A Technical Assessment of

Protection of Underground Sources of Drinking Water under the UIC Rule and Aquifer Exemption Program

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Prepared with support from the American Petroleum Institute (API)

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Table of Contents

Tables

Figures

Appendices

1.0 EXECUTIVE SUMMARY

This paper examines the adequacy of groundwater protection under the "aquifer exemption" provision of the Underground Injection Control (UIC) rule that was issued in 1980 by the U.S. Environmental Protection Agency (USEPA). It focuses on injection wells used for oil and gas operations and provides a technical assessment of the aquifer exemption program, including its history, its specifications, and its regulatory enforcement – all within the context of future underground drinking water needs. This study finds that the current UIC program, properly implemented, adequately protects both existing and future sources of potential drinking water.

The UIC rule recognizes that injection wells are needed for safe management of produced water from oil and gas operations, and reflects the Congressional directive to minimize constraints on energy production while still protecting drinking water (H. Rpt. 93-1185, 1974). Injection of wastewater into an Underground Source of Drinking Water (i.e., an aquifer with a Total Dissolved Solids (TDS) content below 10,000 mg/L) is not allowed, unless an aquifer exemption is granted. The exemption application must demonstrate, at a minimum, that drinking water will not be harmed because: i) the aquifer TDS is above 3,000 mg/L and is not likely to be used as a public drinking water supply, or ii) the aquifer is an oil and gas production reservoir. Commonly, the application process entails review and approval by the tribal or state regulatory agency, followed by a second round of review and public meetings by USEPA.

Today, in arid regions of the country, desalination of brackish groundwater (TDS > 1,000 mg/L) is increasingly used to supplement public water supplies (Maupin et al., 2014). In light of increased demand for potable water, this paper assesses the effectiveness of the UIC rule and finds that:

1) ***Evaluations of state regulatory agencies show that the current UIC regulations have been effective for protection of underground sources of drinking water (USDW)***. In some cases, significant gaps in proper regulatory management of the current rules must be addressed. However, these cases have not resulted in groundwater impacts, and nationwide surveys find impacts on drinking water aquifers by produced water injection wells to be very rare and to entail local and isolated problems when observed (GAO, 2014; ICF, 1995; Michie, 1989; GAO; 1989).

2) ***For aquifers that are not oil and gas reservoirs, the aquifer exemption criteria are protective of the saline groundwater resources that are currently in use or expected to be used in the future.*** Today, nearly all groundwater desalination plants use groundwater with TDS below 3,000 mg/L (USEPA, 2014; Hildebrandt, 2015), into which injection is not allowed. Future plants will continue to rely principally on low-salinity groundwater due to lower energy use, cost, and waste (CDWR, 2014; NRC, 2008).

3) ***For aquifers that are oil and gas reservoirs, use as a drinking water supply is commonly infeasible due to the need to both desalinate and remove dispersed and dissolved petroleum.*** No groundwater desalination plants currently use oil and gas reservoirs. However, in certain low-salinity reservoirs, advanced pretreatment by oilfield operators provides water suitable for irrigation, as a compatible use.

4) ***Stricter TDS limits for a USDW or an aquifer exemption would not improve protection of drinking water, but would impose a significant economic impact on many industries.*** For many industries, disposal by underground injection is essential to the license to operate. Modifying the UIC rule, which has been found to be protective, would impair their economic viability, with no net environmental benefit.

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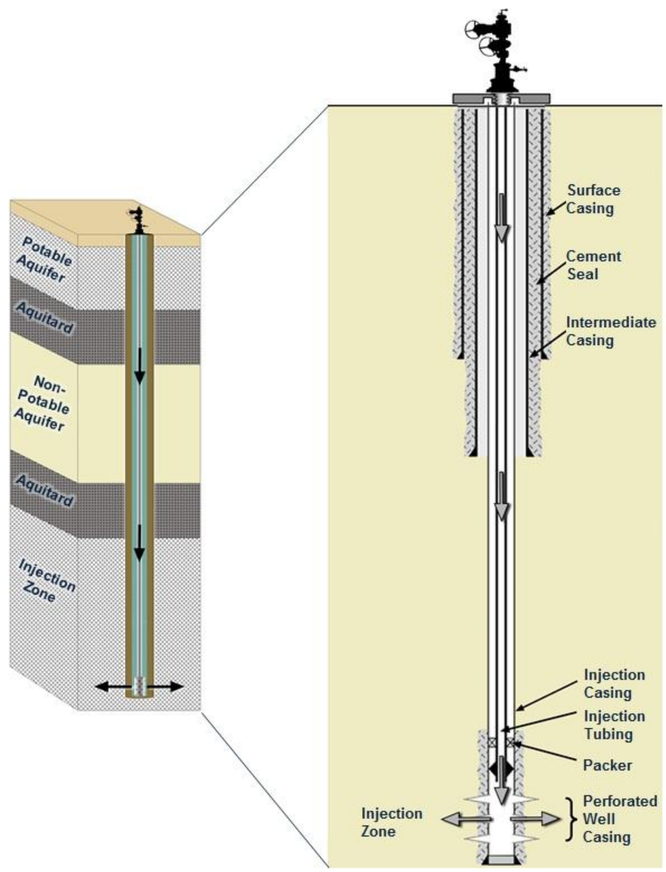
2.0 USE OF UNDERGROUND INJECTION WELLS

Wastes disposed of by injection are generated by a broad range of commercial, industrial, and municipal operations, including: chemical, steel, plastics, and pharmaceuticals manufacturing; municipal water desalination facilities; oil and gas production; metals mining and refining; electric power generation; animal and food processing; carbon dioxide sequestration; and environmental remediation (Knape, 2005; GWPC, 2016). In total, more than 680,000 injection wells (USEPA, 2015d) are currently operating in the U.S. for the subsurface disposal of liquid waste materials, replenishment of depleted aquifers, prevention of salt water intrusion, sequestration of carbon dioxide, enhancement of oil and gas recovery, extraction of minerals, and many other uses (USEPA, 2002).

Figure 1. *Typical Injection Well Design.*



As shown on **Figure 1,** an injection well used for waste disposal or mineral extraction consists of several concentric strings of steel pipe that are used to pump liquids into deep geologic formations. As specified by applicable regulations for each well classification, the injection wells must be designed, constructed, and operated with multiple safeguards to deliver liquid to the injection zone, without impacting the other water-bearing zones through which the well may pass (USEPA, 2002).

Under U.S. Environmental Protection Agency (USEPA) regulations, injection wells are organized into six different classifications based on their use (type of activity, type of fluid injected, and depth of injection) (USEPA, 2002), as described on **Table 1**. Among these various classes, Class II wells are distinct from many other injection wells in that they *re-inject* waste fluids originating from the subsurface in association with oil and gas operations rather than injecting a newly generated waste material (USEPA, 2002).

The total dissolved solids (TDS) content of produced water ranges from less than 10,000 milligrams per liter (mg/L) to over 200,000 mg/L (IOGCC, 2006), and is commonly more saline that seawater (approximately 35,000 mg/L TDS) (**Figure 2**) (USGS, 2016; Veil, 2015). (Definitions of salinity vary among different publications. In this report, the terms “fresh,” brackish,” and “saline” match the definitions as shown on **Table 2.**)

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The characteristics of produced water vary with the type of hydrocarbon being produced, the geographic location of the well, and the method of production used (GAO, 2012).

In a 2012 report on produced water management, the U.S. Government Accountability Office (GAO) compiled and reviewed data on produced water: i) volume and water quality; ii) management and treatment practices; iii) federal and state regulations; and iv) federal research and development efforts (GAO, 2012). GAO found that water quality limitations specified in state and federal regulations are the key reason that most produced water is managed through underground injection (GAO, 2012). USEPA and state regulatory agencies have determined that underground injection "is a safe, widely used, proven, and effective method for disposing of produced water" (Veil, 2015).

Over 186,000 Class II injection wells are presently in use in the U.S., with the greatest number of wells located in Texas and California, as shown on **Figure 3** (USEPA, 2015d). In general, two types of injection wells are used for the management of produced water: 1) enhanced oil recovery (EOR) wells that replace the water in the oil and gas formation to improve oil production and maintain reservoir pressure (Veil, 2015; Veil et al., 2004), and 2) disposal wells that inject treated produced water into compatible formations (Veil et al., 2004; GAO, 2012).

Table 1. *Classes of UIC Wells (USEPA, 2016c).*

UIC WELL CLASS	*DESCRIPTION*
I	Used to inject hazardous and non-hazardous wastes into deep, confined rock formations. **(0.1% of Wells.)**
II	Used only to inject fluids associated with oil and natural gas production. **(26% of Wells.)**
III	Used to inject fluids to dissolve and extract minerals. Production wells, which bring mining fluids to the surface, are not regulated under the UIC program. **(3% of Wells.)**
IV	Shallow wells used to dispose hazardous or radioactive wastes into or above a geologic formation that contains a USDW. New Class IV wells are prohibited by rule. **(<<1% of Wells.)**
V	Used to inject non-hazardous fluids underground. Most Class V wells are used to dispose of wastes into or above underground sources of drinking water. Most Class V wells are for septic systems, stormwater drainage, and agriculture. **(70% of Wells.)**
VI	Used to inject carbon dioxide into deep rock formations. **(<<1% of Wells.)**

Figure 2. *Salinity of Produced Water from Conventional Oil and Gas Wells (Source: Guerra et al., 2011).*

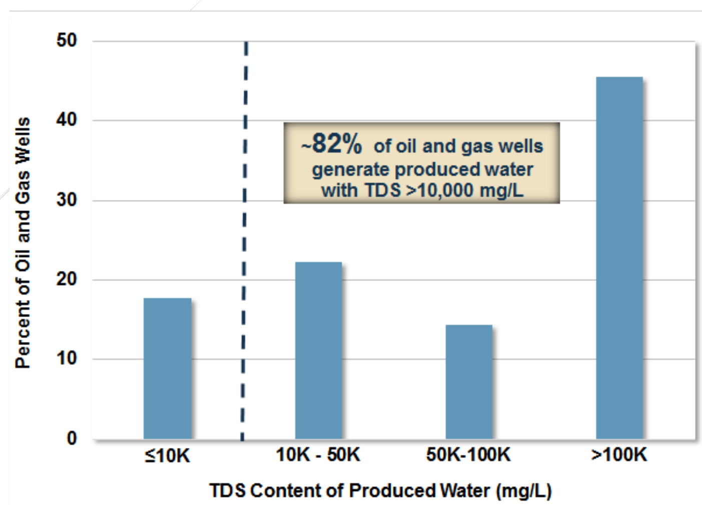

Table 2. *Definitions of Fresh, Brackish, and Saline Water (USGS, 2016; LBG-Guyton, 2003).*

WATER CLASSIFICATION	*TDS RANGE*
FRESH WATER	Less than 1,000 ppm.
BRACKISH (SLIGHTLY SALINE WATER)	From 1,000 ppm to 3,000 ppm.
BRACKISH (MODERATELY SALINE WATER)	From 3,000 ppm to 10,000 ppm.
HIGHLY SALINE WATER	From 10,000 ppm to 35,000 ppm.

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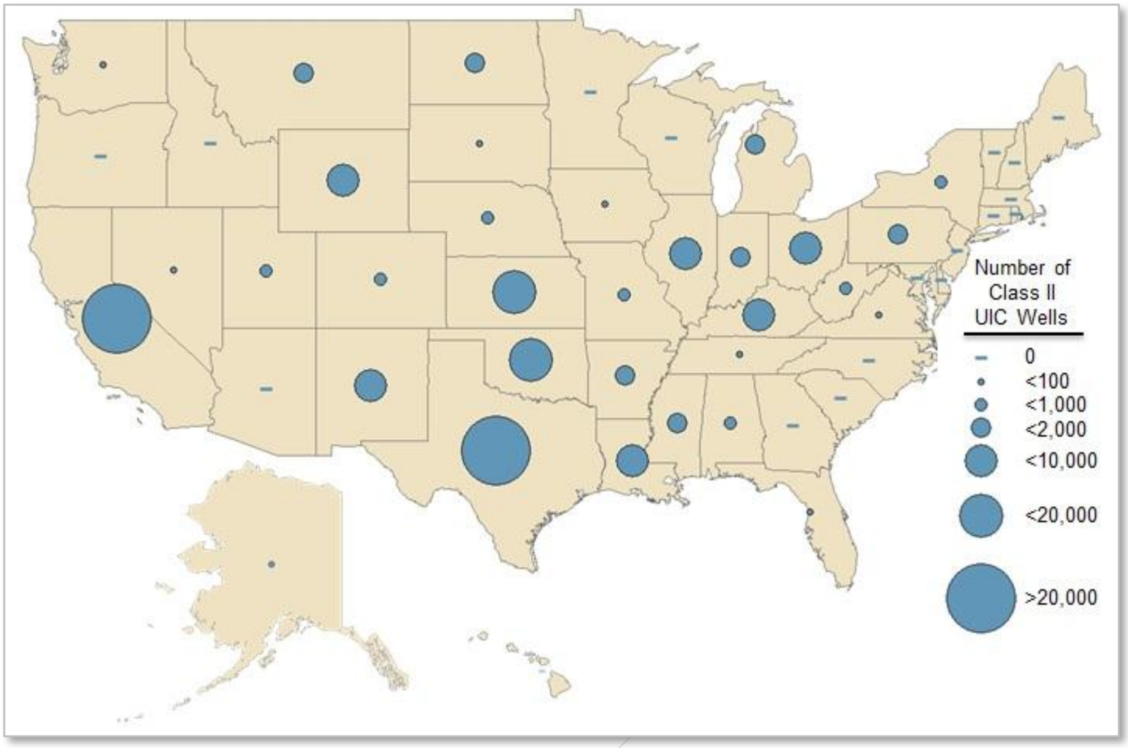
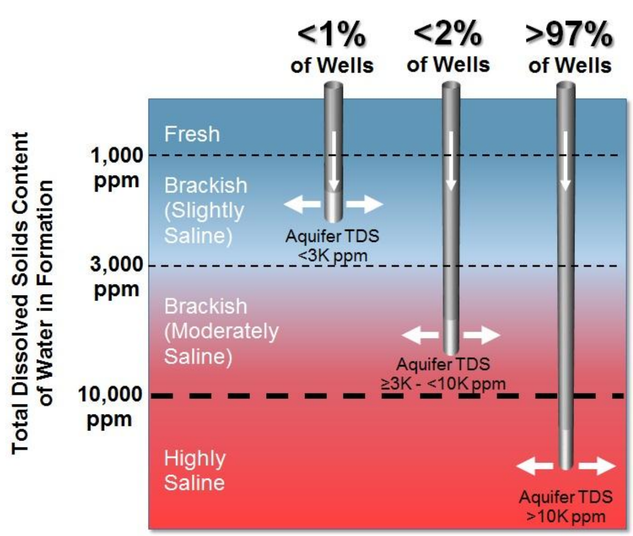
Figure 3. Number of Class II Injection Wells by State.



Source: USEPA, 2015d.

Figure 4. *Salinity of Zones Used for Class II Injection Wells.*



Source: USEPA, 2015d,e.

Injection zones that typically receive the produced water are either the same formation from which the produced water was extracted or a formation that is similar (GAO, 2012) and commonly contain highly saline water, as indicated on **Figure 4**. Based on the USEPA 2015 Injection Well Inventory (USEPA, 2015d) and the number of available approved aquifer exemptions for Class II wells providing water quality information (Bergman, 2015; USEPA, 2015e), over 97% of Class II injection wells inject into formations containing water with TDS levels greater than 10,000 mg/L – a salinity level that is commonly considered unusable for drinking water, agriculture, or industrial purposes (Warner, 2001; IOGCC, 2006). Less than 1% of injection wells return produced water to formations containing water with TDS levels below 3,000 mg/L (USEPA, 2015d,e), which requires an aquifer exemption. Water with TDS above 3,000 mg/L is used to a limited extent in the U.S. today, most commonly following treatment and/or blending with fresh water to reduce its salt content suitable for irrigation and livestock watering (Warner, 2001). Saline water with a TDS content exceeding 3,000 mg/L is "not reasonably expected" to supply a public water system (CDWR, 2014).

Key Findings Regarding Use of Underground Injection Wells: *Injection wells are designed and constructed to protect underground sources of drinking water. Waste fluids are injected only into the approved injection zone. Class II injection wells are used to inject fluids that are produced in conjunction with oil and gas operations. Approximately 97% of these oil and gas injection wells inject into aquifers with TDS > 10,000 mg/L, a salt concentration that is generally considered unusable for drinking water, agriculture, and industrial uses and is not considered a USDW.*

3.0 HISTORY, RATIONALE, AND TECHNICAL SPECIFICATIONS OF THE UIC REGULATION AND AQUIFER EXEMPTION PROVISION

The federal Safe Drinking Water Act (SDWA) of 1974 established measures for protection of the nation's drinking water resources (including lakes, rivers, and groundwater) that remain in effect today and provide the foundation for state and federal regulations on drinking water quality, treatment, and preservation (GAO, 2012). The 1980 federal Underground Injection Control (UIC) regulations built upon and established minimum requirements for state UIC programs that had been initiated in the 1960s. Technical provisions of the federal UIC rules include the definition of an Underground Source of Drinking Water (USDW); the engineering specifications for injection well design, construction, and operation; and the rationale and criteria for an aquifer exemption application. These rules reflect an effort to balance the need for and benefits of subsurface injection with the preservation of groundwater resources that could reasonably be used as drinking water today or in the future. Today, the aquifer exemption process entails a multi-step process of review by USEPA, including public notification and hearing sessions, and USEPA response to public comments, to evaluate the suitability of the specific case for an exemption from the USDW criteria. For states or tribal agencies that have primacy for the UIC program, the application process entails sequential reviews by both the state or tribal agency and the USEPA with separate public notification, hearing, and response cycles.

This section reviews the history, rationale, and current specifications of the UIC aquifer exemption program as a foundation for evaluation of adequacy of the regulations for groundwater protection.

3.1 The UIC Rule sought to balance the protection of groundwater with the need for safe underground disposal of wastewater.

The increased use of underground waste injection wells in the 1960s was accompanied by state regulations for well design, permitting, and operation. By 1970, sixteen states had established regulations for injection wells (Warner, 1967). The SDWA authorized these state UIC programs and directed the USEPA to create a Federal-State system of regulation to ensure underground drinking water sources were not adversely impacted by underground injection activities (H. Rpt. 93-1185, 1974; Tiemann, 2010). At that time, the USEPA policy on the "Subsurface Emplacement of Fluids" (USEPA, 1974) noted that:

> *The emplacement of fluids by subsurface injection often is considered by government and private agencies as an attractive mechanism for final disposal or storage owing to: (a) the diminishing*

> *capabilities of surface waters to receive effluents without violation of quality standards, and (b) the apparent lower costs of this method of disposal or storage over conventional and advanced waste management techniques. Subsurface storage capacity is a natural resource of considerable value and like any other natural resource its use must be conserved for maximum benefits to all people* (USEPA, 1974).

USEPA policy also recognized the importance of injection wells to the energy industry for safe management of produced water:

> *The EPA policy recognizes the need for injection wells in certain oil and mineral extraction and fluid storage operations but requires sufficient environmental safeguards to protect other uses of the subsurface, both during the actual injection operation and after the injection has ceased* (USEPA, 1974).

This consideration also reflected instructions from the U.S. Congress regarding the SDWA:

> *This amendment prohibits regulations for State UIC programs from prescribing requirements which would interfere with production or oil or natural gas or disposal of by-products associated with such production, except that such requirements are authorized to be prescribed if essential to assure that underground sources of drinking water will not be endangered by such activity* (H. Rpt. 93-1185, 1974).
>
> *[T]he Committee sought to assure that constraints on energy production activities would be kept as limited in scope as possible while still assuring the safety of present and potential sources of drinking water* (H. Rpt. 93-1185, 1974).

In passing the SDWA, Congress ratified the USEPA policy regarding the importance of deep well injection and incorporated the practice of underground storage and disposal into the legislation (H. Rpt. 93-1185, 1974). In June of 1980, USEPA issued minimum requirements for state regulatory programs to protect underground drinking water sources from endangerment by the subsurface emplacement of fluids through well injection (USEPA, 1980). Today, 41 states, three territories, and two tribes have primacy for implementation of the federal UIC program for Class II wells (USEPA, 2017), and directly manage the injection well program subject to USEPA oversight (40 CFR Part 147). USEPA has direct authority over Class II UIC programs in nine states, two territories, and all other tribes (USEPA, 2017).

3.2 UIC permit specifications require injection wells to be designed, constructed, and operated to protect groundwater resources.

Federal rules specify design, construction, and operating procedures for each of the six classes of injection wells (**Table 1**) to ensure protection of underground drinking water sources. All injection wells, including Class II injection wells used to dispose produced water from oil and gas operations, must meet the following requirements:

- **All injection wells must be permitted by a regulatory authority:** Before use, the injection well must meet all relevant design and construction specifications and be approved by rule or by permit issued by the regulatory authority.
- **The injection well must be designed and operated to prevent movement of the injected fluid into a USDW:** Injection wells must be constructed, operated, maintained, converted, plugged, and, when permanently shut down, abandoned in a manner protective of underground drinking water resources. No injected fluid may migrate into underground sources of drinking water if constituents

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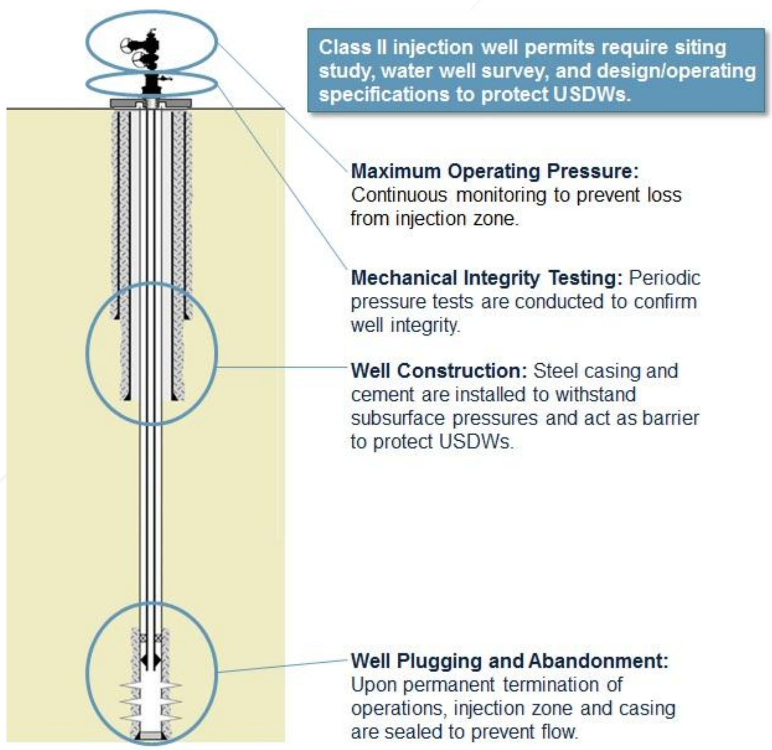
present in the fluid will cause a violation of a primary drinking water regulation or otherwise endanger human health (40 CFR Part 144).

- **The area surrounding the well site must be reviewed to ensure safe conditions:** Within a large radius around the injection well, water wells that could be harmed by the injection activity and other features that could serve as a conduit for fluid migration to a USDW must be identified and assessed. Wells that are found to be improperly sealed, completed, or abandoned must be addressed as needed to protect USDWs (40 CFR Part 146).
- **The mechanical integrity of the injection well must be maintained and routinely tested:** Injection wells must be periodically tested to ensure that there are no leaks in the casing, tubing, or packer that could result in fluid movement into a USDW. Pressure tests, monitoring, records of injection pressure and injection flow rate, logs, cementing records, or other routine operations are required to demonstrate proper mechanical integrity (40 CFR Part 146).

A typical Class II injection well (**Figure 5**) is designed with safeguards to protect underground drinking water sources as required by federal regulations (40 CFR Part 146). These safeguards include casing, cementing, tubing, and packer; mechanical integrity testing; injection pressure control; and well operation monitoring and reporting (GAO, 2014). State regulations for injection wells must be equal to or more stringent than federal requirements, but cannot be less stringent.

***Figure 5.** Design and Operating Requirements for Class II Injection Wells.*



3.3 The definition of a USDW is intended to provide a margin of safety for usable groundwater.

UIC regulations specify which types of aquifers are to be protected from impacts by injection wells. In general, the rules define groundwater containing TDS concentrations less than 10,000 mg/L to be potentially usable as drinking water. Under 40 CFR §144.3, the key definitions regarding protected groundwater are as follows:

- *An* aquifer *is a geological formation, group of formations or part of a formation that is capable of yielding a significant amount of water to a well or spring.*
- *An* underground source of drinking water *is an aquifer, which:*

   i. Supplies any public water system.

ii. Contains a sufficient quantity of groundwater to supply a public water system and either currently supplies drinking water for human consumption or contains fewer than 10,000 mg/L TDS.

iii. Is not an exempted aquifer.

The 10,000 mg/L TDS limit for definition of a USDW was based upon the U.S. House of Representatives report (H. Rpt. 93-1185, 1974) for the SDWA which stated "the Committee expects the Administrator's regulations at least to require states to provide protection for subsurface waters having less than 10,000 ppm dissolved solids, as is currently done in Illinois and Texas." In the final UIC rules issued in June 1980, USEPA responded to comments regarding the reasonableness of the 10,000 mg/L TDS level as the definition of a USDW:

> *EPA has carefully reviewed these alternative suggestions [for an alternative concentration level for TDS] and has once more decided to retain the standard of 10,000 mg/L of TDS. None of the alternative concentrations have any superior justification in terms of current State practice, human health, or technological considerations. In the absence of any overriding argument to the contrary, the Agency will follow the standard in the House Committee Report accompanying the SDWA* (USEPA, 1980).

The 10,000 mg/L TDS threshold has an established history in federal regulatory policy, and has been reviewed by USEPA over time to ensure that underground sources of water for human consumption are protected under the UIC program (USEPA, 2002).

The federal 10,000 mg/L TDS limit significantly exceeds the common TDS thresholds for drinking water consumption and irrigation water use (**Figure 6**), and provides a margin of safety for protection of potentially usable groundwater. Water supply systems that provide drinking water to consumers have the voluntary goal of meeting the federal drinking water guideline of 500 mg/L for TDS, which may not be practical in all cases. To be feasible for irrigation use, the TDS content of the water must generally be less than 3,000 mg/L, to prevent crop damage, although specific crops may have more or less stringent salinity requirements (Warner, 2001; Guerra et al., 2011).

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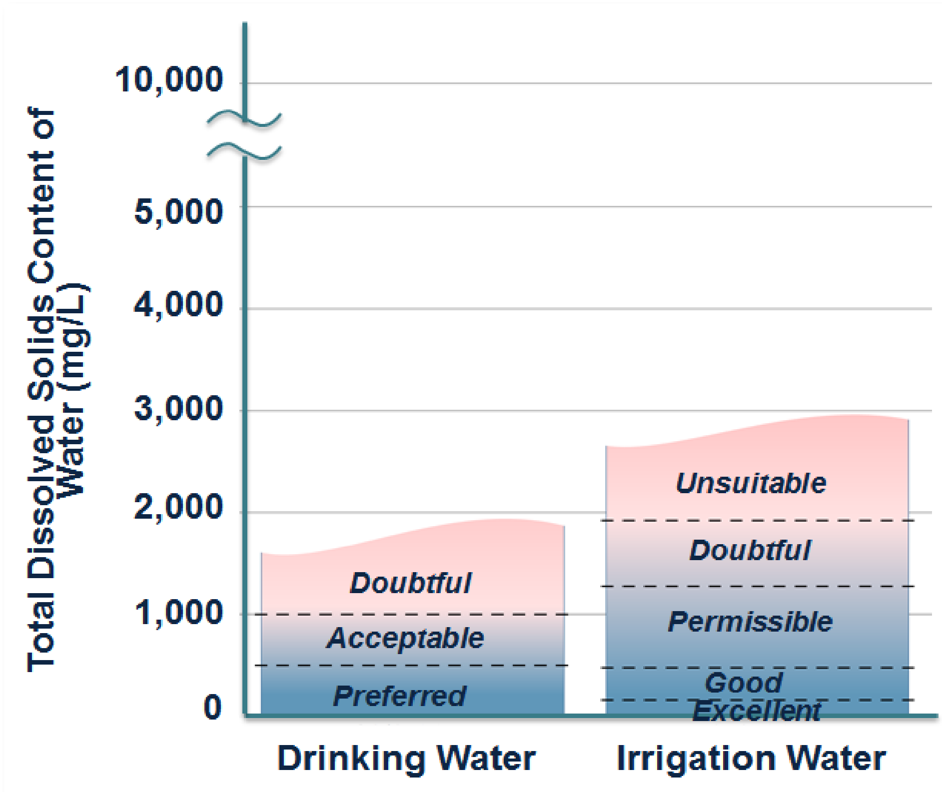
Figure 6. *General Water Use Criteria for Human Consumption and Irrigation.*



Source: Guerra et al., 2011; USEPA, 2016b.

3.4 The UIC aquifer exemption provision recognizes that usable groundwater is commonly classified as having a TDS under 3,000 mg/L and that considering all aquifers with a TDS below 10,000 mg/L as sources of drinking water would be overly restrictive.

In the UIC regulations, USEPA allowed that an aquifer containing TDS levels less than 10,000 mg/L could be exempted from classification as a USDW if the aquifer met the criteria of an "exempted aquifer." As stated in the USEPA proposed regulations (USEPA, 1976a):

> *[I]t would be a misallocation of resources to seek to protect as potential drinking water sources aquifers which in fact will not be used by public water systems.*
>
> *EPA believes that there should be some means of excluding individual aquifers or parts of aquifers which are not in fact potential sources of drinking water even though they have total dissolved solids levels of less than 10,000 mg/L. For example, an aquifer may be oil-producing even with a TDS level of less than 10,000 mg/L, and in such a case it may be wise to give the oil-producing qualities of the aquifer precedence over its ability to provide drinking water. Also, some aquifers below the 10,000 mg/L level are so contaminated that as a practical matter they are not potential drinking water sources.*

Accordingly, the UIC rules allow groundwater with TDS less than 10,000 mg/L, but higher than 3,000 mg/L to be exempt from definition as a USDW under certain conditions. USEPA stated that the 3,000 mg/L TDS limit was selected as follows:

> *Discussion with major oil producing States indicated that existing practice requires protecting groundwater containing up to 3,000 mg/L TDS with surface casing as potential drinking water sources. In light of these existing provisions, the 3,000 mg/L limit has been established as a minimum standard* (USEPA, 1976a).

The water use criteria on **Figure 6** support 3,000 mg/L as a reasonable lower TDS limit for injection of wastes, as most drinking and irrigation supplies require much less saline water (Warner, 2001; Guerra et al., 2011). In 1981, USEPA re-affirmed the use of the 3,000 mg/L TDS lower limit for aquifer exemptions:

> *[T]he Agency believes that the use of aquifers containing water between 3,000 and 10,000 mg/L of TDS is likely to be a function of economics and specific local hydrogeologic circumstances. Therefore, the Agency is proposing to provide flexibility to the Director for exempting such aquifers* (USEPA, 1981).

In describing the history of the federal UIC program and TDS limits in its review of the Utah and Nebraska Class II UIC regulatory programs, the Groundwater Protection Council (GWPC) stated:

> *Most groundwater used for public drinking water today contains less than 500 milligrams per liter of Total Dissolved Solids (TDS), and most water that is treated for drinking water contains less than 3,000 milligrams per liter TDS. Therefore, the UIC Program ensures that water resources that could be treated and used as drinking water in the future are protected today* (GWPC, 2015; 2016).

3.5 Exempted aquifers must be demonstrated to be neither a current nor a likely future underground source of drinking water.

The federal rule language for aquifer exemptions reads as follows (40 CFR §146.4):

> *An aquifer or a portion thereof which meets the criteria for an ''underground source of drinking water'' in §146.3 may be determined under §144.7 of this chapter to be an ''exempted aquifer'' for Class I–V wells if it meets the criteria in paragraphs (a) through (c) of this section:*
>
> *a) It does not currently serve as a source of drinking water.*
> *b) It cannot now and will not in the future serve as a source of drinking water because:*
>
> *1) It is mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.*
>
> *2) It is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical.*
>
> *3) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption.*
>
> *4) It is located over a Class III well mining area subject to subsidence or catastrophic collapse.*

c) *The total dissolved solids content of the ground water is more than 3,000 and less than 10,000 mg/l and it is not reasonably expected to supply a public water system.*

d) *The areal extent of an aquifer exemption for a Class II enhanced oil recovery or enhanced gas recovery well may be expanded for the exclusive purpose of Class VI injection for geologic sequestration under §144.7(d) of this chapter if it meets the following criteria:*

   1) *It does not currently serve as a source of drinking water.*

   2) *The total dissolved solids content of the ground water is more than 3,000 mg/l and less than 10,000 mg/l.*

   3) *It is not reasonably expected to supply a public water system.*

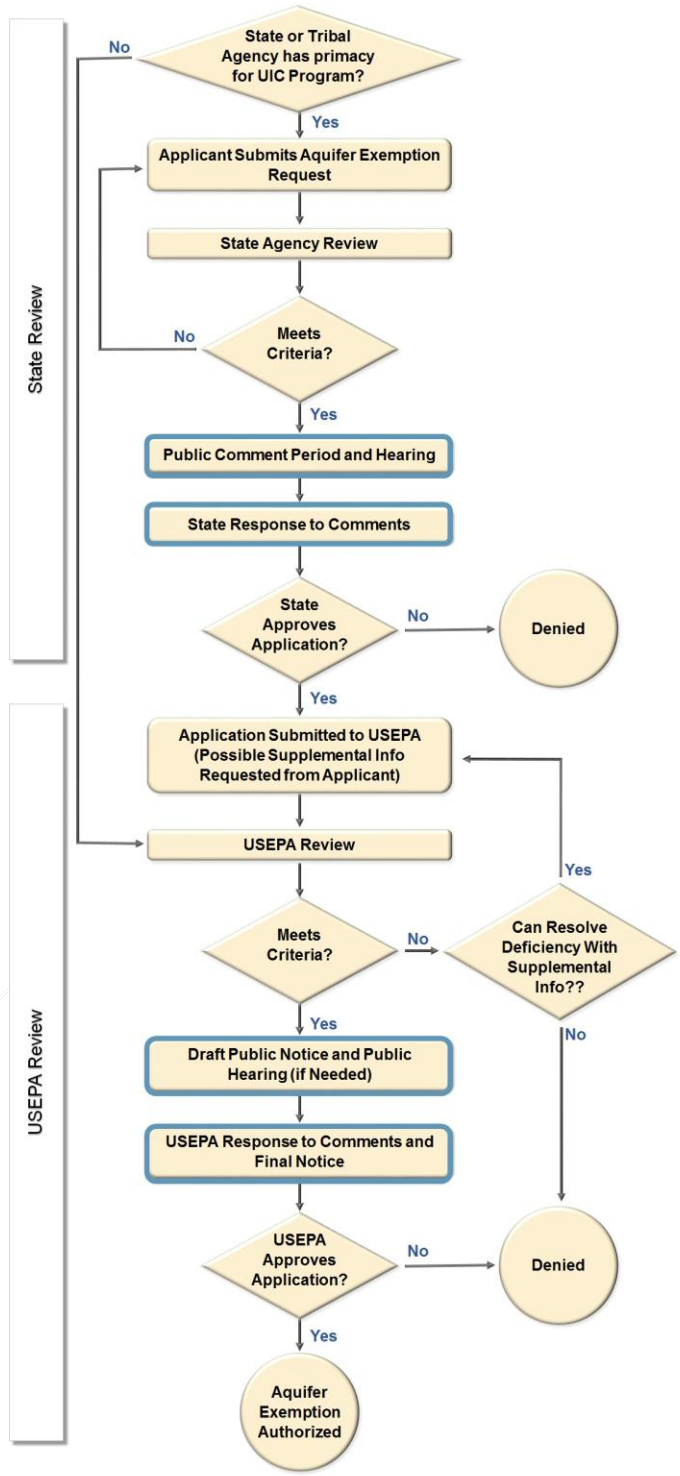
Key elements of this provision relevant to Class II injection wells for oil and gas operations are 40 CFR §146.4(b)(1) and 40 CFR §146.4(c). In simple terms, the first of these two provisions specifies that geologic formations containing commercially productive levels of crude oil or natural gas will not be considered underground sources of drinking water, such that produced water can be disposed into this same formation, without a restriction on the salinity of the aquifer. Alternatively, for aquifers that do not produce oil or gas, the aquifer may be exempted if it contains TDS levels below 10,000 mg/L but above 3,000 mg/L and is not reasonably expected to be used as a public water supply.

The UIC aquifer exemption policy recognizes the presence of commercially productive quantities of minerals or hydrocarbons as a reason that an aquifer "cannot now and will not in the future serve as an underground source of drinking water." Exclusion of reservoirs used for oil and gas production from classification as USDWs reflects Congressional intent (H. Rpt. 93-1185, 1974), as well as both practical and economic considerations. In certain cases, such as Coal-Bed Methane (CBM) operations or exceptionally low-salinity oil and gas formations, the groundwater extracted from oil and gas reservoirs is suitable for use as irrigation water, following separation of crude oil and gas liquids (IOGCC, 2006; Guerra et al., 2011). However, more commonly, practical limitations preclude the use of water extracted from oil and gas-containing aquifers for either drinking or irrigation water, due to elevated salinity and the presence of residual hydrocarbons and trace elements (Veil et al., 2004) that require costly treatment to meet water quality criteria prior to use. As further discussed in Section 6 of this report, in the small percentage of oil and gas reservoirs that contain fresh to slightly saline water (< 7%), oil and gas production and groundwater use for irrigation have been shown to be compatible in a number of cases.

3.6 Aquifer exemption applications undergo review at the state/tribal and federal levels, subject to detailed technical specifications and public participation.

USEPA and state oil and gas regulatory agencies have issued technical guidelines or rules to assist injection well owners and operators in the preparation of exemption applications and to facilitate consistent evaluation and processing of these applications by regulatory agency staff (DOGGR, 2015a; USEPA, 1984; USEPA, 2014). Figure 7 shows the principal steps of the application review process at the state/tribal and federal level. The process commences with the applicant's submittal of a request containing the information required by the regulatory authority for the provision in question, such as records of hydrocarbon production for an oil and gas formation or, alternatively, an analysis of the suitability of the saline aquifer for use as a public water supply, the availability and adequacy of alternative water supplies, and the likelihood of the future use of the aquifer. For states or tribal agencies that have been granted primacy for management of the UIC program, each application is first reviewed by the state or tribal agency and then submitted to USEPA for final review and approval.

Figure 7. *Evaluation Process for Aquifer Exemption Application (Sources: Adapted from USEPA 2014; Hildebrandt 2015).*



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As shown on **Figure 7,** the application review process entails several opportunities for review and comment by the public. First, the state or tribal agency issues a public notice of the application and allows time for members of the public to review and comment on the application. If sufficient public interest is shown, the agency holds a public hearing to invite questions and commentary. The agency will then issue a summary of the comments provided by the public and its response to those comments prior to making a final decision to approve the application and forward it to USEPA for final evaluation.

In the USEPA review process, the public participation steps are repeated, with USEPA publishing a public notice, soliciting comments, holding a hearing if sufficient interest is shown by the public, and responding to public comments. The USEPA may choose to grant or deny the exemption application, regardless of the prior state or tribal agency approval.

Under this process, for the 41 states, three territories, and two tribal agencies that have primacy for the UIC Class II program, each application for an aquifer exemption requires two public notice and comment periods, as well as two public hearings, if needed, prior to final approval or denial by USEPA. Guidelines have been issued by USEPA in 1984 and 2014 to facilitate the aquifer exemption request review and approval process.

When the state does not have primacy for the UIC program, an applicant for an aquifer exemption submits the request directly to USEPA for review and approval, and the agency works with the applicant to ensure all information requirements are fulfilled. Public notice is issued by the USEPA Regional Administrator and an opportunity for public comment and a public hearing may also be provided by the agency.

USEPA has worked directly with state regulatory agencies and the GWPC to make improvements in the aquifer exemption review process (USEPA, 2014). The agency has affirmed that a regulatory approach consisting of a broad definition for USDWs, combined with a case-by-case aquifer exemption application process, is an effective system for protecting USDWs while also allowing underground injection associated with industrial activities (USEPA, 2014).

Key Findings Regarding the Rationale and Procedures for an Aquifer Exemption: *Injection wells have long been recognized as important to many industries, including the energy industry, for safe management of wastes. The UIC rule sought to balance the protection of groundwater with the need for safe underground disposal of wastewater. The Federal-State system of regulations ensures underground drinking water sources are not adversely impacted by underground injection activities and has a long-established history. Federal and state UIC rules specify design, construction, and operating procedures for injection wells to ensure protection of USDWs. The aquifer exemption application process requires multiple reviews of technical data and provides opportunities for public comment prior to USEPA approval of the exemption. Exempted aquifers must be demonstrated to be neither a current nor a likely future underground source of drinking water.*

4.0 EVALUATION OF STATE AGENCY MANAGEMENT OF THE UIC REGULATORY PROGRAM

4.1 Overview of Evaluation Process for State UIC Regulatory Agencies

The state or tribal agencies to which USEPA has granted authority to manage the Class II UIC regulatory program are subject to audits or evaluations of their performance by USEPA. In addition, these agencies may participate in voluntary Class II UIC program performance reviews directed by the GWPC under the recently formed joint GWPC and Interstate Oil and Gas Compact Commission (IOGCC) States First Initiative. This section reviews the procedures and findings of the reviews conducted of USEPA and state regulatory agencies that are responsible for enforcement of UIC programs, including management of aquifer exemption applications.

4.2 Evaluation of state and USEPA-managed UIC programs have, in some cases, found need for improvement of administrative processes but have not found these deficiencies to have resulted in impacts to groundwater resources.

The findings of performance audits for state and USEPA-managed Class II UIC regulatory programs are summarized in Appendix A. In general, these audits found UIC programs to include the necessary permitting, inspection, and enforcement components to protect USDWs from impacts by Class II injection wells. In each case, recommendations were provided for improvement of the Class II UIC program implementation, including updating regulations, and ensuring the proper documentation has been submitted for USEPA review and approval of aquifer exemptions (DOGGR, 2015b).

The GAO reviewed six state and two USEPA-managed Class II UIC regulatory programs in 2014 and 2016, and provided recommendations for improving USEPA oversight of the UIC programs, including aquifer exemption requests (GAO, 2014; GAO, 2016). In response to the GAO reports, USEPA supplemented their 1984 guidelines for review and approval of aquifer exemption applications by issuing a memorandum "to promote a consistent and predictable process for the review of Aquifer Exemption requests" (USEPA, 2014).

In no case did the performance audits of the federal and state Class II UIC programs find that the UIC program had failed to adequately protect USDWs. For example, the California UIC program was found to have permitted a number of Class II injection wells in areas that had not been previously approved for aquifer exemptions (DOGGR, 2015b). These wells have been required to permanently terminate injection operations, suspend injection operations subject to re-application and approval of an aquifer exemption, and/or plug and abandon nearby water supply wells that had been completed in the same aquifer as the injection well. However, an investigation by the California Environmental Protection Agency (CalEPA) found: *"[t]o date, preliminary water sampling of select, high-risk groundwater supply wells has not detected any contamination from oil production wastewater"* (CalEPA, 2015).

4.3 Surveys of groundwater conditions at Class II injection well sites have found no widespread groundwater impacts, with problems limited to infrequent and localized effects.

USEPA has found injection wells, when properly designed, constructed, and operated, to be a safe method for disposal of wastes (USEPA, 2002). Key findings from reviews of Class II injection well operations conducted over the past three decades included the following:

1) **GAO, 2014:** *"The [Class II] programs in the eight states [six states with primacy for the Class II UIC program and two USEPA-managed Class II UIC programs] that we have reviewed report few instances of alleged contamination caused by potential leaks from underground injections into underground drinking water sources. State and USEPA officials reported this information from two sources: (1) data on well violations that could be significant enough to contaminate underground sources and (2) data on citizen complaints of water well contamination and resulting state investigations. According to*

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California officials, all of the instances of alleged contamination California reported in 2009, and 9 of the 12 instances of alleged contamination reported in 2010, resulted from one operator injecting illegally into multiple wells".

2) **ICF, 1995:** *"[D]ocumented cases of contamination due to underground [injection] are very few in number, and most of these cases are attributable to operating practices that were in violation of existing state and federal regulations governing underground injection. Thus, in absolute terms, the risk of groundwater contamination from Class II injection operations is quite low."*

3) **Michie, 1989:** This study involved a detailed evaluation of 170,000 injection wells in 39 basins across the U.S. and found the risk of injection well failure and a resultant impact on a USDW to be quite low. In basins with low potential for corrosion of the exterior well casing, the risk of impact on a USDW was found to be negligible. In basins with a significant potential for corrosion, the risk of an impact was estimated to be 1 in 1,000 years of operation to 1 in 1 million years of operation, depending on whether the surface casing extended through the full depth of the USDW.

4) **U.S. General Accounting Office (now GAO), 1989:** A survey of 88,000 Class II wells found a total of 23 cases of impacts on groundwater, corresponding to an impact rate of less than 0.03% of injection wells. Response actions were taken to resolve the impacts in each case. *"Once contamination was discovered, regulatory authorities in either EPA regions or the states directed responsible companies to prevent further contamination by plugging their injection wells or the abandoned wells, reworking injection wells to repair cracked casings, or extending the wells below the USDW".*

These findings are consistent with the results of performance evaluations of state and federal Class II UIC programs described in Section 4.2 and in Appendix A that concluded that the existing Class II Federal-State UIC program is effective for protecting underground drinking water resources and addressing isolated impacts when and if they occur.

Key Findings Regarding Current Management of the UIC Program: *Evaluation of Class II UIC regulatory programs shows that the current regulations have been effective for protection of USDWs. Evaluations of Class II UIC programs have, in some cases, found need for improvement of administrative processes but have not found these deficiencies to have resulted in impacts to groundwater resources. USEPA and state regulatory agencies are committed to improving Class II UIC regulatory programs as necessary. Surveys of groundwater conditions at Class II injection well sites have found no widespread groundwater impacts, with problems limited to infrequent and localized effects.*

5.0 PRACTICAL CONSIDERATIONS FOR DEVELOPMENT OF SALINE GROUNDWATER RESOURCES

5.1 Protection of USDWs under Current UIC Regulatory Program

As discussed in Sections 3.3 and 3.4 above, groundwater with TDS levels below 10,000 mg/L is to be protected as a potential underground source of drinking water, except in those cases where a lower threshold (such as a TDS of 3,000 mg/L) is shown to be sufficiently protective or the aquifer is a mineral or petroleum production zone, according to the criteria contained in the aquifer exemption provision. Recently, given the increasing demand for water and the evolution of improved technologies for water

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desalination, concerns have been raised that these criteria may not adequately protect potential underground drinking water resources.

USEPA and others have previously reviewed the 10,000 mg/L TDS threshold for the definition of a USDW and the 3,000 mg/L TDS lower limit for an aquifer exemption and found these criteria to be appropriate (GWPC, 2015, 2016; Warner, 2001; USEPA, 1976a; USEPA, 1980; USEPA, 1981). In revisiting these criteria today, concerns regarding protection of potential underground drinking water resources must be evaluated in the context of both the benefits and the practical constraints on the use, development, and treatment of saline groundwater. On this basis, the current UIC criteria provide appropriate protection for the saline groundwater resources that are used today and are likely to be used in the future under a sustainable water management program. As discussed in further detail below, groundwater desalination facilities do not commonly use groundwater with TDS above 3,000 mg/L due to energy consumption, waste generation, and other constraints. Key observations in this regard are addressed below.

5.2 Current groundwater use and future water management plans rely upon low salinity groundwater, with TDS under 3,000 mg/L.

In the U.S., apart from compacts or disputes among state governments, water rights are managed at the state rather than federal level (UDNR, 2013). State government agencies also direct the planning and development of future water resources, including regulation of groundwater withdrawals, and/or delegating planning and regulatory authority to local entities. The adequacy of the current UIC regulations for protection of underground drinking water resources can, therefore, be evaluated in context of the state and local water management plans. Of particular importance is the degree to which these state and local water management plans anticipate the demand for moderately saline groundwater with TDS less than 10,000 mg/L and greater than 3,000 mg/L.

In this section of the report, water use projections are reviewed on the national scale, as reported by the U.S. Geological Survey (USGS), and in two states, California and Texas. These states are exemplary for this purpose because they are among the principal oil producing states in the U.S., as well as significant consumers of groundwater for public supply and irrigation (Maupin et al., 2014). Both of these states face water shortages that may be addressed, in part, by development of saline water resources, and, in combination, represent approximately 30% of the desalination capacity in the U.S. today (Mickley and Jordahl, 2013).

5.2.1 USGS Survey of Water Use in the U.S., 2010

Every five years, the USGS compiles data on water use into a national water-use data system and publishes a report containing state-level data. The most recent report, issued by Maupin et al. in 2014, presents water use statistics for the year 2010 and identifies changes in water use patterns over the past 60 years. This report finds that the total water use in the U.S. has decreased moderately since 1980, despite a 30% increase in the population over that time period. In 2010, total water withdrawals were estimated to be 355 billion gallons per day (Bgd), which was 13% lower than in 2005, and the lowest level observed since 1965. With regard to public water supplies, which are the principal source of drinking water in the U.S., overall water use decreased by 5% from 2005 to 2010, despite a population growth of 4% over this five-year time period (Maupin et al., 2014). These data indicate that, despite population growth, total water consumption has not increased in the U.S. in recent decades, due in part

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to improved conservation efforts including more efficient use of water in the industrial and agricultural sectors.

Total groundwater withdrawal has been relatively constant since 1975, averaging approximately 80 billion gallons per day (Bgd) (Maupin et al., 2014). The states with the greatest use of groundwater are California (12,700 million gallons per day (Mgd) and Texas (7,710 Mgd). Nationwide, saline groundwater (defined by USGS as TDS > 1,000 mg/L) represents 4% of all groundwater withdrawals, and is used primarily for industrial supply, mineral extraction (which includes oil and gas), and thermoelectric power (geothermal). With regard to public water supply, the states that reported the greatest use of saline groundwater for public supply are Florida, California, Texas, Virginia, and Utah. In these states, the combined saline groundwater withdrawal represents less than 1% of the total public water supply (Maupin et al., 2014). Use in some states and in certain localities (e.g., in proximity to desalination facilities) is a higher percentage; however, saline groundwater does not currently represent a significant percentage of the overall public water supply in the U.S.

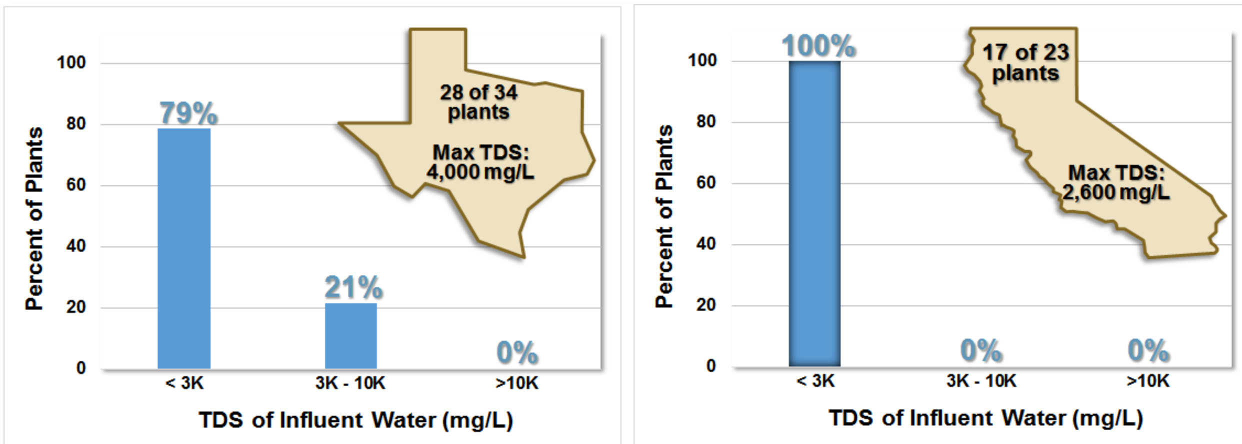
5.2.2 California Water Plan: Anticipated Use of Saline Groundwater

The California Department of Water Resources issued an update to the 2013 California Water Plan (CDWR, 2014), addressing a variety of resource management strategies to meet water demand, including desalination of brackish water and seawater. In 2010, of the 2,830 Mgd of groundwater consumed in California for public water supply (Maupin et al., 2014), 71 Mgd (2.5%) came from groundwater desalination facilities, principally located in southern California (22 of 23 facilities) (CDWR, 2014). Seventeen additional groundwater desalination plants are expected to be operational by 2030, providing an additional capacity of approximately 67 Mgd, potentially boosting the portion of public water supply provided by saline groundwater to nearly 5% (assuming no growth in public water supply demand, which would serve to decrease this percentage) (CDWR, 2014).

The California Water Plan identifies several challenges to increased use of saline groundwater in coming decades, including 1) increased energy use, 2) higher capital and operating costs, 3) the need to dispose of the concentrated brine waste, and 4) the potential effects of increased groundwater pumping, such as land subsidence and seawater intrusion (CDWR, 2014).

As shown on **Figure 8**, 17 of the 23 groundwater desalination facilities in California, for which data on influent water salinity is available (GSI, 2016), all use groundwater with a TDS content below 3,000 mg/L. The use of relatively low salinity groundwater results in a lower treatment cost and energy consumption relative to groundwater with TDS greater than 3,000 mg/L (Watson et al., 2003). In addition, a recent study found that the volume of slightly saline groundwater underlying the Central Valley of California may be three times greater than the volume of fresh water (TDS < 1,000 mg/L) previously estimated for this region by the USGS (Kang and Jackson, 2016). While this study has yet to be validated, the implication is that groundwater with TDS under 3,000 mg/L may be readily available to meet desalination demand, without need for use of more saline groundwater.

Figure 8. *TDS Content of Groundwater Used in Desalination Plants in Texas and California.*



Sources: TWDB, 2016b; GSI, 2016.

Planning for future use of slightly saline groundwater (TDS < 3,000 mg/L) is consistent with the 2016 characterization of the California Regional Water Quality Control Boards (RWQCBs) of water that is usable as a public water supply:

> *The primary safeguard against pollution of source waters is the RWQCBs, through their permitting systems for discharges and other nonpoint-source control programs. These permits are based on protecting the beneficial uses of water bodies specified in water quality control plans. By default, bodies of surface and groundwater in California are considered suitable or potentially suitable for municipal or domestic water supply and are classified as MUN in water quality control plans (SWRCB, Resolution No. 88-63). <u>One of the exceptions is water bodies where the TDS exceeds 3,000 mg/L, because these saline water bodies are not reasonably expected by RWQCBs to supply a public water system</u>* (CDWR, 2014). *(Emphasis added.)*

These data suggest that, while the portion of the California public water supply provided by saline groundwater is expected to expand moderately over the next two decades, the groundwater used for this purpose will most likely have TDS levels below 3,000 mg/L. In this regard, the existing UIC regulatory program, which protects groundwater with TDS below 10,000 mg/L, provides a margin of safety for the groundwater resources subject to future use. Similarly, the aquifer exemption provision is also protective of this low salinity groundwater, as it allows injection into aquifers with TDS greater than 3,000 mg/L, when these aquifers can be shown unlikely to be used as a public water supply and the injection well meets applicable permit specifications.

5.2.3 Texas Water Plan: Anticipated Use of Saline Groundwater

The 2017 Texas Water Plan projects water demand and availability through the year 2070 for public water supply, power generation, agriculture, mining, and manufacturing (TWDB, 2016a). Groundwater provides roughly half of the existing water supply, corresponding to approximately 6,400 Mgd, and is the principal source for irrigation and livestock use. However, the current groundwater supply is expected to diminish by 24% over the next 50 years, due to declining groundwater availability. Over that same time period, public water supply needs are expected to increase from approximately 11% of all

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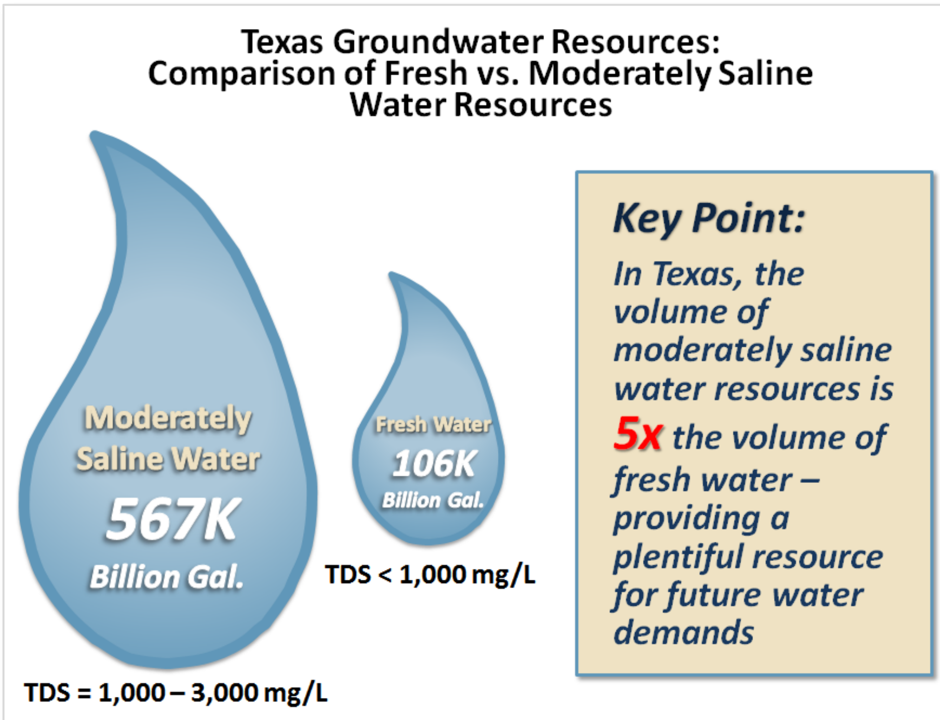
state water needs in 2020 to 38% of state water needs in 2070 – a demand that will be met principally by additional surface water, water conservation, and water reuse projects (TWDB, 2016a).

Groundwater development is also an important part of the water strategy, but groundwater desalination itself is expected to decrease as a component of the overall future water supply (TWDB, 2016a). Groundwater desalination is projected to be 2.1% of the total water supply in 2020 but only 1.3% in 2070. Other water management strategies such as irrigation conservation, new reservoirs, and municipal conservation are projected to be larger components of the future water supply in Texas. In contrast to groundwater desalination, seawater desalination is expected to increase from 0.1% to 1.4% of the total water supply over this same period (TWDB, 2016a). The principal challenges faced by groundwater desalination projects are the relatively high costs of energy use and disposal of the concentrated brine waste (Wythe, 2014).

The Groundwater Advisory Unit of the Railroad Commission of Texas (RRC), the authority which regulates the oil and gas industry in Texas, defines usable-quality groundwater as water containing TDS below 3,000 mg/L or any other water specified by the Texas Water Development Board (TWDB) for use in desalination (16 TAC §3.30(e)(7)). As shown on **Figure 8**, 28 of the 34 groundwater desalination facilities (79%) in Texas have available data on influent water salinity (TWDB, 2016b). The majority of these plants use groundwater with a TDS content below 3,000 mg/L, and the maximum influent TDS of any plant is 4,000 mg/L. None of the plants are using groundwater with a TDS above 10,000 mg/L. The use of relatively low salinity groundwater results in a lower treatment cost and energy consumption relative to groundwater with TDS greater than 3,000 mg/L (Watson et al., 2003).

As shown on **Figure 9**, studies conducted for the TWDB find that the volume of groundwater in Texas with TDS below 3,000 mg/L is approximately 567,000 billion gallons, which is more than five times the current freshwater supply in the state (LBG-Guyton, 2003; Ruesink, 1982; Kalaswad et al., 2004). This finding suggests that future groundwater desalination plants will have sufficient access to slightly saline water (TDS <3,000 mg/L) and are not likely to require use of higher salinity groundwater, depending on local availability.

Figure 9. *Comparison of Fresh v. Moderately Saline Water Resources in Texas.*



Sources: LBG-Guyton, 2003; Ruesink, 1982; Kalaswad et al., 2004.
(Note: Similar data are not presently available for California.)

RRC regulations (16 TAC §3.13(a)(1)) require the surface casing on oil and gas wells and injection wells to seal off groundwater with TDS below 3,000 mg/L, which provides a margin of safety for groundwater potentially used by desalination facilities (which primarily rely on groundwater with a TDS below 3,000 mg/L and a maximum TDS of 4,000 mg/L) (TWDB, 2016b; GSI, 2016). Consistent with federal regulations, authorization to inject produced water into aquifers with TDS less than 10,000 mg/L and above 3,000 mg/L is addressed by the RRC on a case-by-case basis per the state aquifer exemption criteria (16 TAC §3.30(e)(7)).

5.3 Practical limitations on groundwater desalination will continue to drive dependence on lower salinity groundwater resources.

Groundwater desalination is a valuable technology for addressing future demands for public water supply. However, as indicated by the Texas and California water plans, saline groundwater will likely remain a minor percentage of the total public water supply due to constraints related to energy use, costs, waste disposal, and other factors. Although technologies exist for desalination of highly saline water, use of slightly saline groundwater (TDS < 3,000 mg/L) will most likely remain the norm for these same considerations. In addition, the National Research Council (NRC) has identified potential environmental consequences associated with increased pumping and desalination of groundwater to meet water supply demands, including physical sustainability (recharge to withdrawal and discharge

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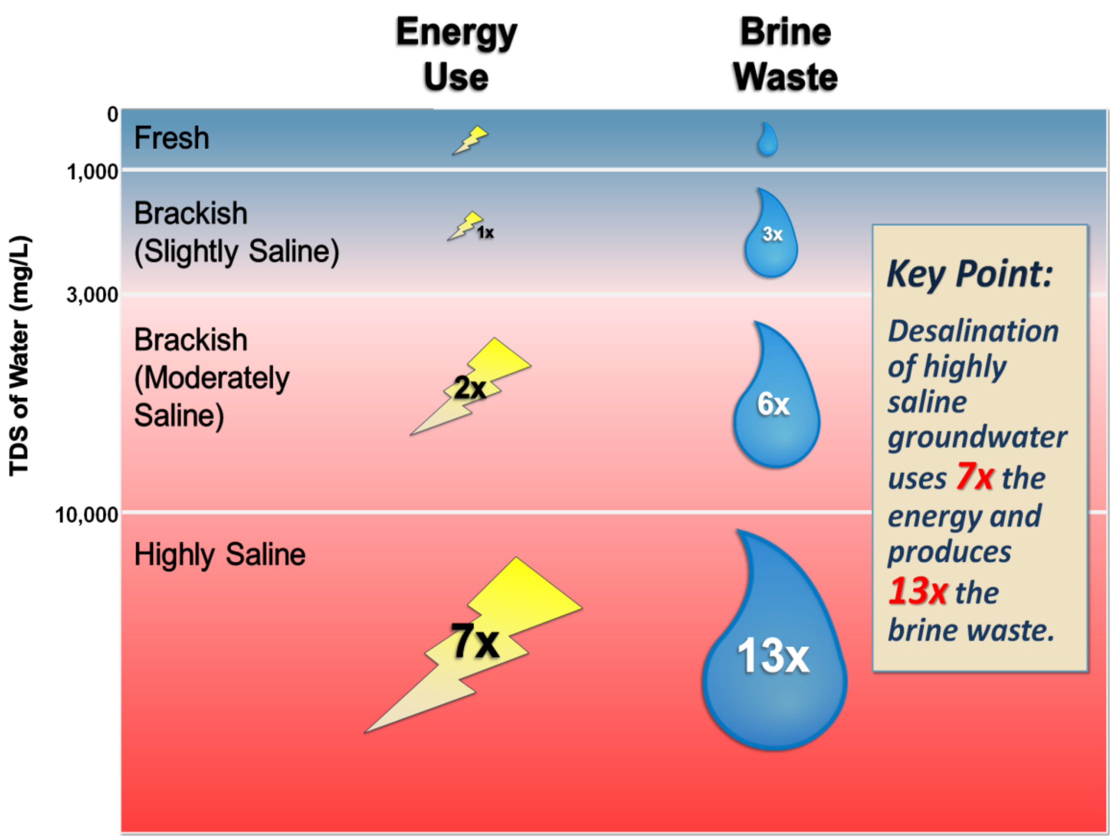
balance), land subsidence, effects on hydraulically connected surface water, and management/ disposal of brine concentrate (NRC, 2008).

As illustrated on **Figure 10,** energy use and waste production become more critical concerns with increased salinity of the influent water, which in many cases will render desalination of moderately saline (TDS > 3,000 mg/L) to highly saline (TDS > 10,000 mg/L) groundwater environmentally unsustainable for public water supply (Xu et al., 2013; NRC, 2008; Watson et al., 2003). These practical limitations on desalination and their implications with regard to the adequacy of current groundwater safeguards under the UIC program are discussed in further detail below.

Figure 10. *Practical Constraints on the Use of Brackish and Saline Groundwater as Drinking Water.*



Sources: Xu et al., 2013; Watson et al., 2003

5.3.1 Energy Use of Water Desalination Facilities

The California Water Plan identifies higher energy consumption as a key constraint on the development of desalination facilities (CDWR, 2014). The energy intensity of desalination of both seawater and brackish groundwater significantly exceeds that of local groundwater or surface water supplies (Cooley and Heberger, 2013). Electricity, gasoline, and fuels are required to construct, operate, maintain, and eventually decommission a desalination plant (Cooley and Heberger, 2013). **Figure 11** illustrates the minimum theoretical energy consumption for reverse osmosis as a function of the salinity of influent water (Watson et al., 2003). For water desalination by electrodialysis reversal and low energy reverse

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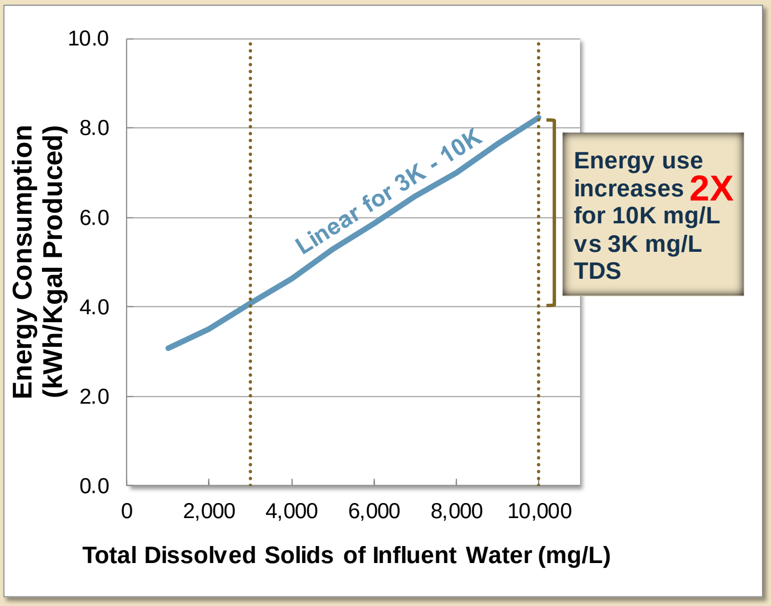
osmosis, the relationships of energy consumption to the TDS of feed water are similar (Watson et al., 2003). Regardless of the technology employed, on average, desalination of water with a TDS within the range of 3,000 mg/L to 10,000 mg/L will cost at least twice as much as water with a TDS below 3,000 mg/L, while desalination of water with TDS significantly above 10,000 mg/L will cost seven times as much (as calculated from data in Xu et al., 2013, Watson et al., 2003).

Figure 11. *Desalination Energy Use for Standard Pressure Reverse Osmosis vs. Total Dissolved Solids.*



Source: Watson et al., 2003.

Efforts are presently underway to develop and test more energy efficient desalination technologies (Wythe, 2012; CDWR, 2014; LBG-Guyton, 2003); however, the energy advantage of treating lower salinity water will continue to provide an incentive for use of slightly saline waters (TDS < 3,000 mg/L), as has been observed for the groundwater desalination facilities constructed to date.

5.3.2 Costs of Water Desalination Relative to Other Alternatives

Cost is commonly identified as a principal constraint on the greater use of water desalination (TWDB, 2016a; CDWR, 2014; NRC, 2008; Graham, 2015). By 2070, the Texas Water Plan estimates treatment costs for groundwater desalination to average approximately $710 per acre-foot compared to approximately $490 per acre-foot for non-saline groundwater – a 45% increase, but a smaller margin than is presently observed (TWDB, 2016a).

Higher energy consumption accounts for roughly half of the increased cost associated with current desalination plants (Graham, 2015; NRC, 2008). Other cost factors include the increased capital costs for pre-treatment, desalination, post-treatment equipment, and concentrate disposal facilities (WRA, 2012). Membrane treatment systems, which represent the most common desalination technology currently in

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use, also entail increased operating costs due to fouling of the membranes by particulate or colloidal matter, organics, microorganisms, and breakthrough from upstream pre-treatment units, such as granular activated carbon (Characklis, 2004).

The cost figures reported for groundwater desalination vary significantly, depending on the facility location, technology (**Figure 11**), and energy and water sources. Overall, costs are anticipated to decrease with development of more efficient technologies (Wythe, 2014; CDWR, 2014). However, compared to other alternatives, the cost margin, particularly for higher salinity groundwater, will likely continue to limit the adoption of this technology in the U.S.

5.3.3 Waste Production and Disposal from Desalination Facilities

Desalination involves the removal and concentration of dissolved salts and other substances from the influent saline water so as to provide treated water that has a sufficiently low salinity to meet drinking water criteria directly or by blending with another fresh water stream. However, the treated water stream is only a portion of the influent water, and the remainder is a concentrated brine waste with a very high TDS concentration. In general, desalination systems recover from 40 to 90% of the influent water volume, with the balance being a waste concentrate that commonly requires disposal (Graham, 2015).

Management of this brine concentrate is one of the most significant challenges associated with treating highly saline waters (Xu et al., 2013). The higher the TDS of the influent water, the lower the percentage of treated water that is recovered. For example, for influent brackish water with TDS under 5,000 mg/L, desalination using present-day membrane technologies can achieve an average of approximately 82% recovery, while recovery rates average 65% for brackish water with TDS in the range of 5,000 to 15,000 mg/L, and 45% for seawater (TDS > 30,000 mg/L) (Xu et al., 2013; NRC, 2008). At an 82% recovery rate, for every 10 Mgd of treated water produced by the desalination facility, another approximately 2 Mgd of brine waste must be managed and disposed (Xu et al., 2013).

The feasibility of desalination at any given location depends on the ability to manage and dispose of the waste brine containing elevated levels of TDS in a cost-effective and environmentally sound manner. A nationwide survey of 288 municipal desalination plants in the U.S. published in 2013, sponsored by the U.S. Bureau of Reclamation and the California Department of Water Resources for the WateReuse Research Foundation, found that brine concentrate is disposed by a variety of methods, including discharge to surface water (49% of all plants), sewer discharge (24%), injection wells (16%), land application (7%), and evaporation ponds (4%) (Mickley and Jordhal, 2013) (see **Figure 12**). The trend toward larger capacity desalination plants and stricter regulations on surface water discharge reduces the feasibility of discharge to surface water, sewers, and evaporation ponds, as well as land application. For this reason, over 40% of large capacity desalination plants (> 6 Mgd) in the U.S. use Class I municipal, and under specific conditions, Class II and Class V injection wells for brine disposal (Mickley and Jordhal, 2013).

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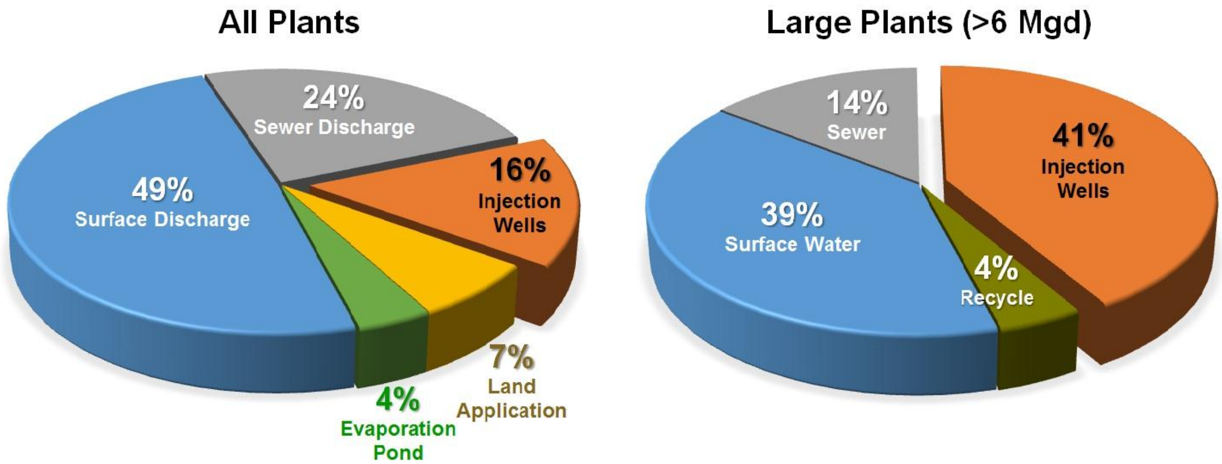
Figure 12. *Disposal Methods Used by Municipal Desalination Plants for Brine Concentrate.*



Note: Data from survey of 288 desalination plants with capacity >25,000 gallons per day (Mickley and Jordhal, 2013).

5.3.4 Other Environmental Consequences of Groundwater Desalination

In addition to the challenges regarding energy consumption, costs, and concentrate management, the potential aquifer impacts caused by increased groundwater extraction can also affect the feasibility of groundwater desalination (NRC, 2008; CDWR, 2014). As with any aquifer, increased pumping of saline groundwater can pose unintended consequences for hydrologically connected units. For example, withdrawal of saline water can lead to lowering of groundwater levels in overlying freshwater aquifers or seawater intrusion (GWPC, 2011). In addition, depressurization of saline aquifers can contribute to land subsidence, as has been observed in heavy groundwater pumping areas in Texas and California (NRC, 2008; GWPC, 2011; CDWR, 2014). These factors are site-specific in nature and may limit the feasibility of increased pumping and treatment of saline groundwater in some areas.

Key Findings Regarding Use of Saline Groundwater: *Current groundwater use and future water management plans rely upon slightly saline groundwater, with TDS under 3,000 mg/L, which is prohibited for waste injection under the UIC rules unless an aquifer exemption is granted by USEPA. Projections of future water use anticipate that groundwater desalination could increase from approximately 2% of public water supplies today to as much as 5% in the principal oil-producing states of Texas and California. However, practical considerations regarding energy consumption, cost, waste disposal, and other environmental consequences will limit the feasibility of groundwater desalination in many areas. Energy consumption, cost, and waste production all increase with the increasing salinity of the influent water. These factors, in combination with the relative abundance of lower salinity groundwater (TDS < 3,000 mg/L), in many areas, will continue to make lower salinity water the first choice for water development. In addition, groundwater desalination requires management of the concentrated brine waste, which, at 40% of large facilities, involves disposal via injection wells.*

6.0 PRACTICAL CONSIDERATIONS FOR USE OF GROUNDWATER FROM OIL AND GAS RESERVOIRS

An aquifer exemption is required for injection into any oil and gas reservoir containing groundwater with a TDS below 10,000 mg/L. For reservoirs with groundwater falling in the range of 3,000 mg/L to 10,000 mg/L, use of the groundwater as a drinking water resource faces the same challenges with regard to desalination as described in the prior section of this report. However, in addition to dissolved minerals, groundwater from oil and gas reservoirs commonly requires removal of dissolved and dispersed oil and organic compounds, suspended solids, and other constituents (Igunnu and Chen, 2014; Duraisamy et al., 2013; Arthur et al., 2005) prior to use as a water supply.

Treatment to remove the various organic components commonly present in such groundwater requires advanced treatment methods beyond the conventional filtration and/or demineralization steps commonly performed at desalination facilities (Igunnu and Chen, 2014; Duraisamy et al., 2013). Conventional filtration methods using multi-media filters and cartridge filters can remove water impurities such as sand and silt but not oil droplets (Dickhout et al., 2017; Boysen, 2007). Rather, such treatment may require use of specialized microfiltration (MF) and ultrafiltration (UF) systems (Igunnu and Chen, 2014; Duraisamy et al., 2013; NRC 2008). Membranes used in the reserve osmosis (RO) treatment process for salinity reduction are sensitive to damage, corrosion, and fouling by organic and inorganic constituents in feed water unless pre-treatment is conducted to protect the RO system (Igunnu and Chen, 2014; Arthur et al., 2005).

The complexity, energy consumption, and cost of sequential treatment, first to remove dissolved and dispersed oil and then to reduce salinity, commonly renders the use of groundwater from oil and gas reservoirs impractical as a drinking water supply, particularly for reservoirs with TDS > 3,000 mg/L. None of the groundwater desalination facilities presently in operation in Texas and California (the two states that are both important oil and gas producers and among the top consumers of desalinated groundwater) extract water from oil and gas reservoirs (TWDB, 2016b; CDWR, 2014; Camacho et al., 2013; Nicot et al., 2004). Rather, slightly saline aquifers (TDS < 3,000 mg/L) that are not commercial oil and gas reservoirs and do not pose the additional challenge of oil removal are available and preferable, as discussed in Section 5 of this paper.

An aquifer exemption based on the demonstration that the aquifer is a commercially viable oil and gas reservoir can also be granted for aquifers with TDS values below 3,000 mg/L. Common examples include enhanced oil recovery wells that return low-salinity produced water to the low-salinity reservoir from which it came. A small percentage of oil and gas reservoirs do contain groundwater that falls within the salinity range of fresh (TDS < 1,000 mg/L) to slightly saline (TDS < 3,000 mg/L). Analysis of the USGS produced water database (Blondes et al., 2016) shows that, among the over 74,000 conventional wells tested, 7% produce water with a TDS content under 3,000 mg/L and 0.5% produce water with a TDS content under 1,000 mg/L. Data on unconventional wells in shale deposits indicate that approximately 3% produce fresh to slightly saline groundwater. Of the ten major coal bed methane (CBM) basins, two generate produced water with a TDS below 3,000 mg/L (i.e., Powder River Basin in Wyoming and Montana and the Raton Basin in Colorado and New Mexico) (USEPA, 2010).

In the exceptional case of a low-salinity oil and gas reservoir, the protectiveness of the aquifer exemption policy depends on the degree to which reinjection of low-salinity produced water affects the utility of the reservoir as a drinking water supply. Low-salinity groundwater is more practical for

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desalination than brackish groundwater; however, in the case of an oil and gas reservoir, use of this low salinity groundwater still entails pre-treatment to remove dissolved and dispersed oil and other natural organic compounds prior to desalination and/or blending. Such advanced treatment commonly involves primary separation of oil, gas, and water, followed by further treatment of the water stream using a series of methods to remove solids and organics, such as mechanical separation, flotation, enhanced filtration, and/or electrocoagulation (Igunnu and Chen, 2014; Duraisamy et al., 2013; Arthur et al., 2005).

In a number of cases, these pretreatment steps are being conducted by oil and gas operations to generate an irrigation water supply from the portion of the produced water that is not reinjected (CWD, 2016; CVRWQCB, 2015; Boschee, 2015). Monitoring of water quality of these treated water streams finds them to meet applicable irrigation water requirements, as well as drinking water criteria for the organic compounds in question (Waldron, 2005; CWD, 2016; CVRWQCB, 2015). In these cases, oil and gas operations, including reinjection of produced water, have been found to be compatible with co-production of a usable water supply from the same reservoir.

Key Findings Regarding Use of Groundwater from Oil and Gas Reservoirs: *Injection of produced water into an oil and gas reservoir with a groundwater TDS content under 10,000 mg/L requires an aquifer exemption. Groundwater from oil and gas reservoirs contains dissolved and dispersed oil and organic compounds, suspended solids, and other constituents. Removal of these constituents to meet either irrigation or drinking water criteria requires advanced treatment methods not commonly performed at groundwater desalination facilities. Given the complexity, energy consumption, and cost of pretreatment followed by desalination, use of groundwater from an oil and gas reservoir as a drinking water supply is commonly impractical. None of the drinking water desalination facilities in Texas or California presently use groundwater from an oil and gas reservoir. However, in certain low-salinity oil and gas reservoirs, oilfield operators are performing the pretreatment steps needed to generate a water stream useable for irrigation, showing oil and gas development and groundwater production to be compatible activities.*

7.0 ECONOMIC IMPACTS OF POSSIBLE MODIFICATIONS TO THE AQUIFER EXEMPTION POLICY

A broad range of industries - including chemical manufacturing, desalination facilities, pharmaceuticals, refining, mineral extraction, and oil and gas production - rely upon the UIC program to safely and cost-effectively dispose of waste in a manner that is protective of underground drinking water resources. For each of these industries, underground injection was adopted as an environmentally sound alternative to the discharge of wastes to surface water, which was considered to pose greater environmental risk (Clark et al., 2005; GWPC, 2015, 2016; USEPA, 2004). In addition, for some waste streams, treatment to meet surface water discharge criteria can prove energy intensive and prohibitively expensive (USEPA, 2002). In such cases, the ability to dispose of wastes by underground injection is a critical component of their ability to operate.

Major industry sectors, such as chemical production, food production, manufacturing, and mining, rely upon underground injection of waste for their economic viability (GWPC, 2011). Of the large capacity municipal desalination facilities in the U.S. (> 6 Mgd), nearly 40% use underground injection wells for

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disposal of brine concentrate (Mickley and Jordahl, 2013). Modifying the UIC regulation to repeal the aquifer exemption provision and/or changing the definition of a USDW to include groundwater with TDS levels above 10,000 mg/L could leave many desalination plants and industrial facilities with no feasible alternative for waste disposal.

For the onshore oil and gas industry, in the 1976 and 2016 “Effluent Guidelines and Standards for the Oil and Gas Extraction Point Source Category” documents, USEPA mandated "no discharge of waste water pollutants into navigable waters from any source associated with oil and gas development.” (USEPA, 1976b; USEPA, 2016a). USEPA anticipated that the technology used to achieve no discharge of pollutants would be injection of produced water for enhanced oil recovery or disposal (USEPA, 1976a). As of 2012, approximately 93% of produced water was re-injected in the U.S., with 46% injected via enhanced oil recovery wells, 47% injected into disposal wells, and the balance managed by surface discharge, evaporation, and beneficial reuse (Veil, 2015). If injection of oil and gas fluids was further restricted, oil and gas production could be significantly curtailed. In addition, costs associated with treatment of produced water for other forms of disposal could render oil and gas development uneconomical in many areas (CSM, 2009).

Of the total aquifer exemptions granted by USEPA as of 2013, 93% are for aquifers (or portions of aquifers) where Class II wells are used for re-injection of oil and gas fluids (Bergman, 2015). Of these Class II aquifer exemptions, roughly 66% pertain to enhanced oil recovery (Bergman, 2015) whereby the produced water is replaced in the oil and gas formation to improve oil production and maintain reservoir pressure (Veil et al., 2004). Another 27% of the Class II aquifer exemptions involve produced water disposal wells, and the remaining 7% of these exemptions are for the re-injection of other oil and gas fluids (Veil et al., 2004; GAO, 2012). As discussed in Section 3.6, these exempted aquifers have been demonstrated to be neither a current nor likely future underground source of drinking water. Consequently, loss of these aquifer exemptions would result in a significant reduction in oil and gas production and increased produced water treatment costs in many areas, without a measurable improvement in groundwater resource protection.

Raising the USDW threshold would also significantly impact oil and gas operations. Approximately 40% of conventional oil and gas wells generate produced water with a TDS level less than 50,000 mg/L (**Figure 2**) (Guerra et al., 2011). If re-injection into formations with this salinity or less were no longer allowed, the loss of oil and gas production and increased waste disposal costs could affect the viability of this same 40% of conventional oil and gas wells. This action would be contrary to the SDWA requirement that the UIC regulations not interfere with oil or natural gas production, except for those measures that are essential for the protection of underground drinking water resources (H. Rept. 93-1185, 1974; GAO, 2014; Tiemann, 2010)

In addition to modifying the aquifer exemption criteria, recommendations have been made that the UIC program be restructured to place primary administrative responsibility with the USEPA rather than the state agencies. A Congressional Research Service report issued in 2015 reported that an estimated $100 million per year in program administration costs would be needed by USEPA to meet the needs of the full UIC program (Tiemann and Vann, 2015). This cost could increase significantly if state agencies subsequently chose to terminate their UIC programs and transfer their UIC program administration to the USEPA.

Key Findings Regarding Economic Impacts: *Modification of the UIC regulations, either to terminate the aquifer exemption provision or raise the threshold TDS limit for definition of a USDW, would impose a significant economic impact on the many industries that rely upon injection wells as an environmentally sound alternative to surface discharge of wastes. For the oil and gas industry, the suggested changes could impair the economic viability on the order of 40% of oil and gas wells. These costs would generate no net environmental benefit, as the current UIC program is adequately protective of underground drinking water resources.*

8.0 CONCLUSIONS

Injection wells are used by many industries in the U.S. for safe management of waste liquids. The UIC rule of 1980, which set out specifications for the design, construction, and operation of injection wells, was directed toward balancing the protection of groundwater with the need for safe underground disposal of wastewater. Today, the vast majority of the Class II injection wells that are used for management of oil and gas produced water inject into aquifers with TDS > 10,000 mg/L - a salt concentration that is generally considered unusable for drinking water, agriculture, and industrial uses and is not considered a USDW. For aquifers with TDS below 10,000 mg/L, injection may be allowed subject to approval of an aquifer exemption application - a process which entails multiple reviews of technical data by tribal/state and/or federal regulatory agencies and opportunities for public comment prior to final USEPA approval.

Concerns have been raised that, in light of changing water use and increased demand for potable water, the current UIC program may not adequately protect saline aquifers that could serve as a future drinking water supply. However, studies of state regulatory programs conducted by various authorities have found the current regulatory programs to be effective for protection of USDWs. In some cases, these inspections have found need for significant improvement of state administrative processes; however, these deficiencies have not resulted in impacts to groundwater resources.

The most common bases for granting an aquifer exemption for Class II injection wells are either that: i) an aquifer "cannot now and will not in the future serve as a source of drinking water" due to the presence of commercially productive quantities of minerals or hydrocarbons, or ii) the aquifer contains TDS levels below 10,000 mg/L but above 3,000 mg/L and is not reasonably expected to be used as a public water supply.

Today, drinking water supply systems, including groundwater desalination facilities, rely upon groundwater with TDS < 3,000 mg/L, and state water management plans do not foresee significant use of groundwater with TDS above 3,000 mg/L due to practical limitations related to energy consumption, cost, waste disposal, and other environmental consequences associated with desalination. These factors, in combination with the relative abundance of lower salinity groundwater (TDS < 3,000 mg/L), in many areas, will continue to drive the preference for use of this lower salinity groundwater. These data show the current UIC rule and aquifer exemption provision to be directed toward protection of the groundwater resources that are amenable to use as a current or future drinking water supply.

For aquifers that are oil and gas reservoirs, use as a drinking water supply is commonly impractical due to the need to remove dispersed and dissolved petroleum prior to desalination, a process that entails

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advanced treatment methods and much higher energy use and cost than desalination alone. A small percentage of conventional oil and gas reservoirs do contain groundwater with TDS < 3,000 mg/L. In some of these low-salinity reservoirs, advanced pretreatment of the produced water by the operator has generated a water supply suitable for irrigation, as a compatible use.

Terminating the aquifer exemption provision or increasing the 10,000 mg/L TDS limit used for definition of a USDW would have a significant economic impact on the many industries that rely upon injection wells, while generating no net environmental benefit, as the current UIC program has been found to be adequately protective of underground drinking water resources.

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Appendix A. Performance Audits of State Class II UIC Regulatory Programs.

PROGRAM REVIEWER: U.S. ENVIRONMENTAL PROTECTION AGENCY

Agency Reviewed	Key Review Findings	Reviewer Recommendations
Texas RRC Class II UIC Program *Reference:* USEPA, 2016d	• "[M]ore than half of the reported number of authorized injection wells in Texas are inspected annually ... RRC collects and reviews operator-submitted monitoring information from approximately 97 percent of the Class II well inventory annually. Those numbers assure more than adequate inspection and monitoring surveillance actions." • "[T]he RRC testing and surveillance program exceeds the testing requirement for the MIT five-year performance measure."	USEPA and RRC are working together to address identification and delineation of aquifers exempted since state primacy was granted in 1982.
Nebraska OGCC Class II UIC Program *Reference:* USEPA, 2015b	• "Overall, EPA finds that NOGCC is operating the Class II UIC program consistent with its primacy approval." • "The review findings indicate the program is strong in all aspects of the UIC regulatory authorities. These include permitting, enforcement and compliance, monitoring, reporting, well construction and operations, mechanical integrity testing, inspections and data management."	USEPA provided recommendations on improvements to the Class II program regarding: i) documentation; ii) updating of state regulations for financial assurance, protection of USDWs with TDS content of 3,000 - 10,000 mg/L, and cementing of conversion wells; iii) clarification of previously approved aquifer exemptions; iv) additional staffing; and v) better defining aquifer boundaries within aquifer exemption areas.
Ohio DNR Class II UIC Program *Reference:* USEPA, 2015c	• "Ohio runs a good quality program for Class II wells ..." and "... is strong in several areas including permitting, inspections and resolving violations found during inspections." • USEPA reviewed new Ohio Class II program regulations and found that "these changes strengthen the program."	USEPA recommended that Ohio DNR identify operator reporting gaps or inaccuracies, take enforcement action for reporting violations, and escalate enforcement for recalcitrant and repeat violators.
California DOGGR Class II UIC Program *References:* CalEPA, 2015; USEPA, 2015a	• "We [USEPA] continue to be encouraged by the efforts DOGGR is making to restore the CA Class II UIC Program to compliance, as well as the strong support of the Water Board in this undertaking" (USEPA 2015). • "To date, preliminary water sampling of select, high-risk groundwater supply wells has not detected any contamination from oil production wastewater" (CalEPA 2015).	• USEPA will continue to work with DOGGR and the Water Board to ensure California's UIC program remains protective of public health and underground drinking water resources. • DOGGR and the State Water Board will continue to eliminate injection into non-exempt aquifers between 3,000 - 10,000 mg/L TDS by 15 February 2017, unless an aquifer exemption is applied for by the state and approved by USEPA.

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PROGRAM REVIEWER: U.S. GOVERNMENT ACCOUNTABILITY OFFICE

Agency Reviewed	Key Review Findings	Reviewer Recommendations
California DOGGR; Colorado OGCC; North Dakota ICOGD; Ohio DNR; Oklahoma OGCD; Texas RRC Class II UIC Programs USEPA-Managed Class II UIC Programs in Kentucky and Pennsylvania *Reference:* GAO, 2016	• "GAO found in June 2014 that EPA does not consistently conduct oversight activities, such as annual on-site program evaluations. According to EPA guidance, such evaluations should include a review of permitting and inspection files or activities to assess whether the state is protecting underground water. In California, for example, EPA did not regularly review permitting, and in July 2014, after a state review of permitting, EPA determined that the program was out of compliance with state and EPA requirements." • "[T]he agency does not have the location or supporting documentation necessary to identify the size and location of all aquifers for which it has approved exemptions from protection under the act."	• GAO recommended USEPA: i) require and collect well-specific data on inspections from state and USEPA-managed programs; ii) acquire complete, updated information on approved aquifer exemptions; and ii) enforce state program requirements if the requirements have not been enforced by the state in a timely and appropriate fashion. • USEPA generally agreed with GAO's findings on the Class II UIC program, and has been updating information on approved aquifer exemptions and making the information available on the agency's web site. USEPA further stated that they did not currently need well-specific inspection data.
California DOGGR; Colorado OGCC; North Dakota ICOGD; Ohio DNR; Oklahoma OGCD; Texas RRC Class II UIC Programs USEPA-Managed Class II UIC Programs in Kentucky and Pennsylvania *Reference:* GAO, 2012	• "Class II programs from the eight selected states that GAO reviewed have safeguards, such as construction requirements for injection wells, to protect against contamination of underground sources of drinking water. Programs in two states [Kentucky and Pennsylvania] are managed by EPA and rely on EPA safeguards, while the remaining six programs are state managed [California, Colorado, North Dakota, Ohio, Oklahoma, and Texas] and have their own safeguards that EPA deemed effective at preventing such contamination." • The Class II injection well programs in the eight states "we reviewed reported few known instances of contamination from the injection of fluids into Class II wells in the last 5 years. State and USEPA officials reported this information from two sources: (1) data on well violations that could be significant enough to contaminate underground sources and (2) data on citizen complaints of water well contamination and resulting state investigations."	• GAO provided recommendations to USEPA regarding: i) prevention of emerging risks to protection of USDWs; ii) focused and efficient enforcement, iii) consistent annual on-site evaluations of state Class II UIC programs; and iv) a publicly available UIC report database. • USEPA agreed with the GAO report's characterization of the resource challenges facing state and USEPA-managed Class II UIC programs.

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PROGRAM REVIEWER: GROUNDWATER PROTECTION COUNCIL (GWPC)

Agency Reviewed	Key Review Findings	Reviewer Recommendations
Ohio DOGRM Class II UIC Program *Reference:* GWPC, 2017	• The peer review of the Ohio Department of Natural Resources, Division of Oil and Gas Resource Management (DOGRM) Class II UIC regulatory program was conducted by a team of UIC managers and technical staff from state Class II agencies outside of USEPA Region 5. • The review team performed an in-depth examination of the Ohio laws and regulations, responses to questions, and a two-day state interview of UIC and DOGRM personnel. • In all subject areas investigated as part of the peer review, the DOGRM managed program was found to be protective of USDWs.	• "[T]he review team suggests DOGRM consider ... expanding public notification procedures and comment periods." • "The review team suggests DOGRM consider substantially increasing the required blanket bond amounts."
Nebraska OGCC Class II UIC Program *Reference:* GWPC, 2016	• The GWPC and Interstate Oil and Gas Compact Commission (IOGCC) conducted a peer review of the Nebraska Oil and Gas Conservation Commission (NOGCC) to assess the effectiveness of the Class II UIC program in meeting Safe Drinking Water Act (SDWA) requirements. • The peer review examined Class II UIC program requirements related to: i) permitting and file review, ii) financial assurance, iii) public outreach, iv) well construction, v) mechanical integrity testing, vi) inspections, and vii) compliance and enforcement • In each area of review, the team determined that the NOGCC program provided an adequate level of protection to USDWs.	• "The review team finds that the Nebraska Class II UIC program managed by the NOGCC is well run and managed. The review team finds that the program provides appropriate protection for USDWs in accordance with the provisions of federally delegated UIC program requirements. The program is well organized and makes excellent use of professional staff and the latest data management processes to assure that USDWs are adequately protected." • "Suggestions made in this report are intended to provide the state with considerations the team believes would make the program even better than it is currently. They are not intended to convey shortfalls in the program."

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PROGRAM REVIEWER: GWPC CONT'D

Agency Reviewed	Key Review Findings	Reviewer Recommendations
Utah DOGM Class II UIC Program *Reference:* GWPC, 2015	• The GWPC and Interstate Oil and Gas Compact Commission (IOGCC) conducted a peer review of the Utah Division of Oil, Gas, and Mining (DOGM) to assess the effectiveness of the UDOGM Class II UIC program in meeting SDWA requirements. • The peer review examined Class II UIC programs for: i) program administration; ii) permitting / compliance, including Area of Review and Aquifer Exemptions; iii) well construction, including Mechanical Integrity Tests (MIT) and cementing; and iv) inspections, including compliance and enforcement and emergency response. • "The review team finds that the program provides appropriate protection of USDWs in accordance with the provisions of federally delegated UIC program requirements. The program is well organized and makes excellent use of professional staff and the latest data management processes to assure that USDWs are adequately protected."	• "The review team finds that the Utah Class II UIC program managed by DOGM is well run and managed. The review team finds that the program provides appropriate protection for USDWs in accordance with the provisions of federally delegated UIC program requirements. The program is well organized and makes excellent use of professional staff and the latest data management processes to assure that USDWs are adequately protected." • "Suggestions made in this report are intended to provide the state with considerations the team believes would make the program even better than it is currently. They are not intended to convey shortfalls in the program."

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PROGRAM REVIEWER: UNDERGROUND INJECTION PRACTICES COUNCIL (UIPC) (NOW THE GROUNDWATER PROTECTION COUNCIL)

Agency Reviewed	Key Review Findings	Reviewer Recommendations
California DOGGR; Texas RRC; Louisiana DNR; Ohio DNR; Oklahoma CC; Kansas CC Class II UIC Programs, *Reference:* Lynn and Stamets, 1990	• [Underground Injection Practices Council] UIPC conducted peer reviews of state underground injection control (UIC) programs to assess their effectiveness in protecting underground sources of drinking water (USDWs) from operation of injection wells related to the production of oil and gas (Class II injection wells). • State UIC programs were evaluated on seven program elements related to: i) permitting and file reviews; ii) inspections; iii) mechanical integrity testing; iv) compliance and enforcement; v) plugging and abandonment; vi) inventory and data management; and vii) public outreach. • "The overall consensus for the six state reviews completed to date is that, with only minor exceptions, the states are maintaining efforts to effectively protect USDWs from contamination by Class II UIC injection wells."	• Results of the review teams' evaluations were presented orally and in writing to each state. Reports reflected teams' recommendations for areas of improvement in the seven program elements.