Issue Paper 1

U.S. Inland Municipal Membrane Desalination: Background and General Barriers

1.1 Introduction

Access to fresh water resources is becoming an increasingly critical issue in the arid West and many other portions of the United States. Over the past several decades, a tremendous growth in population and industry has increased the demand for water in this region (Hightower, Undated). In addition, many surface and groundwater supplies in the arid West have been tapped to their maximum, or perhaps even tapped at levels now recognized as unsustainable. Accordingly, many communities find themselves facing limits on their abilities to extract additional waters from the array of supply options that have been available to them in the past.

Water scarcity in this region will be further impacted by climate change, which has a likely potential for increasing water demands for municipal water as well as competing water use sectors (e.g., agriculture, energy production). Hotter temperatures, especially in summer, coupled with projected changes in seasonal precipitation patterns (e.g., drier summers), are expected to *increase water demands related to outdoor use.*

To meet these challenges, communities will need to better balance water demands with available water resources in a sustainable manner. In addition to conservation and water reuse, desalination (desal) of brackish groundwater resources is becoming an increasingly important option for increasing water supplies. In the arid West (and many other areas), desal is a logical candidate because it is based on proven technologies, is used extensively around the world, has capital costs that are decreasing, and is becoming more competitive with other new water supply alternatives. In addition, desal provides communities enhanced reliability as a drought-resistant supply, which is a benefit that does not accrue under most other water supply options (e.g., drawing from surface water sources).

As shown in Figure 1.1, much of the United States, including much of the arid West, contains extensive brackish groundwater resources (Krieger et al., 1957). Since much of this supply underlies more easily-accessible and higher-quality fresh water resources, it has remained primarily untapped (Hightower, Undated). The U.S. Geological Survey (USGS) reports that in 2005, only 4% of total groundwater withdrawals in the United States were saline [saline groundwater suitable for desal is generally defined as groundwater with total dissolved solids (TDS) levels between 1,000 and 10,000 mg/L]. This amounts to 3020 million gallons per day (mgd) of the 82,620 mgd total of groundwater withdrawals. However, as freshwater supplies become more limited, desal of these brackish water resources will become more common.[1]

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[1] It also is feasible to desalinate groundwaters with TDS concentrations considerably greater than 10,000 mg/L, as evident from the widespread global desal of seawaters with TDS levels exceeding 30,000 mg/L. This suggests that the potentially available quantity of usable saline groundwater could be much greater than indicated by USGS.

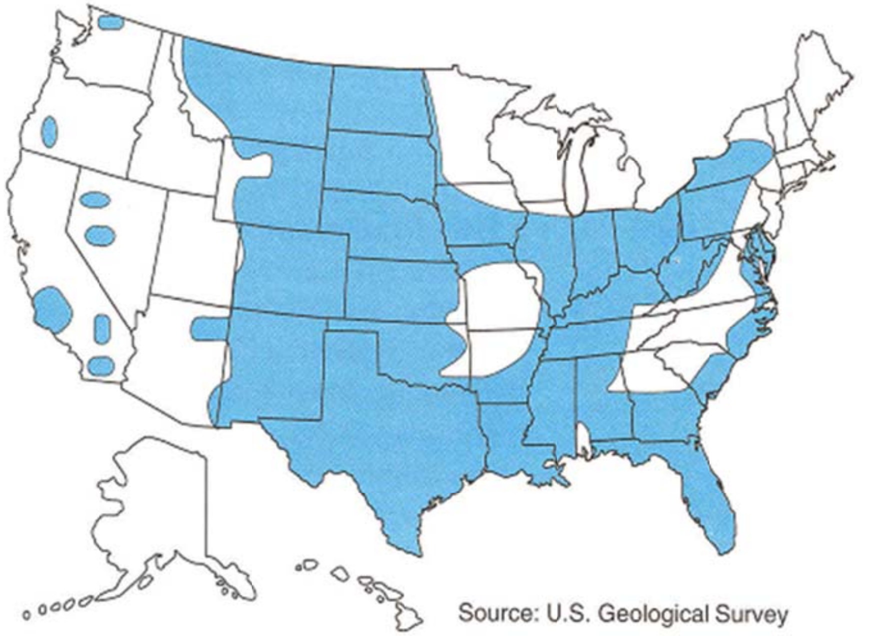

Figure 1.1. Availability of brackish groundwater resources in the United States.

Source: Hightower, Undated.

Despite the potential benefits of desal, a suite of issues—both technical and institutional—create uncertainties, delays, cost escalations, and other complexities that have inhibited brackish water desal implementation. *In particular, the challenges associated with concentrate management (CM) have made brackish water desal implementation a very complex*, uncertain, time consuming, and often frustrating endeavor for utilities in Texas, New Mexico, and other arid, water-limited regions of the United States.

This issue paper describes the practice of inland municipal desal in the United States and the general barriers limiting its implementation, with a focus on challenges associated with CM in the arid southwestern region of the United States.

1.2 Status of U.S. Municipal Desal

A series of surveys conducted over the last 20 years provides a detailed representation of U.S. municipal desal (Mickley et al., 2012). The surveys are estimated to include greater than 90% of all such facilities built. For sizes equal or greater than 25,000 gpd (typically large enough to supply roughly 40 or more households per year), there were an estimated 324 desal facilities built through 2010. All are membrane plants with about 94% producing drinking water and 6% being associated with processing wastewater treatment plant (WWTP) effluent for water reuse. Only 4% of the drinking water plants are seawater facilities. Figure 1.2 shows the cumulative number of plants over time, and Figure 1.3 shows an estimate of the cumulative capacity of the plants over time. The greater slope of the capacity curve reflects the increasing average plant size over time.

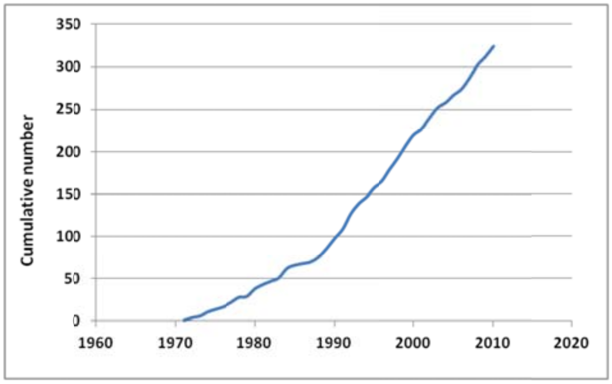

Figure 1.2. Cumulative number of U.S. municipal desal plants over time.

Source: Mickley et al., 2012.

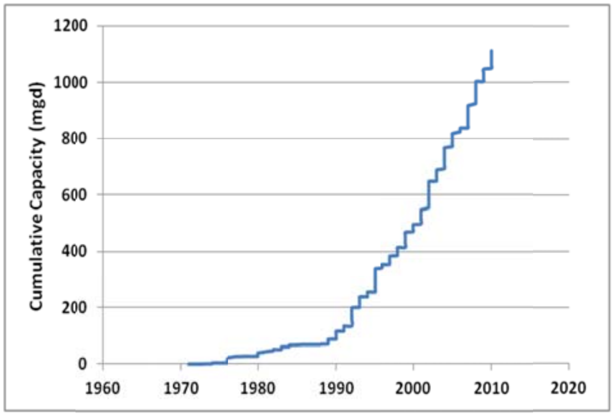

Figure 1.3. Cumulative capacity of U.S. municipal desal plants over time.

Source: Mickley et al., 2012.

Figure 1.4 shows the number of different types of membrane plants built in three time periods. There are presently no municipal thermal (i.e., evaporation/distillation) desal plants in the 50 U.S. states. The membrane processes used are brackish water reverse osmosis (BWRO), nanofiltration (NF), seawater reverse osmosis (SWRO), and electrodialysis reversal (EDR). Also represented in Figure 1.4 are processes that include microfiltration (MF) prior to reverse osmosis (RO) and NF. Table 1.1 shows the percentage use of the different membrane processes.

Table 1.2 lists the number of municipal desal plants in various states as of 2010. The plants are located in 32 states (up from 14 in 1993 and 26 in 2003). Florida has 45% of the plants, followed by California and Texas with 14% and 9%, respectively. Together these states account for 68% of the U.S. municipal desal plants. Thus the remaining 32% of the plants are spread over the 29 other states. From 2003 through 2010, 39% of the plants were built in states other than Florida, California, and Texas—up from 19% for plants built prior to 2003.

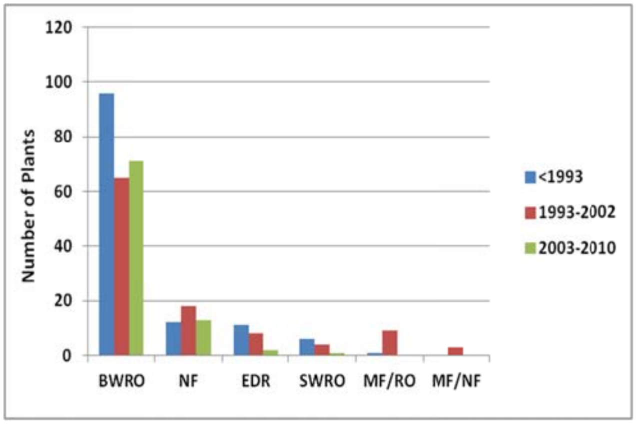

Figure 1.4. Number of plants by type and time period.

Source: Mickley et al., 2012.

Table 1.1. Percentage Use of U.S. Municipal Membrane Desal Processes

Membrane Process	Percent of Total
BWRO	78
NF	13
EDR	5
SWRO	4

Source: Mickley et al., 2012.

Figure 1.5 shows the number of plants built in Florida, California, Texas, and other states in three time periods. In 1993, over 62% of the plants were in Florida. While in each time period more plants were built in Florida than in any other state, the total percentage of plants in Florida has declined to the 2010 percentage of 45%. The large number of plants in Florida is due to the state's growing population in areas where more traditional supplies are not as readily available (e.g., the flat terrain does not allow for the easy capture and storage of rain water).

Average plant size for all inland desal plants (BWRO, NF, EDR) has increased over time from approximately 1.6 mgd in 1993 to 3.5 mgd in 2003 and 5.5 mgd in 2010.

1.3 General Barriers to Desal

The major limitations to the increased implementation of municipal desal plants are:

- High costs relative to more traditional freshwater supply options (e.g., fresh surface or groundwater)
- High energy requirements
- Limited options for disposing of desal concentrate in inland settings

Table 1.2. Number of U.S. Municipal Desal Plants by State

State	Number of Plants	State	Number of Plants
Florida	148	Minnesota	2
California	45	Missouri	2
Texas	30	Nebraska	2
North Carolina	12	Nevada	2
Illinois	11	New York	2
Arizona	10	Oklahoma	2
Iowa	10	Pennsylvania	2
Colorado	7	Utah	2
South Carolina	6	Alabama	1
Virginia	6	Mississippi	1
Ohio	5	New Jersey	1
North Dakota	4	South Dakota	1
Kansas	3	Washington	1
Montana	3	Wisconsin	1
Alaska	2	West Virginia	1
Massachusetts	2	Wyoming	1

Source: Mickley et al., 2012.

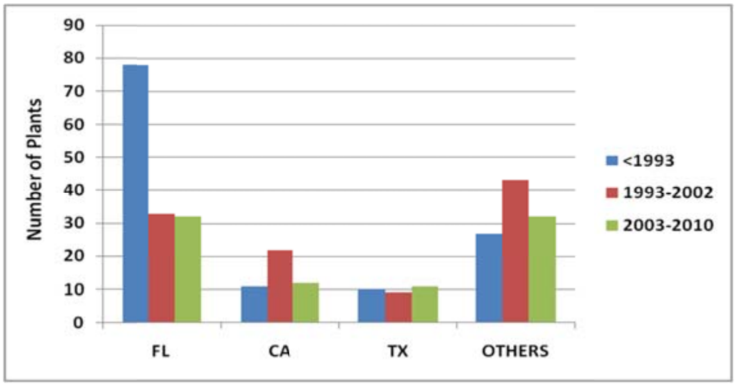

Figure 1.5. Number of plants by state and time period.

Source: Mickley et al., 2012

Desal production costs have decreased significantly over the past 20 years due to several factors, including:

- More efficient membranes (requiring lower operating pressure and having higher fluxes)
- Use of energy recovery devices
- Increased production of membranes and greater competition among equipment manufacturers

All three of these factors reduce equipment and operating costs. Cost, however, remains a factor in consideration of desal plants as the costs remain significantly greater than those of conventional water treatment processes. However, as traditional water sources become fully utilized, desal is becoming cost competitive relative to other options available for meeting growing demands. For example, recent case studies reveal that groundwater desal is less expensive than importing water from distant areas, and provides a more reliable yield.

Energy requirements are primarily due to pumping needs, and the aforementioned improvements in membrane efficiency and in pressure recovery have reduced the energy requirements somewhat. As with production costs, however, relatively high energy requirements still remain a factor in making decisions about supply options. The high energy requirements of desal may conflict with other utility goals to reduce energy consumption and lower greenhouse gas emissions.

New desal technologies (including forward osmosis and membrane distillation) may play a role in reducing both equipment and energy costs. However, both present and future desal technologies produce concentrate/brine that requires disposal. And it is the barriers associated with the disposal of concentrate that are increasingly dictating the general feasibility of municipal desal, particularly at inland settings (as compared to coastal and near-coastal desal facilities, which have ocean outfalls as a viable and relatively inexpensive alternative for CM).

A recent study of desal by the National Resource Council (NRC, 2008, p. 107) stated that "Few, if any, cost-effective environmentally sustainable CM options have been developed for inland desalination facilities."

While desal production costs have decreased, costs associated with concentrate disposal have not, and include costs associated with:

- Determining disposal option feasibility
- Permitting
- Pumping, transportation, and other capital costs associated with the various concentrate disposal options

As a result, the costs of concentrate disposal are becoming an increasing proportion of the total desal costs (production + concentrate disposal).

Recognizing the importance of the challenges associated with all of the barriers to inland desal implementation (as outlined above), this project focuses on the challenges associated with CM. The following sections describe the general barriers to CM, while Issue Papers 2, 3, 4, 5, and 6 provide additional details on specific barriers.

1.4 Barriers to CM

The focus of this project is on CM barriers which may fall into several categories:

- Regulations/permitting
- Hydrogeology
- Water quality
- Water quantity
- Economic (i.e., cost)
- Environment
- Technology
- Public/political

These barriers are included in Issue Paper #2, which discusses CM options in greater detail.

1.5 Arid Southwest

While the previously quoted statement by NRC applied to municipal desal throughout the United States, the concerns are particularly urgent in the arid Southwest, which is also an area of project focus. Arbitrarily the project team has defined this area as including the following states:

- Texas
- New Mexico
- Colorado
- Arizona
- Nevada
- Utah
- California

In general, these are areas where low freshwater resources are highly stressed. The region has only limited precipitation and desal is increasingly being considered to support population growth. The low level of freshwater resources also results in limited flows in potential receiving waters (e.g., rivers and streams) for concentrate discharge. Generally, concentrate disposal options for all but extremely small desal plants are more limited in this region than in other parts of the United States. As will be discussed in Issue Paper #2, the CM options that hold the most promise for application in the arid Southwest are deep well injection, evaporation ponds (for smaller facilities), and high recovery processing (which produces smaller volume concentrate/brine or solids for disposal).

References

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Krieger, R.A., J.L. Hatchett, and J.L. Poole. 1957. Preliminary Survey of the Saline-water Resources of the United States. Geological Survey Paper 1374. U.S. Geological Survey, Washington, DC.

Mickley, M., J. Jordahl, and A. Arakel. 2012. Development of a Knowledge Base on Desalination Concentrate and Salt Management. WateReuse Foundation Project, Alexandria, VA.

NRC. 2008. Desalination: A National Perspective. Committee on Advancing Desalination Technology. National Research Council, Washington, DC.

Questions for Readers

- Is the representation of desal helpful, accurate?
- Is the representation/discussion of general barriers accurate?
- Does the discussion help to narrow the project focus down to CM issues in the arid Southwest?
- What changes, modifications do you suggest?
- Other comments?
- Do you agree that the size of in-land desal facilities will continue to increase? Will there be an upper bound on the size of facilities?

Issue Paper 2

Overview of Concentrate Management Options and Barriers

2.1 Introduction

Desalination (desal) is of growing importance and application in meeting increased demands for water resources and to improving the quality of drinking water. Its application is also of growing importance in providing higher-quality reuse water. The net result is more concentrate to manage. The concentrate management (CM) dilemma is that it is increasingly difficult to manage concentrate in a way that is cost-effective, regulatory-expeditious, and environmentally prudent.

The challenge of managing concentrate is a function of its volume and composition. Concentrate contains greater concentrations of all constituents found in the feed water, concentrated to different degrees by the membrane process.

Historically CM has amounted to disposal. Unfortunately, the most widely used disposal options can impact source waters. The same environmental and health concerns that have led to the demand for higher-quality potable water treatment and the increased use of desal have also led to increased protection of source waters. As a result, it has become more difficult to find a long-term sustainable concentrate disposal option and, in some cases, desal plants have not been built due to the seemingly insurmountable challenges associated with CM issues.

Over 96% of the municipal desal facilities in the United States are inland facilities. For these and seawater desal plants, CM has become a major factor in determining the feasibility of building a desal plant. Moreover, increasingly it has become a significant cost factor. A recent study of desal by the National Resource Council (NRC, 2008, p. 107) stated that “few, if any, cost-effective environmentally sustainable CM options have been developed for inland desal facilities.”

2.2 Concentrate Management Options

As of 2010, five conventional concentrate disposal options have been used by over 98% of the estimated 324 municipal desal plants built in the United States (Mickley et al., 2012). The five conventional disposal options include:

- Surface water discharge
- Discharge to sewer
- Deep well injection (DWI)
- Evaporation pond
- Land application

These general categories have several subcategories (see Table 2.1). The application of each option is a function of plant size (i.e., concentrate volume), water quality, location, regulatory policy, and cost.

Table 2.1. Concentrate Management Options[a, b]

1. Five conventional CM options (for concentrate of any salinity)
    - Surface water discharge
        - Direct ocean outfall [includes brine lines both when direct to ocean and via wastewater treatment plant (WWTP) on way to ocean]
        - Shore outfall
        - Co-located outfall (with power plant cooling water or WWTP effluent discharges)
        - Discharge to river, canal, lake
    - Discharge to sewer
        - Sewer line
        - Direct line to WWTP
    - Injection wells
        - DWI
        - Shallow well (beach well)
    - Evaporation pond
        - Conventional pond
        - Enhanced evaporation ponds/schemes
    - Land application
        - Percolation pond/rapid infiltration basin
        - Irrigation
2. Beneficial use (other than irrigation)
    - Several potential uses (for concentrate or solids)
3. Landfill (for solids)
    - Dedicated monofill
    - Landfill accepting industrial waste

[a] The options apply to concentrate of any salinity; thus concentrate from high recovery [including zero liquid discharge (ZLD)]/brine minimization processes as well as from conventional recovery processes are included.
[b] The options also apply to desal processing involving salt recovery.

Source: Mickley et al., 2012.

In addition to the conventional disposal options, the beneficial use of concentrate has also been explored. While several possible beneficial uses of concentrate have been identified (besides irrigation), none are widely applicable, most are unproven, and most do not result in the disposal of concentrate. There are very few viable uses of concentrate thus far demonstrated, although some—such as treatment wetlands—may contribute to improved water quality through the removal of specific problematic constituents such as selenium or nitrate, making some form of blending and discharge more viable (Jordahl, 2006; Mickley et al., 2012). However, given the challenges of CM, it is prudent to explore any and all beneficial use options early in project planning as the options are site-specific and a feasible option may present itself. A combination of methods such as linking more conventional options with beneficial uses may provide redundancy, reliability, and potentially some ancillary benefits. Together these options recognize the possibility of managing concentrate in a more beneficial way and reflect that concentrate might be considered a resource.

In the last decade, and largely due to various challenges associated with CM (discussed in a following section), increasing attention has been given to high-recovery processing. This has been referred to under different names as concentrate minimization and volume reduction (of concentrate). In special cases where no liquid crosses the facility boundary, high-recovery processing amounts to what is known as ZLD.

Other drivers for consideration of high-recovery processing include:

- Increased concern for concentrate being a lost water resource.
- The realization of a longer-term need to develop sustainable technologies/solutions. While CM options remain costly, the recovery of salts and other constituents in concentrate may be an approach toward more sustainable practices. Wastes in other industries also have limited disposal options available and the beneficial recovery of values from waste is proving to be a cost-effective and important step toward more sustainable business practices.

The final wastes from high-recovery processing are either concentrate/brine or solids. In theory, concentrate/brine from high-recovery processing may be disposed of by any of the five conventional disposal options. Landfills (for solids) are added to the list to account for solids produced by the high-recovery processing, where solids result from either accumulation in evaporation ponds or from a final evaporation step to produce mixed solids. At WWTP sites utilizing desal for water reuse, the low salinity concentrate may be recycled to the front of the WWTP.

The solids bring a new disposal option into consideration: disposal to landfills. A subcategory of high-recovery processing is where one or more products (e.g., salts, trace metals, or other constituents) are recovered as part of the processing scheme. As of 2010 there was one municipal ZLD facility in Tracy, CA. Presently there is at least one other high-recovery reverse osmosis (RO) plant being built along with a few high-recovery nanofiltration (NF) membrane plants. The higher salinity concentrate/brine and the solids produced introduce new disposal challenges to municipal desal and are the topic of Issue Paper # 6, which addresses high-recovery processing.

2.3 Concentrate Management Practices

Table 2.2 shows the percentage use of the five conventional disposal options for desal plants within the United States, as well as the number of states having municipal desal plants utilizing each option. As shown, few states have plants that use DWI, land application, or evaporation ponds as a method of disposal. For these options, the states and the number of sites using the option in each state are given. Thirty-two states presently have municipal desal plants. From Table 2.2 it may be seen that:

- Seventy-one percent of the plants discharge concentrate to surface water or to the sewer (though these are largely in states where surface waters have relatively high volume flows and/or the desal facilities are very small)
- DWI and land application are used in only 5 of the 32 states
- Evaporation ponds are used in only 3 of the 32 states
- Thus, 100% of the plants in 26 states discharge either to surface water or to the sewer
- Roughly 95% of the DWI sites are in Florida
- Twenty of the 23 land application sites are in Florida
- Florida is the only state utilizing all five conventional disposal options

Table 2.2. Number of States Using Disposal Options for Municipal Desal Concentrate as of 2010

	Percent of Facilities	Number of States	States (number of sites) Using Option
Surface water discharge	47[a]	25	Many
Discharge to sewer	24	22	Many
Deep well injection	17	4[b]	FL (53), CA (1), KS (1), TX (1)
Evaporation pond	4	3	FL (3), TX (7), AZ (3)
Land application	7	4	FL (20), CA (1), TX (1), AZ (1)
Recycle	1	3	CA (2), AZ (1), PA (1)

[a] The 47 % includes plants in California that discharge to brine lines which eventually discharge to the ocean. The number may represent approximately 20% of all surface water discharges.
[b] Colorado has since permitted DWI for two municipal desal plants, Texas for one, and Florida for more than three.

Figure 2.1 shows the percentage of plants built in three time periods using different disposal options. While surface water discharge and discharge to sewer are used at relatively high levels regardless of the time period, there are distinctive trends for three of the other four disposal options. DWI has been increasingly used with time, while disposal to land and to evaporation ponds has decreased with time.

Figure 2.2 provides additional information on how the disposal options are used as a function of size of the municipal desal plant. The combinations represented [such as surface water discharge for brackish water reverse osmosis (BWRO)/electrodialysis reversal (EDR) plants] eliminate the bias introduced when seawater RO plants and NF plants are included in the data. While discharge to surface water is used at a consistently high level regardless of plant size:

- Discharge to sewer is used less as the plant size increases
- Use of DWI is increasingly used with larger plants
- Use of evaporation ponds and land application are restricted to small-sized plants

While the representations of Figures 2.1 and 2.2 are accurate, they are somewhat misleading in that they may imply that all disposal options are available regardless of location. As reflected in Table 2.2, this is not the case. To account for this, Figures 2.3, 2.4, 2.5, and 2.6 represent the percentage use of the disposal options by time period for Texas, Florida, California, and all other states, respectively.

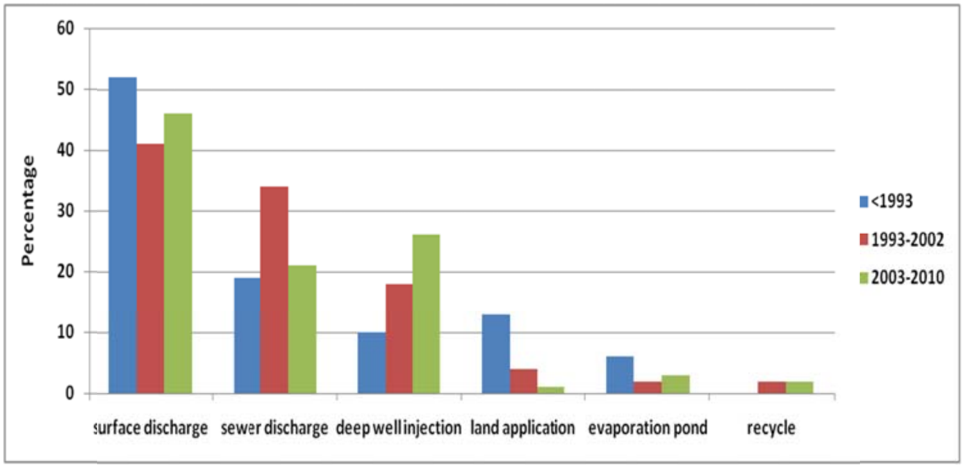

Figure 2.1. Use of disposal option by time period.

Source: Mickley et al., 2012.

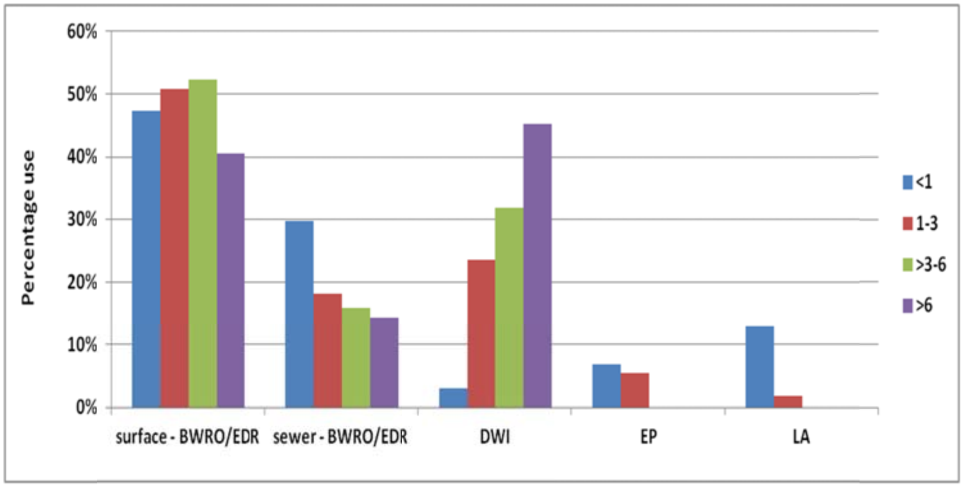

Figure 2.2. Disposal option use by plant size [million gallons per day (mgd)].
DWI = deep well injection, EP = evaporation pond, LA = land application.

Source: Mickley et al., 2012.

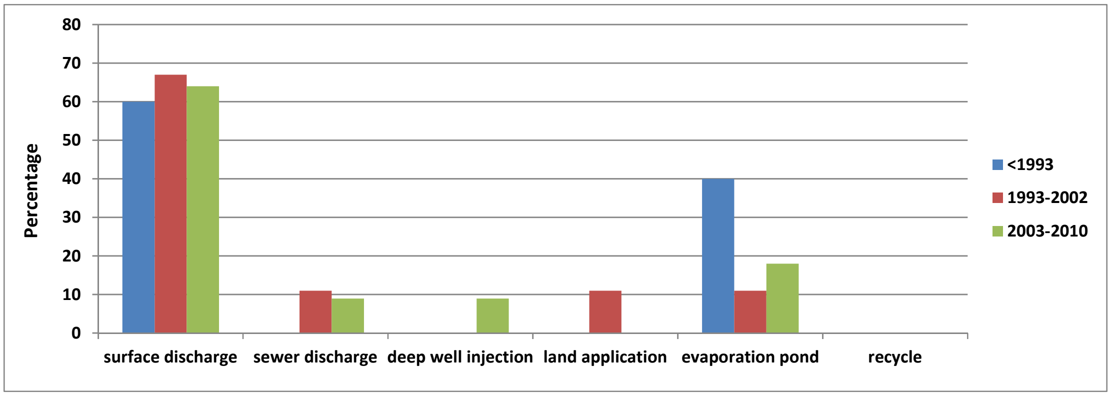

Figure 2.3. Texas.

Source: Mickley et al., 2012.

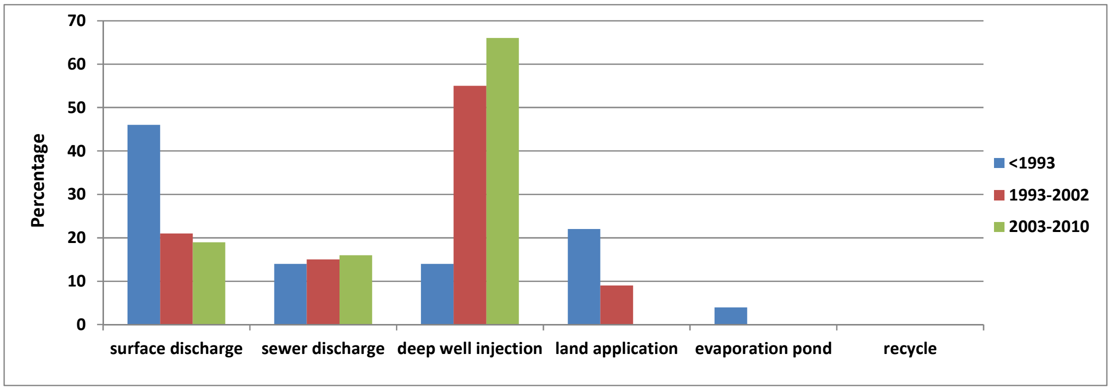

Figure 2.4. Florida.

Source: Mickley et al., 2012.

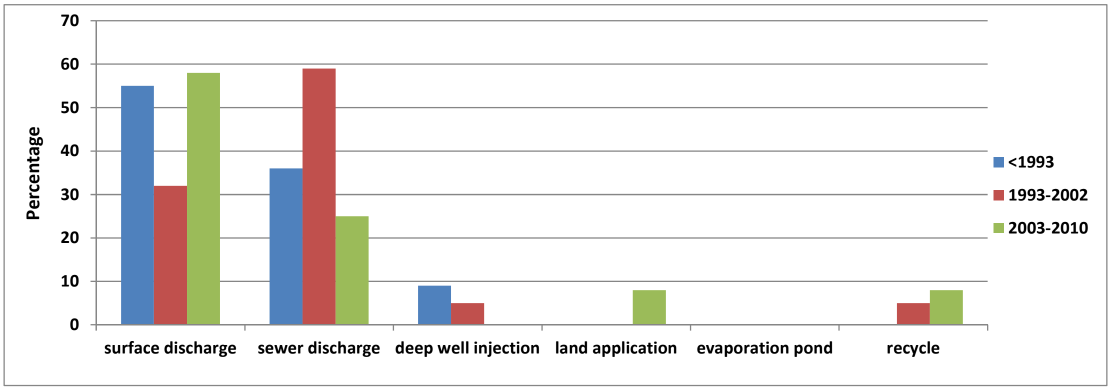

Figure 2.5. California.

Source: Mickley et al., 2012.

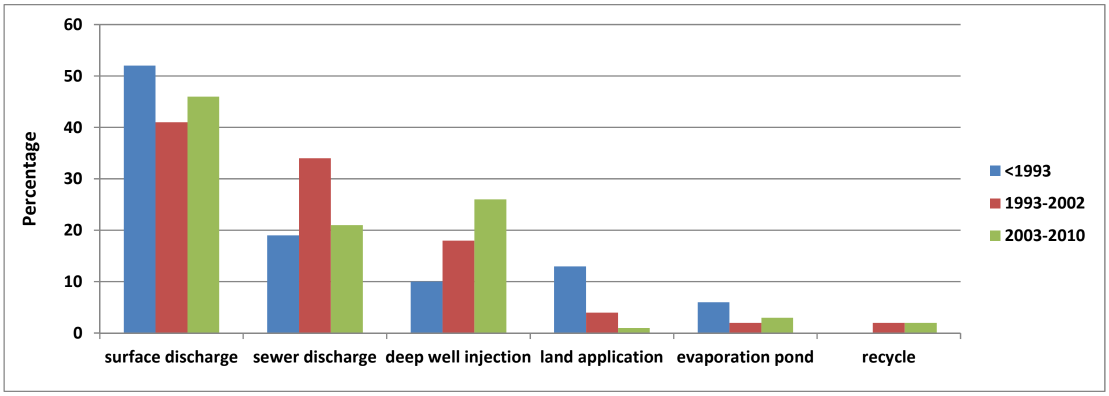

Figure 2.6. All other states.

Source: Mickley et al., 2012.

While the details are masked by the small size of the figures, it is the general distribution of the data that stands out. Most notably:

- Texas has a higher percentage of evaporation ponds than the other areas, with most of the ponds from smaller and older facilities
- Florida has the largest use of DWI and a strong trend toward increasing use of this disposal method
- California is similar to the fourth group representing all other states in that predominantly discharge to surface water and to sewer account for most of the disposal

2.4 Summary of CM Practices

A recent survey (Mickley et al., 2012) to determine desal plant characteristics and CM practices for plants built through 2010 coupled with past surveys, allows comparison of data and identification of trends. Findings from the survey of municipal desal plants include:

- Over 94% of the municipal desal plants are at water treatment plants, with the remaining 6% at WWTPs and recharge facilities.

- Of the identified 324 plants, 45% are located in Florida, 14% in California, and 9% in Texas.

- Florida, California, and Texas account for 68% of the municipal desal plants; the other 32% are scattered over 29 states.

- A greater percentage of plants are being built outside of the three states where most desal plants and overall capacity currently are found (Florida, California, and Texas).

    - In 2003, only 19% of plants were built in other states.
    - Between 2003 and 2010, 39% of the plants built were in other states.

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

- The operating capacity of desal plants has been increasing (from 1.57 mgd for plants built prior to 1993 and 5.53 mgd for plants built between 2003 and 2010).

- There has been an increased use of DWI and a declining use of evaporation ponds and land application.

- The past several years have resulted in the increased consideration and investigation of DWI in states other than Florida and of enhanced evaporation. Few plants in states other than Florida, however, have implemented these options.

- An increased number of plants are treating source water for removal of contaminants in addition to salinity.

- An increased number of plants have concentrate-containing contaminants that restrict the application of CM options or require treatment to remove the contaminants prior to disposal.

- Increasing CM challenges have led to planning-phase consideration of plants with high-recovery processing of concentrate. To date one ZLD plant has been built, (Mickley et al., 2012) and one is being built. A few high-recovery NF plants are also being built.

2.5 Concentrate Management Challenges

As with most industrial waste disposal situations, few options exist for managing concentrate from desal plants. Monies available for achieving more effective processing and recovery of wastes are limited in the municipal water treatment industry due to the undervaluing (and under-pricing) of water. As a result, technologies and approaches that are cost-effective in many other industries are not cost-effective in the municipal setting.

As reflected in Table 2.2., a major concentrate disposal challenge is the limitation in the local availability of options. Rarely are more than one or two conventional CM options considered potentially feasible after an initial screening evaluation. While surface water discharge and discharge to sewer will continue to play an important role in many parts of the United States (where sufficient flows enable adequate dilutions), there is growing environmental concern with salt loading of receiving waters. In other locations, and particularly in the arid Southwest, most conventional disposal options are not possible or cost-effective for anything but very small desal plants.

Other concerns and challenges associated with CM include:

- *Increasing size of plants:* Desal plant size has been increasing, and the increased volume of concentrate represents an increased impact on receiving waters and less likelihood of discharge to sewer, land application, and evaporation pond whose use have historically decreased with increasing concentrate volume.
- *Increasing number of plants in a region:* An increasing number of plants in a given region increases the risk of cumulative impacts.

- *Increasing regulation of discharge:* Source water quality has declined in many areas due to human activities, and drinking water standards have become more stringent. As a result, a strong case can be made for increased application of desal. However, the same environmental and health concerns that have led to tighter drinking water standards have also resulted in the increased protection of water sources. This presents a challenge to CM as 80% of the municipal desal plants discharge concentrate via options that can affect source waters (i.e., surface water discharge, discharge to sewer, and land application).
- *Lack of public understanding:* Part of the challenge in getting a desal plant implemented in a timely manner is resolving public concerns. Frequently the public has a limited understanding of issues involved and often has misconceptions about the nature of the desal process and the actual risk of concentrate effects on the environment. The public may be unaware of the benefits of desal technology relative to conventional water treatment technologies and supply options.
- *Increasing CM costs:* The treatment cost of desal has decreased considerably due to more efficient, longer lasting, and less expensive membranes; use of energy recovery devices; and increased competition among equipment manufacturers and system suppliers. CM costs, however, have not decreased. Capital costs associated with conventional disposal options have not decreased (with one exception being enhanced evaporation ponds), and operating costs have increased due to more detailed monitoring requirements. As a result, CM costs have become an increasing percentage of total desal plant costs and, in some cases, the most significant factor in determining the feasibility of building a new desal plant.
- *Increasing occurrence of contaminants in concentrate:* A recent survey (Mickley et al., 2012) found a handful of concentrates with spikes of contaminants (e.g., nitrate, perchlorate, selenium, arsenic) that required removal before discharge. This occurrence is associated with plants built within the past decade and appears to represent a growing trend.
- *The regulatory interactions* can be complex, time-consuming, and uncertain. Permitting is complicated by the lack of desal concentrate-specific federal and state regulations and limited experience of the regulation community with desal concentrate disposal permitting.

2.6 General Barriers Associated with CM Options

Tables 2.3 and 2.4 summarize the challenges and issues that limit the use of the options. Both tables list various potentially limiting issues for the disposal options and high-recovery processing. Table 2.3 lists different factors that can limit the feasibility of concentrate disposal options. Table 2.4 was adapted from a table published in 2008 (NRC, 2008). While Table 2.3 is more specific as to why a given factor may be limiting for a disposal option, Table 2.4 ranks different factors as to the level of challenge they typically represent to a disposal option. Together, they provide a more detailed and accurate summary than either table alone.

Figure 2.7 brings into consideration an additional perspective, that of the relative capital costs (not including conveyance costs) of the disposal options. It also shows that both evaporation ponds and land application may be cost-effective for small volume concentrates—something that the capital cost column of Table 2.4 does not imply. It also reflects the high costs of DWI for small concentrate flow due to high front-end feasibility study costs associated with drilling test wells and hydrogeological studies.

Table 2.3. Requirements, Characteristics, and Barriers for In-land Concentrate Management Options

	Discharge to Sewer	Discharge to Surface Water	Evaporation Ponds	Land Application	Underground Injection	High Recovery Processing (including ZLD)
Regulatory requirements	• Permit not required, but responsibility falls on wastewater facility to meet their NPDES permit requirement • May be subjected to pretreatment requirements	• Requires an NPDES permit	• State permit—regulations vary by state • In most cases, lining and monitoring is required	• State permit—regulations vary by state. • May be regulated by land-use criteria or groundwater protection requirements	• UIC permit—regulation vary by state. Multiple agencies may be involved • Limited experience in many states • Practice may not be allowed in some states	• Permit required for disposal of final waste—regulations vary by the type of final waste produced (brine and/or solid)
Cost factors	• Conveyance to collection system • May be a connection or discharge fee • [Cost is typically a not a barrier]	• Conveyance to outfall • Outfall design and construction • [Cost is typically not a barrier]	• Major costs are pond lining, leak monitoring system, and land • Little or no economy of scale	• Conveyance to distribution system • Little or no economies of scale	• Conveyance to injection wells • Large costs associated with permitting and determination of injection feasibility; • Well construction costs	• High capital and energy and chemical costs associated with additional processes • Final waste disposal costs
Concentrate water quality influence	• Effect of concentrate salinity and constituents on wastewater effluent conditions and treatment	• Effect on permit discharge conditions (limits)	• Effect on evaporation rate and solids accumulation rate	• Effect on soil, vegetation, and groundwater	• Effect on precipitation potential in well and aquifer; corrosion, and disposal well class feasibility	• Effect on level of recovery, and final brine or solids nature

Table 2.3. Requirements, Characteristics, and Barriers for In-land Concentrate Management Options (cont.)

	Discharge to Sewer	Discharge to Surface Water	Evaporation Ponds	Land Application	Underground Injection	High Recovery Processing (including ZLD)
Environmental concerns	• Impact on flora and fauna as part of the WWTP discharge	• Impact on flora and fauna of receiving water WWTP discharge	• Control of wildlife access to the ponds • Requires a large amount of land • Concern for drift due to winds	• Impact on soil, vegetation, and groundwater	• Potential migration from the target aquifer • Potential for well failure • Potential to cause earthquakes • Impact on other aquifers through migration and leakage	• Impact from waste disposal
Technical issues	• Can impact WW processes, inhibit microbial growth, corrosion, and changing settling characteristics	• Suitability for year-round operation • Challenges associated with outfall design and construction • Time-limited antiscalant effect in preventing precipitation of sparingly soluble salts/silica	• Must ensure that evaporation exceeds precipitation • Higher salt concentrations decrease evaporation • Ensure that there are no leaks from the liner • Suitability for year-round operation	• Understanding the maximum loading acceptable • Suitability for year-round operation	• Potential for precipitation prior to injection • Potential for down hole precipitation/ plugging • Unknowns regarding high salinity down hole effects • Nearby aquifer and geology may not be suitable for injection	• Need to understand what to do with the waste • Technical improvements needed to reduce capital costs, energy and chemical requirements
Public perception factor	• In some areas, public concern with potential impact on freshwater flow to bays and estuaries	• Environmental concerns associated with potential impacts on receiving waters	• Potential adverse response from the public due to drift, odor	• Environmental concerns from land discharges (impact on soil, vegetation, groundwater)	• Association of DWI with fracking concerns • Concern over injection of an industrial waste • Concerns over earthquake potential	• Generally considered a beneficial option by the public • May be some concern over disposal of final waste

Table 2.3. Requirements, Characteristics, and Barriers for In-land Concentrate Management Options (cont.)

	Discharge to Sewer	Discharge to Surface Water	Evaporation Ponds	Land Application	Underground Injection	High Recovery Processing (including ZLD)
Other	• Must have an effective relationship with the WW treatment facility				• Experience in drilling deep wells is only found in the oil and gas industry. Contractors are often unfamiliar with the requirements of municipalities or from non-oil and gas regulatory agencies.	
Water quantity effect	• Effect on WWTP capacity	• Effect on permit discharge conditions (limits)	• Land requirement (and cost) can be excessive	• Land and dilution water requirements can be excessive	• Effect on aquifer capacity and number of injection wells	• Impacts processing costs

NPDES: National Pollutant Discharge Elimination System; UIC: underground injection control.

General barriers applying across the board:

- Risk adverse—The water industry is generally risk adverse and looks for technologies and approaches that minimize risk. More expensive approaches/technologies may be applied that reduce risk but lead to increased costs.
- Tightening environmental regulations—Environmental regulations in general are becoming more stringent. For example, new Total Maximum Daily Load (TMDL) which impact NPDES permits will limit surface water discharges. This may also impact discharge to water treatment and/or land application.
- Public perception—Public perception can impact all the disposal options. All disposal options have some impact and may touch different stakeholder groups.
- Continuous vs. intermittent—It is typically preferred to operate a desal facility on a continuous basis, which in turn would produce a steady stream of brine. Some disposal options can be seasonal (i.e., may be impacted by seasonal low flows) or intermittent (i.e., enhanced oil recovery wells). Matching these two approaches present a barrier to certain technologies.
- Long approval time—Review and approvals of applications may take a long time because there is not sufficient history and experience with CM. Regulators take a very conservative approach in absence of history and experience.
- Market size—The opportunities for inland desal industry are relatively small. There is little incentive for manufacturers and other vendors to tackle the large obstacles associated with municipal projects, approval times, and uncertain regulatory environment for such a small market.

Table 2.4. In-land Concentrate Disposal Barriers

Issue Type:	Technical				
Method	**Land Area Required**	**Applicability for Large Conc. Flows**	**Pre-Treatment Needed**	**Climate Limitation**	**Special Geological Requirements**
Surface water discharge	--	Y	M	Maybe[a]	N
Sewer discharge	--	N	L	N	N
Deep well injection	L	Maybe	L	N	Y
Evaporation pond	H	N	L	Y	Y
Land application	H	N	L	Y	Y
Thermal evaporation to solids	L	N/M?	L	N	N

Table 2.4. Concentrate Disposal Barriers (cont.)

Issue Type:	Cost				Environment/ Regulatory		Public
Method	**Unit Capital Costs ($/mgd)**	**Unit[b] O&M Costs ($/kgal)**	**Labor Needs and Skill Level (for operation)**	**Energy Use**	**Permitting Complexity**	**Potential Environmental Impact**	**Public Perception Concerns**
Surface water discharge	L[c]	L[c]	L	L[d]	M/H	M	H
Sewer discharge	L[c]	L[c]	L	L[d]	M	M	L
Deep well injection	H[c]	M[c]	L/M	M[d]	H/M[e]	L	L-M
Evaporation pond	H[c]	L[c]	L	L[d]	M	M	L-M
Land application	L/M[c]	L[c]	L	L[d]	M	M-H	H
Thermal evaporation to solids	H[c]	H[c]	H	H[d]	L[a]	L[a]	L

L =low; M = medium; H = high; Y = yes; N = no; dashes indicate not applicable. Water quality of the concentrate and composition of landfill solids can eliminate feasibility of each of the disposal options due to presence of toxins, precipitation of solids upon blending, or presence of hazardous levels of contaminants.

O&M: operations and maintenance.

[a] Climate can affect amount of rainfall and surface water available for dilution..

[b] Unit O&M costs increase with the amount of monitoring and analytical lab support required.

[c] Costs are highly site specific; general trends in relative costs are indicated; capital cost for all options can be higher if distance from the desal facility to the disposal site is large, necessitating long pipelines and possibly pumping stations or hauling.

[d] Energy use for each option can be higher due to distance from desal plant to option site; also if land application area is large and a distribution system is required.

[e] Deep wells are not permitted in some states.

Source: Adapted from NRC, 2008 and Mickley et al., 2012.

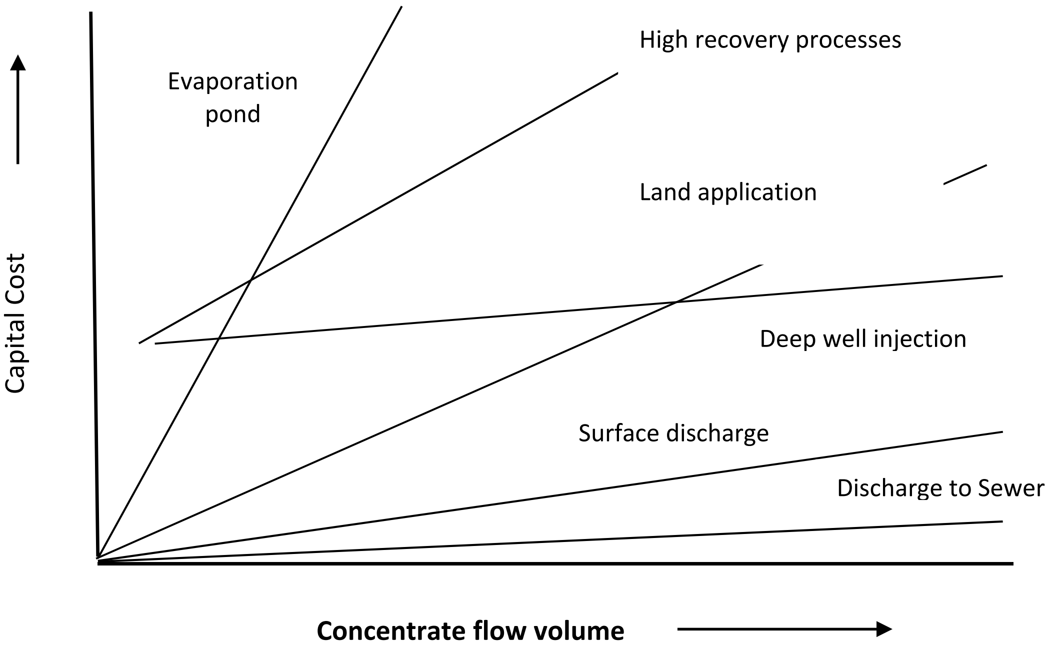

Figure 2.7. Relative capital costs of concentrate management options (not considering conveyance).

Not considering the distance of conveyance from the desal plant to the disposal site, the major barriers associated with the different disposal options and high-recovery processing include:

- *Surface water discharge:* As discharge regulations become increasingly stringent, concentrate disposal via surface water discharge may ultimately become a non-sustainable practice.
- *Discharge to sewer:* High salt concentrations can have a negative effect on WWTP operations and may impact the ability to meet discharge permit requirements. DWI: key challenges include restrictive regulatory policy and related permitting requirements, unknown hydrogeological conditions in many locations, and high costs associated with determining feasibility and with implementation.
- *Evaporation ponds:* Land requirements are suitable for only small volume concentrates. In addition there are high capital costs associated with this option, and low economies of scale.
- *Land application:* This option requires dilution water to limit impacts on soil, vegetation, and groundwater.
- *High-recovery processing:* These processes have high capital costs associated with additional processing equipment. In addition, there are questions concerning the impact of high salinity brine of disposal options.

2.7 Concentrate Management Options for the Arid Southwest

Since beneficial use options are rare and site-specific, they were not chosen for further consideration. This leaves the following options:

- Surface water discharge
- Discharge to sewer
- Land application
- DWI
- Evaporation pond
- High recovery processing

As previously discussed, the first five bullet items are conventional disposal options and the final one is a CM option that produces concentrate/brine or solids for disposal.

Of the remaining CM options, the first three are considered unsuitable for implementation in the arid Southwest:

- The arid Southwest is characterized by limited waters available for surface water discharge, which restricts its consideration to only small volumes of concentrate. Further long-term discharge to inland surface waters is not a sustainable practice.
- Discharge to sewer is limited to WWTPs where the impact of concentrate on their operations and discharge permits would be minimal—thus where the concentrate salt load is relatively small. While this situation may be found, the option is further restricted by the growing use of WWTP effluent for water reuse.
- Land application of concentrate generally requires low total dissolved solids (TDS) dilution water (scarce in the arid Southwest) to meet soil, vegetation, and groundwater restrictions. The option is restricted to low volumes of concentrate.

This leaves the following three CM options as potentially viable for desalting at inland locations in the arid Southwest:

- Evaporation ponds are suitable for low volumes of concentrate due to both large land requirements (a net evaporation rate of 3 gpm/acre is a high value) and to low economies of scale. The arid Southwest has high net evaporation rates, more available land, and in some cases can be the only approved disposal option. Technical innovation (enhanced evaporation systems), which have the potential to decrease costs, need to be considered. The use, however, of evaporation ponds will still be restricted to low concentrate volumes. Evaporation ponds are considered further in Issue paper #5.

- Of the five conventional disposal options, DWI holds the most promise for increased implementation. The specific barriers to increased application are the subject of Issue Paper #4. Issue Paper #3 provides the background to the regulation of DWI.

- As explained previously, due to the increasing challenges of concentrate disposal, high-recovery processing is a subject of considerable attention. While it does not necessarily solve the disposal problem, it does bring into consideration possible alternatives and benefits which include:

  - Landfill of solids
  - Possible recovery of values from concentrate
  - More efficient use of the water resource

In addition to these options, Issue Paper # 6 discusses the use of high-recovery processing.

References

Jordahl, J. 2006. Beneficial and Non-traditional Uses of Concentrate. WateReuse Foundation Report, Alexandria, VA.

Mickley, M., J. Jordahl, and A. Arakel. 2012. Development of a Knowledge Base on Desalination Concentrate and Salt Management. WateReuse Foundation Project, Alexandria, VA.

NRC. 2008. Desalination: A National Perspective. Committee on Advancing Desalination Technology. National Research Council, Washington, DC.

Questions for Readers

- Is the representation of CM options accurate, clear, sufficient? What changes would you recommend?
- Is the representation of CM practices clear, helpful? What changes would you recommend?
- Is the representation of CM challenges accurate, clear? What changes would you recommend?
- Are the general barriers to implementation of the CM options represented well? What changes would you recommend? Would you add or emphasize any additional barriers?
- Do you agree with our assessment of eliminating from further consideration surface water discharge, discharge to sewer, and land application? and of focusing attention on DWI, evaporation ponds and high recovery processing?
- Any other comments or changes to recommend?

Issue Paper 3

Overview of Deep Well Injection and the Underground Injection Control Program

3.1 Subsurface Injection for Desalination Concentrate

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

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

Subsurface injection can also be done in shallow wells (such as beach wells used for seawater desalination concentrate). However, DWI is needed for the isolation of injected liquid wastes and for inland municipal desalination concentrate disposal.

As of 2010, about 16% of the roughly 320 municipal desalination plants in the United States (of size greater than 25,000 gpd—roughly large enough to serve 40 households or more) disposed concentrate to deep wells (Mickley, 2006; Mickley et al, 2012). While other states are increasingly exploring the use of DWI for municipal desalination concentrate, as of 2010, only Florida, California, Texas, Colorado, and Kansas had such wells. Florida, with approximately 50 wells was the only state having more than one well for municipal desal concentrate disposal. The high number of wells in Florida is due to the state's large population, population growth, and the exhausted availability of fresh groundwater and as a result the proliferation of inland brackish water municipal desalination plants (approximately 46% of all U.S. municipal desalination plants are in Florida). In addition there are limited disposal options in many locations, yet near-ideal hydro-geological conditions for DWI in parts of Florida., Further, several concentrates in Southwest Florida have high levels of naturally occurring radioactive materials (NORMs) making the concentrate unsuitable for surface water discharge and, thus, leaving DWI as the only viable disposal option.

Due to significant front-end feasibility determination costs associated with test wells and hydrogeological studies, DWI has not usually been cost-effective for small municipal plants. For larger desal plants, DWI is often the only reasonably feasible concentrate management (CM) option. As a result, DWI use increases significantly with desal plant size. High deep well costs are also due to the regulatory classification—under Class I of the Underground Injection Control (UIC) program of the federal Safe Drinking Water Act (SDWA)—of municipal desalination concentrate as an industrial waste. This Class I designation is the same classification that applies to injection of other industrial wastes and hazardous waste. Class I wells have stringent construction requirements.

3.2 Regulation of DWI

Under the SDWA, the U.S. Environmental Protection Agency (EPA) sets standards for drinking water quality and protection of source water, and oversees the states, localities, and water suppliers who implement those standards. The law requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. Prior to the SDWA in 1974 there were few national enforceable requirements for drinking water. The oil and gas industry had been injecting saltwater into deep rock formations to increase oil recovery for more than a quarter of a century. The SDWA established the requirements and provisions for the UIC Program, and 40 CFR part 144 provides the minimum requirements for the UIC program promulgated from the SDWA. It took nearly a decade after passage of the SDWA for EPA to implement a standardized UIC program governing underground injection. Part of the challenge of defining a regulatory approach for protecting possible drinking water sources was resolved by defining USDW as any aquifer water with total dissolved solids (TDS) levels of 10,000 mg/L or less. Injection into or above USDW zones is restricted depending on the type of injection fluid - regardless of the water quality of the USDW zone. (As noted below, this limited criterion of 10,000 mg/L TDS for defining an USDW may now be overly limiting for managing drinking water and underground injection.)

The purpose of the UIC program is to ensure that underground injection of fluids is managed so as to protect USDW. This goal is accomplished by setting the physical and operational standards that apply to the practice (GWPC, 2007).

EPA developed the Statement of Basis and Purpose for the UIC Program to support regulations. These documents (published in 1979 and in 1980) identified the technical reasons for developing the UIC program regulations. In the 1980s, federal UIC regulations were passed that define five classes of injection wells and set minimum standards that state programs must meet to receive primary enforcement responsibility (primacy) of the UIC Program.

Since inception of the UIC Program, additions have been made to the program. Congress amended the SDWA to allow existing oil and gas programs to regulate, provided they are effective in preventing endangerment of USDW and include traditional UIC Program components such as oversight, reporting, and enforcement. Congress also passed the Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA), requiring additional UIC regulations for deep wells injecting hazardous waste. More recently the UIC Program has had challenges from new uses of injection wells:

- Managing treatment residuals from drinking water treatment plants
- Increasing drinking water storage options through aquifer storage and recovery wells.
- Limiting carbon dioxide (CO_2) emissions through geologic sequestration (GS)
- Evaluating the impact to USDW by hydraulic fracturing of non-conventional gas sources

In 2010, EPA finalized regulations for the GS of CO_2 using the existing UIC Program regulatory framework modified with criteria and standards specific to GS, thus creating a new class of Wells; Class VI. With proper site selection and management, this new class of well could play a role reducing emissions of CO_2.

The UIC regulations establish specific performance criteria for each well class to assure that drinking water sources, actual and potential, are not rendered unfit for such use by underground injection of the fluids common to that particular category. The UIC Program is responsible for regulating the construction, testing, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal (U.S. EPA, 2012c).

3.3 Classes of Injection Wells

In simplified descriptions, deep injection well classes are defined under the UIC program as follows:

Class I wells: Technologically sophisticated wells that inject wastes into deep, isolated rock formations below the lowermost USDW. Class I wells may inject hazardous waste, non-hazardous industrial waste, or municipal waste. Desalting wastes (i.e., concentrated brines) fall under Class I.

Class II wells: Wells that inject brines and other fluids associated with oil and gas production, or storage of hydrocarbons. Class II well types include salt water disposal wells, enhanced recovery wells, and hydrocarbon storage wells.

Class III wells: Wells that inject fluids associated with solution mining of minerals. Mining practices that use Class III wells include salt solution mining, in-situ leaching of uranium, and sulfur mining using the Frasch process.

Class IV wells: Wells that inject hazardous or radioactive wastes into or above a USDW. These wells are banned unless authorized under a federal or state groundwater remediation project.

Class V wells: Wells not included in Classes I to IV and Class VI. Wells inject non-hazardous fluids into or above a USDW and are typically shallow, on-site disposal systems (e.g., septic systems); however, this class also includes some deeper injection operations. There are approximately 20 subtypes of Class V wells.

Class VI wells: Wells that inject CO_2 for the purposes of long-term storage, also known as CO_2 GS.

The vast majority of injection wells existing prior to the UIC program were associated with oil and gas production (which became Class II wells) and with a wide range of other wells (which became Class V). Most Class V wells are shallow disposal systems that depend on gravity to drain fluids directly in the ground. There are over 20 well subtypes that fall into the Class V category and these wells are used by individuals and businesses to inject a variety of non-hazardous fluids underground. Most of these Class V wells are unsophisticated shallow disposal systems that include storm water drainage wells, cesspools, and septic system leach fields. However, the Class V well category also includes more complex wells that are typically deeper and often used at commercial or industrial facilities.

A national UIC database project was launched in 2008. It is not complete. Some EPA regions have databases that can be obtained by request through the Freedom of Information Act. There is a 2011 EPA Injection well inventory (U.S. EPA, 2012b) whose statistics are summarized in Table 3.1. A database of Class I wells was published in 2007 by the Ground Water Protection Council (GWPC, 2007).

Table 3.1. 2011 EPA Injection Well Inventory

Category	Number
Class I hazardous wells	117
Class I non-hazardous and municipal wells	561
Class II wells	168,089
Class V wells	468,543
Number of states having no Class I wells	33

Source: U.S. EPA, 2012b.

Of note are the much greater use of Class II and Class V wells compared to Class I wells. Several states (36 at this time) do not have or do not allow Class I wells. Reasons for states having no Class I wells include Class I wells not being allowed and Class I wells not having been applied for (in some cases this is because suitable hydro-geological conditions have not been found).

The classes also have different construction requirements. Class I wells require a confining layer between the injection zone and the lowermost USDW. Class I federal construction requirements are found in 40 CFR 146.12 and dictate that all Class I wells have to be “cased and cemented to prevent movement of fluids into or between USDWs.” Further requirements are that all class I wells except municipal wells injecting non-corrosive fluids shall inject fluids through tubing and packer set immediately above the injection zone, or tubing with an approved fluid seal as an alternative.

Class II wells which inject into an oil/gas bearing formation (typically sandstone) have a confining layer that defines the zone. This zone is typically below the lowermost USDW but may be above it. As with Class I wells, all Class II wells must be “cased and cemented to prevent movement of fluid into or between USDWs.” There is no requirement for tubing and packer, however most EPA regions require them. Some states allow no surface casing; some allow no tubing or no packer (U.S. EPA, 2012a).

Figure 3.1 shows a schematic for a Class I well. The design includes concrete covering of all well casing down to the injection zone, as well as a tubing and packer arrangement for monitoring for well leaks from the injection tubing. The packer is the means of isolating the annular fluid from injection fluid at the bottom of the casing string. An annular space between the innermost casing and the injection tubing is filled with fluid whose conductivity is monitored for indication of leakage from the injection tubing. Well and aquifer leakage is also monitored through required monitoring wells.

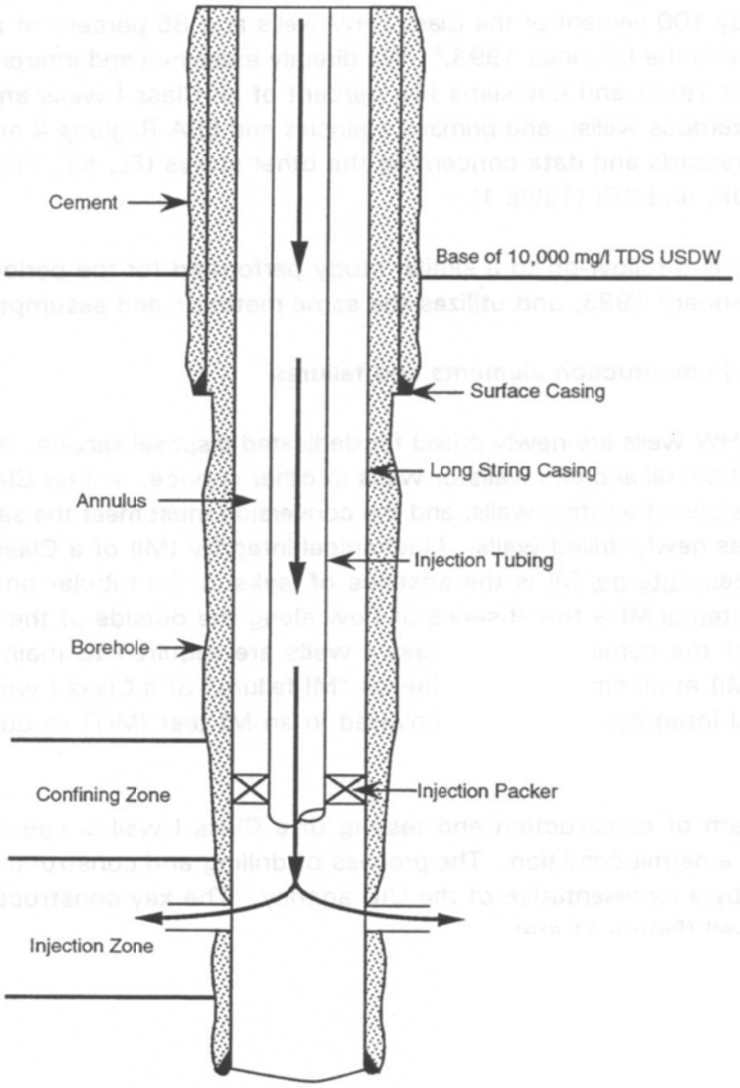

Figure 3.1. Schematic of Class I well.

3.4 Primacy

Primacy or primary enforcement authority is the authority to implement the UIC Program. To receive primacy, a state, territory, or tribe must demonstrate to EPA that its UIC program is at least as stringent as the federal standards. The state, territory, or tribal UIC requirements may be more stringent than the federal requirements.

States can apply for primacy in the following ways:

- To gain authority over all classes of wells or Class I, III, IV, V, and VI state programs must be as stringent as the federal program and show that their regulations contain effective minimum requirements. State regulations must be as stringent as the federal requirements, but may be more stringent Such states are authorized under section 1422 of the SDWA.

- To gain authority over Class II wells only, states with existing oil and gas programs may demonstrate that their program is effective in protecting USDW. Such states are authorized under section 1425 of the SDWA.
- To gain authority over Class VI wells only, states may apply for Class VI primacy under section 1422 of the SDWA for managing UIC GS projects under the Class VI Program. EPA will publish guidance for obtaining primacy for Class VI after the Final Geologic Sequestration Rulemaking (U.S. EPA, 2012c).

EPA has delegated primacy for all well classes to 33 states and 3 territories. It shares responsibility with 7 states. If a state does not obtain primacy for all or some of the well classes, EPA implements the program directly through one of its Regional offices. Currently EPA implements the program for all well classes in 10 states.

Table 3.2 describes the UIC regulatory responsibilities as well as Class I well statistics for states of interest in this report. This includes states in the arid southwest and Florida (included because of the large-scale use of DWI). Note that:

- The primacy status of states for the well classes varies considerably
- The frequent separation of Class II oversight from that of the other well classes
- The widely divergence of experience with Class I wells
- In 2007, only the state of Florida had injection wells for concentrate disposal, but in 2012 both Texas and Colorado also had permitted desal concentrate injection wells

3.5 Minimum Federal Requirements

The UIC regulations establish specific performance criteria for each well class to assure that drinking water source, actual and potential are not rendered unfit for such use by underground injection of the fluids common to that particular category. The requirements are called “minimum” requirements that must be met in all oversight situations. States having primacy may institute more stringent requirements beyond the minimum ones. Areas of minimum requirements include:

- Permit life
- Area of review
- Mechanical integrity testing
- Other well testing
- Monitoring
- Construction
- Logging
- Operation
- Reporting
- Abandonment

Table 3.2. UIC Regulatory Responsibilities for States of Interest/Class I Well Statistics

State	EPA Region	State Regulatory Agencies Involved	Class I, III, IV, V Oversight Agency	Class II Oversight Agency	Prohibited Wells	# UIC Class I Wells[a]	# Municipal Desalination Plant Class I Wells–2007[b]	# Municipal Desalination Plant Class I Wells–2012[b]
Texas	6	• TCEQ • TRRC	TCEQ[c]	TRRC		98	0	2 permits; El Paso; 1 in progress (general permit for SAWS)[f]
New Mexico	6	• NMED • OCD of the New Mexico Energy, Minerals and Natural Resources Department	NMED and OCD[d]	OCD	I for hazardous waste	5	0	0; One application (Sandoval County); later dropped
Colorado	8	• COGCC	EPA	COGCC		5	0	2 permits; ECCV, Sterling
Arizona	9		EPA	EPA	[e]	0	0	1 historical application for injection into a salt dome
	9	• DOGGR	EPA	DOGGR		13	0	0
Nevada	9	• NDEP	NDEP	NDEP	I, II	0	0	0
Florida	4	• FDEP	FDEP	EPA	I for hazardous waste	168	36	50

COGCC: Colorado Oil & Gas Conservation Commission; DOGGR: Department of Conservation, Division of Oil, Gas, and Geothermal Resources; ECCV: East Cherry Creek Valley Water District; FDEP: Florida Department of Environmental Protection; NDEP: Nevada Division of Environmental Protection; NMED: New Mexico Environment Department; OCD: Oil Conservation Division; SAWS: San Antonio Water System; TCEQ: Texas Commission on Environmental Quality; TRRC: Texas Railroad Commission.

[a] Wells from all industries; based on 2007 GWPC report.

[b] Based on Mickley et al., 2012.

[c] Shared oversight -with TRRC.

[d] Mix of oversight.

[e] All aquifers are considered drinking water aquifers; Class I injection is possible but would require aquifer reclassification which has never been done and which would likely be an involved and unmapped process.

[f] El Paso KBH plant operates under a Class V authorization although well is constructed to Class I standards.

Class I, II, and III permitted wells have two major technical requirements that are similar: (1) a mechanical integrity testing requirement is established to assure that leaks do not result in significant movement of fluids into a USDW, and (2) an area of review requirement is established for new wells to assure that existing, improperly completed, and abandoned wells or transmissive faults or fractures within that area (area of endangering influence) do not provide avenues for vertical migration into USDW. Although the technical requirements for Class I, II, and III wells are similar, there are differences warranted by the nature of the waste, well design, and operational characteristics. The specific regulations which address each well class are found in 40 CFR 146, 147, and 148.

3.6 Potential Use of Other Well Classes

Based on well class definitions, disposal of municipal desalination concentrate may, under certain conditions be possible in Classes I, II, V, and perhaps a future new class specific for concentrate. Examining these possibilities further:

Class I: As an “industrial” waste, Class I remains the designated category for disposal of municipal desalination concentrate. Current DWI of membrane concentrate is through Class I wells. The injection zone must be below the lowermost USDW and there are stringent construction requirements (tubing and packer; casing; cementing; etc.) surpassed only by Class I—Hazardous requirements. Concentrate is rarely hazardous and is different from most other “industrial” effluents in having very few process added chemicals; it is essentially concentrated raw ground water.

Class II: Injection of concentrate into a Class II well has the advantage of disposing municipal desalination concentrate into a well that is already constructed. In Texas, for instance, if non-hazardous, concentrate may be used for enhanced recovery of oil and gas without getting a permit; an approval is required from the Railroad Commission, the regulatory group overseeing Class II wells in Texas. Most Class II wells are below the USDW and the well design in many cases is as stringent as Class I wells. Matching the volume of concentrate to the capacity of Class II wells may result in the need for more than a single well as many Class II wells are of limited size. A concern is that a desalination plant may have a much longer lifetime than the Class II wells used for enhanced recovery, which may make the option temporary. Presently, concentrate cannot be injected into Class II disposal wells.

Class V: Injection of concentrate into a Class V well has the advantage of having a shallower, less costly well. The concentrate may need to be diluted with low TDS water to meet the TDS restriction of being less than 10,000 mg/L, and the concentrate must meet primary (and in some states secondary) drinking water standards. This is typically not possible without dilution and sometimes would require removal of isolated contaminants. A large concern and challenge in Florida is with meeting the gross alpha primary standard and as a result many concentrates cannot meet Class V standards just on this parameter. The option is not practical with high recovery (high salinity) brine as it would require too much dilution water to meet the TDS and other standards. The injection aquifer, which by definition is a USDW aquifer, may be exempted if the aquifer is not currently being used, and will not be used in the future as a drinking water source, or it is not reasonably expected to supply public water system due to a high TDS content. An aquifer exemption (AE), if issued by the primacy agency and approved by EPA, would not require dilution of the concentrate.

If permitted the way Class V wells are currently permitted, there would not be the same casing and tubing and packer requirements as for Class I wells - resulting in lower costs.

To date, only one inland facility (the KBH Desalination Facility, in El Paso) has sought and received a Class V permit for injection of municipal desalination concentrate. The well is constructed to Class I specifications, however, to minimize risks. For the operating conditions of the plant, meeting the Class V standards requires diluting the concentrate with fresh water. The facility has obtained an AE which would not require dilution of the concentrate to meet the drinking water standard (Maximum Contaminant Level, MCL) for arsenic.

Class VII (hypothetical new class): The potential advantage would be a class based on concentrate characteristics which might mean in some cases (it would likely be case by case) fewer design and/or operating constraints and thus lower costs. The special class might also represent important policy changes reflecting the urgency of finding CM solutions for municipal desalination concentrate and for an efficient permitting process.

The effort involved to accomplish a new class likely requires much money, effort, and time to bring about. The new classification, Class VI, for CO_2 sequestration, took several years and a considerable lobbying effort by powerful entities, including the US Department of Energy, two Presidential Administrations, and the private energy sector.

These possible options have potential to address the cost aspects of constructing and operating a concentrate disposal well. Other well permit issues such as elapsed time and uncertainties regarding the final disposition from permit application to final well operation also need attention.

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Questions for Readers

- Is the representation of the UIC background information accurate and helpful?
- Is the distinction between deep well classes and their characteristics clear?
- Is the present opportunity for concentrate injection into different well classes clear?
- What changes if any would you recommend?

Issue Paper 4

Deep Well Injection: Barriers and Potential Solutions

4.1 Case to Be Made for Focusing on Deep Well Injection

The focus on deep well injection (DWI) was explained in Issue Paper #2. To recap, concentrate disposal (as opposed to beneficial use) occurs at nearly all municipal desalination (desal) facilities and is a limiting factor in the implementation of municipal desal plants. This is particularly true in the arid Southwest United States where concentrate disposal options most frequently used elsewhere are not widely available. Of the five conventional concentrate disposal options (i.e., surface water discharge, discharge to sewer, evaporation pond, land application, and DWI), DWI has the greatest potential for increased application. However, there are several barriers that presently limit implementation of DWI. This issue paper discusses these barriers and possible means of addressing them.

4.2 General Changes Sought

Changes sought can be listed simply as:

- Making DWI regulations more appropriate to municipal desal concentrate will:
  - Make permitting less burdensome, easier, less time-consuming, and less uncertain
  - Reduce costs—primarily capital and other upfront costs

- Making DWI regulations more scientifically based, taking into consideration the specific nature of the municipal desal concentrate

- Making these changes while also recognizing and addressing all scientifically based environmental concerns

- Making DWI more widely available for disposing of municipal desal concentrate (where hydrogeologic conditions are suitable)

In addition to regulatory/permitting changes, it is anticipated that recommended changes might include:

- Increased education for the public and public officials
- Increased cooperation among regulatory agencies
- Research into technical issues that are not well understood

Table 4.1. Barriers Affecting Implementation of DWI for Inland Desal Concentrate Management

Barrier	General Explanation of Category
Regulatory—General 1. Multiple agencies involved 2. Lack of UIC program funding 3. Limited experience in some states 4. Different mentalities for Class I and II regulations 5. Resistance to making changes 6. Regulations are not specific for desal concentrate	Factors that limit permitting process efficiency, create uncertainties and delays, and inhibit possibilities for change
Regulatory—Specific to Well Class 7. Definition of underground sources of drinking water (USDW) (Class I) 8. Non-use (or prohibition) of Class I in some states 9. Primary standards requirement for Class V (linked to USDW definition) 10. Class II only option is enhanced oil recovery (EOR)	Factors limiting use of individual well classes, or increasing costs, resource loss, and availability of DWI as a viable concentrate management (CM) option
Cost 11. Feasibility study—cost of USDW 12. Feasibility study—general costs (identification and assessment of aquifer hydrogeology and other characteristics) 13. Class I compliance costs 14. Capital cost of final well system 15. Operating cost of final well system	High costs associated with determination of DWI feasibility (test well, testing, hydrogeological studies) and with capital costs of the well system
Hydrogeology 16. Feasibility of injection aquifers not assured 17. Site properties (aquifer confinement, porosity, permeability, capacity) may dictate process changes 18. Distance of suitable aquifers from facility 19. Seismic concerns	Factors that can limit implementation of DWI system

Table 4.1. Barriers Affecting Implementation of DWI for Inland Desal Concentrate Management (cont.)

Barrier	General Explanation of Category
Water Quality 20. Potential for precipitation prior to injection 21. Potential for downhole precipitation/plugging 22. Unknowns associated with high-salinity brines	Factors that require study and could complicate implementation of DWI system
Water Quantity 23. Aquifer capacity may limit concentrate volume or injection life	Volume limitation
Environmental risk 24. Migration from injection aquifer to other aquifers 25. Leaks from well 26. **Potential earthquakes**	Barriers addressed by regulatory requirements (not necessarily suitable for concentrate)
Public Perception 27. Industrial classification 28. Association of DWI with hydraulic fracturing, or “fracking” concerns	Most permits require public review/comment periods; public perceptions affect public approval, and public hearings can significantly delay the process
Lack of Technical Knowledge 29. Guidelines for evaluating downhole injectate-aquifer compatibility 28. Unknowns regarding high-salinity downhole effects	Technical areas that could benefit from research study

4.4.2 2006 UIC National Technical Workgroup Report

The UIC National Technical Workgroup is composed of experts from across EPA's UIC program, and periodically investigates specific issues and generates reports. In December 2006, the workgroup issued a report entitled *Drinking Water Treatment Residual Injection Wells: Technical Recommendations* as part of an ongoing effort to develop an Agency position on Drinking Water Treatment Residual (DWTR) disposal. The definition of DWTR includes, but is not limited to, desal concentrate. The study group identified 104 currently permitted or authorized injection wells which were classified as Class I non-hazardous or Class V wells and their permit requirements. The requirements were stated to be generally similar to federal Class I requirements. The report makes the statement:

> "The resulting recommendations address the concern that the existing regulations contain unnecessary administrative, construction, operation, and monitoring requirements because they are not specific to DWTR injection. Another benefit of using this (recommended) approach is that it allowed for flexibility and additional cost saving opportunities."

The terms "appropriate" and "flexible" are used throughout the report, suggesting that permit requirements could be improved if made on a case-by-case basis that reflected the nature of desal concentrates (and other DWTR).

4.4.3 General Permit (Texas)

In the early 2000s, representatives from the Texas Water Development Board (TWDB) met with EPA to explore potential changes to UIC Class II regulations to facilitate injection of municipal desal concentrate under the oil and gas UIC category. EPA indicated that it did not have the resources nor was the Agency inclined to make rule changes to facilitate CM through the Class II program. EPA suggested that Texas should instead consider relaxing their Class I regulations (but keeping them equivalent to or more stringent than the federal regulations) for municipal concentrate that could be shown to meet appropriate standards. They suggested a "general permit" for Class I non-hazardous wastes for municipal drinking water desal concentrate.

In 2007, Texas began developing a General Permit for Class I desal concentrate and other drinking water residuals. The permit, issued in 2009, offers several changes relative to the existing Class I requirements, including:

- A 0.25-mile radius for review and public comment (as opposed to the 2.5-mile radius previously required for detailed characterization and study)No requirement for concrete on all casing in all casing strings if it can be shown that the design is adequate for the risks
- Less frequent mechanical integrity tests (every five years as opposed to annually)
- Permit review every 10 years (as opposed to every five years)

The major advantage is that the General Permit is more reliant on professional geologists interpreting the data and applying their Professional Engineer (P.E.) seals, rather than requiring internal agency review. The end result is the intent to get permits approved in 90 days rather than the one-year minimum typical time it has taken. The importance of the

General Permit approach taken by Texas is that it is a path for making meaningful changes at the state level and still meeting the requirements of the federal regulations.

Together, the GWPC and UIC National Technical Workgroup reports and the Texas General Permit approach offer:

- Confirmation of the real regulatory challenges associated the injection of municipal desal concentrate.
- Examples of how regulations and permitting might feasibly change for the better.
- A concrete example of one apparently successful approach to making useful changes. (The San Antonio Water System currently is the first water agency in Texas to apply for and obtain a Class I permit under the new General Permit approach, and initial indications are that this has made the DWI permitting process much quicker and simpler.)

4.5 Possible Regulatory Requirement Changes

The following is a tentative interpretation of possible regulatory changes, given for the purpose of fostering workshop discussion.

4.5.1 Concentrate Characteristics

Two characteristics of municipal desal concentrate are:

- Concentrate is different from most industrial wastewaters in that there are few process-added chemicals and, thus, unlike most industrial waste waters, the water quality is not strongly defined/determined by process-added chemicals. Concentrate is, to a large degree, concentrated raw water.
- Simultaneously, since raw water is site-specific, so is the concentrate generated by the membrane process. The specific composition of concentrate can vary (e.g., the constituents and their concentrations), as well as the salinity.
- The solutions that are to be reinjected contain precisely the same materials that were taken out of an aquifer, with the exception of a small amount of antiscalant.

Both of these characteristics might be considered in regulatory requirements for concentrate that go beyond those presently being applied to concentrate as an industrial waste. The first characteristic suggests different regulations for concentrate than for other industrial wastes, and the second factor suggests having flexible regulations to allow for site-specific concentrate characteristics.

4.5.2 Types of Regulatory Requirements

Regulatory “requirements” might be considered to be of two types:

- *Broad event-related, procedural items,* such as represented in a process flow chart or roadmap that describes the required steps involved in navigating the permitting process. This type of event-related roadmap would also include the timing and scheduling of the steps, such as the time limit for agency application review, the frequency for permit renewal, and the need for public comment on every permit.
- *Detailed technical requirements,* such as the specific testing, construction, and monitoring requirements.

Improvements to the regulatory requirements should consider the value and burden of both types of requirements—procedural and technical.

4.5.3 Possible Options for Changes in Regulatory Requirements

Options for changes in regulatory requirements for desal concentrate might include:

- Changes in the first type of regulations (i.e., broad situation-related, procedural regulation requirements)
- Changes in the second type of regulations (i.e., detailed technical requirements)
- Changes in both types of regulations

Such changes in regulatory requirements might apply to concentrate in general (without the flexibility of a case-by-case application), or to concentrate that includes the flexibility of a case-by-case application.

The recommendations of the UIC National Technical Workgroup stress the terms “flexible” and “appropriate” and apply these to the technical type of regulatory requirements. One interpretation of flexible and appropriate is that permit conditions be defined more on a case-by-case basis than is presently done.

The Texas General Permit has aspects of both types of regulatory requirements. However, it appears to provide a set of requirements applicable to concentrate but without consideration for a case-by-case flexibility.

Changes in regulations for concentrate might apply to a given existing well class, such as for changes for Class I, II, and V regulations. Another option is for the designation of a separate class, such as a new “Class VII” that would be specific for community water supply desal concentrate.

4.6 Possible Outcomes for Reducing Barriers

General Regulatory Changes

- Changes that reflect the general nature of concentrate
- Changes that consider the site-specific nature of concentrate
- Changes in permitting (roadmap) events and scheduling (procedural)
- Changes in detailed technical requirements

Regulatory Changes Specific to Class

- Change the definition of USDW for municipal concentrate (Class I)
- Remove/change the requirement of meeting primary drinking water standards for injection under Class V (this may also tie into the issue of how USDW is defined, and the Aquifer Exemption process); perhaps make the applicable requirement be non-degradation of the aquifer water, or based on the ability of existing treatment technologies to render the receiving aquifer water potable, if or when needed
- Allow injection of desal concentrate in Class II disposal wells (in addition to the allowance for EOR)

Level of Change

- Make changes at the state level and/or (less likely) at the federal level (e.g., a federal General Permit under Class I, to apply in states where EPA retains primacy)

Public and Stakeholder Outreach

- Conduct education efforts

Inter-agency Cooperation

- Increase sharing of information across state and federal agencies

Recommend Research Concerning

- Effects of injection of high-salinity concentrate
- Effects of downhole compatibility issues and means of determining effects
- Effect of organic level on antiscalant
- Effects of aquifer media on adsorption phenomena
- Updated cost models
- Characterization of Class II aquifer (capacity, well size, depth with respect to USDW, etc.)

Determine Path for State Reconsideration

- States that currently do not allow Class I to allow some avenue for municipal desal concentrate injection (e.g., a viable process for reclassifying some groundwaters in Arizona as not being USDW)

In sum, the changes sought may be addressed through:

- Changes in regulatory requirements (procedural and technical)
- Increasing inter-agency cooperation
- Public/stakeholder outreach
- Well-defined research

Questions for Readers

Please comment on questions below:

- Is the representation of the case to be made and the general changes sought clear?
- What modifications would you suggest?
- Is the representation of barriers clear, complete?
- What modifications would you suggest?
- Is the representation of possible outcomes clear, complete?
- What modifications would you suggest?
- What do you believe to be the major barriers, and how might they best be addressed?
- Are the descriptions in Section 4.5.1 of Concentrate Characteristic persuasive? If not, how would you change them?

4.3 Barriers to DWI Implementation

While regulatory issues appear to represent the most limiting barriers to DWI, obstacles go beyond regulatory concerns and include impediments in the areas of:

- Hydrogeology
- Water quality
- Water quantity
- Cost
- Environment
- Technology
- Public/political issues

Table 4.1 summarizes presently identified barriers. The entries are not necessarily independent nor complete. They are listed by category with a short description included.

4.4 Framing Events for Regulatory Barriers and Possible Changes

Three events have occurred in the past five years that help to characterize DWI regulatory challenges and suggest changes that might address the regulatory barriers.

4.4.1 2006 Ground Water Protection Council Report

A report describing, among other groundwater issues, the challenges in implementing DWI and underground injection control (UIC) problems in general was published by the Ground Water Protection Council (GWPC) in 2006, entitled *Ground Water Report to the Nation: A Call to Action.*[1] The report lists the main UIC problems as:

- Some UIC regulations are unnecessarily burdensome and have no environmental benefits and, as a result, place impediments on beneficial new technologies that provide new sources of safe water supplies (e.g., desal and associated concentrate disposal) and the ability to capture and sequester carbon dioxide (CO_2). The GWPC message was for the U.S. Environmental Protection Agency (EPA) to revise the classification scheme (which was subsequently done for CO_2, creating a new Class VI for sequestering carbon).
- Severe shortfalls of UIC program resources have limited the implementation of standardized programs and program revisions. The GWPC message was for Congress to increase annual funding for the UIC program.
- Class V wells represent a higher risk area than generally perceived. Class V regulation is an historical and ongoing area with lack of clarity, which is somewhat understandable given the large number of wells and several types (20 subcategories) of wells and injectates. The GWPC message was that from an environmental impact perspective, historical Class V wells have more risk than Class I and Class II wells, and should receive more study and regulation.

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[1] GWPC is a nonprofit 501(c)6 organization whose members consist of state groundwater regulatory agencies which come together within the GWPC organization to mutually work toward the protection of the nation’s groundwater supplies. The purpose of the GWPC is to promote and ensure the use of best management practices and fair but effective laws regarding comprehensive groundwater protection.

Issue Paper 5

Evaporation Ponds

Evaporation ponds are a relatively low-technology approach to concentrate management, where the concentrate is pumped into a shallow lined pond and allowed to evaporate naturally using solar energy. Evaporation ponds can be a viable option for disposing of low volume concentrate flows in regions with relatively warm, dry climates, high evaporation rates, level terrain, and low land costs (Mickley, 2006).

This issue paper describes the opportunities and challenges associated with the use of evaporation ponds for concentrate disposal, including key cost considerations and permitting requirements and processes.

5.1 Opportunities and Challenges

Evaporation ponds are relatively easy and straightforward to construct. Properly constructed ponds generally require little maintenance (e.g., except for pumps to convey the desal concentrate to the pond, no mechanical equipment is required). For smaller volume flows, evaporation ponds are frequently the least costly means of disposal, especially in areas with high evaporation rates and low land costs. Under suitable climatic conditions, evaporation ponds can enable the operation of desal plants under zero liquid discharge (ZLD) conditions, where no liquid waste leaves the plant boundary (NRC, 2008).

Despite these advantages, there are a number of factors that often preclude the use of evaporation ponds as means of concentrate management (Mickley, 2006; NRC, 2008):

- The most significant issue associated with evaporation ponds is the substantial land requirement. Land requirements are a direct function of evaporation rates and concentrate volume.
- Seepage from poorly constructed evaporation ponds can contaminate underlying potable water aquifers.
- Most states require the use of impervious liners of clay or synthetic membranes to prevent the saline concentrate from percolating into the water table. Monitoring requirements also may be applicable. These requirements substantially increase the costs of disposal to evaporation ponds.
- Due to the extensive land requirements and costly liners, ponds are generally only feasible for small volume concentrates.
- If the ponds accumulate solids at a high rate, they may need to be dredged and disposed in a landfill or replaced during the life of the desal plant. This can be a significant added cost.
- Despite preventative berms at the pond edge, there is a potential for wind to blow mist into work areas and onto adjacent land. This may be of environmental and human health concern, particularly if the concentrate contains hazardous materials (e.g., concentrated levels of arsenic or other constituents found in the source waters.

Evaporation ponds can have the potential to provide wildlife habitat; however, elevated levels of salinity and trace elements in the discharge water may have negative impacts on breeding and migrating birds, as was seen with the effects of selenium at the Kesterson National Wildlife Reserve (NRC, 1989; Hannam et al., 2003; NRC, 2008 from Hoffman et al., 1988).

While maintenance needs can be relatively minor, the need for active erosion control and wildlife management should be considered in all cases (NRC, 2008). Other factors that affect environmental water quality include sufficient basin storage volume to prevent overflow in case of major precipitation events, and location of sites topographically above long-term flood reoccurrence intervals of nearby water sources (NRC, 2008).

Finally, researchers have been investigating approaches to enhance net evaporation through methods such as spraying of water into the air and evaporating water from porous vertical surfaces. Some of the methods will likely significantly reduce evaporation pond area requirements and reduce capital costs. While operating costs are typically increased with the use of these methods, the net result is a decrease in total annualized costs.

5.2 Cost Factors

The costs associated with construction of the evaporation ponds are highly site specific. For some applications, an evaporation pond can be a cost-effective disposal alternative; in other locations, costs can be prohibitive (Mickley, 2006). Mickley (2006) identifies the major factors contributing to the cost of an evaporation pond as follows:

- Land costs
- Earthwork
- Lining
- Miscellaneous costs

The cost of land can vary greatly from site to site. Costs vary not only from city to city, but also in the vicinity of a particular municipality itself. Earthwork costs include expenses for activities associated with land clearing and dike construction. The major variable in dike design/cost is the required height of the pond. The pond depth is set by the volume required to accumulate sludge and the height required to prevent overflows (Mickley, 2006).

Miscellaneous costs can potentially include expenses associated with leak detection, disposal of concentrated salts, and contaminated ground/groundwater clean-up. Seepage monitoring or leak detection may be required, depending on the pond construction, the proximity and quality of nearby aquifers, or both.

In addition, the solids collected in the pond may require periodic disposal if the pond is not large enough to hold the total solids volume produced during the life of the plant. Costs associated with solids disposal include dredging the solids from the pond (if feasible), transporting the solids, and landfill disposal costs. In isolated cases, the solids may require stabilization if hazardous materials (e.g., heavy metals) are present. A land intensive alternative is to cover and retire the pond and construct a new pond.

Finally, the earth surrounding the evaporation pond may become contaminated due to seepage or pond overflows. Cleanup of contaminated soils can be a significant cost factor (Mickley, 2006).

As reported in the New Mexico case study developed as part of this research, the Bureau of Reclamation operates three evaporation ponds at their Brackish Groundwater National

Desalination Research Facility (BGNDRF) in Alamogordo. Two of the ponds have a capacity of 341,000 gallons (without freeboard), while the third pond has a capacity of 721,000 gallons (without freeboard). Each pond is constructed with two layers of high density polyethylene (HDPE) with a leakage detector system between each layer. The first layer is 80-mils thick and the secondary liner is 40-mils thick. A 200-mil HDPE geonet acts as a spacer between the primary and secondary liners. The installed cost for these ponds, which were built in 2007, was about $562,700, excluding land costs (only about $0.40 per gallon of capacity for a 1 million gallons per day facility). The Bureau of Reclamation estimates annual repairs and maintenance to be around $1,000 per year for simple repairs to the evaporation ponds. The Bureau of Reclamation costs are relatively inexpensive compared to other costs reported in the literature, due in part to the fact that land costs are not included in this estimate.

5.3 Permitting

Permits for evaporation ponds are not specifically required under either the National Pollutant Discharge Elimination System (NPDES) or underground injection control (UIC) programs. However, individual state requirements and permits apply. In most states, the permit process seems to be relatively straightforward, although permit applications can require extensive technical information, especially related to the assurance that the ponds will not contaminate nearby groundwater.

Because the potential for groundwater contamination exists with any evaporation pond, most states require impervious liners of clay or synthetic membrane. Where the waste discharged to the pond can be verified as nonhazardous and the groundwater in the area is of poor quality, or substantially distant from the pond, a single liner may be acceptable. However, if the water has the potential to contain even trace amounts of hazardous substances, or high-quality groundwater exists in shallow aquifers, double-lined ponds with leak detection systems are typically required (Mickley, 2006).

Some states also require that measures be taken to prevent adverse effects to wildlife. For example, to comply with state of New Mexico Environment Department (NMED) permit requirements, the City of Alamogordo will include netting around their planned evaporation ponds to prevent birds from entering. In Texas, however, no special measures for wildlife protection are required.

A permitting example: Texas Land Application Permit

In order to construct and operate an evaporation pond for concentrate disposal in Texas, desal facility operators must obtain a Texas Land Application Permit (TLAP) from the Texas Commission on Environmental Quality (TCEQ). TCEQ reports that permits are typically issued within 6 to 9 months from the date the permit application is submitted (TCEQ technically has 330 days to issue a permit). This timeframe includes a public comment period.

TCEQ reports that the technical portion of the permit application is quite extensive and is most often completed by consultants. Several studies are typically necessary, including soil surveys, and information on groundwater and wells within a certain area of the proposed pond site. Throughout the permitting process, there is typically a lot of back and forth between TCEQ and the applicant. Once the application is submitted, TCEQ conducts an administrative review and sends out a notice for public comment. In certain circumstances, a hearing may be required.

Following the administrative review, the permit application is reviewed for technical information and adequacy. During the technical review, TCEQ determines/confirms the proposed size of the pond(s) and whether liners and leak detection will be necessary. TCEQ's main concern is that the water stays in pond (i.e., they are cautious of infiltration and overflow). Ponds can be lined with compacted soils (sometimes) or a synthetic liner. Storage capacity is calculated based on the average rainfall and evaporation rate for the area, and ponds are built to meet worst case scenarios. TCEQ requirements assume that the daily average flow is at capacity every day, there is no accumulation from year to year, and that there must be 2' of free board. Once the technical review is completed, TCEQ and the applicant have two weeks to negotiate final requirements.

TLAP is often the only permit needed for concentrate disposal via evaporation ponds. However if solid waste is being kept on site, the desal facility will also likely need to probably obtain a solid waste permit.

It is interesting to note that because desal concentrate is considered an industrial waste in Texas, the TLAP application and requirements for evaporation ponds are different for a desal facility than they are for a municipal water treatment plant (which falls in the municipal waste category). There are actually fewer requirements associated with TLAPs for desal concentrate evaporation ponds because there are fewer requirements related to the treatment process/design chain.

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Questions for Readers

- Are the opportunities and challenges associated with using evaporation ponds clearly stated?
- What modifications would you suggest?
- Are there regulatory, cost, or other factors that impact the viability of evaporation ponds as a CM method, that you believe should be added or discussed in greater detail?

- Is the representation of barriers clear, complete?
- What modifications would you suggest?
- Do you have any suggested solutions to reduce barriers and make evaporation ponds more viable as a CM option?
- Is there any documentation that we can draw upon concerning the disposal of solids from evaporation ponds?

Issue Paper 6

High Recovery Processing

6.1 Introduction

One approach to increasing the potable water yield from desalting—which also reduces the volume of concentrate—can be accomplished using what are referred to as high recovery processes. While the use of high recovery processes is not a concentrate management (CM) option per se, it does alter the volume and nature of the residuals generated by the desalting process and, therefore, ultimately impacts the management of the remaining concentrate.

The volume of first-pass concentrate in municipal desalting systems can be quite large, amounting to 20 to 25% of the input volume. High recovery processing occurs most often from additional processing of the concentrate. This has been referred to in different ways including:

- Concentrate minimization
- Volume reduction
- Zero liquid discharge (ZLD, which applies only in special circumstances where no liquid crosses the plant boundary)

The first pass concentrate is most typically generated by a brackish water reverse osmosis (RO) step, but may result from processing by an electrodialysis reversal (EDR) or nanofiltration (NF) step. In a limited number of cases and depending on the feed water quality, high recovery (i.e., recovery rates of greater than 90%) may also result from the initial membrane step.

High recovery processing is widely and increasingly used in other industries, and is now more frequently being considered for municipal desalination (desal) settings. The reasons for this include:

- The significant and increasing challenges in managing concentrate via the five conventional concentrate disposal options (i.e., surface water discharge, discharge to sewer, deep well injection (DWI), evaporation ponds, land application). High recovery (including ZLD) processing is another way to address CM beyond the five conventional disposal options and beneficial use of concentrate.
- To make more efficient use of the water resource (i.e., to increase usable water yields).
- To provide increased product water when increased facility capacity is not viable.
- The perception (albeit not always correct) that it will be simpler to dispose of a lower volume of concentrate than a larger one.

Although high recovery processing offers an option for managing concentrate, there are barriers to its implementation in the municipal setting. Higher salinity brine may pose challenges for management of the remaining concentrate via conventional options (i.e., DWI and evaporation ponds). Processing all the way to solids requiring disposal, without the involvement of DWI or evaporation ponds, brings a new disposal option to municipal desal facilities—that of landfilling solids, which can be costly.

6.2 High Recovery Processing Options

High recovery processing arguably began with the development of ZLD systems in the 1970s, which were designed to limit discharges from power plants into the Colorado River. The initial systems treated cooling tower blowdown and consisted of thermal brine concentrators (BCs, also known as evaporators) that were either:

- BC → evaporation pond
- BC → crystallizer (thermal evaporator producing solids)

Due to the high capital costs and high energy requirements associated with the evaporator steps, a next generation of systems used brackish water reverse osmosis (BWRO) to reduce the volume of concentrate going to the thermal process steps. These systems included:

- BWRO → BC → evaporation pond
- BWRO → BC → crystallizer

Some systems included only a membrane step such as:

- BWRO → evaporation pond

Further volume reduction prior to thermal evaporation steps is possible by:

- BWRO → coagulation → SWRO → BC → evaporation pond
- BWRO → coagulation → SWRO → BC → crystallizer

Where: SWRO = seawater RO
coagulation = some form of chemical coagulation to reduce the level of sparingly soluble salts and/or silica which limited the BWRO recovery

For municipal desal concentrate from a BWRO facility, these last two options are the ones most often considered for ZLD processing due to their development and commercialization status.

High recovery processing of desal concentrate, however, has been the subject of extensive research and today several other processing options have been considered, some of which have patents and are commercially available.[1]

The bulk of the research has demonstrated that high recovery processing is technically feasible, but it remains costly in all its present forms. The high capital costs result from the additional processing equipment required. The high energy costs are associated with the use of thermal evaporative equipment. These energy costs can be lessened by membrane volume reduction steps, but these in turn impose high chemical costs and increased solids requiring costly disposal. As a result, high recovery processing used in many other industries is not usually cost-effective within the municipal water supply setting.

6.3 Status of High Recovery Processing at U.S. Municipal Desal Plants

In the last decade, high recovery processing has been considered in several initial feasibility studies for municipal desal. However, it typically does not make it past the initial screening of processing options. To date there are only a limited number of high recovery municipal desal facilities: the first in Tracy, California, and others being implemented in Florida. Two examples include:

- A system at the Deuel Vocational Institute in Tracy, California is touted to be the world's first BC system as a key component of an RO drinking water plant at a ZLD facility. It treats 250 gallons per minute (gpm) of groundwater RO concentrate using a seeded slurry BC to reduce the concentrate volume by 97%. The remaining 3% goes to evaporation ponds. The system was commissioned in 2009.
- City of Palm Coast, FL, Water Treatment Plant #2 is a 6.4 million gallons per day (mgd) NF facility currently discharging concentrate to a canal. Permit renewal was denied in 2006 because a mixing zone was no longer allowed. The facility was given a 48-month administrative order to allow continued operation. After studying several alternatives, a pilot lime softening/microfiltration/RO system to treat the NF concentrate was successfully operated. Over 80% of the concentrate was recovered to give an overall recovery rate of 98%. The final concentrate was mixed with lime process sludge that is further mixed with sludge from wastewater treatment plant (WWTP) #1 and used for road base stabilization. This approach avoids concerns with surface water discharge including upcoming numerical nutrient criteria.

6.4 Barriers to Implementation of High Recovery Processing at Municipal Sites

There are several barriers to the broader use of high recovery processes at municipal water utilities, including:

- Costs

    - High capital and operating costs make high recovery approaches cost-ineffective for most municipal water suppliers.

- Regulatory

    - As described in Issue Paper #2, the regulatory barriers are similar to those for lower-salinity concentrate, with some differences. For example, with DWI, high-salinity concentrate is less likely to be suitable for Class V injection.

- Possible increased disposal costs and/or technical challenges

    - For DWI the higher-salinity brine may result in higher precipitation potential within the well and injection aquifer.
    - For evaporation ponds the higher salinity leads to lower evaporation rates, which reduces the time until the pond fills with solids. This in turn leads to increased costs associated with additional pond clean-outs or the construction of new ponds.

  - For landfills the solids from the pre-treatment steps and possibly from final crystallization or evaporation ponds requires disposal at a suitable landfill. Landfill costs can be high for disposal of solids or near solids, including costs for hauling, possible solidification, and final disposal. In some cases (likely limited), highly concentrated brines or mixed solids can be hazardous, which can significantly increase disposal costs.
  - For surface discharge and sewer discharge the options are somewhat less suitable; discharged solids load may be the same as for lower recovery concentrate, but with less accompanying water, such that greater levels of dilution may be required.
  - Unknowns regarding the effects of higher salinity brine on DWI and evaporation ponds.

- Technology

  - Some vertical BCs do not comply with California height limits.

- Water quantity

  - Higher salinity brine has a greater impact for a given volume than lower salinity concentrate.

- Water and environmental quality

  - Higher levels of concentration from high recovery processing lead to higher levels of contaminants, which may render the concentrate/brine as hazardous.
  - Possible greater impacts of the higher salinity/higher constituent concentrations previously mentioned (these impacts are countered somewhat by a reduced volume, which results in a similar salt load).

- Public perception

  - Perhaps better than for conventional recovery concentrate, as the smaller volume may be perceived as having less environmental impacts.
  - The more efficient use of water resources may be positively perceived.

6.5 Changes Sought (Specific for High Recovery Processing)

- Lower costs

  - For both capital and operating costs, through continued research and innovation

- Clarity on research issues

  - Effects of high-salinity brine on DWI feasibility and performance
  - Effects of high-salinity brine on evaporation pond feasibility and performance
  - Likelihood of brine and solids from various high recovery operations being hazardous

6.6 Possible Outcomes (for Reducing Barriers)

- Clarity gained from research
- Change in regulations (similar to that for conventional concentrate)
- Impact of new technologies on costs

Questions for Readers

Please comment on questions below:

- Is the representation of high recovery processing accurate?
- Do you see high recovery processing being more frequently considered, and more frequently implemented in municipal settings?
- What are the major drivers that can increase its consideration?
- What are the major barriers restricting its implementation?
- What changes are needed to make high recovery processing more feasible for the municipal water supply setting?

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1. A more detailed discussion of technical approaches to high recovery processing are not directly relevant to this Issue Paper, but will be included in the final project report. The final report will briefly discuss how the key to achieving high recovery is in how to address precipitation/scaling potential in the concentrate feed to the volume reduction (second desal) step treating concentrate. Various approaches include those where:

- Precipitates are inhibited from happening within the desal equipment
- Precipitates are allowed to happen within the desal equipment
- Precipitating species are removed before desal steps
- Unique processing sequences are used that allow high recovery by other means

Abbreviated examples will be given for each of these approaches (including Tom Davis' ZDD and Tony Tarquin's CERRO systems/approaches). A listing (with minimal description) of various technologies/studied processing schemes under these approaches will also be provided and include SPARRO^{TM} seeded RO, Seeded ($CaSO_4$) thermal BC, New Logic Research VSEP^{TM}, VACOM^{TM} high turbulent MVR evaporator, WaterVap (FBHX^{TM}) fluidized bed heat exchanger evaporator, Altela Inc's ALTELARAIN^{TM} low temperature evaporation system, ZDD's ZLD process, O'Brien & Gere's ARROW^{TM}, EET Corp's HEEP^{TTM}, Aquatech's HERO^{TM}, Tandem RO, RORO^{TM}, Geo-Processors SAL-PROC^{TM}, ACD, ACP, APS, ICCS, ICD, HIPRO, and OPUS.

The purpose of the discussion in the final report will be to (1) reflect the considerable interest in high recovery processing, (2) characterize the directions high recovery processing is taking, and from this (3) more fully characterize the issues and challenges associated with high recovery processing. The final report will also discuss the option of salt recovery as part of high recovery processing. For the purpose of the workshop and this Issue Paper, however, such detail is not required.

Issue Paper 7

Overview of Concentrate Management Case Studies

A series of water utility case studies has been developed as a means to gain a greater understanding of the options and challenges faced by water suppliers in developing inland desalination (desal) operations, with a focus on the concentrate management (CM) options considered and selected, the basis for the selected CM approach, and the cost and permitting issues associated with those CM options. Each case study is written in greater detail, and will be provided as part of the project report. In this issue paper, an overview of the case studies' key issues and findings is provided in summary form. Most of the relevant information is provided in Table 7.1.

The case studies included here consist of the following utilities:[1]

- El Paso Water Utilities (EPWU), which faces severe limits on its allocation of fresh groundwater and surface water, operates the largest inland brackish groundwater desal facility in the United States. The 27.5 mgd facility began operation in 2007. The largest single challenge facing the utility was getting an approved CM approach, which involves deep well injection (DWI) under the Underground Injection Control (UIC) regulatory program delegated to the Texas Commission on Environmental Quality (TCEQ), in accordance with the federal Safe Drinking Water Act (SDWA). This took several years and a considerable sum of money for various studies to obtain the permit and begin operations. Other CM options considered included evaporation ponds, which were economically prohibitive (see Table 7.1); other options (e.g., discharge to surface waters or sewers) were not feasible.

  CM challenges still exist for EPWU, primarily related to the need to have the injectate meet federal drinking water standards [Maximum Contaminant Level (MCLs)], even though the existing quality of the receiving groundwater makes it very unlikely to be considered as a potential drinking water source, and would require extensive treatment if ever tapped for water supply purposes regardless of the concentrate. This MCL requirement is associated with the Class V UIC permit under which EPWU operates, and has necessitated diluting the concentrate (and other operational adjustments) in order to have the injectate comply with the MCL for arsenic. This is expensive and wastes scarce water resources that could otherwise be used to meet the region's water supply needs. EPWU has requested and obtained an Aquifer Exemption (AE) under the State of Texas' UIC regulations, which would be the first step prior to requesting TCEQ's elimination of the requirement that

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[1] Additional, abbreviated inland desal case studies have been examined as well, for Brownsville, TX, Sterling, CO, and the City of North Miami Beach Norwood-Oeffler Water Treatment Plant, FL. These cases were used to gather information to supplement to main case studies summarized here. These supplemental sites will be included in the full project report, and are not included in this Issue Paper because it is intended to be concise, and the additional insights provided by the supplemental sites are limited.

concentrate meet MCLs. AE approvals have been obtained from state and federal regulators.

- The San Antonio Water System (SAWS) is establishing a groundwater desalting facility to help meet growing demands in a highly water-limited setting where freshwater extraction for the Edwards Aquifer has been highly regulated in response to adverse impacts from prior over-exploitation of the aquifer. The range of CM options were evaluated, and DWI was selected as the most suitable (the only other viable alternative was discharge to the San Antonio River, which while feasible under current standards, would likely have undesirable impacts). SAWS is the first utility to use the new Texas "General Permit" for desal concentrate under the state's Class I UIC program, and the General Permit approach appears to have streamlined the regulatory process for DWI considerably (e.g., from over 390 days to about 90 days). The General Permit approach under Class I of the Texas-run UIC program may be a viable model addressing CM challenges in other states.

- The City of Alamogordo, NM, is pursuing groundwater desalting to meet its projected large and growing water supply shortfall. The city has faced several challenges in developing its desal facility, including securing water rights and rights of way, in addition to the CM issue. The city is considering both conventional and high recovery desal processes to maximize water yields and reduce concentrate volumes. The city had initially considered the use of evaporation ponds as its CM strategy (similar ponds are already permitted and in use at a nearby Bureau of Reclamation desal research facility), but there is inadequate land available at the proposed city facility site to accommodate all the brine volume. The city is currently evaluating an accelerated schedule implementing desal, which will include the construction of a temporary small-scale desal plant. The temporary operations will include the use an evaporation pond for CM. The city will later switch to DWI as desal production ramps up toward the targeted production level of 2.9 mgd (and a more permanent facility is completed). The city is in the initial stages of exploring regulatory requirements and permitting-related CM issues pertaining to the evaporation ponds, DWI, and disposal of solids (or near solids) from a high recovery system.

- The East Cherry Creek Valley Water and Sanitation District (ECCV), in the greater Denver metropolitan area of Colorado, began operating a 10 mgd reverse osmosis (RO) groundwater desal system in early 2012, with future plans to expand to 40 mgd to meet growing demands. Initially, surface discharge to an irrigation ditch was considered for concentrate discharge, but this was not a viable CM option because agricultural water needed to dilute the concentrate to acceptable discharge levels is not reliably available. ECCV evaluated a range of other CM alternatives, and determined that DWI, coupled with a high recovery system to reduce concentrate volumes (and increase water yields), would be the most cost effective of the viable options. It has secured a UIC Class I permit from the U.S. Environmental Protection Agency (EPA) Region 8 (because the State of Colorado does not have primacy over the Class I UIC Program) and began operation of an initial disposal well. An additional injection well is being planned to provide redundancy and ensure continuous operation.

- Vero Beach, FL, has been operating a 2 mgd groundwater desal facility since 1992, and is expanding production to 6 mgd to meet growing demands and limited other supply options. At initial production levels, the utility was able to discharge its concentrate to a canal, which in turn flowed to a saline lagoon. A combination of factors preclude continued use of surface discharge, including changes in the applicable water quality criteria for the receiving waters, and the increased volume of concentrate from the expanded desal facility. DWI has been identified as the only feasible CM option, and wells are being developed under the Class I UIC Program administered by the state.

Based on the case studies, a few general observations may be made regarding CM:

- In the arid Southwest (and even in coastal Florida), discharge to surface water or sewer is not likely to be a sustainably feasible option, unless the system is operating at a very small scale (e.g., 0.03 mgd, which is roughly enough water for less than 40 households).
- Evaporation ponds may be a feasible alternative for CM in some locations, but the combination of sizing and associated land requirements, and other expenses (including double lining), make this option economically prohibitive (and often technically infeasible) except for very small-scale desalting operations.
- DWI may often be the only viable option for CM, but UIC permit requirements may create significant challenges in terms of time and expense required to obtain full approvals, uncertainty about whether permits will be issued, and challenges associated with operating under permit conditions. The new “General Permit” provision in Texas under Class I of the UIC Program may serve as a model for a more streamlined approach to DWI permitting.

Table 7.1. Overview of Brackish Groundwater CM Case Studies

	El Paso, TX	San Antonio, TX	Alamogordo, NM	East Cherry Creek, CO	Vero Beach, FL
Project status, and size	Operational since 2007, up to 27.5 mgd.	Under development, 10 mgd by 2016, up to 25 mgd by 2026.	Under development since 2001, planned for 3200 AFY(2.9 mgd).	Initial RO at 10 mgd completed in 2012, planned at 40 mgd at build out.	Operational since 1992 at 2 mgd, expanding to 6 mgd.
CM option(s)	DWI, 22-mile brine line to DWI site, injection at 3 wells of 3700 to 4000 feet deep.	DWI, within 2 miles of desal facility, via 3 wells (depths of 4200 to 4800 feet).	EP for initial small-scale operation, and DWI when production increased. High recovery processes may also be used.	DWI, with HR process added to reduce injectate volume and enhance yield, at 10,500-foot depth.	DWI at upsized desal facility; 2 wells with depths of 1650 and 3000 feet.
CM permit issues	UIC Class V permit, with wells built to Class I standards. 4-year permit approval process, plus over $1.6 million in pre-construction study costs. Discharge must meet MCLs (as Class V permit, because receiving water < 10,000 TDS), unless AE granted (pending, cost close to $1 million).	UIC Class I General Permit (first test of General Permit) Receiving portion of Edwards Aquifer at 90,000 TDS. 5 deep injections wells to be developed (for redundancy, to ensure 3 operable).	EIS includes hydrogeologic assessment and considers site suitable for DWI. HR (ZDD) likely, to increase yield, reduce concentrate volume, and produce some potentially recoverable salts. Solids anticipated to be non-toxic (enabling landfill disposal)?	Pressure testing has been costly and caused delays. Utility siting recognizing concern over earthquake potential. Regulator concern over pressure of injection.	Surface discharge initially used at smaller-scale operation; became unviable as water quality criteria changed and discharge volume increased.
CM costs	DWI-related capital costs of $22.5 million, annual O&M costs of $166,000. Over $1.6 million for pre-construction studies and permit-related efforts. AE effort cost of greater than $1 million.	1 completed well cost $4.8 million to construct, plus $640,000 for planning, design, and permitting. SAWS expects future wells to cost less.	EP concept design cost $175,000 to $250,000 for 500,000 gallon pond (50’x50’x4’), with 2 HDPE liners, netting, and monitoring. DWI well cost estimated at $2.6 million (capital outlay only?) (permit and related costs?). BGNDRF capital cost for 3 EPs about $563,000 (about 1.4 million gallon combined capacity).	$38 million capital outlay ($60 million, including capitalized O&M) for 10 mgd RO system, including HR and DWI. Initial well cost $3.2 million, plus pumps, pipes, etc. Permit costs ~ $100,000. Planned second well estimated total capital cost of $8.9 million. EP total capital cost estimate > $220 million at 10 mgd scale.	Total capital cost of $11 million ($4.7 million for well, and pipeline is largest cost factor).

Table 7.1. Overview of Brackish Groundwater CM Case Studies (cont.)

	El Paso, TX	San Antonio, TX	Alamogordo, NM	East Cherry Creek, CO	Vero Beach, FL
Regulatory agencies	TCEQ for UIC permits, and EPA and TCEQ for AE	TCEQ for UIC permit. TX Railroad Commission also must provide a letter stating that injection will not impact known oil and gas reservoirs.	NM Environment Department.	EPA Region 8 (Colorado does not have primacy for Class I).	Florida Department. of Environmental Protection.
CM options considered	EP (enhanced and passive). Both found to be much more expensive than DWI [by factor of 3 to 4, in present value (PV) terms].	Surface discharge feasible, but not preferred due to concerns for San Antonio River. EP, HR, sewer discharge considered, but none found feasible/reliable.	EP considered for full-scale, but switched to DWI because site limitations on size of evaporation ponds. Also considered sewer disposal and effluent water discharge field.	Surface discharge not viable due to limited, variable (seasonal) dilution of receiving ditch and uncertain availability of blend water. HR and sewer discharge also considered.	Surface discharge via 1-mile discharge line used until desal production expanded. Issues also arose with tighter surface water nutrient standards. No other option but DWI feasible at greater desal production levels.
Other comments	First large-scale inland desal facility completed in United States. Arsenic levels in concentrate challenging to keep below MCL (seek AE). One? injectate well unusable because of proximity to NM border.	General permit approach (new) appears to streamline process (~ 90 days versus > 390 days), and reduce uncertainties.	May be first utility in NM to file for a UIC Class I permit for CM (none issued in state to date).	Step Rate Test (SRT) repeat required by EPA, resulting in snapped cable and loss of pressure transducer to bottom of well. Recovery efforts cost $225,000. Consumptive water rights required to offset concentrate. Municipal contracting requirements limited the number of potential drilling contractors.	Upsizing of desal operation necessitated switch to DWI from surface discharge. Wastewater treatment plant also using DWI for excess reclaimed water. Sewer discharge infeasible (interferes with reclaimed water production).

AE: aquifer exemption; AFY: acre feet per year; DWI: deep well injection; EIS: Environmental Impact Statement; EP: evaporation pond; HDPE: high density polyethylene liner; HR: high recovery (e.g., concentrate minimization, including Zero Liquid Discharge (ZLD); MCL: Maximum Contaminant Level; mgd: million gallons per day; O&M = operations and maintenance; RO: reverse osmosis; TDS = total dissolved solids; UIC: underground injection control, regulatory program under SDWA; ZDD: zero discharge desalination—an HR process developed and applied by UTEP-CIDS/Veolia; BGNDRF: Brackish Groundwater National Desalination Research Facility.

Issue Papers Overview and Summary

Concentrate Management for Inland Desalting

This document provides an overview and summary of key points raised in the Issue Papers developed on the challenges and barriers associated with concentrate management (CM) for community water systems considering inland desalination (desal) as a source of municipal water supply.

Issue Paper 1: U.S. Inland Municipal Membrane Desalination: Background and General Barriers

- Brackish water desal is becoming increasingly important in many regions of the United States because traditional freshwater supply options are highly limited and, in many instances, have already been tapped at their sustainable capacity (or beyond). Inland desalting offers a viable and reliable (e.g., climate-insensitive) supply option in many areas in need of additional water, especially in the arid Southwest (SW) region of the United States.
- The level of municipal inland desal has increased appreciably in the United States since 1990, due to improvements in membrane technology and the increasing need for new water supplies. There has been a notable increase in the number of desal facilities, and also an increase in the typical size of those facilities.
- The key barriers to inland desalting are (1) the overall cost (compared to traditional water supply options drawn from freshwater), (2) relatively high energy demands, and (3) limited options for managing the brine concentrates that are the treatment residual of the membrane process. The relative cost and energy demands associated with inland desalting are becoming less of a barrier as lower-cost traditional water supply options are often unavailable for meeting additional needs and the energy efficiency of membrane processes has improved considerably.
- CM remains the largest impediment to the greater use of inland brackish water desalting in the United States, largely due to regulatory barriers and the associated costs and permitting uncertainties.

Issue Paper 2: Overview of Concentrate Management Options and Barriers

- There are several options for CM that have been applied in the United States. However, the most straightforward and economically viable CM options (i.e., discharge to surface waters, discharge to wastewater treatment plants, and land application) are not feasible in many locations such as the arid SW. They also are infeasible for desal facilities of any appreciable size (e.g., serving 40 or more households).
- Discharge to surface waters, or to sanitary sewers and wastewater treatment plants, is only viable where there is sufficient instream freshwater flow to facilitate compliance with applicable receiving surface water quality standards and associated National Pollutant Discharge Elimination System (NPDES) permits. Only extremely small desal facilities (i.e., serving less than 40 households) and/or those in locations with large freshwater receiving stream flows can use these CM options. Land application

is typically infeasible given the elevated concentrations of the brines found is in desal residuals.

- In the arid SW and many other areas (including Florida), the only viable CM options are (1) deep well injection (DWI), (2) evaporation ponds, and (3) high recovery (HR) processes. HR processes are not disposal options per se, but instead reduce the volume (which increases the concentration) of the residuals, and thus impact CM.
- Data indicate an increasing focus and reliance on DWI over time and as desal facilities get larger. DWI is an important area in which to focus the search for solutions to the CM challenge.
- There are numerous barriers to using the three viable CM options available in the arid SW. Barriers include costs, land area requirements, regulations, and many other factors. Foremost amongst these barriers—especially for DWI—are regulatory requirements and their associated costs and uncertainties.

Issue Paper 3: Overview of Deep Well Injection and the Underground Injection Control Program

- DWI is regulated under the federal Underground Injection Control (UIC) program, established under the federal Safe Drinking Water Act (SDWA). Currently there are six “classes” defined under the UIC program, and desal concentrates (and other drinking water treatment residuals, DWTRs) are officially placed under “Class I.” Class I includes hazardous and nonhazardous industrial wastes, and municipal waste. Class I requirements are stringent because of the hazardous nature of some wastes in this category, and there are relatively few (i.e., less than 600) Class I wells permitted across the United States.

- Under suitable circumstances, desal concentrates also may be discharged under enhanced recovery operations at oil and gas wells, which are regulated under Class II of the UIC program. In some cases, desal concentrate may also be managed under Class V (a miscellaneous category covering a range of nonhazardous substances, including household septic wastes). These alternatives are not generally viable for municipal water utilities using desal (although the El Paso Water Utilities’ groundwater desal facility operates, with operational conditions, under a Class V permit, but its discharge wells are built to the more stringent Class I standards).

- A key feature of the UIC program is the definition of an Underground Source of Drinking Water (USDW), which is intended to indicate groundwaters that are—or might conceivably in the future serve as—a source of drinking water. USDWs are currently defined as any groundwater with Total Dissolved Solids (TDS) levels of 10,000 mg/L or less.

    - Injection above or into an USDW is prohibited under Class I, and most other classes in the UIC program, regardless of (1) the overall quality of the groundwater found in the USDW zone (i.e., concentration of contaminants/constituents other than TDS), (2) the likelihood (or lack thereof) of there being a future need to use the aquifer as a drinking water supply, or (3) the ability to effectively remove relevant injectate constituents from the receiving groundwater if the aquifer is tapped for drinking water purposes in the future.

    - An “Aquifer Exemption” (AE) is required from state primacy agencies and the U.S. Environmental Protection Agency (EPA) for discharging into or above an

USDW any concentrate that exceeds a primary drinking water standard (i.e., a Maximum Contaminant Level, MCL). This issue applies to El Paso's operations under Class V (for the arsenic MCL). This also applies throughout Arizona where all Class I wells are precluded by the state's designation of all of its groundwaters as USDWs.

- Recently, Class VI was added to the UIC program for geologic sequestration of carbon dioxide, as part of a national strategy to reduce greenhouse gas emissions. The creation of a new "class" under the UIC program was difficult and took many years, despite high-level backing by two federal administrations and private energy firms. Nonetheless, the Class VI precedent suggests the possibility (albeit remote) of creating a new "Class VII" for municipal desalting concentrates. However, creating a new "Class VII" specifically for a residuals stream that is already specifically included under Class I might be very difficult, especially given the very limited resources available to EPA and its UIC program.

Issue Paper 4: Deep Well Injection: Barriers and Potential Solutions

- In the arid SW, DWI often is the only practical, viable approach to CM for public water supply desal at any practical community-size scale.

- There are a wide range of barriers to DWI, including regulatory, hydrogeologic, economic, and numerous other factors. Regulatory and related permitting issues often are the most significant obstacles.

- Reports developed in 2006 and 2007 by the Groundwater Protection Council (GWPC) and the federal UIC National Technical Workgroup (NTW)—organizations that represent UIC regulators and regulatory agencies—express a clear recognition that:

    - Some UIC regulations are unnecessarily burdensome and have no environmental benefits and, as a result, place impediments on beneficial new technologies that provide new sources of safe water supplies (e.g., desal and associated concentrate disposal) (GWPC, 2007)

    - "Existing regulations contain unnecessary administrative, construction, operation, and monitoring requirements" because they do not address the specific nature of desal concentrates or similar DWTRs. Recommendations are offered to allow for greater "flexibility and additional cost-saving opportunities" (NTW, 2006, p. 3).

- The Texas Water Development Board (TWDB) met with EPA to explore changes in Class II regulations to broaden the ability to use oil and gas wells for concentrate disposal. EPA instead suggested that Texas develop a "General Permit" for desal concentrate under Class I. Texas has since developed and issued a General Permit under Class I, and initial use of this approach by the San Antonio Water System suggests that the General Permit approach may effectively streamline the permitting process. This suggests a promising route to explore for other states, and perhaps for the federal EPA as well (i.e., to apply in states where EPA retains Class I primacy).

- Future efforts to address UIC-related regulatory hurdles to CM need to address both the *procedural* and the *technical* requirements associated with the permit process (the Texas General Permit accomplishes both). Future efforts also should recognize that desal concentrate is very different from industrial wastes in that it is not significantly impacted by process-added chemicals and, given that it instead reflects the characteristics of the source waters, the composition of desal concentrate is often very site-specific.

Issue Paper 5: Evaporation Ponds

- Evaporation ponds are a relatively low technology, low-cost, and easy-to-permit CM option for desal facilities that are very small (i.e., very low discharge volumes) and located in arid areas (i.e., high evaporation rates) with relatively flat terrain and inexpensive land costs.
- Costs for evaporation ponds can escalate quickly as the size of the facility and volume of concentrate magnify land area requirements. Costs and regulatory requirements also increase in areas with high-quality groundwater underlying the site (as dual liner, monitoring, and related regulatory requirements become more likely), and/or areas prone to large precipitation events (which increase the likelihood of flooding and overtopping).
- Solids and near solids from evaporation ponds may contain constituents at concentrations that render them hazardous, and that may need to be removed and transported to suitable landfills or other waste management facilities. This can significantly increase costs and regulatory issues.
- In some locations, netting and other approaches are required to minimize potential impacts to wildlife.
- Evaporation ponds are not likely to be a viable CM option for community water system desal facilities that are of any appreciable size (e.g., greater than 1 mgd).
- Researchers are investigating approaches to enhance net evaporation through methods such as the spraying of water into the air and evaporating water from porous vertical surfaces. These methods will likely significantly reduce evaporation pond area requirements, potentially increasing the feasibility of evaporation ponds for larger facilities.

Issue Paper 6: High Recovery Processing

- While HR approaches are not a CM option per se, they do impact the volume and characteristics of the concentrate and, thereby, impact the costs and viability of CM options. The benefits of high recovery processing include more efficient use of the water resource (i.e., to increase usable water yields). In addition, high recovery processes allow for increased product water where increased facility capacity is not viable.

- Although reducing the volume of concentrate can be useful, the increased concentration of constituents extracted from the source waters (e.g., arsenic, radionuclides) may create additional challenges for managing the concentrate.
- High recovery processes can increase disposal costs and/or technical challenges associated with conventional disposal options. For example, for deep well injection, higher salinity brine may result in higher precipitation potential within the well and injection aquifer. For evaporation ponds, the higher salinity leads to lower

evaporation rates and separately, to reduced time until the pond fills with solids. This in turn leads to increased costs associated with pond clean-out or construction of new ponds.

- Processing all the way to solids requiring disposal brings a new disposal option to municipal desal facilities—that of landfilling solids. Landfill costs can be high for disposal of solids or near solids, including costs for hauling, possible solidification, and final disposal. In some cases (likely limited), highly concentrated brines or mixed solids can be hazardous, which can significantly increase disposal costs.
- The regulatory barriers associated with high recovery processes generally are similar to those for lower salinity concentrate, with some differences. For example with deep well injection, high salinity concentrate is less likely to be suitable for Class V injection due to the concentrated nature of the brine.
- The bulk of the research has demonstrated that high recovery processing is technically feasible, but it remains costly in all its present forms. The high capital costs result from the additional processing equipment required. The high energy costs are associated with the use of thermal evaporative equipment. These energy costs can be lessened by membrane volume reduction steps, but these in turn impose high chemical costs and increase solids requiring costly disposal. As a result, high recovery processing used in many other industries is not usually cost-effective within the municipal water supply setting.

Issue Paper 7: Overview of Concentrate Management Case Studies

- The project team developed a series of water utility case studies to gain a greater understanding of the options and challenges faced by water suppliers in developing inland desal operations. The case studies are focused on challenges associated with CM in inland settings for the following utilities:

    - El Paso Water Utilities (EPWU)
    - San Antonio Water System (SAWS)
    - The City of Alamogordo, New Mexico
    - East Cherry Creek Valley (ECCV) Water and Sanitation District
    - The City of Vero Beach, Florida

- Each case study details the CM options considered and selected by the utility, the basis for the selected CM approach, and the cost and permitting issues associated with those CM options.

- All of the case study entities found that discharge to surface water or sewer was not a sustainably feasible option for CM due to their relatively large volume of concentrate they would be producing [discharge to surface water or sewer is generally only feasible for desal facilities operating at a very small scale (e.g., 0.03 mgd, which is roughly enough water for less than 40 households)].

- Although evaporation ponds were found to be a technically feasible alternative for CM in some locations, the combination of sizing and associated land requirements, and other expenses (including double lining), made this option economically prohibitive for the case study entities that considered it.

- Ultimately, all of the case study entities implemented, or plan to implement, DWI as their primary means of concentrate disposal. Alamogordo plans to implement evaporation ponds at their desal facility in order to manage concentrate from initial small-scale operations. The city may switch to DWI as production at their desal facility ramps up to 2.9 mgd.

- Although the case study entities found DWI to be the most viable option for CM, UIC permit requirements created significant challenges in terms of time and expense required to obtain full approvals, uncertainty about whether permits will be issued, and challenges associated with operating under permit conditions. The new “General Permit” provision in Texas under Class I of the UIC program may serve as a model for a more streamlined approach to DWI permitting.

References

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