Review of Concentrate Management Options

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This paper presents a historical look at concentrate management options used across the U.S. The paper reviews background statistics and issues that characterize and frame the challenges of concentrate management. Both National and Texas statistics are provided. Concentrate management options are discussed in terms of their nature, frequency of use, cost, and future applicability. Due to the relatively few number of municipal seawater desalination plants in the U.S. and consequently the limited concentrate disposal experience from such plants, the report information necessarily reflects and focuses on inland desalination plants and inland disposal of concentrate.

National Statistics

In the United States membrane processes have been the technology-of-choice to provide new sources of potable water through treatment of lower quality resources (brackish and saline waters).

At the start of 2003, 431 municipal membrane plants of size 25,000 gpd or greater had been built in the 50 states. This included 234 desalination plants (RO, NF, and ED/EDR) and 197 low-pressure plants (UF and MF) (Mickley, 2004a). Figure 1 illustrates the growing number of plants with time and Figure 2 shows number of different types of desalination plants that had been built. Only 4% of the desalination plants are seawater reverse osmosis plants with only the Tampa Bay plant being larger than 2 MGD in size.

Figures 3 and 4 show the number of plants by state. It can be seen that Texas has the 3rd highest total number of plants (28, with 20 desalination and 8 low-pressure). It has the 3rd highest number of desalination plants and 5th highest number of low-pressure plants.

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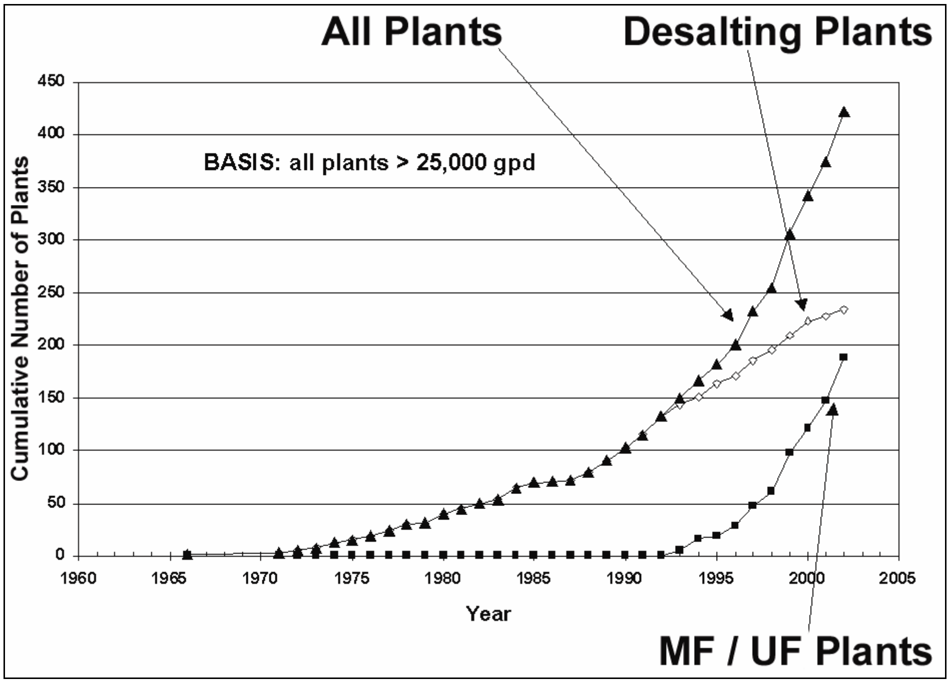

Figure 1-Number of desalting plants

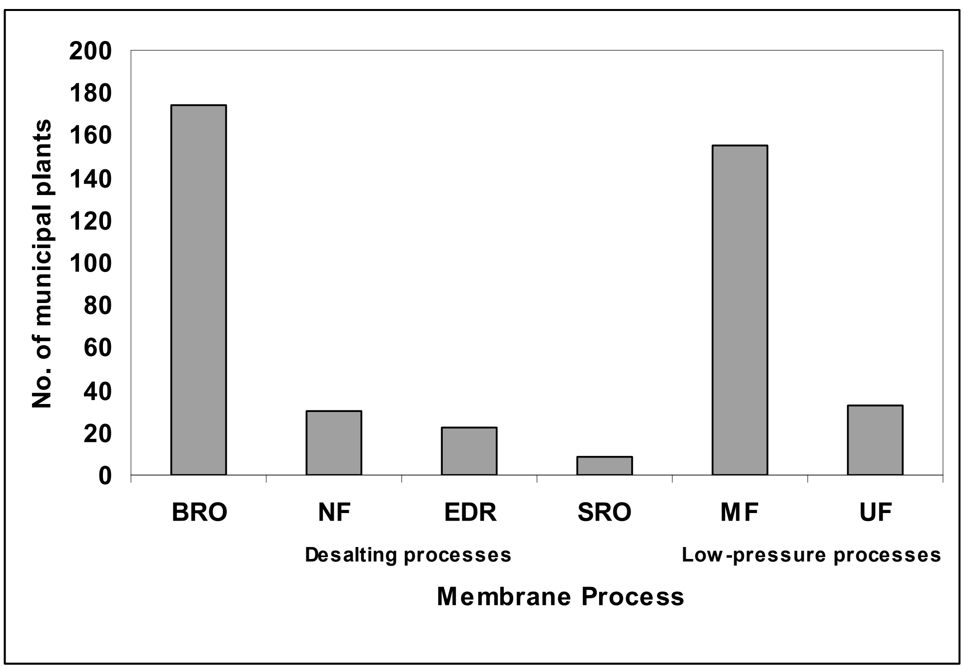

Figure 2-Number of municipal membrane plants of different types >0.025 MGD built prior to 2003 (Mickley, 2004a)

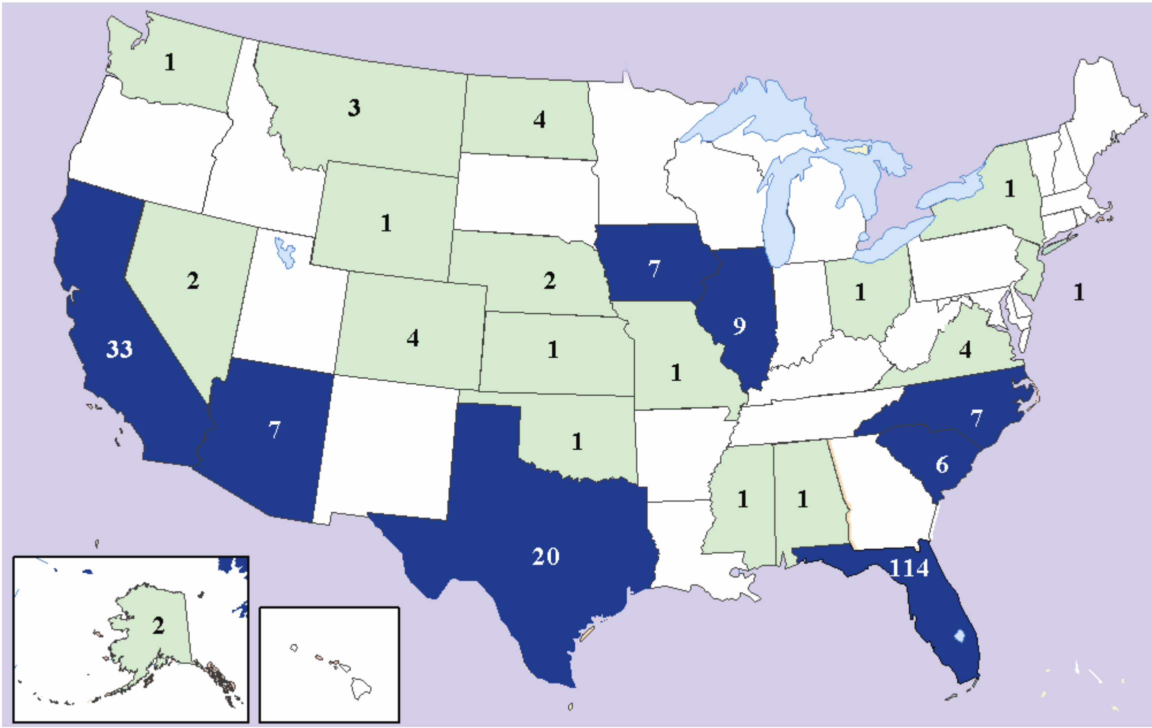

Figure 3-Number of desalting plants by state

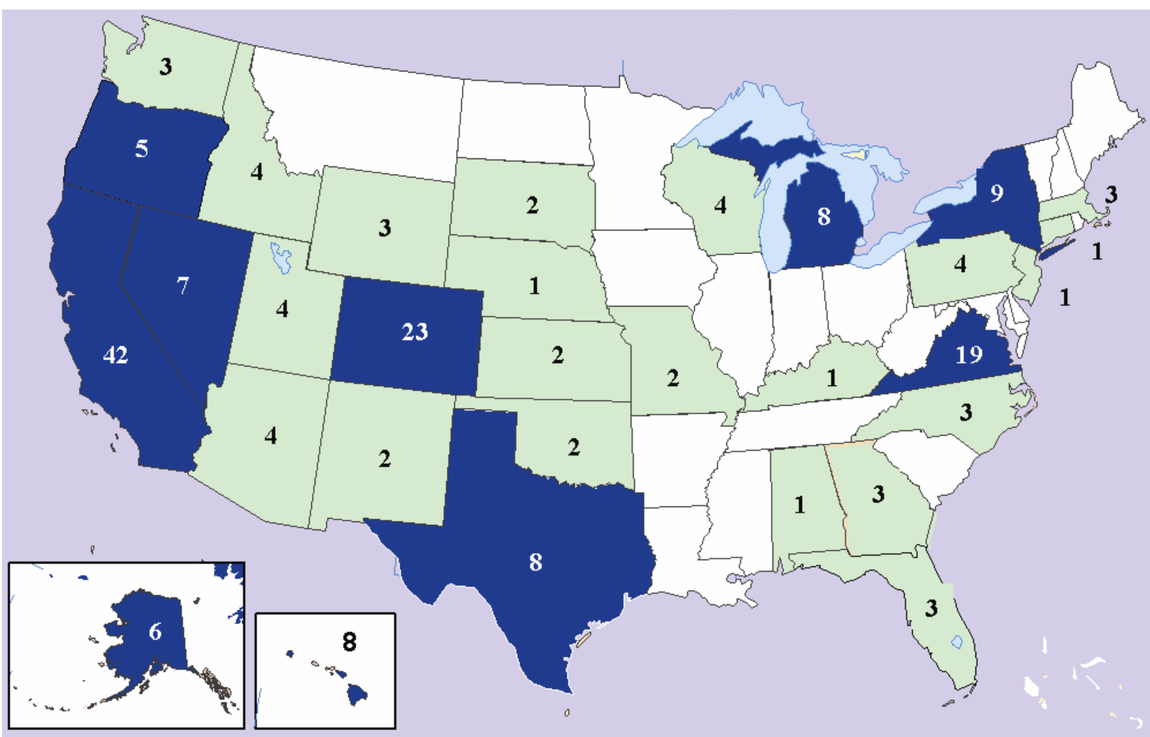

Figure 4-Number of low-pressure plants by state

The growing size of plants (and thus of concentrate volume) with time may be seen in Figure 5. Of the desalination plants built prior to 1993, many were smaller than 0.1 MGD and few greater than 6 MGD. This situation is reversed for plants built between 1993 and 2003.

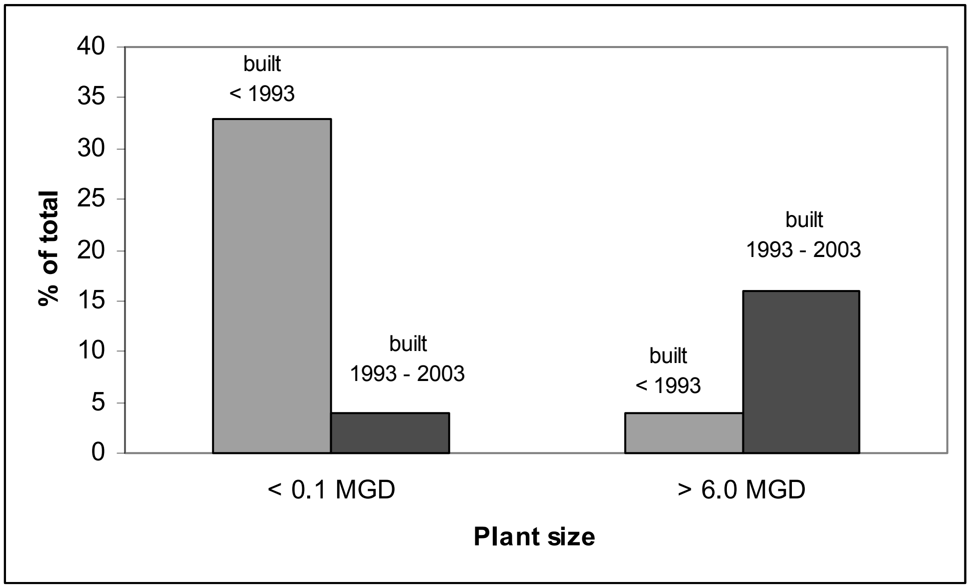

Figure 5 Changes in municipal membrane plant size before and after 1993 (Mickley, 2004a)

Nearly all of the 234 desalination plants have used conventional methods of concentrate disposal. These methods include:

- Disposal to surface water
- Disposal to sewer
- Land application of concentrate
- Disposal to evaporation pond
- Disposal by deep well injection

Figure 6 shows the use of the different disposal methods. Surface water disposal (106 plants or 45%), disposal to sewer (63, 27%), and disposal via deep well (31, 13%) together account for 85% of the disposal situations.

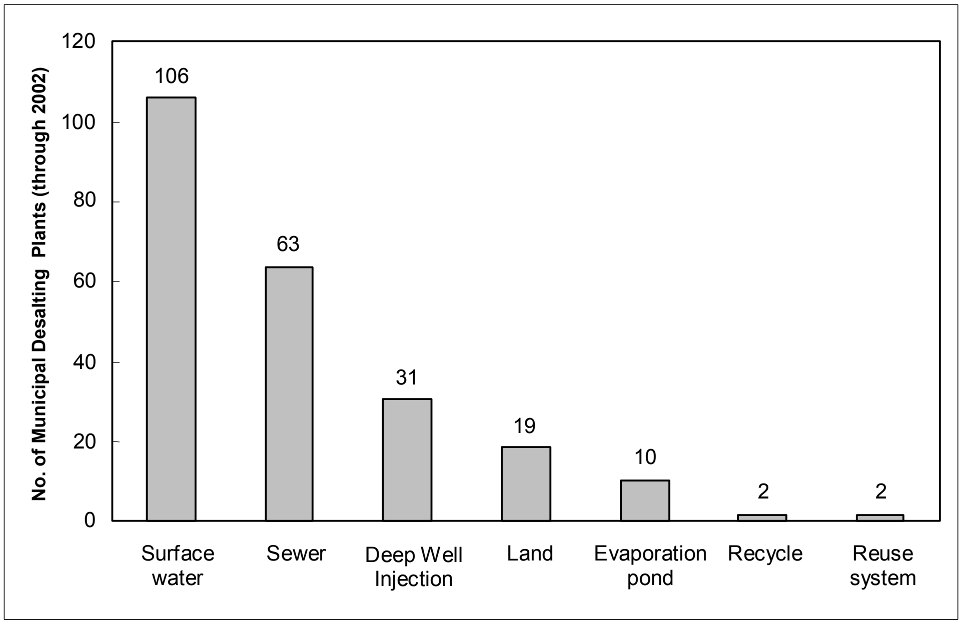

Figure 6 Number of desalting water treatment plants > 0.025 MGD by disposal method (Mickley, 2004a)

Figure 7 shows the use of the conventional disposal options as a function of plant size. Disposal to surface waters is used frequently regardless of plant size. The frequency of disposal to sewer decreases with plant size. The opposite trend is true of disposal to deep well where there are significant economies of scale. Note that disposal to evaporation pond and land is used only for small volume concentrates.

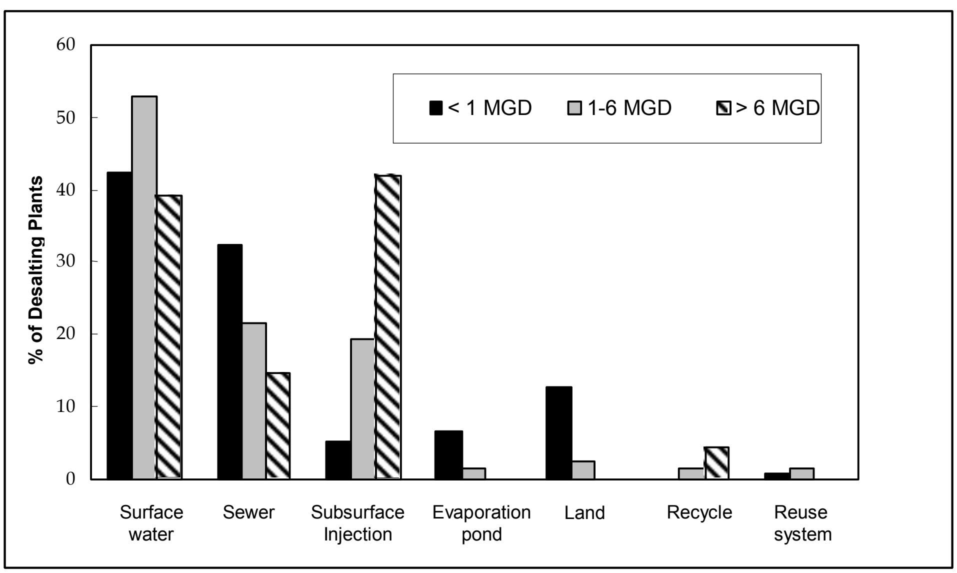

Figure 7 Percentage of desalting plants >0.025 MGD by disposal method and capacity (Mickley, 2004a)

Texas Statistics

The 28 Texas municipal membrane plants operating at the beginning of 2003 include 20 desalination plants (15 BRO and 5 EDR) and 8 low-pressure plants (5 MF and 3 UF). These plants are listed in Table 1 along with some descriptive information.

Table 1-Texas municipal membrane plants of size > 0.025 MGD built before 2003 (Mickley, 2004a)

NAME	LOCATION	MEMBRANE TYPE	PLANT TYPE	PLANT CAPACITY	YEAR START	SOURCE WATER	FEED TDS	REASON FOR TREATMENT	CONCENTRATE DISPOSAL METHOD
Haciendas Del Norte	El Paso	BRO	DW	0.08	1983	Ground	1500	TDS	evaporation pond
Sportsmans World	Strawn	BRO	DW	0.144	1982	Surface	2500	Cl, TDS	surface
Big Bend Motor Inn	Terlingua	BRO	DW	0.05	1989	Ground	2900	Ca, Mg, Na, SO4, TDS	evaporation pond
River Oaks Ranch	Dallas	BRO	DW	0.076	1989	Ground	1500	SO4, TDS	surface
Chemical Waste Management	Port Arthur	BRO	DW	0.066	1989	Other		Hardness, Na, TDS	land
Los Ybanez	Los Ybanez	BRO	DW	0.022	1991	Ground		F, NO3	evaporation pond
Bayside	Bayside	BRO	DW	0.025	1992	Ground		Fe, Na, TDS	surface
Butterfield Water Systems Inc.	Pottsboro	BRO	DW	0.04	1992	Ground		Cl, F, TDS	evaporation pond
Esperanza	Esperanza	BRO	DW	0.0576	1994	Ground	1100	TDS	evaporation pond
City of Robinson WTP	Robinson	BRO	DW	2	1994	Surface	600	TDS	surface
City of Kenedy WTP	Kenedy	BRO	DW	0.72	1995	Ground	1300	Cl, TDS, other	surface
Ft. Stockton	City of Ft. Stockton	BRO	DW	3	1997	Ground	1400	Cl, Tads	surface
Harlingen Waterworks System	Harlingen	BRO	WW	4	1999	Other	1200	water reclamation	surface
City of Seymour - RO Plant	Seymour	BRO	DW	3	2000	Ground	772	Hardness, NO3	surface
Valley MUD #2 R/O Plant	Rancho Viejo	BRO	DW	0.25	2000	Ground	2700	TDS, emergency, demand	surface
Granbury	City of Granbury	EDR	DW	0.62	1984	Surface	1800	Na	surface
Oak Trail Shores	Dallas	EDR	DW	0.144	1985	Surface		TDS	surface
Lake Granbury	Granbury	EDR	DW	7.5	1989	Surface	1200	Cl, SO4, TDS	surface
Sherman	City of Sherman	EDR	DW	6	1993	Surface	1200	THMFP	sewer
Dell City	Dell City	EDR	DW	0.1	1996	Ground	1450	Ca, SO4	land
San Patricio Municipal Water District Plant C	Ingleside	MF	DW	7.8	2000	Surface	301	turbidity, water-demand	surface
Travis County Water District #17 WTP	Travis County	MF	DW	2	2002			biologicals	recycle
Village of Briarcliff	Briarcliff	MF	DW	0.36	2002				
City of San Marcos	San Marcos	MF	DW	1	2002				
City of Abilene	Abilene	MF	DW	8	2002				
Bexar Met. Devel. Corp. Water Production Facility	Von Ormy	UF	DW	9	1999	Surface	350	biologicals	recycle
Georgetown Utility System South Side WTP	Georgetown	UF	DW	3	2000				sewer
City of Del Rio WTP	Del Rio	UF	DW	16	2002				

The sizes of the 20 desalination plants are:

8 plants of size less than 0.1 MGD or less

4 plants of size 0.1 to 0.5 MGD

2 plants of size 0.5 to 1 MGD

6 plans of size 2 to 7.5 MGD (sizes are 2, 3, 3, 4, 6, and 7.5 MGD)

The 20 desalination plants dispose of the concentrate as follows:

12 to surface water	plant sizes range from 0.025 to 7.8 MGD
5 to evaporation pond	plant sizes range from 0.022 to 0.08 MGD
2 to land	plant sizes range from 0.066 to 0.1 MGD
1 to sewer	plant size is 6 MGD

These trends are similar to national trends with disposal to evaporation ponds and land being used only by very small plants.

Concentrate Management Challenges

Management of the concentrate produced by desalination processes has become an increasingly difficult challenge due to several factors that include:

- Growing size of plants which limits disposal options
- Increased number of plants in a region such that the cumulative effect on receiving waters is becoming a limiting factor

- Increased regulation of discharges that makes disposal more difficult and slows the permitting process
- Increased public concern with environmental issues that plays a role in the permitting process
- Increased siting of desalination plants in semi-arid regions where conventional disposal options are limited

As a result of these trends, it is becoming more and more challenging to find a technically, environmentally, and financially viable method of dealing with the concentrate.

The concentrate management challenge is particularly acute in the arid southwest US where frequently disposal to surface water and sewer are not viable options for plants above a small size. As previously mentioned, approximately 72 % of the plants discharge to surface water or to sewer. Another 13 percent discharge to deep well; however nearly all of these plants are in Florida. Thus with the lack of surface water and the growing size of concentrate discharges, the disposal options used by almost 85% of existing plants are not generally available in the arid southwest. While the arid climates may support evaporation ponds evaporation ponds are very expensive except for small volumes. This is reflected in Figure 5, which shows the percentage use of different disposal options with plant size and in the Texas plant statistics.

Another example of increasing disposal challenges involves limiting the continued degradation of waterways caused by discharge of higher salinity effluents. In the Denver, Colorado area, discharge to the South Platte River now requires upstream and downstream modeling / study of the river including the effects of all other dischargers to determine the water quality-based feasibility of discharge. A new discharge may impact discharge limits for existing dischargers and it is a matter of time before new discharges will be severely limited if not prohibited.

The general concentrate disposal situation may be characterized as:

- one of urgent challenges in the arid southwest where there are few, if any, feasible disposal options for large plants
- one of a transition stage in the rest of the U.S. where 10 years ago there were few disposal challenges and 10 year from now there will be many disposal challenges.

This then is the context of concentrate management considerations.

Concentrate Disposal Options and Cost Factors

Cost considerations

While membrane production costs have been decreasing due to less expensive membranes, longer membrane life, energy recovery improvements, etc., the cost of concentrate management has increased. Thus the cost of concentrate management is becoming an increasing percentage of the total plant cost.

Developing costs for concentrate disposal options is somewhat different than developing costs for a treatment process. For most concentrate management options:

- conveyance costs are site-dependent,
- there is less standardization of design (due to more design variables or more design decisions that require making), and

- frequently multiple processing / handling steps may be required.

For the purpose of discussing relative costs, it is assumed that several conditions have been or could be met. These include:

- Each management option is available
- Each management option can be permitted

Also for the purpose of leveling the costs, it is assumed that the costs of conveyance of the concentrate to the site of disposal are the same for each disposal option. This leaves the cost of the particular disposal option as the only issue of question.

Each option is discussed below as to the design factors and cost parameters.

Disposal options and cost factors

The following information is substantially drawn from two papers submitted for publication / presentation (AWWA Membrane Residuals Management Subcommittee, 2004 and Mickley, 2004b)

Surface water discharge. Discharge of desalination concentrate to a surface water body (river, lake, lagoon, canal, ocean, etc.) is the most common management practice, primarily because this method frequently has the lowest cost and most plants are located relatively near surface water. Costs for disposal are typically low provided that pipeline conveyance distances are not excessively long and the concentrate is compatible with the environment of the receiving water body.

The primary environmental concern is compatibility of the concentrate with the receiving water. An assessment of salinity or TDS impact as well as those of specific constituents on the receiving stream is undertaken. Rarely can a higher salinity concentrate be discharged into lower salinity water if the resulting salinity is more that 10% higher than the upstream receiving waters. Some facilities address this by dilution of the concentrate with other water such as other surface water or groundwater, WWTP effluent, cooling water, etc.

Dissolved gases and lack of oxygen can also be concerns for concentrate disposal. Concentrates from the treatment of most groundwater have very low levels of dissolved oxygen (DO). Prior to discharge, DO levels must be increased to avoid negative impacts on receiving stream biota. If the groundwater contains hydrogen sulfide, hydrogen sulfide in the concentrate must be suitably reduced before its discharge to prevent negative effects. ED concentrate typically contains free chlorine, which must be neutralized using a reducing agent such as sodium bisulfite compatible with the receiving stream. As reflected in Figure 7, discharge to surface waters has been used with all sized concentrates.

Surface Water Discharge Costs. The costs for surface water discharge are influenced by a great number of site specific factors and are difficult to generalize. The key factors that determine the costs of concentrate discharge to surface water are:

- Conveyance costs to transport the concentrate from the desalination membrane plant to the surface water discharge outfall;
- Costs for outfall construction and operation;
- Costs associated with the monitoring of the environmental effects of the concentrate discharge on the surface waters.

The costs for the concentrate conveyance are typically closely related to the concentrate volume and the distance between the desalination membrane plant and the discharge outfall. The outfall construction costs are very site specific. In addition to the outfall size and diffuser system configuration, which is driven by the concentrate volume and salinity, these costs are dependent on the outfall length and material, which in turn depends on the site specific surface water body hydrodynamics conditions. The outfall discharge operating costs are closely related to the need to aerate the concentrate before its disposal or to otherwise treat it if it exhibits whole effluent toxicity. These costs also very widely depending on if existing outfall is used or a new outfall has to be constructed. The costs associated with environmental monitoring in the case of surface water discharge may be significant, especially if the discharge is in the vicinity of an impaired water body, environmentally sensitive area or area of limited natural flushing.

Sewer. Sanitary sewer discharge of a small volume of concentrate usually represents a low cost disposal method with limited permitting requirements. The adequacy of sewer capacity and wastewater treatment plant capacity must be addressed. In addition, wastewater effluent quality will change but must still comply with the wastewater treatment plant's discharge permit. If the concentrate salinity and flow levels are significant, impacts of salinity on the biological efficiency of the wastewater plant should be considered. These capacity and/or quality criteria may limit the amount of NF, RO or ED concentrate discharged to the sewer. As shown in Figure 7, discharge to sewer is used more often with smaller and medium sized plants than larger plants due to the effects of larger volume concentrate on the WWTP system.

The WWTP may charge a discharge fee. These are sometimes low, however, the portion of the wastewater treatment plant capacity utilized by the discharge may be considered as a disposal cost. In some situations a one-time 'buy-in' cost has been charged based on this consideration.

Sanitary Sewer Discharge Costs. Sanitary sewer discharge conditions are usually very site-specific and the key cost elements for this disposal method are the cost of conveyance (pump station and pipeline) and fees for connecting to the sanitary sewer, and for treatment/disposal of the concentrate at the wastewater treatment plant. While the conveyance costs are mainly driven by the volume of the concentrate, the sewer connection and treatment fees can vary significantly for a given location from none to several orders of magnitude larger than the conveyance costs. The sewer connection fees usually are related to the available capacity of the sewer facilities and the effect of the concentrate discharge on the operational costs of the wastewater treatment plant, which would provide ultimate treatment and disposal of the concentrate. The connection fees typically depend on the wastewater utility's willingness to take on the volume and the waste stream discharge characteristics such as TDS and heavy metal loads. These fees can be quite large and prohibitive.

Land application. Land application can provide a beneficial reuse of water when membrane concentrates are applied to vegetation, such as irrigation of lawns, parks, or golf courses. Factors associated with land application include the water quality tolerance of target vegetation to salinity, the ability to meet ground water quality standards, the availability and cost of land, percolation rates, and irrigation needs. An assessment of the compatibility with target vegetation is conducted, including assessment of the sodium adsorption ratio (SAR), trace metals uptake, and other vegetative and percolation factors. Regulations governing ground water quality and protection of drinking water aquifers are investigated to confirm the acceptability of this alternative. Usually dilution of the concentrate is required to meet groundwater standards. Where salinity levels are excessive, special salt tolerant species (halophytes) could be considered for irrigation. Land application also includes the use of percolation ponds and rapid infiltration basins. In general, land application is used only for smaller volumes of concentrates. These options are frequently limited by availability of land and/or dilution water. They may also be limited by climate in locations where land application is not possible year around.

Spray Irrigation Costs. Spray irrigation is possible only if the concentrate meets groundwater compatibility limits and a level acceptable for crops/vegetation irrigation. Feasibility depends on the type of the crops/vegetation and on the soil uptake rates. Any blending with a fresh water source to reduce its salinity may increase cost. The key cost factors of this disposal method are the costs of land, the storage and distribution system costs, costs of dilution water, and the irrigation system installation costs, which in turn are driven by the concentrate volume and salinity. As reflected in figure 7, spray irrigation is used for very small systems due to limited economy of scale.

Deep well injection. Regulatory considerations for deep well injection or other subsurface injection alternatives include the transmissivity and TDS of the receiving aquifer and the presence of a structurally isolating and confining layer between the receiving aquifer and any overlying Underground Source of Drinking Water (USDW). A USDW is considered when any water bearing formation contains less than 10,000 mg/L TDS. Deep wells are not feasible in areas subject to earthquakes or where faults are present that can provide a direct hydraulic connection between the receiving aquifer and an overlying potable aquifer. A tubing and packer design is commonly required to allow monitoring of well integrity. One or more small-bore monitoring wells in proximity to the disposal well are also typically required to confirm that vertical movement of fluid has not occurred.

The capital cost for deep well injection is higher than surface water disposal, sewer disposal, and land application in cases where these alternative methods do not require long transmission pipelines. As reflected in Figure 5, disposal to deep wells is usually restricted to larger volume concentrates where economies of scale make the disposal option more affordable. Geologic characteristics are not appropriate for deep well injection in many areas of the United States. A backup means of disposal must be available for use during periodic maintenance and testing of the well.

Deep Well Injection Costs. The key factors that influence deep well injection costs are the well depth and the diameter of well tubing and casing rings. Several other key cost factors are (1) the need for concentrate pretreatment prior to disposal; (2) pump size and pressure which vary depending on the geologic conditions and depth of the injection zone; (3) environmental monitoring well system size and configuration; and (4) site preparation, mobilization and demobilization. Disposal via deep well injection is expensive but does have an economy of scale that makes it more feasible for larger capacity desalination plants.

Evaporation pond. Solar evaporation is a viable alternative in relatively warm, dry climates with high evaporation rates, level terrain, and low land costs. Regulations typically require an impervious lining and monitoring wells, which will increase costs of evaporation ponds. With little economy of scale, evaporation ponds are usually used only for small volume concentrates. While evaporation ponds are typically designed to accommodate concentrate for the projected life of the demineralization facility, precipitation of salts is expected and must be incorporated into the depth requirements of the pond or provisions must be made for periodic removal and disposal or beneficial use of precipitated salts. In addition, the ultimate fate of the concentrated `salts and the future regulatory implications should be considered for any evaporation pond project. Enhanced evaporation systems (Mickley, 2004c) may increase the evaporation rate and thereby reduce the evaporation area required by a factor of two to six.

Evaporation Pond Costs. The costs of evaporation pond systems are mainly driven by the evaporation rate (climate); the concentrate volume; the land and earthwork costs; the liner costs and the salinity of the concentrate, which determines the useful life of the ponds. The main cost variable is the evaporative area and the largest individual cost is frequently the liner cost – particularly where double liners are required. Typically, evaporation rates are lower than soil uptake rates and therefore, disposal of the same volume of concentrate using evaporation ponds requires more land than disposal by spray irrigation. As reflected in Figure 7, construction costs for evaporation ponds have little economy of scale and typically become excessive for all but the smallest plants. The largest municipal plant discharging to evaporation ponds has a capacity of 1.5 MGD and all the others have capacities of less than 0.4 MGD.

Zero Liquid Discharge. Zero liquid discharge systems such as thermal evaporators, crystallizers and spray dryers are available to reduce concentrate to a solid product for landfill disposal. However, the cost for these thermal systems is typically much higher than the cost for the desalination membrane facility, both from a capital and operating (energy) perspective, making this disposal option infeasible except for very small concentrate flows. In certain situations instead of processing concentrate to solids (via a crystallizer or spray dryer) the highly concentrated brine from the brine concentrator may be sent to evaporation ponds. This typically results in a lower cost option than processing concentrate to solids. Use of high recovery RO systems in front of the thermal evaporators can reduce costs for waters of limited hardness. The selective and sequential removal of salts followed by their use may offer promise to reduce zero liquid discharge costs (Mickley, 2004c). Reducing the cost of zero liquid discharge systems is one of the major goals of the National Desalination Roadmap (U.S Bureau of Reclamation and Sandia National Laboratories. 2003).

Zero Liquid Discharge Costs. Achieving zero liquid discharge with brine concentrators or other methods is usually the least cost effective concentrate disposal method, because it requires the use of costly mechanical equipment for evaporation, crystallization and concentration (dewatering) of the salts in the concentrate. Energy costs associated with the evaporation processing are significant. Although this method has found practical application in industrial water reuse facilities, according to the year 2002 survey of the US Bureau of Reclamation (Mickley, 2004a) it has not yet been used for disposal of concentrate from a RO or NF plant.

Others. Other concentrate management and disposal alternatives such as blending with WWTP effluent or blending with power plant cooling water may facilitate concentrate dilution and disposal and may be used in combination with disposal methods previously mentioned. Permitting requirements for blending of concentrate with treated wastewater effluent are dependent upon the fate of the combined stream. Blending concentrate with cooling water from power plants using seawater for once through cooling will reduce concentrations of the discharge and facilitate permitting. Compliance with standard surface water discharge regulations must still be satisfied.

Use of concentrate for dust suppression, roadbed stabilization, soil remediation, etc. has been used occasionally for small volume concentrates. This use (reuse) of concentrate will decrease where environmental testing is required. Concentrate is site-specific in nature and cannot receive a blanket or general approval for such an application. Each plant's concentrate will need to be tested. These applications are further limited by the large amount of road / roadbed surface required for a given amount of concentrate. In addition, due to the cost of transporting water, reuse options need be relatively local. Use of concentrate in wetlands is receiving some research attention as is the evaluation of using desalting membrane concentrates as a feed stock for sodium hypochlorite generation and for solar energy ponds to recovery energy by heat generation.

Figure 8 depicts the relative capital costs of the different concentrate management options and reflects economy of scale factors as well as general (relative) level of cost. More detailed design and cost guidelines are presented in Mickley, 2004a.

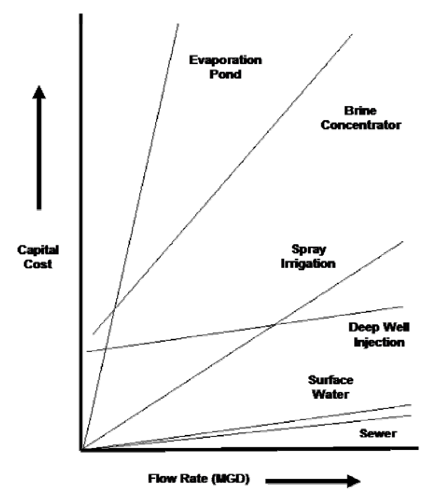

Figure 8-Relative Capital Cost of Concentrate Management Options

New Directions – Increasing Recovery and More Efficient ZLD

A growing issue but one that is still in its infancy is that of moving towards sustainable technologies. While this is not possible in many situations, it is a desirable and ultimately necessary direction. Disposal of concentrate to surface water and groundwater typically results in salt load buildup. In such situations, eventually, the salt load buildup can reach a level that will limit additional discharges.

In areas of limited water resources there is a growing trend of placing a cost on lost water / resources such as concentrate. While the concept is not well defined for assigning costs to concentrate disposed by various options, the author has been asked in several instances to assign a cost to concentrate ranging from $2,500 to $15,000 per AF, an amount generally corresponding to the cost of buying water rights. This viewpoint places increased value on considering higher recovery processing.

The consideration of alternative or new concentrate disposal options thus is driven by several factors:

- Growing challenges / difficulty of disposing concentrate
    - growing number and size of membrane plants and resultant concentrate volume
    - Increasing regulatory pressures
    - growing public awareness and concern of environmental issues
- Ultimate goal / drive towards sustainable technologies
- Increased valuing of 'lost water'

One direction of consideration is for new uses for or reuse of concentrate. This is a worthy consideration that may help a limited number of sites. In general, uses are local and with concentrate having a site-specific nature, any general use or reuse of concentrate needs to take this variability into account.

Another direction of consideration is that of further treatment of concentrate to facilitate disposal, use, or reuse. This direction includes reducing the volume of concentrate and in the extreme leads to zero liquid discharge (ZLD) processes. This area has received some recent attention (Mickley, 2004c) and a recently initiated project (Mickley, 2004d) is focused on ZLD and volume minimization.

Increasing recovery reduces concentrate volume and increases its salinity. This does not help for disposal methods where the concentrate eventually communicates with a receiving water whether a surface water (via surface water disposal or most cases of disposal to sewer) or groundwater (via land applications). It typically makes the concentrate less compatible (in terms of salinity) with the receiving water. Increasing recovery may help other disposal options such as evaporation ponds (now a smaller volume to evaporate), deep well injection (disposal of a smaller volume), and zero liquid discharge (smaller volume going to high cost thermal evaporative systems).

Unless disposal options of evaporation ponds or deep well injection are available there is usually little gained by minimizing the volume of concentrate unless it is minimized as part of a ZLD processing scheme.

Conventional zero liquid discharge technologies are very energy intensive, which results in high annualized costs. These costs can be offset somewhat by increasing membrane system recovery prior to these thermal evaporative systems.

The various means of increasing membrane system recovery are mostly variants of extensive pretreatment of the feed to a two-stage membrane system or interstage treatment prior to the second membrane stage. Such increased treatment has its cost and for situations of high hardness waters such treatment can result in high chemical costs and high solids disposal cost which offset the lower energy cost resulting from the smaller brine concentrator size.

As a result of the above and other studies, the Bureau of Reclamation project (Mickley, 2004b) began looking at the selective removal of individual salts from concentrate. Based on salt solubility and the ionic makeup of a concentrate, a general sequence of salt precipitation may be inferred. During the course of investigating the possibility and issues of selective salt recovery the author became aware of an Australian company, Geo-Processors Pty Limited, which commercially recovers salts from virtually any effluent including membrane concentrates and seawater (www.geo-processors.com.au). Subsequent communication with Geo-Processors provided information from which to conduct a preliminary evaluation of their technology and its applicability to treatment of membrane concentrate. Examples of commercial and pilot projects provided by Geo-Processors showed a variety of applications with some having a net operating income due to the sale of salts produced. Recently, Geo-Processors has formed a U.S. based company, Geo-Processors U.S.A., Inc. One of the stated goals of the Desalination Roadmap (AWWA Membrane Residuals Management Subcommittee. 2004) is to decrease ZLD costs. The use of selective salt recovery may provide such lower cost scenarios for various sites.

Summary

The challenges of concentrate management are increasing. It is becoming more and more difficult to find a technically, economically, and environmentally suitable concentrate disposal option. Further, concentrate disposal costs are increasing and becoming a greater percentage of the total plant cost. This paper reviewed the framework of concentrate disposal in the U.S. and discussed emerging trends, challenges, and new directions. Research, education, new technologies, and process development will be important in addressing these challenges.

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