" is applicable, the approach was to gather information from every facility that could be identified, rather than accept what might be a statistically representative cross-section of facilities.

As in past surveys, the goal is to identify all municipal desalination facilities of 25,000 gpd and above using reverse osmosis (RO), nanofiltration (NF), electrodialysis reversal (EDR), and evaporative processes. This includes:

- Water treatment plants (WTP) producing potable water
- Wastewater treatment plants (WWTP) producing water for disposal or recycle/reuse
- Facilities producing water for aquifer recharge or aquifer storage and recovery (ASR), which may be WWTPs

The information sought is listed in Table 1. The project added 86 facilities to the existing 320 facilities identified in previous surveys.

In addition to obtaining and analyzing facility characterization data, a separate task addressed the challenges of obtaining, representing, and evaluating meaningful cost data from desalination facilities.

Since 1990, a series of detailed surveys (Mickley et. al., 1993; Mickley, 2006, Mickley, et. al., 2012) has been conducted on U.S. municipal desalination plants. The initial survey was conducted to characterize membrane concentrate practices in the first major report focusing on concentrate disposal. Since the initial survey, similar surveys funded by various agencies have been conducted to update the survey results. The funding agencies and reports containing the surveys include:

- AWWARF: [1]Membrane Concentrate Disposal, 1993.
- Bureau of Reclamation: *Membrane Concentrate Disposal: Practices and Regulation - 2nd edition*; DWPRP Report No. 123, 2006.
- Water Reuse Research Foundation (WRRF): *Development of a Knowledge Base on Desalination Concentrate and Salt Management*, 2012.

[1] American Water Works Association Research Foundation, now Water Research Foundation.

While a prime reason for the surveys continues to be documenting concentrate management practices and trends, the data collected include a broad characterization of the treatment processes employed including reasons for treatment. As such, the surveys provide a detailed picture of U.S. municipal membrane desalination facilities over time.

Table 1.—Information Sought from U.S. Municipal Desalination Facilities

GENERAL	Name of facility Owner of facility Purpose of facility Type of technology Start year of desalination operation Reason for desalination as opposed to conventional treatment
TREATMENT CAPACITY	Desalination design production (mgd) Desalination average production (mgd) Plant (desalination + blend) design production (mgd) Plant average production (mgd)
TREATMENT PROCESS	Source water Raw water TDS (mg/l) or conductivity (µS/cm) Feed pressure to the desalination stage (psi) Pre-treatment steps Permeate TDS (mg/l) Membrane recovery (percent) Age of membrane at last replacement
BLENDING	Blending (yes/no) Blend water source Blend ratio (permeate: other) TDS of blend
WASTE MANAGEMENT	Concentrate disposal Fate of cleaning wastewater
POST TREATMENT	Post-treatment of permeate Post-treatment of concentrate

µS/cm = microSiemens per centimeter
TDS = total dissolved solids
mg/l = milligrams per liter
psi = pounds per square inch

Survey results have been used in many books, reports, and presentations discussing various aspects of the municipal desalination industry. In addition, the resulting database, maintained by Mickley & Associates, has been sought by various universities and governmental agencies for use in studies.

One of the prime benefits of the survey is to document trends over time, including:

- Cumulative number of facilities
- Cumulative installed capacity
- Types of membrane processes (by time, by location)
- Number of plants by location
- Disposal options used (by time, by location, by type of membrane process, by plant size)
- Size of plants (by time, membrane type, by disposal option)

These surveys are the only source of such information. While Global Water Intelligence provides valuable information on many global desalination facilities, it does not include the same level of detail of information and does not include information on concentrate disposal.

2. Technical Approach and Methods

The data gathered in this project was obtained through a series of interactions with individual municipal facilities to document the nature of and operational characteristics of the facilities. An additional task investigated challenges associated with gathering cost-related information about municipal desalination facilities.

2.1. Information Gathering

Two separate areas of effort gathered information for the survey:

- Assembling a candidate list of facilities that may fit the search criteria (municipal facilities, size 25,000 gallons per day [gpd] and greater, built in 2010 or after) and identifying initial contact information
- Obtaining information through repeated interaction with the facility and/or facility owner

Over the course of conducting multiple surveys, the task of identifying facilities has become more efficient, because a few state regulatory groups provide a means of identifying facilities through facility lists or through access to permits. In addition, plants can be identified through internet searches and search of membrane equipment installation lists. Once desalination plants are contacted, they can helpful identify other plants in the same general region. Once the location/name of a facility is determined, initial contact information is obtained through an internet search of the city of operation and, more specifically, the utility name.

As in past surveys, information comes from multiple sources, with information gathering efforts spreading over an extended period of time. Information about the municipal desalination facilities was gathered by several means that include:

- Mickley & Associates' file material
- Regulatory agency permitting lists—permits typically contain descriptions of facility location and operation
- Utility websites that frequently include descriptions of their WTPs and WWTPs
- Membrane equipment suppliers' installation lists
- Engineering companies' project lists
- Direct contact with each facility through the overseeing utility
- Conference proceedings and journal articles

Over 200 possible facilities were considered and investigated before a final list of 86 was assembled. During this initial phase, the primary objective was to determine if the facility fit the search criteria. Several facilities were eliminated due to:

- Being only pilot or demonstration plants
- Being built prior to 2010
- Being industrial rather than municipal facilities
- Being only future considerations

This phase of identifying facilities was of similar time and effort as the following phase of gathering information.

Prior to contacting the identified facilities, as much information as possible was gathered from the utility website, concentrate disposal permits, and other Internet files. The amount of data available from these sources varied considerably with facility, with more data typically available for larger facilities.

Additional information was then gathered from the 86 facilities over a series of telephone conversations and emails. To get this information, we had 3 – 10 interactions with individual facilities, with many telephone calls only leaving messages. The entire process was time-consuming but necessary.

The data gathering effort was separated into two phases, primarily to not burden the facility representative with a large number of questions. The initial phase gathered more basic data of:

- Name of facility
- Facility owner
- Purpose of facility
- Type of desalination technology
- Start year of the desalination operation
- Design production capacity
- Source water
- Pretreatment steps
- Concentrate disposal method

An additional reason for limiting the initial information gathering task to these information items was to assure comparison of data with that gathered in previous surveys.

The second data-gathering phase focused on information not gathered in previous surveys.

After each of the phases of data-gathering, an email was sent to the facility for review and either confirmation or modification of the information.

2.2. Information Documentation

The gathered information was entered into two different forms: an Excel spreadsheet containing all information on all 86 facilities, and a single page form for each facility. These data are provided in Appendices A and B.

2.3. Analysis of Information

Data were examined to provide representations and trends by year of start-up, facility type, technology type, location, concentrate management option, and facility size. Results are presented in figures and tables in this report.

2.4. Identification of Challenges of Gathering and Working with Cost Information

A separate project task involved reviewing the challenges associated with obtaining and working with facility cost data. There have been many efforts at gathering data on the desalination facilities' capital expenditures (CAPEX) and operating expenses (OPEX), and the challenges of gathering and presenting meaningful data are considerable. In the present project, we identified and analyzed these challenges to help in future cost-related efforts. Past efforts were identified, reviewed, and individuals involved in a few of the past efforts were interviewed.

3. Results and Discussion – Survey Data

The results are documented in two ways: a master spreadsheet (Appendix A) and a single page summary for each facility (Appendix B). An example of the single page summary is shown in Table 2.

Table 2.—Summary of Data for Emmons County WTP – North Dakota.

GENERAL	Name of facility = Emmons County WTP Facility Owner = South Central Regional Water District Purpose of facility = drinking water Type of technology = reverse osmosis Start year of RO operation = 2012 Reason why UF/RO as opposed to a conventional WTP = best available technology
TREATMENT CAPACITY	RO Design production (mgd) = 1.2 RO Average Production (mgd) = 0.4 Plant Design production (mgd) = 2.0 Plant average production (mgd) = 0.7
TREATMENT PROCESS	Source = Lake Oahe Raw water TDS (mg/l) = 500 Feed pressure (psi) = 120 Pretreatment steps = ozone(oxidation), coagulation/sedimentation, ultrafiltration, antiscalant Target TDS of permeate (mg/l) = 30 Membrane recovery (percent) = 80 Age of membrane at last replacement = 6 yr
BLENDING	Blending = yes Blend water source = bypass (surface water) Blend ratio (permeate : other) = 60 : 40 Target TDS of blend (mg/l) = 250
WASTE MANAGEMENT	Concentrate disposal = discharge to lake Fate of cleaning wastewater = blend with concentrate and discharge to river
POST TREATMENT	Post-treatment of concentrate = none Post-treatment of permeate = blend, ozone, chlorine

3.1. Comparison of Data with Data from Previous Surveys

Survey data from U.S. municipal desalination plants were collected during the last 27 years and divided into four time periods corresponding to specific survey reference periods (Mickley, 2018; Mickley et. al., 2012; Mickley, 2006; and Mickley et. al., 1993):

- 1971 - 1992, covering 22 years
- 1993 - 2002, covering 10 years
- 2003 - 2009, covering 7 years
- 2010 - 2017, covering 8 years

For convenience, the survey periods were used to represent the data; however, to minimize the influence of unequal time periods, much of the data are presented as percentages instead of raw numbers.

Numbers used in tables and figures are not always consistent. Differences result from missing information for one or more plants. However, the missing information does not significantly alter the statistical picture presented. The number of facilities included in the data is estimated to represent more than 90 percent of all US municipal desalination plants; therefore, the developed statistics constitute a strong reflection of industry status, trends, and practices.

Currently, two U.S. facilities use thermal (evaporation/distillation) processes, following an initial reverse osmosis (RO) stage – one to increase recovery and one to reduce concentrate volume. All other processes use only membranes for desalination. The membrane processes used are brackish water RO (BWRO), nanofiltration (NF), seawater RO (SWRO), and electrodialysis reversal (EDR). Most facilities use relatively simple pretreatment schemes involving cartridge filters and addition of antiscalant. Some facilities, however, use microfiltration (MF) and ultrafiltration (UF) as part of the pretreatment process. Nearly all of these facilities are potable water plants treating surface water or are wastewater treatment facilities. NF processes are used both for membrane softening and for removal of specific organics and pathogens.

3.1.1. Plant Numbers, Types, and Capacities

The database generated from the surveys lists plants built, with each new survey adding plants built during the new time period. As such, not all of the plants included in the total numbers and other statistics are currently in operation; some of the older plants (particularly older and smaller plants) have been closed.

Chronologies of the number of U.S. municipal desalination plants and their cumulative capacities (at the time of survey) are shown in Figure 1 and respectively. Total capacity is approximate, due to some smaller, older plants no longer operating and due to capacities reported in different ways, including design capacity, permitted capacity, and average capacity.

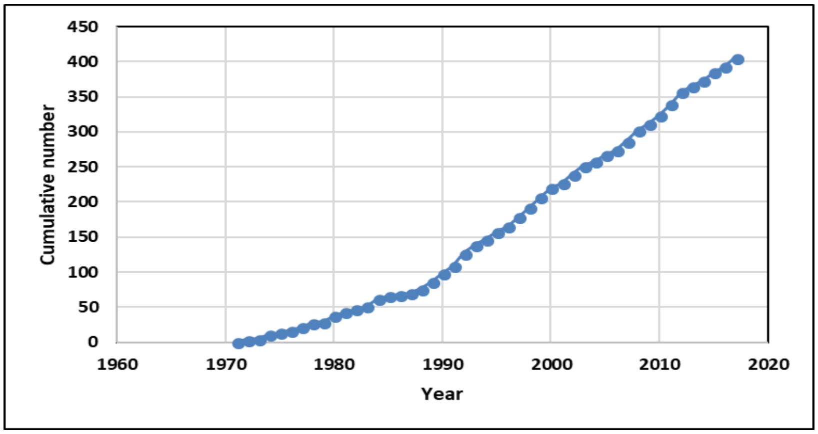

Figure 1.—Cumulative number of U.S., municipal desalination plants.

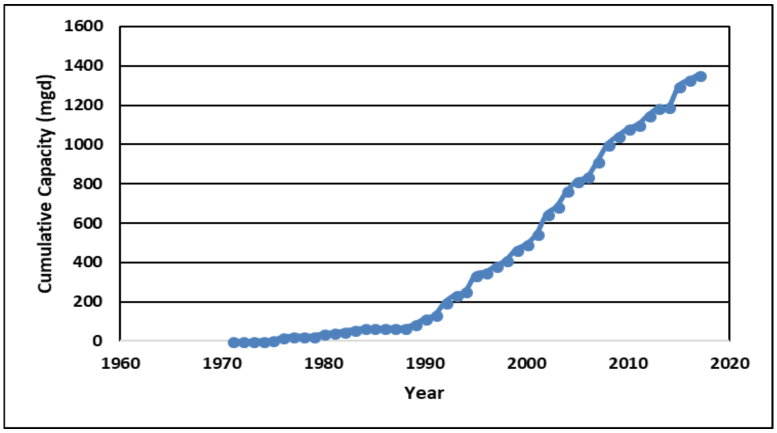

Figure 2.—Cumulative capacity of U.S., municipal desalination plants (in million gallons per day [mgd]).

The figures are based on 406 municipal desalination plants identified from 1971 through 2017 of size 0.025 mgd or greater. The plants are categorized as the following:

- Water treatment plants (WTP) producing potable water
- Wastewater treatment plants (WWTP) producing water for disposal or recycle
- Facilities producing water for aquifer recharge or aquifer storage and recovery (ASR), which may be WWTPs.

A few exceptions occur and include one facility thickening WWTP digester contents for flow into a second digester, and another facility treating urban runoff for reuse purposes.

Potable water plants (379) far outnumber WWTP plants (24), which outnumber recharge/ASR plants (3). Table 3 details the number and percentage of each membrane process used. The number of plants by membrane type and time period are summarized in Figure 3.

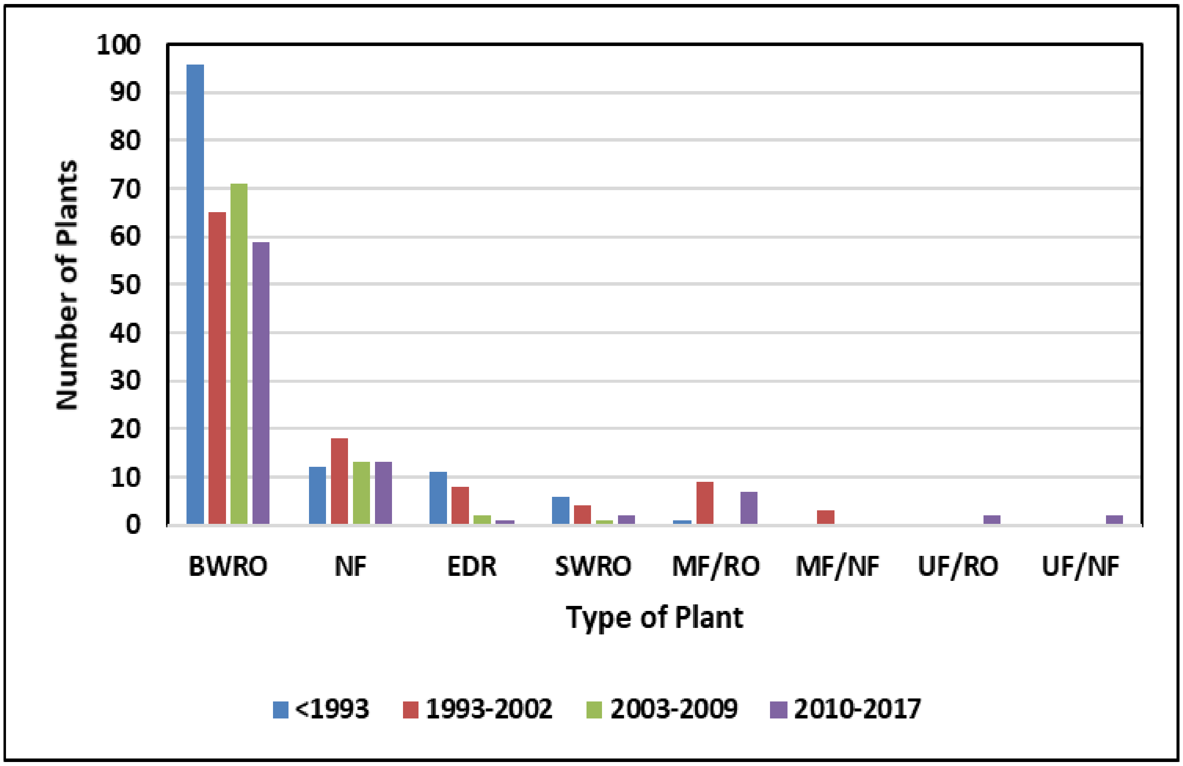

Figure 3.—Number of U.S. municipal desalination plants by membrane type and time period.

Table 3.—Number and Percentage of Different Membrane Processes Used at U.S. Municipal Desalination Sites

Plant Type	Number of Plants	Percent of Total
BWRO	295	72.1
NF	56	13.7
EDR	22	5.4
MF/RO	17	4.1
SWRO	13	3.2
MF/NF	3	0.7
UF/RO	2	0.5
UF/NF	2	0.5

Data in the figures and table illustrate several points:

- The predominance of inland BWRO plants
- The small number of SWRO plants
- The relative decrease in the number of EDR plants over time

As shown in Figure 4, the average number of plants built per year was lower in the most recent time period than in the previous period—likely due to the downturned economy for most of the period.

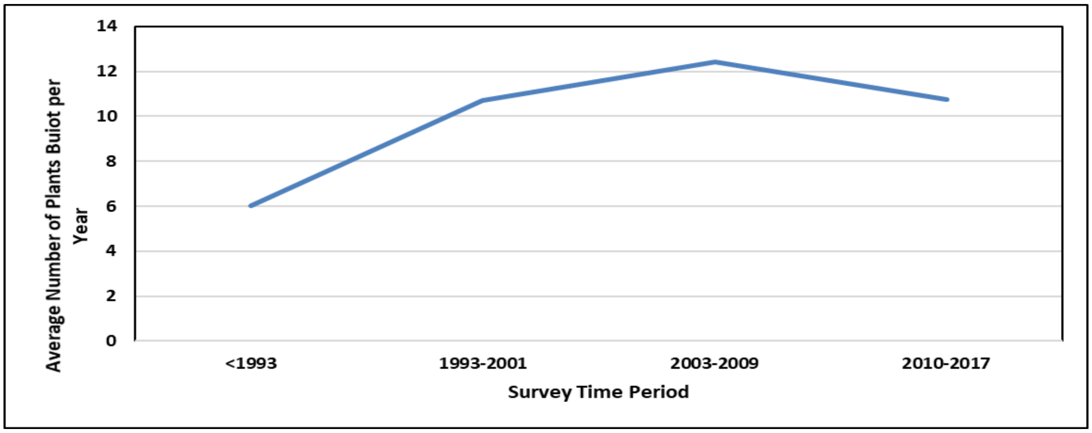

Figure 4.—Average number of plants built per year in time period.

The average plant capacity increased in each of the first three time periods, from approximately 1.6 mgd in 1993 to 3.5 mgd in 2003 and to 5.5 mgd in 2009. In the most recent time period, the average capacity decreased to 3.71 mgd.

Table 4 lists the average plant size by location for the present survey period (2010-2017). The state averages are biased by the larger facilities such as Carlsbad in California and San Antonio in Texas. Of note also is the very small average size of facilities in Texas; most of these facilities are in rural small towns.

Table 4.—Average Plant Size by Location for 2010-2017 Survey

Location	Average capacity (mgd)
All states	3.71
California	7.1 (3.52 without Carlsbad)
Florida	5.57
Other states	2.83
Texas	1.4 (0.99 without San Antonio)

3.1.2. Number of Plants by State

Municipal desalination plants are now in 35 states (up from 26 in 2002 and 32 in 2009). Table 5 shows plant distribution of all facilities built, with 40 percent of the plants located in Florida (down from 45% in 2010), 14 percent in California, and 13 percent in Texas (up from 9% in 2010). Together, Florida, California, and Texas account for 68 percent of US municipal desalination plants. The remaining 32 percent of the plants are spread over 32 other states.

Table 5.—Number of U.S. Municipal Desalination Plants by State.

State	Number of Plants
Florida	**167**
California	**58**
Texas	**52**
North Carolina	18
Iowa	16
Illinois	12
Arizona	10
Colorado	10
Ohio	8
North Dakota	7
South Carolina	6
Virginia	6
Kansas	6
Utah	3
Massachusetts	3
Montana	3
New Jersey	3
Alaska	2

State	Number of Plants
Minnesota	2
Missouri	2
Nebraska	2
Nevada	2
New York	2
Oklahoma	2
Pennsylvania	2
Alabama	1
Georgia	1
Michigan	1
Mississippi	1
South Dakota	1
Tennessee	1
Washington	1
Wisconsin	1
West Virginia	1
Wyoming	1

In the first three surveys, Florida had more facilities built than any other state. In the latest time period, Texas has more. The number of states having facilities has increased with each survey, as shown in Table 6.

Table 6.—Number of States with Facilities by Time Period

Survey period	Number of States with Facilities
< 1993	9
1993-2002	26
2003-2009	32
2010-2017	35

Figure 5 shows the number of plants built in the three major states (Florida, California, Texas) and the other states as a function of the time period. Florida has almost three times as many facilities as any other state and was the most active state in the previous time periods. Since 1993, the percentage of plants built in Florida in a survey period declined from a high in 1993 of 62 percent to the last period level of 24 percent. However, in the most recent time period, Texas had the most facilities of any state, with 24.

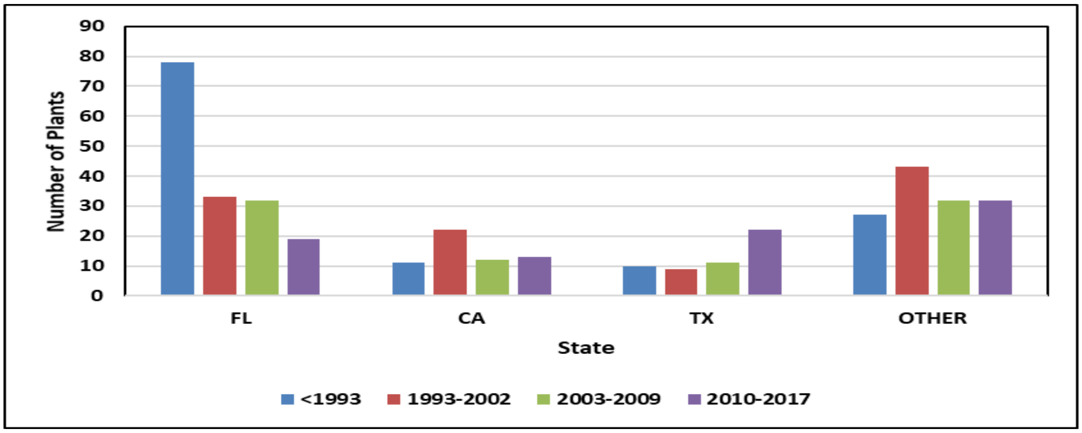

Figure 5.—Number of U.S. municipal desalination plants by state and time period.

Figure 6 shows the average number of plants built per year for the different locations and for the different time periods. Most notable is the steady increase in numbers in Texas.

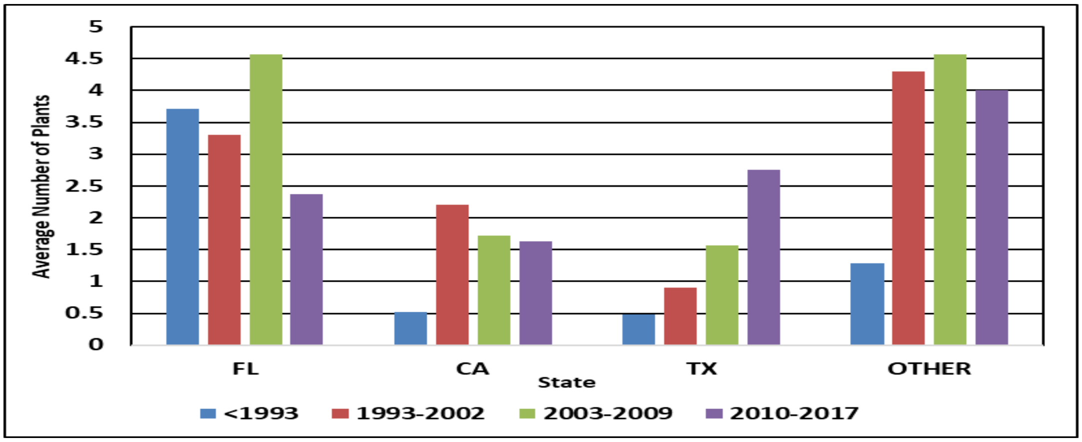

Figure 6.—Average number of plants built per year by state and time period.

3.1.3. Concentrate Management (CM) Options

Table 7 lists the CM options. Despite the more general and more appropriate term "concentrate management," most concentrate is disposed. Five conventional disposal options account for more than 98 percent of municipal desalination sites. Although land application is a beneficial use, in cases in which there is no recapture of drainage water, as with all sites identified, land application is also a disposal option.

Table 7 also lists beneficial use of concentrate as a management option. With the exception of land application; however, beneficial uses rarely have been implemented for municipal desalination concentrate, because, among other factors, most beneficial use options:

- Are not proven
- Are not readily available
- Do not represent a final fate option for concentrate (Mickley, 2006)

Table 7.—Concentrate Management Options

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 sewer	Sewer line Direct line to WWTP Brine line (where brine line goes to WWTP) Trucking concentrate to WWTP
	Subsurface injection	Deep well injection Shallow well (beach well)
	Evaporation pond	Conventional pond Enhanced evaporation ponds/schemes
	Land application	Percolation period/rapid infiltration basin Irrigation
Landfill (for solids)	Dedicated monofill Industrial landfill	
Recycle to front end of WWTP (for low salinity concentrate at WWTP reuse facilities)		
Beneficial use (other than irrigation)		

However, given the growing challenge of finding an environmentally suitable, cost-effective disposal option, it is important to evaluate beneficial-use options for concentrate during a desalination plant's early planning stage.

High-recovery processing facilities (also referred to as minimal liquid discharge [MLD], and zero liquid discharge [ZLD] facilities) have been increasingly considered for municipal desalination. However, such processing involves additional capital and operating (particularly energy) costs that make the processing cost-prohibitive for most municipal settings. To date, there are only two MLD municipal desalination facilities using RO technology and a handful of higher-recovery NF facilities where final concentrate is being considered for beneficial irrigation use (Mickley et. al., 2012).

Unlike many other industries in which MLD and ZLD processing is a frequent—if not standard—consideration, the municipal desalination industry is transitioning toward high-recovery processing, called volume reduction or concentrate minimization. This research considered high-recovery processing, including MLD and ZLD systems, a processing option, not a concentrate management option.

High-recovery concentrate/brine disposal options are the same as the five conventional recovery concentrate disposal options, with one exception: ZLD processing brings into consideration use of landfills (included in Table 7) as a final-fate option for desalination solids.

The recycle option, representing about one percent of surveyed plants, has been used for a few MF/RO and BWRO plants processing low-salinity WWTP effluent. Recycle is toward the front of a WWTP facility.

Of particular note:

- Surface discharge and discharge to a sewer have been used with relatively high frequency in each time period
- Deep well injection use has increased
- Land application, evaporation ponds, and recycle are seldom and decreasingly used options

However, the statistical representations are misleading, because they may suggest that all five conventional concentrate disposal options are:

- Available at any location
- Applicable for every type of concentrate/brine
- Feasible for every volume of concentrate

More specifically, in addition to dependence on survey time period, conventional disposal option use also depends on location, plant size, and concentrate salinity (although this variable was not tracked in the surveys).

3.1.4. Disposal Options by Location and Survey Period

Figure 7 shows the relative use of disposal options considering all 406 facilities built. This figure, however, is highly misleading as disposal practices vary greatly with location.

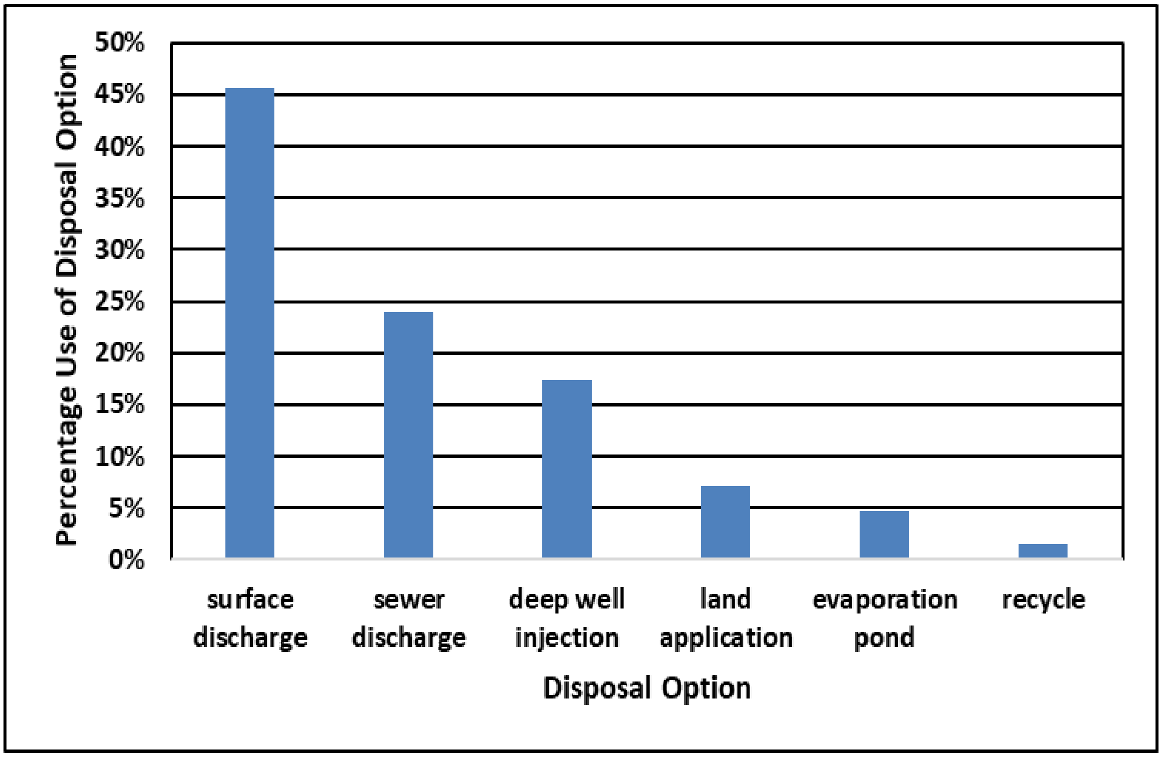

Figure 7.—U.S. municipal desalination concentrate disposal option percentage use.

Figure 8 through Figure 12 show the frequency of the disposal options as a function of location and survey time periods. Figure 13 provides a composite summary of the figures and visually illustrates significant location-specific differences.. A comparison of Figure 8 through Figure 13 shows:

- Each location has a significantly different use pattern:
    - Concerted regulatory/permitting efforts in Florida to reduce surface water discharges in favor of deep well injection Figure 9)
    - Low use of deep well injection in states other than Florida (Figure 10 through Figure 12)
    - Low use of discharge to sewer in Texas (Figure 11)
    - Predominance of discharge to surface water and sewer in states other than Florida, California, and Texas (Figure 12)
- Discharge to sewer is more prevalent in California and states other than Florida and Texas. Of the three featured states, it is used least in Texas.

- Use of land application has increased in Florida primarily due to the reuse of NF concentrate.
- The figures reflect regional differences in climate; hydrogeology; and, in general, availability/suitability of concentrate disposal options.

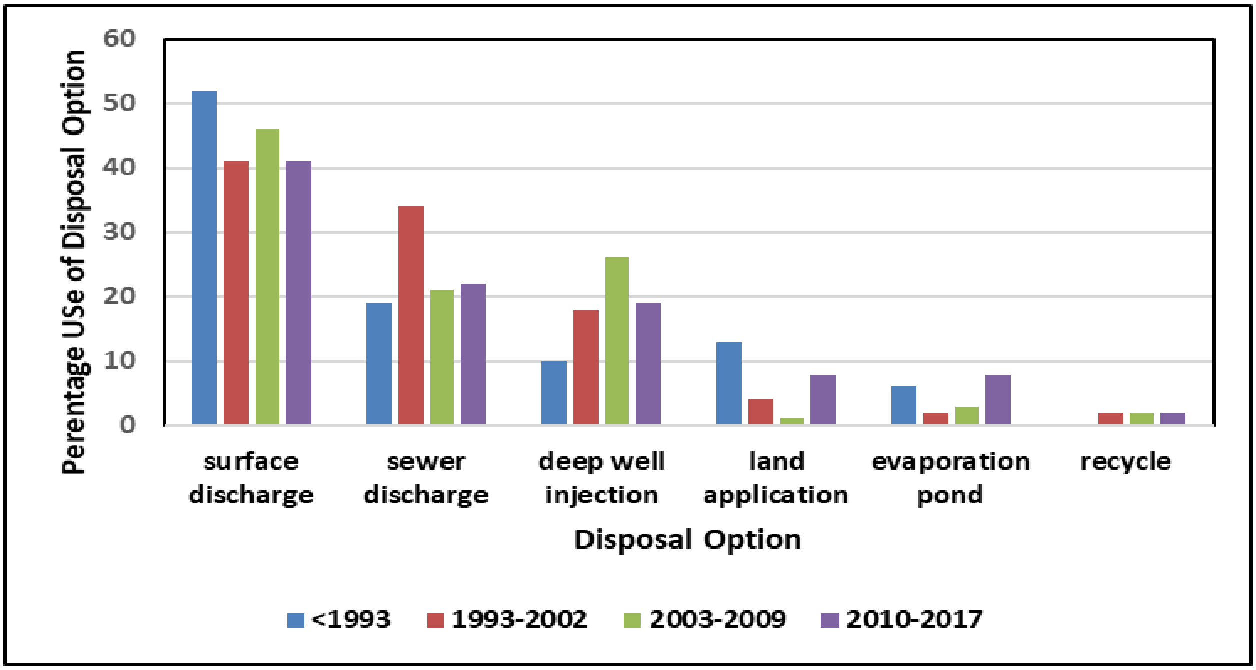

Figure 8.—U.S. municipal desalination concentrate disposal option use by time period.

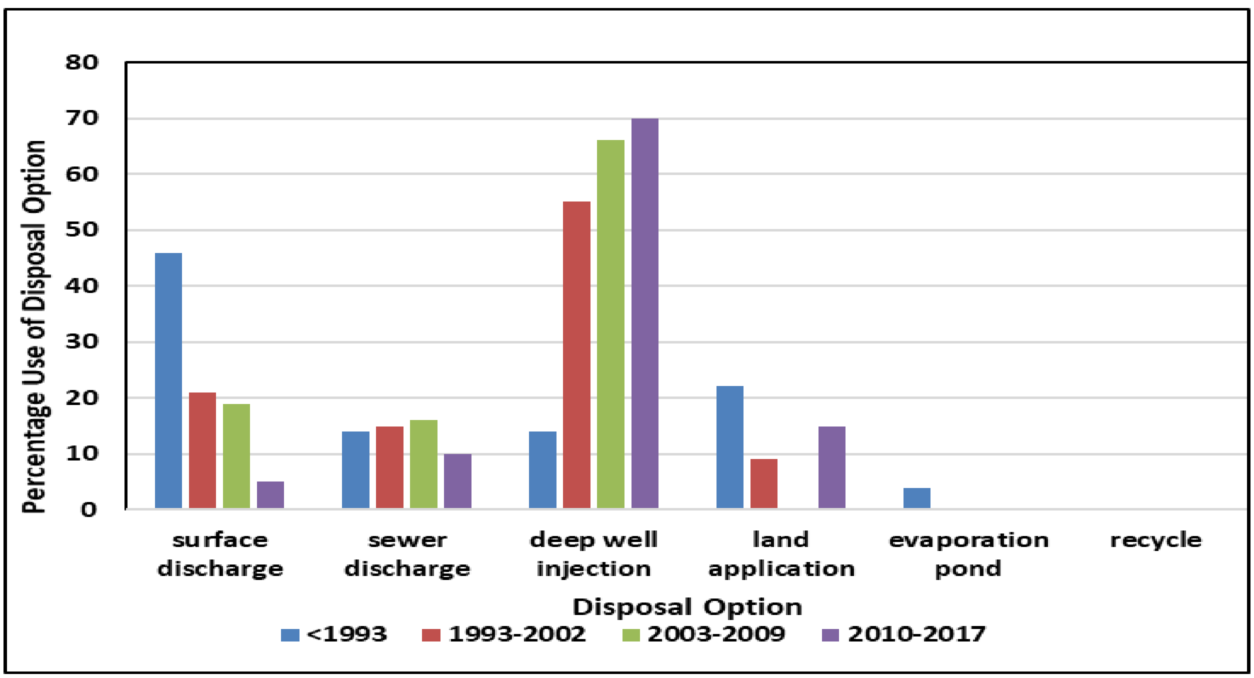

Figure 9.—Florida municipal desalination concentrate disposal option use by time period.

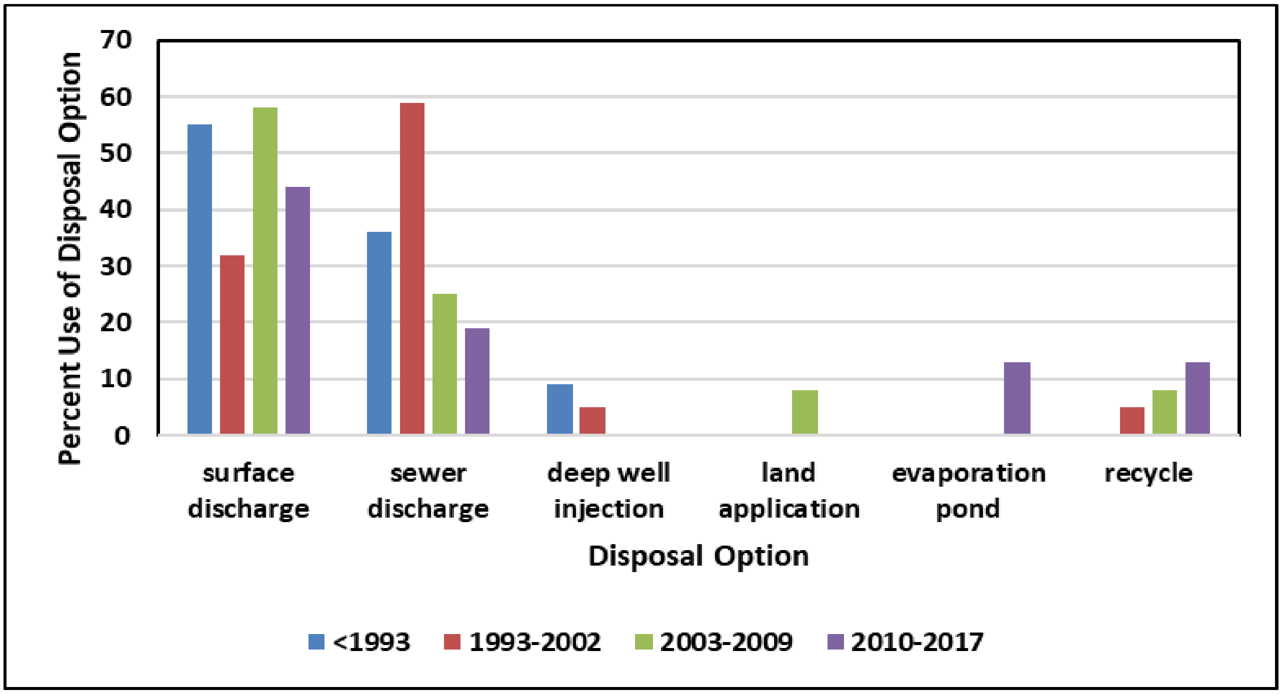

Figure 10.—California municipal desalination concentrate disposal option use by time period.

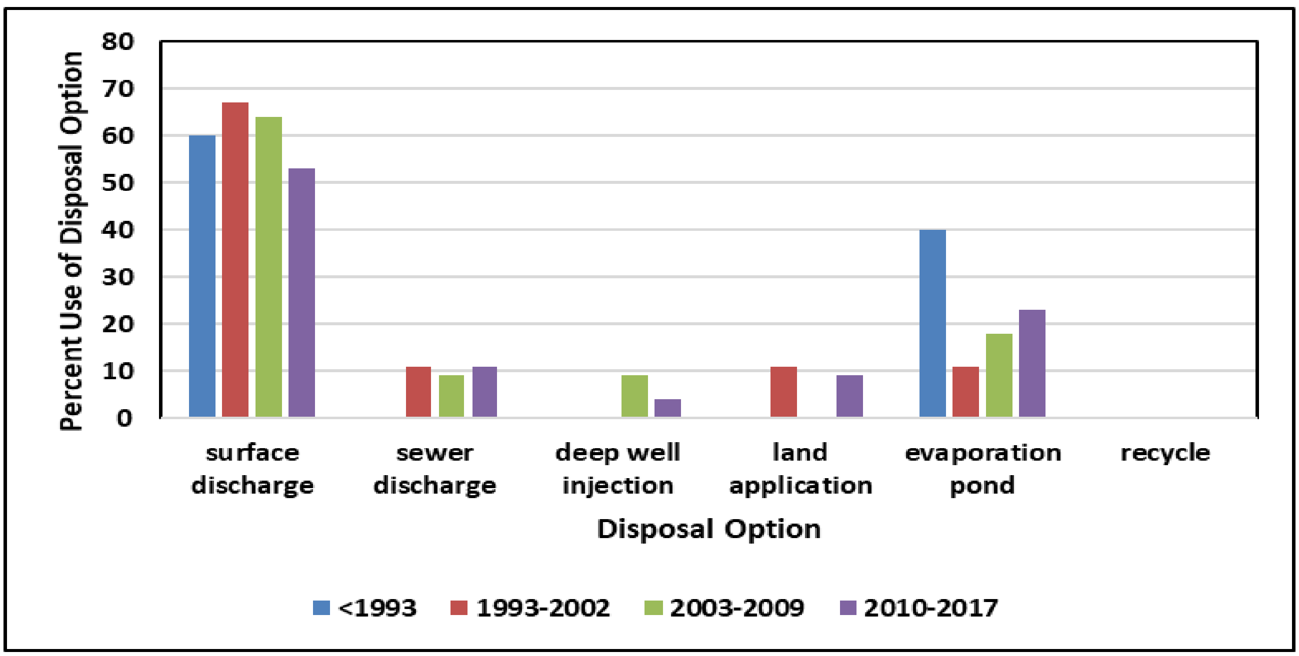

Figure 11.—Texas municipal desalination concentrate disposal option use by time period.

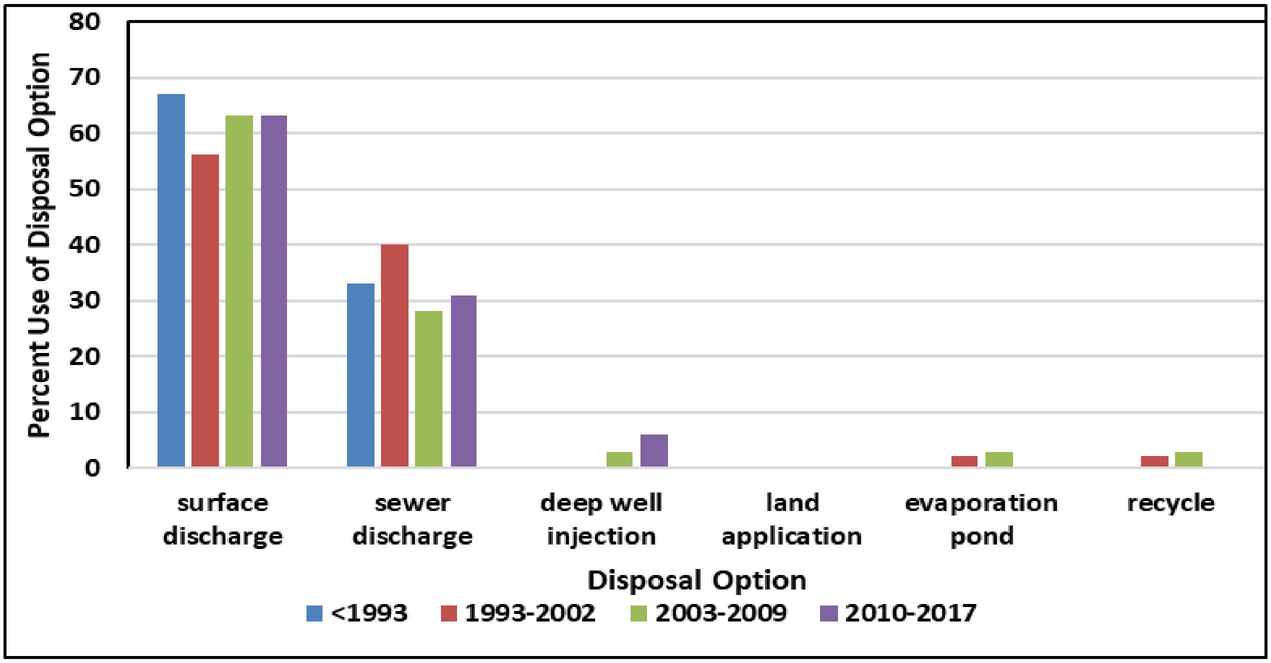

Figure 12.—Other States' municipal desalination concentrate disposal option use by time period.

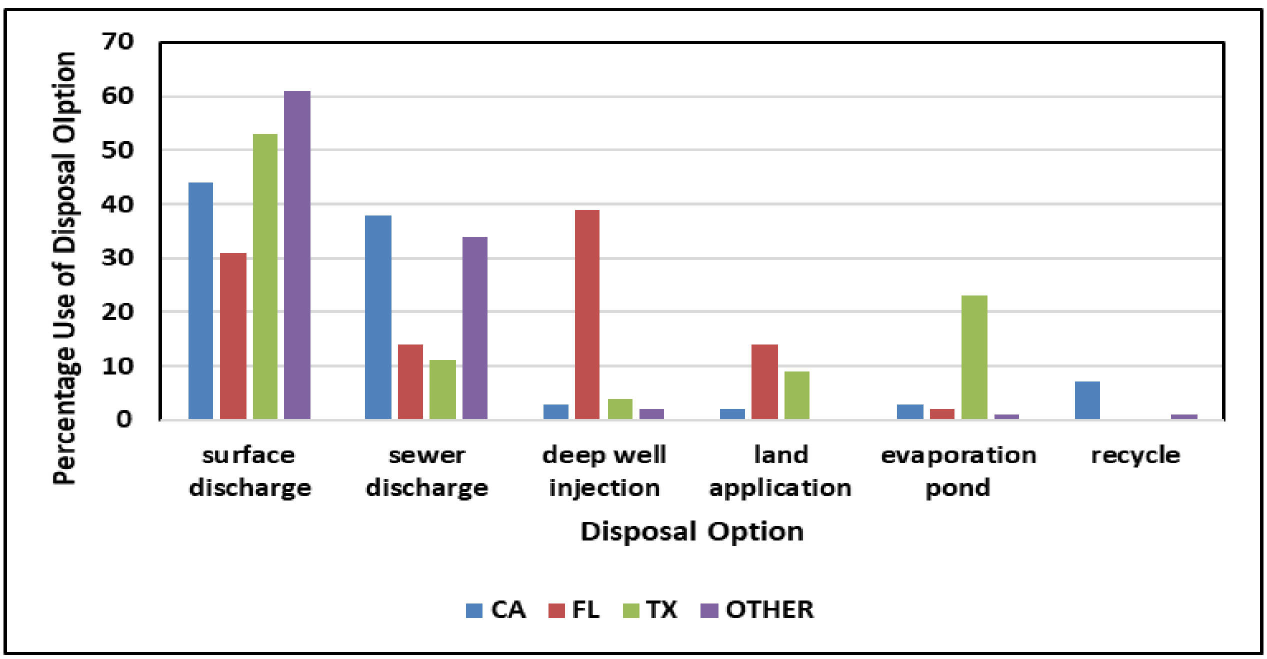

Figure 13.—U.S. municipal desalination concentrate disposal option use by location.

The location-specific nature of disposal options is also illustrated in Table 8 and Table 9. Discharge to surface water or sewer account for 70 percent of the plants nationwide and all plants in 27 of the 35 states with municipal desalination plants. Only five states use deep well injection and 62 sites of 69 of those sites are in Florida. Only four states use land application with 23 sites of the 27 of those sites being in Florida. Evaporation ponds are used in only four states with Texas having 13 of those 21 sites. Florida is the only state using all five disposal options.

Table 8.—Number of States Using the Disposal Options

	Percent use	Number of states
Surface discharge	45	27
Discharge to sewer	25	24
Deep well injection	17	5
Land application	7	4
Evaporation ponds	4	4
Recycle	1	3

Table 9.—States and Number of Facilities in Each State Using Various Disposal Options

	TOTAL	FL	CA	TX	KS	AZ	PA	CO
Deep well injection	70	64	1	2	1	0	0	2
Land application	27	20	1	5	0	1	0	0
Evaporation ponds	21	3	2	13	0	3	0	0
Recycle	6	0	4	0	0	1	1	0

3.1.5. Disposal Options by Plant Size

Disposal options depend somewhat on the membrane process and process application. For example, all U.S. SWRO plants discharge to coastal waters, and most NF plants treat lower salinity WWTP effluent and produce a relatively low-salinity concentrate. This lower salinity concentrate can more readily be discharged to surface waters and a sewer than higher-salinity concentrate from inland BRO or EDR plants. This tendency is reflected in Figure 14.

Figure 15 shows the frequency of use of conventional disposal options as a function of desalination plant size. Size was based on as-built capacity at the time of the survey. Figure 15 illustrates that discharge to surface water has a high level of application regardless of plant size. Discharge to sewer, however, is used less frequently as plant size increases because of the impact of concentrate salinity and volume on WWTP operation. Deep well injection has the opposite pattern because of high costs associated with feasibility determination, regardless of plant size. These costs are less of a burden to larger facilities. Disposal by land application (mainly irrigation) and to evaporation ponds are land intensive and climate dependent. These options have little economy of scale and are used only for small plants.

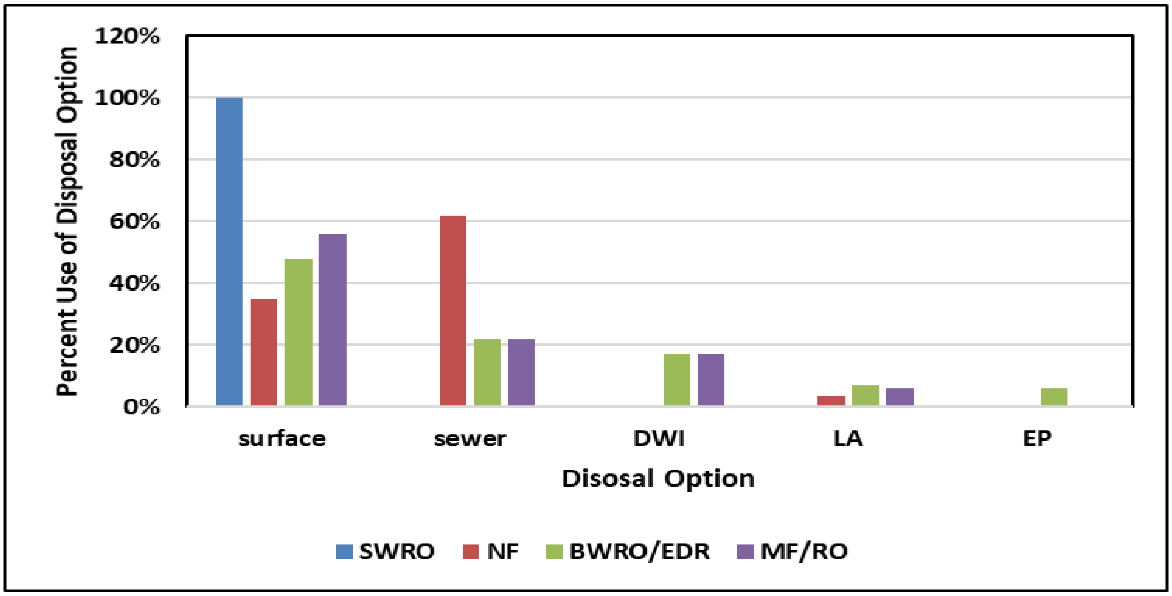

Figure 14.—U.S. municipal desalination concentrate disposal option use by type of membrane process.

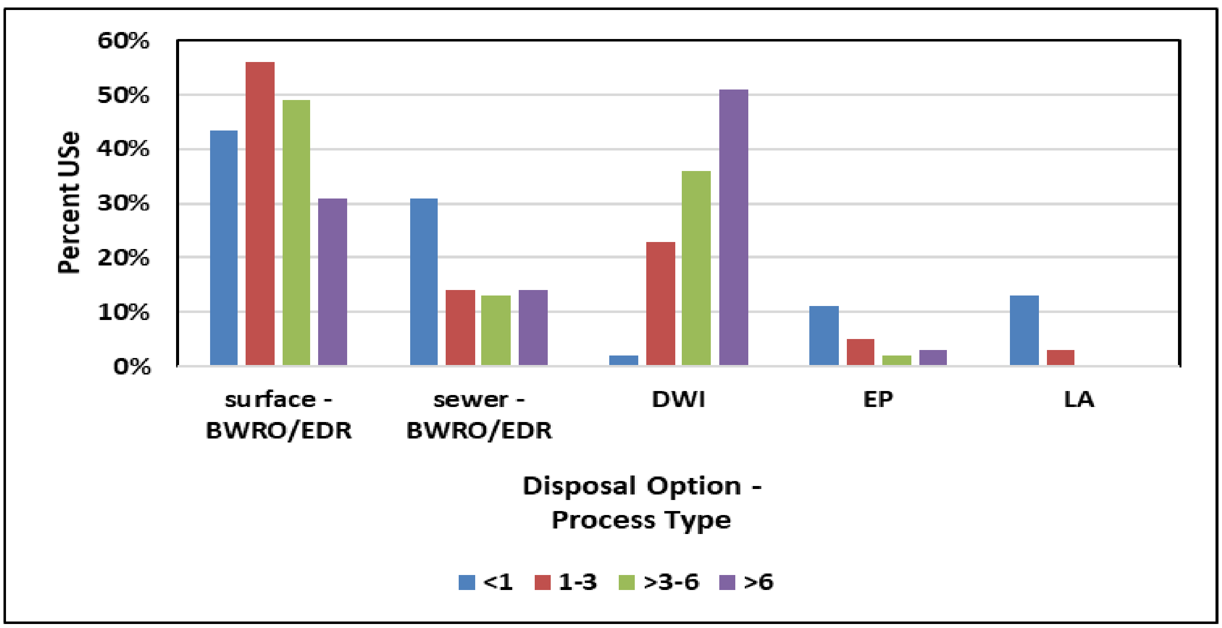

Figure 15.—U.S. municipal desalination concentrate disposal option use by plant size.

Figure 16 shows a significant change in size of facilities over the survey periods. Average plant size increased significantly in the first three survey periods and then decreased significantly in the most recent period.

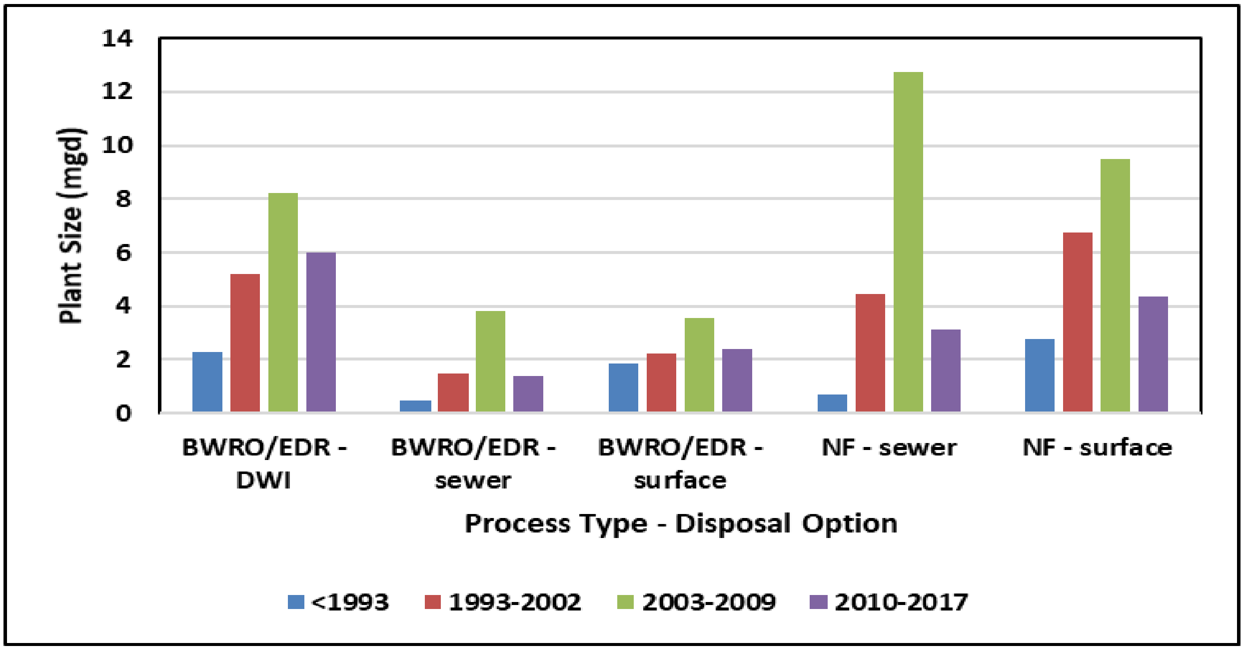

Figure 16.—U.S. municipal desalination plant size by membrane-disposal option and time period.

3.1.6. Summary

The survey found:

- The number of plants being built continues to steadily increase. From 2010 - 2017, 86 plants were built that produce more than 95 m^3/day (25,000 gpd).

- There are 406 U.S. municipal desalination facilities.

- However, the number of plants built per year was less in this latest time period than the previous (2003 - 2009) time period.

- The cumulative capacity of these plants is greater than 1.34 billion gallons per day (bgd), (5,000,000 cubic meters per day [m^3/d])

- Most US municipal desalination plants (97 percent) are inland (e.g., BWRO, NF, and EDR facilities). Only 3% of the facilities treat seawater (SWRO).

- More than 96 percent of the plants are drinking water facilities. 4 percent are reuse or aquifer storage facilities.

- 35 states have municipal desalination facilities.

- Florida accounts for 40 percent of municipal desalination plants.

- Three states (Florida, California, and Texas) account for 68 percent of the municipal desalination plants; the other 32 percent are scattered over 32 other states.

- The percentage of plants being built outside of Florida, California, and Texas has varied with time period:

    - In 2003, only 19 percent of plants were built in other states.

    - From 2003 - 2010, 39 percent of plants were built in other states.

    - From 2010 - 2017, 31% of the facilities were built in other states.

- More than 98 percent of the municipal desalination plants use one of five conventional disposal options.

- Disposal options are a function of plant size, water quality, location, and regulatory policy.

- The pattern of use of concentrate disposal options varies greatly among regions represented by Florida, California, Texas, and the other states.

- Plants in 27 states discharge concentrate only to surface water or to a sewer.

- Of the plants injecting concentrate into subsurface wells, 90 percent are in Florida.

- Use of the other disposal options is very location specific: Only 5 of the 35 states have deep well injection sites; only 4 states use land application, and only 4 states have sites disposing to evaporation ponds.

- The average plant size increased significantly with each survey until this last survey, where there was a significant decrease in average size. The average size decreased in Florida, Texas and other states—including California when the Carlsbad plant is not included.

- The average size of facilities in Texas is much lower than in Florida and California.

3.2. Additional Data Gathered in Present Survey

Other information gathered from the 86 facilities was not gathered in previous surveys and was less complete in terms of the number of facilities providing the information. These results are presented on a number basis. The data presented in this report reflect the nature of and characteristics of U.S. municipal desalination facilities. Data on individual facilities are contained in Appendices A and B.

3.2.1. Treatment of Concentrate

Table 10 lists how concentrate was treated by various facilities.

Table 10.—Various Treatments of Concentrate

Treatment	Number of facilities	Disposal Comment
None	57	
Neutralization	2	1-DWI, 1-sewer
Blend with lime softening wastewater	1	sewer
Filter, antiscalant	1	DWI
Antifoam added	1	Sewer

DWI = deep well injection

3.2.2. Permeate Blending

Facilities using blending totaled 48; those not blending totaled 20. The different sources of blend water are listed in Table 11.

Table 11.—Blend Water Sources

Blend Water Source	Number of facilities
Bypass	33
Lime softened water	4
Surficial aquifer water	2
IX treated water	1
MF permeate	1
NF permeate	1

In most cases, the bypass stream was filtered.

3.2.3. Raw Water TDS or Conductivity

Raw water salinity was given either as mg/l TDS or conductivity (µS/cm). Table 12 lists the ranges of responses along with the number of responses.

Table 12.—Raw Water TDS or Conductivity

Process	TDS range (mg/l)	Number	Conductivity range (µS/cm)	Number
BWRO	< 1,000	8	< 2,000	9
	1,000 – 3,000	12	2,000 – 4,000	3
	>3,000	2	> 4,000	4
NF	<1,000	6		
	1,000 or >1,000	0		
EDR	<1,000	1		

3.2.4. Pretreatment Steps

Various pretreatment steps were identified with several different combinations of steps. The most frequent combinations were acid-antiscalant-cartridge filter and acid-cartridge filters. Table 13 lists the occurrence of various pretreatment steps.

Table 13.—Occurrence of Various Pretreatment Steps

Facility Type:	**BWRO – drinking water**	**NF**
Number of responses:	52	13
Pretreatment Step	Number of facilities	Number of facilities
Antiscalant	43	10
Cartridge filters	42	8
Acid	14	4
Sand filter	6	3
Chlorination/dechlorination	5	1
UF	4	0
Fe/Mn oxidation	4	0
Coagulation	2	0
MF	2	0
GAC	1	0
Degasification	1	0

3.2.5. Feed Pressure

Provided feed pressures (psi) are listed in Table 14 for BWRO and NF facilities.

Table 14.—Feed pressure to RO or NF Drinking Water Facilities

Facility Type:	**BWRO – drinking water**	**NF**
Number of responses:	45	8
Pressure range (psi)	Number of facilities	Number of facilities
< 70	0	3
70-100	5	2
>100-130	7	3
>130-160	13	0
>160	20	0

3.2.6. Source Water

Table 15 lists the source water for RO and NF drinking water facilities.

Table 15.—Source Water

Facility Type:	**BWRO – drinking water**	**NF – drinking water**
Number of responses:	60	11
Ground water	55	11
Surface water	7	0

Two of the RO facilities have both groundwater and surface water sources.

3.2.7. Age of Membranes at Last Replacement

All of the plants surveyed were built in 2010 or later. Not surprisingly, of the 49 responses, 40 of the facilities are on their original membranes. Other responses included:

- One system replaced membranes on the 3rd stage after 18 months
- One system was replaced after 3 years
- One system was replaced after 5 years
- One system had lead membranes replaced after 5 years
- Two systems were replaced after 6 years
- One system was replaced at start-up due to an excessive chlorination incident
- One system was replaced under warranty at start-up due to an unnamed incident
- A design flaw led to early scaling on some membranes; membranes were replaced

3.2.8. Fate of Cleaning Wastewater

Table 16 lists how the cleaning wastewater is disposed along with the corresponding concentrate disposal option used. The number of facility responses was 31. One facility sends membranes off-site to be cleaned.

Table 16.—Fate of Cleaning Wastewater

Cleaning wastewater disposal option	Concentrate disposal option	Number of facilities	Number neutralizing cleaning wastewater before disposal
Sewer	Sewer	5	0
Sewer	Surface	4	3
Sewer	DWI	4	0
Surface	Surface	8	0
DWI	DWI	7	2
EP	EP	1	0
Recycle	EP	1	1
LA	LA	1	0

DWI = deep well injection
EP = evaporation pond
LA = land application

3.2.9. Membrane Recovery

Membrane recovery is highly dependent on the raw water quality and the pretreatment steps prior to the membrane step. The ranges of recovery reports are typical. BWRO recoveries range from 65 to 85%; NF, from 70 to 98%, and the lone EDR example has a recovery of 92%.

3.2.10. Permeate TDS or Conductivity

Permeate salinity from the reported facilities covers a wide range from a low of 15 mg/l to a high of 800. Table 17gives a more detailed description of the reported values that were given in mg/l units.

Table 17.—Permeate TDS

BWRO and NF permeate TDS (mg/L)	Number of facilities
Number of responses	24
<50	11
50-100	7
>100 - 200	2
>200-300	1
>300-500	1
>500	2

3.2.11. Post-Treatment of Permeate

The post-treatment steps listed are not necessarily independent, but care has been taken to interpret the facility responses. While every case involved some form of disinfection and many used pH adjustment, there were many different combinations of post-treatment steps. Table 18 presents the frequency of various post-treatment steps used by the subgroups of BWRO-drinking water, MF/RO, and NF facilities.

Table 18.—Post-treatment of Permeate

Facility type:	BWRO drinking water facilities	NF facilities	MF/RO facilities
Number of responses:	45	9	5
Post-treatment steps	Number of facilities	Number of facilities	Number of facilities
Chlorine	33	5	1
pH adjustment	32	6	3
Anti-corrosion	14	2	0
Fluoride	14	0	0
Chloramination	12	3	0
Degasification	11	3	0
Stabilization	5	2	0
Lime	5	0	0
CO_2	4	1	0
Aeration	4	0	0
Ozone	2	0	0
Air stripping	1	0	0
Bioscrubbing	1	0	0

3.2.12. Source Water for Integrated Membrane Facilities

Integrated (dual type) membrane systems are primarily used to treat surface water and WWTP effluent as shown in Table 19. Facilities involving UF technology first appeared in the 2010-2017 time period.

Table 19.—Feed Water for Integrated Membrane Facilities

	Total	Feed water		
	Number	Surface	WWTP	Groundwater
MF/RO	17	5	11	1
MF/NF	3	3	0	0
UF/RO	2	1	1	0
UF/NF	2	2	0	0
Totals:	24	11	12	1

4. Results and Discussion: Cost Data

4.1. Introduction

There are several challenges associated with obtaining and working with cost data from desalination facilities. Historical CAPEX data from facilities are more difficult to obtain than current descriptive facility and process information, such as gathered in the project survey. One reason is that there are few facility people familiar with cost data and who have access to it. Another reason is the frequent reluctance of facilities to provide cost-related information that might be taken as an indication of how well the facility was planned and is operated. Due to these factors as well as the limited project budget, the survey did not attempt to collect cost data. However, to help future efforts in collecting and working with cost data, we have identified challenges associated with such efforts and recommending an approach to address the challenges.

Available data can vary significantly in terms of the degree of accuracy and corresponding level of detail. There are different cost estimate classifications (Classes 1 through 5) as defined by the American Association of Cost Engineers (AACE), with cost estimate accuracy increasing in moving from Class 5 to Class 1. There are also different facility design levels as a project moves from project conception to final design, with line item detail and the cost estimate accuracy increasing in moving from project conception design to final design. Thus, project cost estimate accuracy nominally corresponds to design level. This is reflected in Figure 17. The most accurate cost data would be based on final design and construction costs. Data at this level of detail, however, are not frequently available. Most publicized cost data about a facility are at the other extreme of detail, such as simply CAPEX and OPEX values, perhaps broken up into a few subcategories.

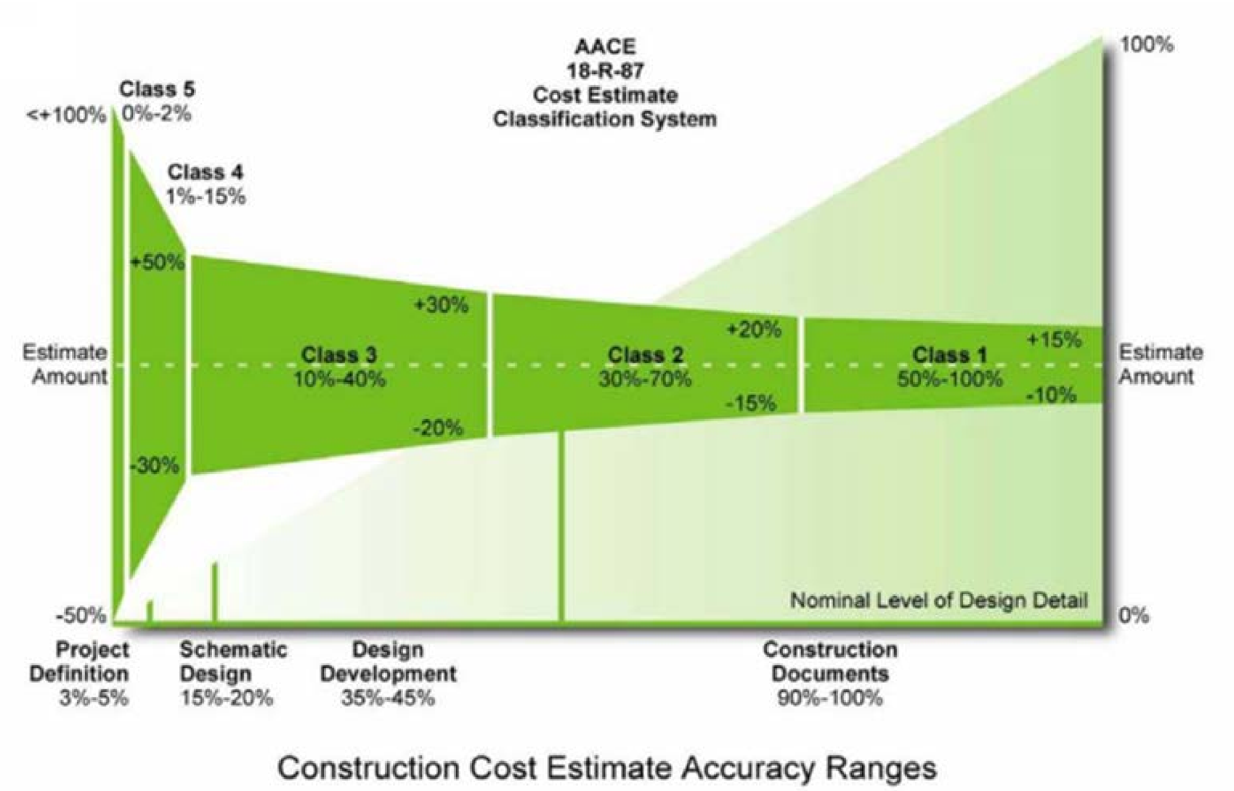

Figure 17.—Construction cost estimate accuracy ranges.

When data are available in more detail, they are usually not in a consistent format, as there is no standard set of line items—at any level of design—for representing CAPEX and OPEX for membrane desalination facilities. Therefore, another variable of cost data is the representation of the data in terms of categories, subcategories, and line items.

As a result, there are significant challenges in collecting cost-related data of sufficient detail and of consistent representation from desalination facilities to allow meaningful comparison of cost-related information between facilities.

There are also many factors that present challenges in comparing costs of different facilities, including several cost factors that can vary widely with time and location including:

- Type of treatment plant
- Characteristics of feedwater
- Size of plant
- Amortization basis (years)

- Cost of borrowing money (% interest)
- Cost of energy ($ per kilowatt hour [kWh])
- Year of data
- Level of performance requirements (more an international factor)
- Level of risk or responsibility taken (more an international factor)
- Subsidies provided by government agencies (not always declared in international facilities)

4.2. Potential Use and Benefits: Standard Representation of Cost Data

An early task focus was on developing an approach to portray or represent cost information on a more consistent basis—an approach that might be used in future, more extensive cost surveys and that could benefit sectors of the municipal desalination industry and other organizations.

Questions of cost are central to the growing worldwide consideration of desalination and it is important to explain and compare desalination costs of recent plants. Evaluation or comparison of costs may involve both comparing costs of different desalination facilities and comparing actual costs with expected or estimated costs. Thus, while the present task has a restricted focus, the need and benefit are related to broader efforts of cost evaluation and cost estimation, and both areas will benefit from standardization of line items and terminology.

In general, a standard format to represent desalination facility costs:

- Creates uniform terminology
- Improves communication and mutual understanding
- Facilitates comparison, identification of patterns and trends
- Facilitates understanding of why a facility’s costs may deviate from typical patterns
- Helps utilities interested in implementing desalination to understand cost drivers.

4.3. Standardized Representation of Cost Data

4.3.1. General Areas of CAPEX and OPEX

This section discusses the broadest framework of representing costs. There is no exacting standard form of representing costs; however, there is general agreement as to major categories.

As an example, a typical framework for representing costs defines implementation costs as construction or starting costs (CAPEX) and O&M costs (OPEX).

CAPEX (construction costs) are further broken down into the categories of direct costs and indirect costs, and bulleted subcategories such as:

Direct costs
- Land
- Production wells or surface water intake structure
- Process equipment
- Auxiliary equipment
- Buildings
- Concentrate disposal

Indirect costs (usually estimated as percentage of the total direct capital cost) such as:
- Freight and insurance (5%)
- Construction overhead (15%)
- Owner's cost (10% of direct materials and labor costs)
- Contingency cost (10%)

Indirect costs may also be represented using different terms but covering the same costs as:
- Project engineering costs
- Project development costs
- Project financing costs

OPEX (O&M costs) are broken down into fixed costs and variable costs such as:

Fixed costs
- Insurance (usually 0.5% of total capital cost)
- Amortization (annual interest payments depend on interest rate and life-time of the plant; typically, in range of 5-10 % of total capital cost

Variable costs
- Chemicals (depends on feedwater quality, degree of pre- and post-treatment, and cleaning process)
- Labor (can be site-specific; depends on ownership – private or public)
- Energy (location-specific)
- Maintenance

Total annual costs are typically represented as amortized CAPEX plus annual OPEX.

4.2.1. More Specific Inclusions under CAPEX and OPEX

The subcategory items listed above under direct and indirect CAPEX and fixed and variable OPEX can vary within this general framework. Other representations of cost line items shown in Table 20 reflect the lack of standardization of terms, different levels of detail, and different division of the parts of a desalination facility.

4.2.2. Suggested Requirements of a Standardized Representation

A standardized format for representing cost data would have a set framework of categories, subcategories, and line items for both CAPEX and OPEX and with this:

- Set names for the categories, subcategories, and line items
- A prescribed level of detail
- Separation of different operation parts of the desalination facility
- Clarity of battery limits of what is covered in each of the operating parts.

Table 21 more directly illustrates different levels of detail in line items; for example, with the level of detail increasing from left to right and following the path of CAPEX >> Direct capital cost >> desalination plant >> pretreatment >> equipment, we have the levels of:

- Level 1 = direct capital cost (subcategory of CAPEX)
- Level 2 = desalination plant (separation into parts of the facility-subcategory of level 1)
- Level 3 = pretreatment (separation into subcategories of level 2)

Ideally, a standardized level of cost representation suitable for comparing costs among facilities and allowing for possible explanation of cost differences would require level 3 detail. Level 2 does not include enough information and level 4 contains too much.

Table 21 also reflects separation of cost categories by physical portions/functions of the plant. Shown here for level 2 description are:

- Source to plant
- Desalination plant
- Plant to residuals fate
- Plant to distribution system

The issue of battery limits can be illustrated by whether or not level 3 water storage and disinfection are included under the level 2 desalination plant category or the distribution system category.

Table 20.—Examples of Cost Representations

Younos	Huehmer et al.	Al-Bazedi et al	Voutchkov (2007)	UCM
Direct capital costs				
land production wells surface water intake structure process equipment auxiliary equipment buildings concentrate disposal	wells intake raw water conveyance pretreatment desalination post-treatment pretreatment residuals management water storage and conveyance brine management	land major process equipment auxiliary process equipment construction	site preparation, roads, parking intake pretreatment RO system equipment post-treatment concentrate disposal waste and solids handling electrical & instrumentation auxiliary and service equipment utilities buildings start up,, commissioning and acceptance testing	(costs incurred in construction) (submitted in a bid) materials labor equipment engineering land acquisition contingencies env./arch/cultural studies interest during construction pump stations pipelines water treatment plants dams and reservoirs off-channel reservoirs water storage tanks well fields relocations water distribution system improvements
Indirect costs				
freight and insurance construction overhead owner's cost design administration commissioning startup legal fees land acquisition	procurement of land obtaining of right-of-ways permitting engineering escalation contractor overhead and profit taxes	freight and insurance construction overhead contingency	project engineering project engineering pilot testing detailed design construction mgt. and oversight project development costs admin, contracting, mgt. environmental permitting project financing costs debt service reserve other contingency	engineering (design, bidding, construction phase services geotechnical, legal, financing, contingencies land and easements environmental - studies and mitigation interest during construction

Table 21.—Example of Levels of Representation of CAPEX Line Items

CAPEX Levels of Description				
1	2	3	4	5
Direct capital cost	source to plant	intake/production wells raw water conveyance		
	desalination plant	land & site preparation pretreatment desalination part	land (acquisition) land preparation (site preparation, roads & parking) major process equipment auxiliary equipment equipment utilities electrical & instrumentation buildings	individual equipment items
	plant to residuals fate	concentrate conveyance concentrate disposal pretreatment residuals		
	plant to and including distribution	post-treatment water storage disinfection distribution system		
Indirect costs	project engineering	project engineering pilot testing detailed design construction mgt. and oversight		
	project development	administrative, contracting, mgt. environmental permitting legal services		
	project financing costs	interest during construction debt service reserve contingency		

4.2.3. Recommendation of a Standardized Cost Framework

Recommendations to compare CAPEX for brackish RO facilities are:

Level of detail of costs:

- Level 3 degree of detail is best suited for representing costs. Level 2 does not contain enough information to allow a means of understanding where costs of different facilities differ. Level 4 contains an unnecessary level of detail for this purpose.

Specific line items for inclusion:

- To be determined in future work for levels 1, 2, and 3.
- Relative to level 2 description, a meaningful comparison of desalination costs will require breaking down direct capital costs into categories such as:
  - Source to plant costs
  - Desalination plant cost
  - Concentrate and residuals disposal costs
  - Distribution system costs
  - Distribution system considerations and costs are usually quite independent of the desalination facility considerations and the recommendation is to not include distribution costs in any cost representation, evaluation, and comparison of desalination facilities.

Development of consensus on battery limits:

- To be determined in future work.

In a future project using such an approach, these recommendations would be re-evaluated based on data gathering of costs and early experience with implementing the recommendations.

One outcome of this exercise is the realization that data of greater detail than the final representation of it are needed to accurately cast the data into the more general categories/subcategories. This has implications on the data availability and collection.

4.4. Brief Review of Cost Collection and Cost Estimation Efforts

While the initial task focus was on an approach to standardize representation of data, the historical efforts of gathering cost data were also reviewed to better define how standardized data might be used.

In 2017, Kevin Price organized a cost workshop sponsored by the Middle East Desalination Research Center (MEDRC) entitled *International Workshop on Desalination Costing: Towards an International Standard.* The workshop was held at MEDRC Headquarters in Muscat, Oman, April 11 - 12, 2017. As part of the workshop, Price presented the history of costing. The entries included:

- 1956 – A Standardized Procedure for Costs of Saline Water Conversion – U.S. Office of Saline Water
- 1967 – Guideline for Uniform Presentation of Desalting Cost Estimates – U.S. Office of Saline Water
- 1972 and 1979 – Desalting Handbook for Planners – U.S. Office of Water Research and Technology
- 1990s – Leitner – IDA Desalting Costs Program, Brackish and Seawater
- 1999 – Water Treatment Estimation Routine – Bureau of Reclamation (Reclamation)
- 1999 – Desalination Economic Evaluation Program (DEEP) International Atomic Energy Agency (now in version 5)
- 2003 – Desalting Handbook for Planners –Reclamation, 3rd ed.
- 2004 – International Desalination Conference on Desalination Costing – MEDRC
- 2004 – Glueckstern – History of Desalination Cost Estimations – International Desalination Conference on Desalination Costing
- 2006 – Reddy and Ghaffour – Overview of the Cost of Desalinated Water and Costing Methodologies – MEDRC
- 2008 WT Cost II – Modeling the Capital and Operating Costs of Thermal Desalination Processes Utilizing a Recently Developed Computer Program that Evaluates Membrane Desalting, Electrodialysis and Ion Exchange Plants –Reclamation.
- 2010s – desaldata.com – GWI

- 2011 – Huehmer – Cost Modeling of Desalination Systems, Perth International Desalination Association (IDA) Conference.

- 2015 – Voutchkov – Cost Estimating of Seawater Reverse Osmosis Desalination Plants, MEDRC training (WTII Cost and DEEP)

At the 2017 MEDRC workshop a presentation was given by Pankratz entitled: *The Total Water Cost of Seawater Desalination*. This presentation included the statement: “There is no global standard for reporting desalinated water costs and a direct comparison is often meaningless. The scope, and all technical and commercial aspects of the projects must be considered.”

Another effort that involved cost estimation of both seawater and brackish desalination facilities was:

- Frenkel, V. 2012. Consideration for the Co-Siting of Desalination Facilities with Municipal and Industrial Facilities: Final Project Report and Decisions Tool. WateReuse Research Foundation.

Many of the above references address seawater facilities with a broad international focus.

The present task is focused on inland brackish reverse osmosis desalination facilities in the U.S., and cost-related efforts with these restrictions include:

- Samer Adham, Manish Kumar, Bill Pearce. 2004. Development of a Model for Brackish and Reclaimed Water Membrane Desalination Costs; Desalination Research and Innovation Partnership (DRIP).

- Montgomery Watson & Harza (MWH) Brackish Ground Water Desalination: Treatment Process Evaluation & Cost Model Development / Guidance Tool. Draft Final Report, 2008 prepared for The City of San Diego.

Both above references refer to the same project.

- Arroyo, J. and S. Shirazi. 2012. Cost of Brackish Groundwater Desalination in Texas. Texas Water Development Board.

- Reclamation. 2014. Estimating the Cost of Brackish Groundwater Desalination in Texas: Final Report Submitted to the Texas Water Development Board.

All above references reflect the interest in estimating and documenting desalination costs and several give insights into the challenges involved.

4.5. General Cost Evaluation Approach

Examination of past cost evaluation efforts suggests a general approach to compare and evaluate costs of different facilities. The DRIP project mentioned above is the primary reference for this approach. This approach is represented in Figure 18. While these are mostly simplifications of this approach that have been used in cost-related studies, the general approach helps to understand the issues and challenges in working with cost data.

Figure 18 illustrates the 5 steps or tasks involved in this evaluation process. The initial step is obtaining cost data. The second step is casting the data into a standardized set of categories, sub-categories, and line items, as previously discussed. Since the age of the data obtained will vary, it is important to normalize the data to reduce the influence of variables—the most obvious one being the time value of costs. There may be other variables to consider for normalization, such as the time and location-specific unit costs of electricity, labor, etc. Normalization of data is the third step. The fourth step is to compare the standardized/normalized costs from different facilities. A typical means of showing this is in a graphical representation of, for instance, unit CAPEX versus treatment capacity of the facility. An example of this is shown in the left-most graph of Figure 19. A final step is to explain the cost differences between facilities.

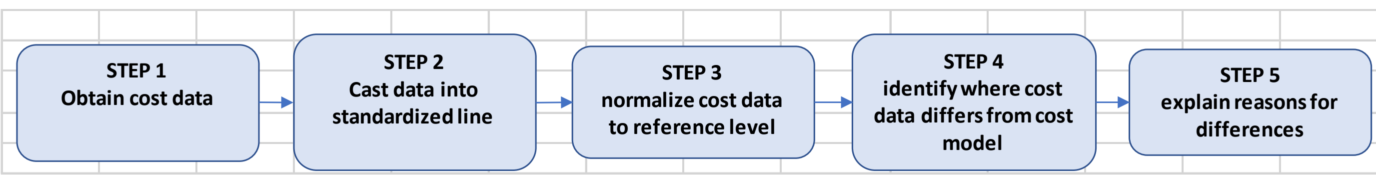

Figure 18.—General cost evaluation approach.

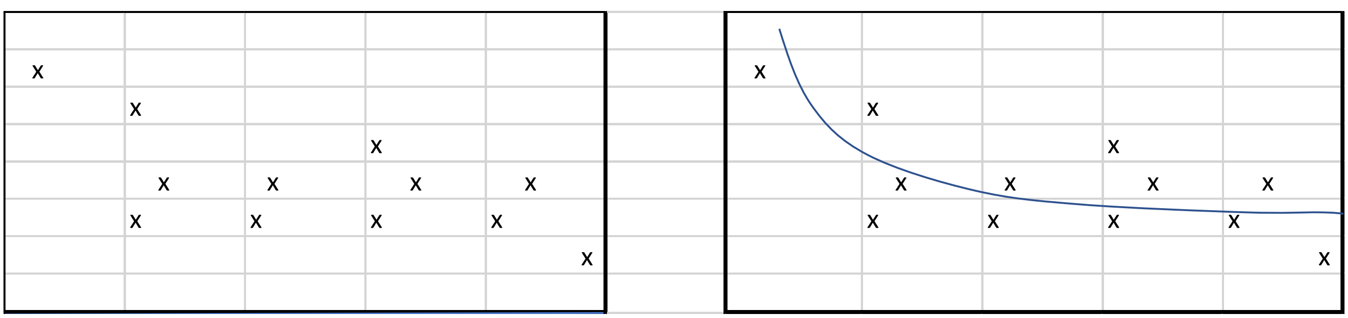

Figure 19.—Example of CAPEX as function of facility capacity

As part of the evaluation process, it is helpful to have some indication of how costs differ from ‘expected’ costs. This is represented in the right-most graph of Figure 19 as a curve representing expected costs developed by cost estimation models or programs.

The evaluation process depicted in Figure 4.2 can also be considered as an approach to developing the ‘expected’ cost curve such as represented in the right-most graph of Figure 19.

Several questions need to be addressed at each of these steps that influence the effort and feasibility of accomplishing the purpose of the step. Some of these questions include:

Step 1: Obtain cost data

- How can the data best be obtained?
- What level of detail of data can be obtained?

Step 2: Cast data into standardized line items

- What should the standardized line items be?
- How easy is it to case data into the standardized line items?

Step 3: Normalize the cost data to a reference level

- What parameters are of importance to normalize?
- What should the values of the reference levels be?

Step 4: Identify where the cost data differ from a cost model of expected costs

- Is a new or existing model required for the task?
- What existing cost models might be considered?

Step 5: Explain why the facility costs differ from the expected costs

- What are the possible reasons for the differences?
- How does the breakdown in cost categories, subcategories, and line items help in identifying the reasons?

The cost evaluation approach depicted is complicated, and the benefit of undertaking such an effort as opposed to a more simplified approach needs to be carefully considered. The approach, however, serves as a context for considering the value of Step 2 – the standardization of cost line items and in discussing efforts at comparing and estimating costs.

4.6. Chapter Conclusions and Recommendations

The challenges of obtaining and using cost data to compare and evaluate costs are considerable. Many facilities and organizations are reluctant to provide detailed cost data and when data are available, they can differ significantly in terms of:

- Accuracy
- Level of detail
- Representation: cost categories, subcategories, and line items

It is difficult to obtain data from different facilities that are consistent in these aspects.

Separate from this, cost data vary due to:

- The type of desalination facility
- The time (year) of cost data
- The location of the facility
- The general state of the economy at the time of bidding
- The feedwater quality and treatment targets

As a result, a meaningful comparison of cost data from different facilities is best served with:

- Data on similar types of facilities
- Data on facilities treating feed water of similar quality
- Data available at a level suitable for resolving into a meaningful standard representation
- Data taken from facilities built during a limited time period

As examples of where some cost data variables can likely be minimized:

- Data from locations where one organization oversees contracting and thus the costs associated with desalination facilities. This is not possible in the U.S., but sometimes exists in other countries. Mekorot, for example, oversees this function in Israel, and there are organizations in a few other countries where a single organization has a similar responsibility.
- Data obtained from a single engineering/construction company where their bid documents for different facilities are of similar format. This somewhat guarantees a standard level of data detail and representation. An example of this situation was the DRIP project referenced above, where the cost data were from MWH projects.
- Data from a certain type of facility and from a limited location area where water quality parameters are similar. Examples of this were the Texas Water Development Boards studies previously mentioned for Texas municipal brackish water facilities.

A cost estimation and comparison project approached along the lines of Figure 18 would be one of considerable effort. It is more feasible in terms of time and effort in situations such as the three just mentioned, where cost data variability can be reduced. This, however, somewhat defeats the goal of determining and explaining variability in costs from a general type of facility over a range of locations.

4.7. Chapter Summary

The project effort at addressing desalination facility costs was limited in scope and the conclusions and recommendations made are tentative. They may provide a starting point for a more a more detailed study or a document for consideration in projects undertaking cost estimation and comparison studies.

5. Project Summary

The survey was the fourth conducted since 1990 on municipal desalination facilities in the 50 U.S. states. Data similar to that of previous surveys were gathered for plants built from 2010 through 2017. The data are presented in a series of figures that allow comparison with data obtained in the previous surveys and together portray 48 years of the history and trends of U.S. municipal desalination.

In addition, the present survey sought data not included in previous surveys, data which provide a more detailed characterization of the 86 facilities identified and built from 2010 through 2017.

Cost data were not gathered due to the challenges of gathering meaningful data. Instead, the challenges associated with gathering and representing cost data were identified and discussed in hope that the findings might aid future cost gathering efforts.

The composite survey data are provided in Appendix A in a series of spreadsheets. The same data are provided in Appendix B in a summary of data for each facility.

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Metric Conversions

Unit	Metric equivalent
1 gallon	3.785 liters
1 gallon per minute	3.785 liters per minute
1 gallon per square foot of membrane area per day	40.74 liters per square meter per day
1 inch	2.54 centimeters
1 million gallons per day	3,785 cubic meters per day
1 pound per square inch	6.895 kilopascals
1 square foot	0.093 square meters
°F (temperature measurement)	(°F–32) × 0.556 = °C
1 °F (temperature change or difference)	0.556 °C
1 kWh (kilowatt per hour)	3.6 megajoule