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The Class V Underground Injection Control Study

Volume 9

Spent Brine Return Flow Wells

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SPENT BRINE RETURN FLOW WELLS

The U.S. Environmental Protection Agency (USEPA) conducted a study of Class V underground injection wells to develop background information the Agency can use to evaluate the risk that these wells pose to underground sources of drinking water (USDWs) and to determine whether additional federal regulation is warranted. The final report for this study, which is called the Class V Underground Injection Control (UIC) Study, consists of 23 volumes and five supporting appendices. Volume 1 provides an overview of the study methods, the USEPA UIC Program, and general findings. Volumes 2 through 23 present information summaries for each of the 23 categories of wells that were studied (Volume 21 covers 2 well categories). This volume, which is Volume 9, covers Class V spent brine return flow wells.

1. SUMMARY

Naturally occurring surface and underground brines are used as the source for commercial production of a variety of mineral commodities, including common salt, calcium chloride, sodium sulfate, and/or magnesium, iodide, or bromide compounds. When underground brines serve as the raw material for production of mineral commodities, the brine is extracted from the subsurface through production wells, the target compounds or elements are extracted, and the resulting "spent brine" is normally[1] returned to the subsurface through spent brine return flow (injection) wells.

The chemical characteristics of the injected spent brine are determined primarily by the characteristics of the brine that is withdrawn for processing and the nature of the extraction and production processes used. As a result, spent brine characteristics can vary substantially from facility to facility, although in some cases the brine characteristics are similar when several facilities withdraw brine from a common formation, as is the case in Arkansas. In Arkansas, available data indicate that concentrations of barium and boron in spent brine routinely exceed primary maximum contaminant levels (MCLs) or health advisory levels (HALs). Data available for Michigan facilities indicate that chloride, copper, iron, manganese, total dissolved solids, and pH levels frequently exceed secondary MCLs. Data are not available to determine whether concentrations of some other constituents, including some heavy metals, are present at concentrations above health-based levels.

Spent brine return flow wells inject spent brine into the same formation from which it was withdrawn, which in all current cases is below the lowermost USDW. (In fact, most spent brine return flow wells were initially drilled as production wells and subsequently converted to injection wells.) The chemical composition of the spent brine is generally similar to that of the produced brine except that the concentration of target elements (e.g., magnesium) has been reduced and the concentration of other elements (e.g., calcium) may have been increased through substitution. Thus, the MCL exceedances observed for the spent brine are also typical for the produced brine and the receiving formation.

[1] At least one facility disposes of spent brines from extraction of minerals from brine withdrawn from underground sources by surface discharge (to a playa lake bed) instead of by injection.

No incidents of USDW contamination by spent brine return flow wells were identified during preparation of this report. In addition, spent brine return flow wells are not likely to receive accidental spills or illicit discharges. Corrosion of some well materials by the brine is a common problem, however. Therefore, injection is through corrosion-resistant tubing and well integrity is monitored on an ongoing basis.

According to the state and USEPA Regional survey conducted for this study, there are 98 documented spent brine return flow wells that are regulated as Class V injection wells in Arkansas (74) and Michigan (24). Several other states, including New York, Tennessee, California, and Oklahoma, indicate that spent brine wells exist, but they are regulated as Class II or III wells.

The specific features of well construction and operation may vary somewhat with the location and timing of construction of the well, but in general, all the wells are built according to regulatory or permit requirements that have many features in common with Class I and Class II injection wells. Arkansas has placed jurisdiction over spent brine return flow wells in its Oil and Gas Commission, which applies Class II UIC permitting requirements as well as a special set of construction and operating standards. For wells in Michigan, individual UIC permits are issued by USEPA Region 5.

2. INTRODUCTION

Spent brine return flow wells are described in 40 CFR 146.5(e) as "wells used to inject spent brine into the same formation from which it was withdrawn after extraction of halogens[2] or their salts." Also included in the scope of this discussion are wells used for injection of spent brine (also commonly referred to as tail brine) that results from production of non-halogen compounds such as calcium salts, sodium sulfate, and magnesium compounds. Spent brine wells by definition do not include wells used to reinject brines produced from oil and gas wells or brines injected as part of oil and gas enhanced recovery operations. Such wells are in the Class II injection well category. In addition, injection wells used in solution mining of salt are not spent brine wells. Rather, they are solution mining wells that are in the Class III injection well category.

The spent brine subcategory includes wells that inject into a formation that is below the lowermost USDW, as defined in 40 CFR 146.3, and wells that inject into or above a USDW.[3] Injection wells that are used to reinject geothermal brine after extraction of both heat and minerals (e.g., metals), such as operations that will occur in connection with the zinc recovery facility currently being

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[2] Any of the five elements that form part of group VIIA of the periodic table (i.e., fluorine, chlorine, bromine, iodine, and astatine).

[3] Spent brine return flow wells were explicitly identified as Class V wells in the technical corrections to the UIC Technical Criteria and Standards (40 CFR 146) published on August 27, 1981 (46 *FR* 43156) and subsequently have been considered to be Class V wells regardless of whether injection occurs above, into, or below a USDW. At the present time, all active spent brine return flow wells inject below the lowermost USDW.

constructed near the Salton Sea in California, are covered along with other electric power geothermal injection wells in Volume 17 of the Class V study.

3. PREVALENCE OF WELLS

For this study, data on the number of Class V spent brine return flow wells were collected through a survey of state and USEPA Regional UIC Programs. The survey methods are summarized in Section 4 of Volume 1 of the Class V Study. Table 1 lists the numbers of Class V spent brine return flow wells in each state, as determined from this survey. The table includes the documented number and estimated number of wells in each state, along with the source and basis for any estimate, when noted by the survey respondents. If a state is not listed in Table 1, it means that the UIC Program responsible for that state indicated in its survey response that it did not have any Class V spent brine return flow wells.

As shown in Table 1, there are a total of 98 spent brine return flow wells in Michigan (24) and Arkansas (74) that are regulated as Class V injection wells. Spent brine return flow wells are also used in Oklahoma in association with iodine recovery from brines. These wells in Oklahoma were generally drilled as oil and gas wells and the state, which is Primacy State for Class V wells (see Section 7.1 for the definition of Primacy State), applies Class II requirements to these wells. Several other states, including New York, Tennessee, and California, indicated in the survey that wells that inject brines are considered Class II or III wells. This report only covers spent brine return wells that are regulated primarily as Class V wells.

Use of Class V spent brine return flow wells may decrease in Michigan because injection may be changed to a different formation due to increasing pressure in the source (and current injection) formation. Such a change would cause the new (replacement) injection wells to be classified as Class I wells (Micham, 1999). The number of wells in use in the future may also increase or decrease depending on the relative competitiveness in world markets of the mineral production processes that currently rely on these wells for brine disposal.

Table 1. Inventory of Spent Brine Return Flow Wells in the U. S.

State	Documented Number of Wells[1]	Estimated Number of Wells: Number	Estimated Number of Wells: Source of Estimate and Methodology
USEPA Region 1 -- None			
USEPA Region 2 -- None			
USEPA Region 3 -- None			
USEPA Region 4 -- None			
USEPA Region 5			
MI	24	24	N/A
USEPA Region 6			
AR	74	74	N/A
USEPA Region 7 -- None			
USEPA Region 8 -- None			
USEPA Region 9 -- None			
USEPA Region 10 -- None			
All USEPA Regions			
All States	98	98	

[1] The number of wells in Michigan is based on July, 1999 information provided by USEPA Region 5.
N/A Not available.

4. INJECTATE CHARACTERISTICS AND INJECTION PRACTICES

4.1 Injectate Characteristics

Injectate characteristics are determined primarily by the characteristics of the brine source, the extraction process and reagents used, and whether or not other wastes are mixed with the spent brine for disposal by injection.[4] Underground brine brought to the surface for processing (often referred to as "feed brine") may contain natural gas, crude oil, ammonia, and hydrogen sulfide in addition to dissolved mineral salts.

[4] For the purposes of this discussion, other wastes, if any, injected with spent brine are assumed not to have characteristics that would change the classification of the injection well (e.g., are non-hazardous).

4.1.1 Arkansas

All of the Class V spent brine return flow wells in Arkansas are associated with facilities that produce bromide compounds from brine extracted from the Smackover formation. Data from routine sampling by the Arkansas Department of Environmental Quality (DEQ) in December, 1998 of spent brine prior to reinjection into the Smackover formation are presented in Attachment B to this document (Arkansas DEQ, 1999). As shown, concentrations of barium, boron, copper, and manganese exceed MCLs or HALs.[5] It can not be determined if concentrations of arsenic, cadmium, chromium, iron, lead, nickel, and selenium are above MCLs or HALs because the reported detection levels are above these set values. Although some constituents exceed MCLs, it is important to note that the injection zone is more than 6,000 feet below the lowermost USDW with several confining units separating the two.

4.1.2 Michigan

Class V spent brine return flow wells in Michigan are associated with three companies (Martin Marietta Magnesia Specialties, Morton Performance Chemicals, and The Dow Chemical Company) that produce magnesium compounds, bromide compounds, and/or calcium chloride from natural brines in the Filer Sandstone or Sylvania Sandstone formations.[6] The top of the production/injection formation is found at approximately 2,600 feet below ground surface (bgs) (with the exact depth dependant on the well location), approximately 2,000 feet below the lowermost USDW.

Characteristics of feed brine produced from the Filer Sandstone and spent brine injected into the same formation at the Martin Marietta Magnesia Specialties plant in Manistee are summarized in Table 2. As shown, the typical characteristics of the spent brine are generally similar, with some exceptions, to the characteristics of the brine in the Filer Sandstone. The spent brine is essentially devoid of magnesium and contains a higher concentration of calcium than the source brine as a result of the substitution of calcium for magnesium in the brine during reaction with dolime to precipitate magnesium hydroxide. The concentration of all constituents is reduced by the addition of water. Water is injected in small quantities at the source brine well head [7] and it is added during the process to generate a relatively chloride-free magnesium hydroxide product. The pH of the spent brine is adjusted

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[5] Monitoring for volatile compounds is also conducted, but the results are reported by the laboratory as questionable due to the presence of bubbles in the samples. (Volatile samples are collected with zero headspace in the sampling container, but bubbles form as the brine cools following sampling.)

[6] Some geologists say that the Filer Sandstone is a part of or is the same as the Sylvania Sandstone, which is the lowest member of the Detroit River Group. Others say that the Filer Sandstone is a member of the Amhertsburg formation. The Filer Sandstone is believed to be a closed lens and is restricted to the western portion of the Michigan Basin. The Filer Sandstone is overlain by the dolomite of the Amherstburg formation and is underlain by the Bois Blanc formation (Richmond, 1999a).

[7] Water is added to prevent salt precipitation from the saturated brine caused by the temperature reduction that occurs during transport in the pipeline to the plant and during storage at the plant.

to approximately 6 prior to injection as compared to an in-situ pH of about 4.5 to 5.0 (Richmond, 1999a and 1999b).

As shown in Table 2, the available data indicate that the concentration of boron in the spent brine at the Martin Marietta facility exceeds the HAL while the concentrations of chloride and iron exceed secondary MCLs and pH levels are outside the secondary MCL range. It is important to note that the boron concentration is higher and the pH lower in the receiving formation than in the spent brine that is injected (Richmond, 1999a).

Table 2. Characteristics of Produced and Injected Brine for Wells in Manistee, Michigan

Parameters	Units	Typical Composition		Drinking Water Standards		Health Advisory Levels	
		Brine from the formation	Spent brine to the formation	mg/l	P/S*	mg/l	N/C*
$CaCl_2$	mg/l	215,000	280,000	--		--	
$MgCl_2$	mg/l	120,000	2,000	--		--	
NaCl	mg/l	45,000	40,000	--		--	
KCl	mg/l	10,000	9,000	--		--	
$SrCl_2$	mg/l	4,000	3,000	--		--	
Chloride	mg/l	265,000	220,000	250	S	--	
Boron	mg/l	60	32	--		0.6	N
Iron	mg/l	10	<1	0.3	S	--	
pH		5	6	6.5 to 8.5	S	--	
Bromide	mg/l	3,000	2,000	--		--	
Sulfur	mg/l	500	--	--		--	
Lithium	mg/l	105	90	--		--	
Specific Gravity		1.28 - 1.29	1.22 - 1.25	--		--	

* P=primary; S=secondary; N=non-cancer; C=cancer

Source: Richmond, 1999a

The Dow Chemical facility in Ludington, Michigan manufactures calcium chloride, magnesium hydroxide, and bromide compounds from natural brine produced from wells in the Filer Sandstone. Table 3 presents data from annual analysis of the characteristics of injected spent brine over the period of 1994 through 1998. Variation in the characteristics of the injected brine are in part due to changes in plant activities. Manufacturing processes at the plant are highly integrated; the byproducts of each process are raw materials for another product. Exactly which processes are operated on a given day depend on market conditions (Ryder, 1999b). The following paragraphs describe the production process used (or not used, depending on market conditions) to illustrate how injectate characteristics may vary depending on the products the plant chooses to produce.

Table 3. Injectate Characteristics for Wells in Ludington, Michigan

Parameter	Units	Annual Analysis of Reinjected Brine 1994 - 1998				Drinking Water Standard		Health Advisory Level	
		Average	Median	Minimum	Maximum	mg/l	P/S*	mg/l	N/C*
Sodium	mg/l	22,374	21,619	13,160	33,050	--		--	
Calcium	mg/l	48,424	54,925	15,625	89,125	--		--	
Magnesium	mg/l	1,120	565	169	7,086	--		--	
Barium	mg/l	0.15	0.15	0.05	0.6	2	P	2	N
Total Iron	mg/l	1.6	1.3	0.4	13.4	0.3	S	--	
Chloride	mg/l	145,415	130,117	69,688	333,557	250	S	--	
Sulfate	mg/l	21	17	4	64	500	P	--	
Carbonate	mg/l	91	98	0	166	--		--	
Bicarbonate	mg/l	63	47	4	377	--		--	
Sulfide	mg/l	<0.5	<0.5	<0.5	<0.5	--		--	
Total Dissolved Solids	mg/l	204,727	206,800	20,300	345,600	500	S	--	
pH @ 25°C		9.18	9.2	8.9	9.4	6.5-8.5	S	--	
Ohm-meter @ 25°C		0.064	0.06	0.04	0.12	--		--	
Specific Gravity		1.16	1.15	1.08	1.61	--		--	

* P=primary; S=secondary; N=non-cancer; C=cancer
Source: Ryder, 1999a

In the first process, bromide ion in the brine is converted into liquid bromine by chlorine oxidation, steam stripping, and condensation. This bromine is sold as elemental bromine or converted into bromide compounds by downstream processes. The debrominated brine from the bromine stripping tower is acidic; it is neutralized with alkali so that it can be pumped through steel pipes and stored in steel tanks. If market demand for calcium chloride and magnesium hydroxide is slack, the debrominated brine is pumped directly to a mixing tank and then reinjected. Otherwise, it is pumped to the magnesium hydroxide manufacturing process. Scrubber water from the bromine process vents is also high in halides and may be sent directly to the mixing tank or added to the debrominated brine stream for further processing (Ryder, 1999b).

The second process produces magnesium hydroxide by precipitating the magnesium ion in the brine with alkali. The alkali used is typically lime, so the calcium ion from the lime replaces the magnesium ion in solution to form an intermediate strength calcium chloride solution. Magnesium hydroxide is separated from the calcium chloride solution by settling, filtration, and washing with water. The clear fluids from the settling and filtration steps are usually pumped to an evaporator to produce concentrated calcium chloride solution. If calcium chloride demand is low, these fluids may also be sent to the mixing tank and injected. Wash water from the magnesium hydroxide process may also be used to produce calcium chloride solution if market demand is sufficient. Otherwise, it is added to the mixing tank and injected. The calcium chloride solutions from this process are alkaline because they are saturated with magnesium hydroxide. If these solutions are injected, hydrochloric acid or debrominated brine is usually added to reduce the alkalinity of the fluid (Ryder, 1999b).

Evaporation is the third major process in the manufacturing sequence at the Ludington facility. In this step, steam is used to boil water out of the intermediate strength solution and make strong calcium chloride solution for direct sale or for production of dry calcium chloride products. As the calcium chloride solution is concentrated, sodium chloride that was present in the natural brine separates out as crystals. The sodium chloride crystals are redissolved in the mixing tank to increase the density and viscosity of the injected solution (Ryder, 1999b).[8]

Dry calcium chloride manufacturing is the final process in the manufacturing sequence. Concentrated calcium chloride solution is converted into either flakes or pellets for consumer or industrial use by boiling off most of the remaining water. Dust produced during conveying and packaging of the dry product is collected with water scrubbers. The scrubber water is pumped to the mixing tank for subsequent injection (Ryder, 1999b).

After the various streams from the production plants are blended in the mixing tank, the resulting fluid is filtered to remove most of the precipitated solids prior to injection. Solids that pass through the filter (and, thus, are injected) collect on the sandstone face of the well bore and are dissolved by periodic addition of hydrochloric acid to the injected spent brine at each injection well (Ryder, 1999b).

Available data for this Dow facility in Ludington indicate that the average and median concentrations of iron, chloride, total dissolved solids, and pH in the spent brine exceed secondary MCLs (Ryder, 1999a).

The third facility in Michigan using a spent brine return flow well is Morton Performance Chemicals in Manistee. The facility uses brine from the Sylvania Sandstone as feed for the process (USEPA, No date #2). Data from the USEPA Region 5 permit files on characteristics of spent brine reinjected into the formation are summarized in Table 4. As shown, pH levels are outside the secondary MCL range.

[8] High concentrations of halide salts are desirable in the injected fluid because the salts increase the viscosity of the fluid and so reduce the tendency of the injected brine to “finger” through the natural brine in place.

Table 4. Injectate Characteristics for Single Manistee Well

Parameter	Reinjected Brine Analysis 1997		Drinking Water Standard		Health Advisory Level	
	Units	Concentration	mg/l	P/S*	mg/l	N/C*
Sodium	mg/l	10,300	--		--	
Calcium	mg/l	53,800	--		--	
Magnesium	mg/l	2,090	--		--	
Barium	mg/l	0.42	2	P	2	N
Iron	mg/l	0.273**	0.3	S	--	
pH		2.54	6.5-8.5	S	--	
Ohm-meter @ 25°C		0.07	--		--	
Specific Gravity		1.13	--		--	

* P=primary; S=secondary; N=non-cancer; C=cancer
** Low spike recovery reported, so sample result may be biased low.
Source: Great Lakes Environmental Center, 1997 and U.S. Filter Corp., 1997

4.2 Well Characteristics

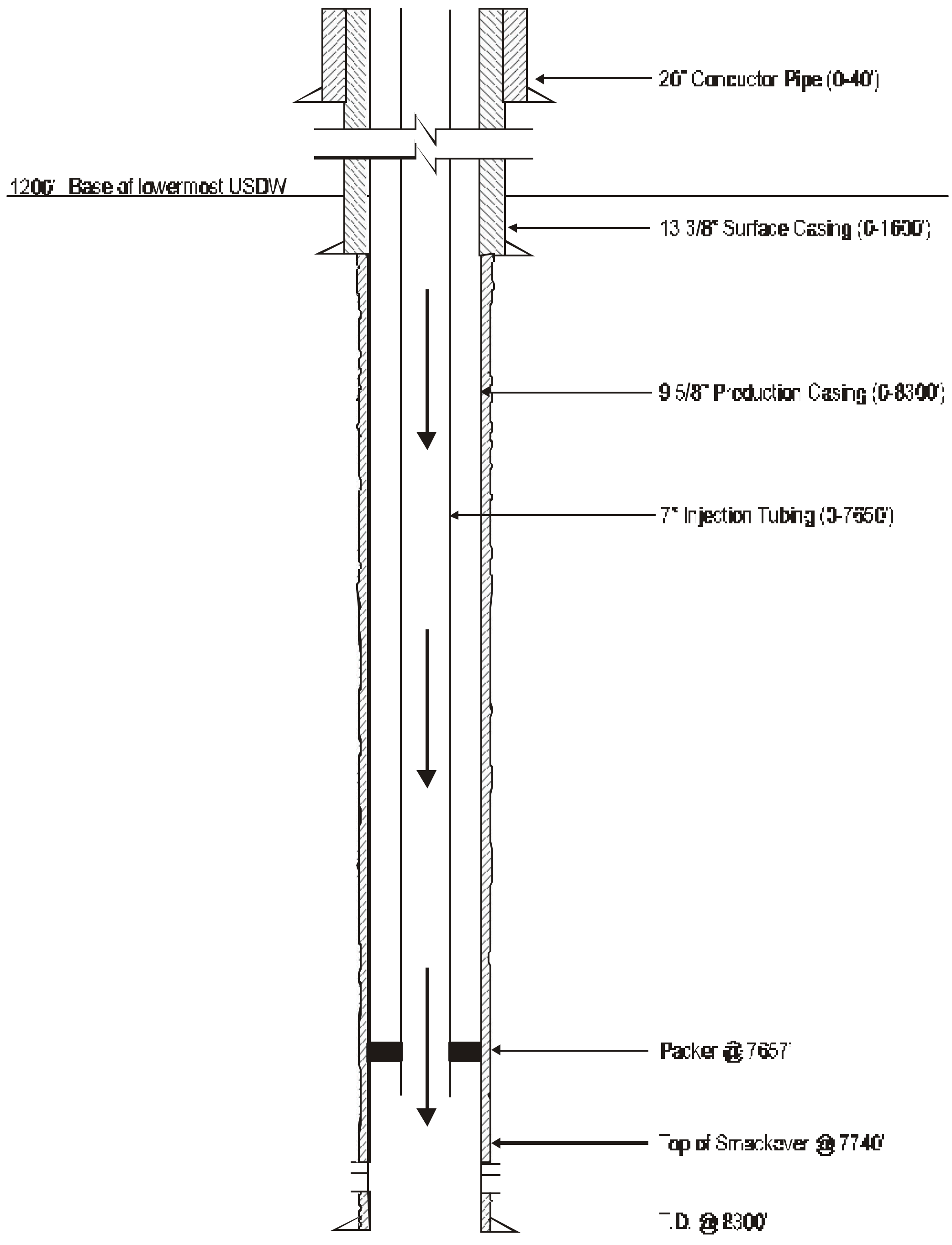
Two general types of well construction are used for spent brine return flow wells. Most wells utilize injection tubing set into a packer immediately above the injection zone. In the other less common arrangement, the tubing (and sometimes a liner as well) is cemented into the well and no annulus is present. This second arrangement makes it harder to monitor the well for loss of mechanical integrity during well operation and this approach is not currently used for new spent brine wells in Michigan or Arkansas. It has sometimes been used when a well is converted to an injection well[9] and or when there is corrosion or another type of damage to the long string (production) casing (Jones, 1988; Looney, 1999; Richmond, 1999a, 1999b).

4.2.1 Arkansas

Figure 1 illustrates a spent brine return flow well from Arkansas. Currently, Great Lakes Chemical Corporation in Union County and the Albemarle Corporation in Columbia County use a total of 74 injection wells to return spent brine to the Smackover formation. The top of the Smackover formation occurs at a depth ranging from 7,150 feet to 8,600 feet, depending on location, while the lowermost USDW lies from 875 feet to 1,200 feet below ground surface. The Midway formation is located just below the USDW and is comprised of shale 400 feet to 700 feet thick. The Midway formation is underlain by alternating layers of shale, sandstone, and limestone, which include several layers of additional separation. Immediately above the Smackover formation is 200 feet of Anhydrite and Shale, the Buckner formation, which acts as a confining bed (Looney, 1998).

[9] For example, Martin Marietta used this approach to convert a well purchased from another company for use an injection well. Because the casing cementing program used when the well was initially constructed was not available, a liner was cemented in place inside the casing.

Figure 1. Example of a Typical Class V Spent Brine Return Flow Well in Arkansas (depths in feet below ground surface)



Source: Looney, 1998

The injection wells are typically constructed with both surface and long string casings ranging from about 7 to 10 inches in diameter. The surface casing is set 250 feet below the lowermost USDW and cemented back to the surface. Long string (production) casing is set at the top of the Smackover formation (the injection zone) and cemented back to the surface. Injection is typically through tubing with a packer set within 100 feet of the top of the Smackover formation. Thus, there are three layers of pipe and two layers of cement between the injected fluid and the USDW. Some wells constructed before 1991 (when current well construction requirements were established) have surface pipe cemented to the surface, long string casing cemented to the surface, and a casing liner (steel or FRP) cemented to the surface (Arkansas Oil and Gas Commission, 1991; Looney, 1998).

4.2.2 Michigan

Figure 2 illustrates the construction of an injection well at the Martin Marietta Magnesia Specialties production facility in Manistee. At this site, the base of the lowermost USDW, located in glacial drift, is approximately 634 feet below the ground surface. Approximately 2,000 feet of sedimentary rock strata separates the injection zone and the lowermost USDW (USEPA Region 5, No date #1). Subsurface characteristics and well construction are similar for the injection well at Morton Performance Chemicals (USEPA Region 5, No date #2).

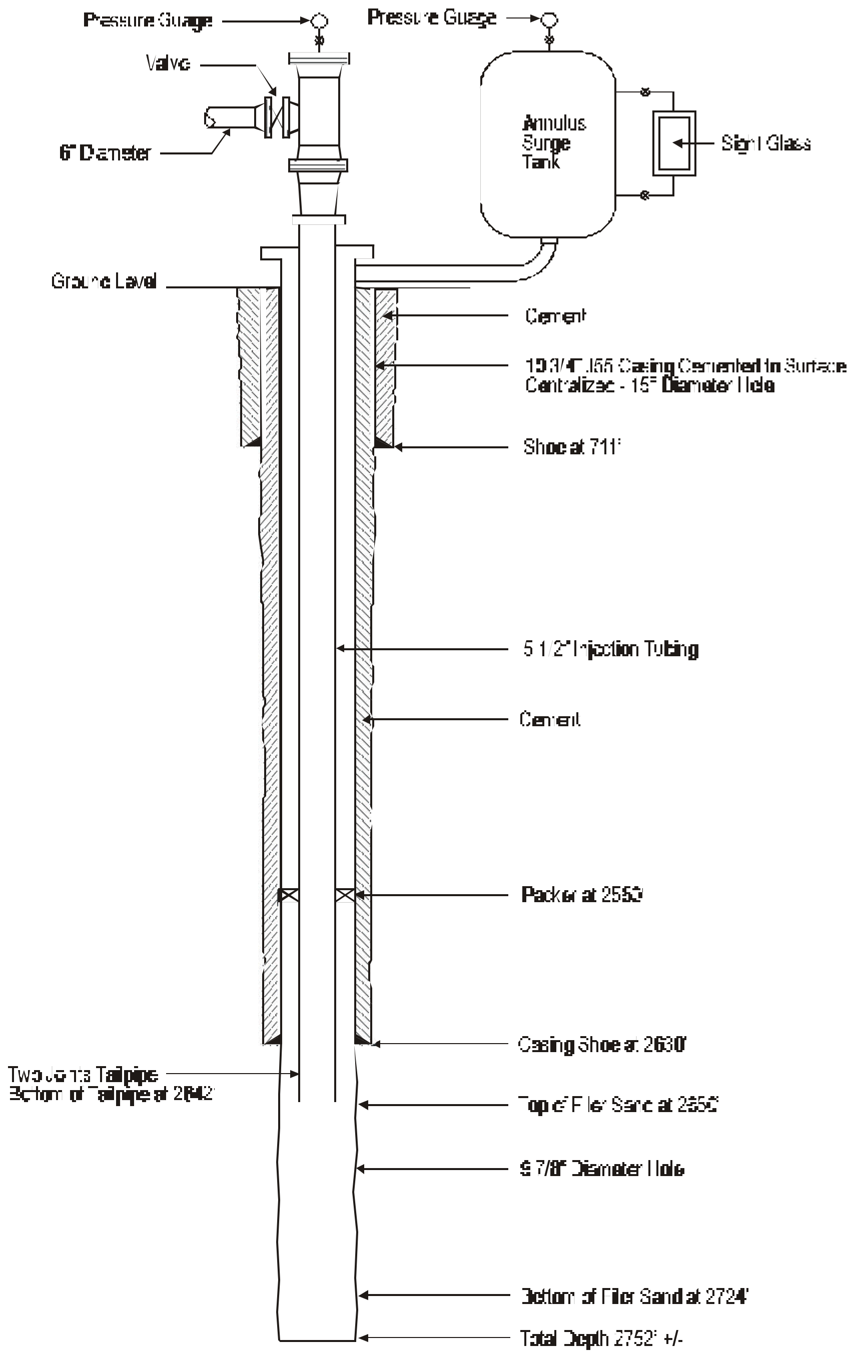
In the example shown in Figure 2, the surface and long string casings are cemented to the surface to prevent the movement of fluids between formations penetrated by the well. Injection is through tubing with a packer set in the long string casing adjacent to a cemented interval that is within or below the nearest impermeable confining layer immediately above the injection zone. A variety of tubing materials may be used to resist corrosion, including fiberglass reinforced plastic, steel casing with a thick film internal coating, and PVC-lined steel casing (Richmond, 1999a).

4.3 Operating Practices

The operation of Class V spent brine return flow wells is typically integrated with overall facility operation, because plant production is dependent on injection in at least two ways. First, plant production may need to be curtailed if injection capacity is limited. Second, injection can also interfere with production if the injected fluid lowers the concentration of the target constituents in the formation at the production wells.

Basic operating characteristics such as injection pressure and flow rate may vary with changes in production. These characteristics may be limited by permit conditions or regulations. In addition, requirements for monitoring and reporting of injectate quality, operating conditions, and mechanical integrity testing are specified by permit or regulations.

Figure 2. Example of a Typical Class V Spent Brine Return Flow Well in Michigan (depths in feet below ground surface)



Source: Richmond, 1999a

4.3.1 Arkansas

Mechanical integrity testing is conducted before injection is allowed to commence and then every five years at a minimum. Annual mechanical integrity testing is required for any well without tubing and packer. The annual test could either be a Radioactive Tracer Survey, a Spinner Survey, or the use of coil tubing with an inflatable packer to prove integrity of the well bore and proper disposal of spent brine (Looney, 1998).

4.3.2 Michigan

Under the terms of permits issued by USEPA Region 5, mechanical integrity must be demonstrated before well operation and every five years thereafter, as indicated by a two-part test. Part I must demonstrate no significant leaks in the casing, tubing, or packer, and Part II must ensure no significant fluid movement into a USDW through vertical channels adjacent to the wellbore. Therefore, facilities must conduct Part I mechanical integrity testing by pressure testing the annular space between the tubing and casing. Part II mechanical integrity testing requires conducting a noise, temperature, or oxygen activation log test (State of Michigan, 1998).

In addition to Part I and Part II testing, the annular between the injection tubing and the casing is filled with a liquid to permit continuous monitoring of the mechanical integrity during operation of the well. At the Martin Marietta Magnesia Specialties facility, for example, the annular space is filled with either fresh water or produced brine treated with a corrosion inhibitor and bactericide, with the top 10 to 50 feet filled with fuel oil to prevent freezing. The annulus surge tank (see Figure 2) is filled to one-third to one-half of its capacity with fuel oil. Nitrogen fills the remaining tank volume and provides the initial pressure on the annulus system. Tank pressure and liquid level are recorded at least three times a week. If a rapid fluid loss or pressure anomaly is observed, pressure testing and/or maintenance of the well is performed to investigate and correct, if necessary, loss of mechanical integrity (Richmond, 1999a).

5. POTENTIAL AND DOCUMENTED DAMAGE TO USDWS

The primary constituent properties of concern when assessing the potential for Class V spent brine return flow wells to adversely affect USDWs are toxicity, persistence, and mobility. The toxicity of a constituent is the potential of that contaminant to cause adverse health effects if consumed by humans. Appendix D of the Class V UIC Study provides information on the health effects associated with contaminants found above drinking water standards or health advisory levels in the injectate of spent brine return flow wells and other Class V wells.

Persistence is the ability of a chemical to remain unchanged in composition, chemical state, and physical state over time. Appendix E of the Class V UIC Study presents published half-lives of common constituents in fluids released in spent brine return flow wells and other Class V wells. All of the values reported in Appendix E are for ground water. Caution is advised in interpreting these values because ambient conditions have a significant impact on the persistence of both inorganic and organic compounds. Appendix E of the Class V UIC Study also provides a discussion of mobility of certain constituents found in the injectate of spent brine return flow wells and other Class V wells.

Based on the information presented in section 4.1, the following constituents routinely or frequently exceed health-based standards in spent brine from one or more facilities: barium, boron, and copper. Manganese, iron, chloride, total dissolved solids, and pH are routinely above secondary drinking water standards at some facilities. The persistence and mobility of these constituents is expected to be approximately the same following injection as in the produced brine because injection is into the producing formation. If spent brine were accidentally released to another formation, the persistence and mobility of these constituents may be different than in the producing formation. Discussion of behavior of these constituents outside the producing formation is not included here because there have been no reported instances in which spent brine return flow wells have contributed to contamination of a USDW. Specifically, the State of Arkansas has not had any incidents in which a spent brine return flow well contributed to contamination of a USDW (Looney, 1998).[10] Similarly, USEPA Region 5, which implements the UIC program in Michigan, reports no incidents in which spent brine return flow wells contributed to contamination of a USDW (Cadmus, 1999).

6. ALTERNATIVE AND BEST MANAGEMENT PRACTICES

Alternatives to injection for disposal of spent brine at the facilities that use spent brine return flow wells appear limited at this time.[11] Although discharge to surface waters may have been common in some locations in Michigan approximately 20 to 25 years ago, injection is now the disposal approach for most spent brine generated by these facilities.

As discussed in the next section, requirements applicable to spent brine return flow wells in Michigan and Arkansas go well beyond the requirements for most Class V wells and are similar in many respects to the requirements applicable to Class I and Class II injection wells. No best management practices in addition to the current requirements were identified during the preparation of this report.

7. CURRENT REGULATORY REQUIREMENTS

Several federal, state, and local programs exist that either directly manage or regulate Class V spent brine return flow wells. On the federal level, management and regulation of these wells fall

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[10] Spent brine from the plant has been injected into the Filer formation for over 45 years to maintain the pressure in the pores of the sandstone and displace the natural brine towards production wells (Ryder, 1999).

[11] Although all facilities in Michigan and Arkansas that currently recover minerals from underground brines use spent brine return flow wells to inject spent brine back into the producing formation, at least one facility in California (near Searles Lake) disposes the spent brine to a playa lake bed instead of injection wells.

primarily under the UIC program authorized by the Safe Drinking Water Act (SDWA). Some states and localities have used these authorities, as well as their own authorities, to extend the controls in their areas to address concerns associated with spent brine return flow wells.

7.1 Federal Programs

Class V wells are regulated under the authority of Part C of SDWA. Congress enacted the SDWA to ensure protection of the quality of drinking water in the United States, and Part C specifically mandates the regulation of underground injection of fluids through wells. USEPA has promulgated a series of UIC regulations under this authority. USEPA directly implements these regulations for Class V wells in 19 states or territories (Alaska, American Samoa, Arizona, California, Colorado, Hawaii, Indiana, Iowa, Kentucky, Michigan, Minnesota, Montana, New York, Pennsylvania, South Dakota, Tennessee, Virginia, Virgin Islands, and Washington, DC). USEPA also directly implements all Class V UIC programs on Tribal lands. In all other states, which are called Primacy States, state agencies implement the Class V UIC program, with primary enforcement responsibility.

Spent brine return flow wells currently are not subject to any specific regulations tailored just for them, but rather are subject to the UIC regulations that exist for all Class V wells. Under 40 CFR 144.12(a), owners or operators of all injection wells, including spent brine return flow wells, are prohibited from engaging in any injection activity that allows the movement of fluids containing any contaminant into USDWs, "if the presence of that contaminant may cause a violation of any primary drinking water regulation . . . or may otherwise adversely affect the health of persons."

Owners or operators of Class V wells are required to submit basic inventory information under 40 CFR 144.26. When the owner or operator submits inventory information and is operating the well such that a USDW is not endangered, the operation of the Class V well is authorized by rule. Moreover, under section 144.27, USEPA may require owners or operators of any Class V well, in USEPA-administered programs, to submit additional information deemed necessary to protect USDWs. Owners or operators who fail to submit the information required under sections 144.26 and 144.27 are prohibited from using their wells.

Sections 144.12(c) and (d) prescribe mandatory and discretionary actions to be taken by the UIC Program Director if a Class V well is not in compliance with section 144.12(a). Specifically, the Director must choose between requiring the injector to apply for an individual permit, ordering such action as closure of the well to prevent endangerment, or taking an enforcement action. Because spent brine return flow wells (like other kinds of Class V wells) are authorized by rule, they do not have to obtain a permit unless required to do so by the UIC Program Director under 40 CFR 144.25. Authorization by rule terminates upon the effective date of a permit issued or upon proper closure of the well.

In Michigan, USEPA Region 5 directly implements the UIC Class V program and requires individual permits for spent brine return flow wells. The specific permit requirements are discussed along with the state's permit requirements in Attachment A of this volume.

Separate from the UIC program, the SDWA Amendments of 1996 establish a requirement for source water assessments. USEPA published guidance describing how the states should carry out a source water assessment program within the state's boundaries. The final guidance, entitled *Source Water Assessment and Programs Guidance* (USEPA 816-R-97-009), was released in August 1997.

State staff must conduct source water assessments that are comprised of three steps. First, state staff must delineate the boundaries of the assessment areas in the state from which one or more public drinking water systems receive supplies of drinking water. In delineating these areas, state staff must use "all reasonably available hydrogeologic information on the sources of the supply of drinking water in the state and the water flow, recharge, and discharge and any other reliable information as the state deems necessary to adequately determine such areas." Second, the state staff must identify contaminants of concern, and for those contaminants, they must inventory significant potential sources of contamination in delineated source water protection areas. Class V wells, including spent brine return flow wells, should be considered as part of this source inventory, if present in a given area. Third, the state staff must "determine the susceptibility of the public water systems in the delineated area to such contaminants." State staff should complete all of these steps by May 2003 according to the final guidance.[12]

7.2 State and Local Programs

Two states, Arkansas and Michigan, reported existing Class V solution mining injection wells that are covered in this document. Attachment A of this volume describes how each of these states currently addresses these wells. Both states issue individual permits. In Arkansas, a UIC Primacy State for Class V wells, jurisdiction over spent brine return flow wells rests with the Oil and Gas Commission, which applies UIC Class II permitting requirements, as well as a special set of construction and operating standards in a rule applicable to Class V (bromine related) injection wells. In Michigan, the Michigan Department of Environmental Quality, Geological Survey Division, issues permits for spent brine return flow wells under the authority of Part 625 of the Michigan Natural Resources and Environmental Protection Act (NREPA). USEPA Region 5 also permits spent brine return flow wells under the nonendangerment clause using standards similar to those applied to Class II wells. Thus, in Michigan spent brine return flow wells are permitted by both USEPA Region 5 and the state.

[12] May 2003 is the deadline including an 18-month extension.

ATTACHMENT A
STATE AND LOCAL PROGRAM DESCRIPTIONS

This attachment describes the control programs in Arkansas and Michigan, the two states with Class V spent brine return flow wells covered by this document.

Arkansas

Arkansas is a UIC Primacy State for Class V wells. The Arkansas Underground Injection Control Code of 1989 (Code) adopts, by reference, federal UIC regulations (Code §3). The Code identifies wells used to inject spent brine into the same formation from which it was withdrawn after extraction of halogens or their salts as Class V, and also specifies that as of the effective date of May 4, 1989, such wells were operating in the state (Code §5(E)(14) and (F)).

The Arkansas Oil and Gas Commission (AOGC) in 1991 adopted the Class V (Bromine Related) Injection Wells Rule (Rule). That rule establishes permitting, construction and operation requirements.

Permitting

The Underground Injection Control Code provides that no person may construct, install, alter, modify, or operate any Class V bromine-related brine disposal well without a permit from the AOGC (Code §4(A)). The AOGC rule applicable to Class V (bromine related) injection wells also provides that the application for a permit to dispose of salt water by subsurface injection shall be the same as is required for Class II wells (Rule § 17). Because the state has adopted by reference federal UIC regulations, including Part 144, Subpart D, the application will include the information required by 40 CFR § 144.31(e). This will include a description of the activities conducted by the applicant, information identifying the business and its location, a listing of all permits or construction approvals required under specified environmental protection programs, maps, and a plugging and abandonment plan.

Siting and Construction

The AOGC rule pertaining to Class V (bromine related) injection wells provides the following.

- All injection must be through tubing and packer with packer set within 100 feet of the top of the Smackover formation, unless otherwise approved by AOGC. On all newly drilled wells, the operator is required to drill into the top of the Smackover formation prior to setting long string, to ensure that when the well is logged the operator will be able to identify the top of the Smackover formation and verify that the water will be injected into it.

- Surface casing must be set 250 feet "below the lowermost USDW." Production casing (long string) must be cemented from the top of the injection zone to the "top of the ground." The setting of the surface and production casing must be witnessed by a representative of the AOGC.

- C On all wells being converted from productive status to injection status, the operator is required to run a cement bond log from the top of the injection zone to the top of the ground. These wells also must be constructed in such a manner as to have surface casing set at least 250 feet below the lowermost USDW. Wells that are completed with one size casing down to a certain point and a smaller size hung inside the larger size down to total depth will have the smaller size pipe run from the surface down to the top of the existing string and cement circulated back to the top of the ground. The larger size casing will be considered surface casing, and the smaller size will be considered production casing. Production casing with cement to the top of the ground, tubing, and packer set within 100 feet of the top of the Smackover formation is required, unless AOGC approves other casing.

- C A cement bond log is required on all wells converted from producing status to injection status and on any newly drilled wells that fail to circulate cement back to the top of the ground. All cement bond logs must be witnessed by an AOGC representative.

- C For any newly drilled well that fails to circulate cement back to the top of the ground, the top of the cement will be determined by a cement bond log. In the event that the top of the cement is not above the Sparta Sand, the operator will be required to bring the top of the cement above the Sparta Sand.

Operating Requirements

The AOGC rules provide the following.

- C All water injection will be into the Smackover formation. Injection into other zones must be approved by USEPA.

- C Injection pressure is not to exceed 0.5 psi per foot of depth to the top of the injection zone. Only debrominated brine will be authorized for injection.

- C All wells must maintain a positive annulus pressure (amount to be determined by the AOGC). The annulus pressure must be monitored by a pressure chart. The chart must be changed weekly and copies filed with the AOGC monthly. Any change in pressure must be explained in writing, and any unsatisfactory explanation will result in the well being tested for mechanical integrity.

- C Any time an injection well is worked over, the operator must notify AOGC prior to the beginning of the work over, and a mechanical integrity test must be run on the well after the work over is completed if the packer has become unseated.

Mechanical Integrity

The AOGC rules provide the following.

- All wells must pass an annulus pressure test once every 5 years. Wells that cannot be tested in this manner must have a radioactive tracer survey run annually.

- All wells that fail to pass a mechanical integrity test (MIT) must be repaired or plugged and abandoned within 90 days of the failure date. The well is to be shut-in immediately after failure to pass the MIT and must remain shut-in until it passes a mechanical integrity test or is plugged and abandoned.

Financial Responsibility

A $25,000 bond is required for each Class V well in Arkansas (Card, 1999). An annual fee of $100 is assessed.

Plugging and Abandonment

Because the state has adopted by reference the federal UIC requirements, plugging and abandonment can be required under the general non-endangerment requirements. The state's rules for Class V (bromine related) injection wells do not contain any plugging and abandonment requirements.

Michigan

USEPA Region 5 implements the UIC Class V program in Michigan. In addition, the Geological Survey Division (GSD) of the Michigan Department of Environmental Quality also has authority under the state's Natural Resources and Environmental Protection Act (NREPA) Part 625 to establish standards for construction, testing, operation, and plugging and abandonment of mineral wells and to permit such wells.

Permitting

USEPA Region 5 requires a permit for spent brine return wells under the non-endangerment clause, and applies permitting standards similar to those applicable to Class II injection wells. Injection is allowed only into a formation that is separated from a USDW by a confining zone free of known open faults or fractures.

The Michigan GSD also separately permits spent brine return wells as disposal wells. NREPA defines a disposal well as a well drilled or converted for subsurface disposal of waste products or processed brine (324.62501(d) NREPA). The statute requires that permits must be issued before drilling or conversion of any brine, storage, or waste disposal well (324.62509 NREPA). The GSD has promulgated rules requiring permits to drill, deepen, rework, or convert brine and waste disposal wells (R299.2201 to 299.2298). Special requirements expedite permits to drill, deepen, rework, or convert brine, storage and disposal wells, which may be issued within 10 days of receipt of the application if the exact location of the well is established. This is accomplished by submitting a survey, map or plat indicating key features, including well depth or deepest zone or formation, and filing a security bond (R299.2211 and .2212). A public hearing on drilling or conversion of a storage or disposal well may be held (R299.2213).

Siting and construction

USEPA Region 5 requires well construction to meet the requirements of 40 CFR 144.52(a)(1). The permittee must submit construction data to USEPA Region 5.

NREPA specifies that the Supervisor of Mineral Wells in GSD may require the locating, drilling, deepening, reworking, reopening, casing, sealing, injecting, mechanical and chemical treating, and plugging of wells to be accomplished in a manner that is designed to prevent surface and underground waste. Toward that end, logs may be required to be kept, and drill cuttings, cores, water samples, pilot injection tests and records, and operating records may be required (324.62508 NREPA). The regulations specify casing and sealing requirements for brine, storage, and disposal wells, including requirements that the drive pipe be landed, or surface pipe set and cemented to the surface, at sufficient depth to protect fresh water aquifers. Tubing is required for use in injection operations (R299.2253).

Operating Requirements

USEPA Region 5 requires a standardized annulus pressure test (SAPT) [Part I of the mechanical integrity demonstration] to be passed prior to commencing injection and every 5 years thereafter. In addition, an SAPT must be performed after any workover of the wells. SAPT's are usually witnessed by the USEPA. Wells must be monitored for injection pressure, flow rate, annulus pressure, and cumulative volume on a weekly basis, annulus liquid loss on a quarterly basis, and chemical composition of injectate annually. SAPT results and monitoring results must be provided to USEPA Region 5. A part II demonstration of a mechanical integrity test, including temperature or oxygen activation measurements, must also be conducted prior to injection every 5 years. The USEPA or its designee has the opportunity to witness all Part I or II mechanical integrity tests.

Requirements for operation of wells also are specified in the GSD rules and additional requirements may be established by GSD in permits. These requirements include records of rates of injection, operating pressures, types and volumes of fluids injected, and other pertinent information. Those volumes, injection rates, and pressures may not exceed those specified in the approval of the well (R299.2268).

Financial Responsibility

NREPA provides that security bonds may be required (324.62508 NREPA). Rules set the security bond for a single disposal well at $15,000 and for 2 or more such wells at $25,000 (R299.2231). The bonds provide security for compliance with the statute and satisfactory plugging and abandonment of the wells.

Plugging and Abandonment

Plugging is required to be carried out based on instructions from the GSD (R229.2282).

ATTACHMENT B
CHEMICAL CHARACTERISTICS OF SPENT BRINE INJECTATE IN ARKANSAS

Parameters	units	Spent Brine Concentration By Facility: Great Lakes South	Great Lakes Central	Great Lakes Newell	Albermarle South	Great Lakes Mville	Drinking Water Standard: mg/l	Primary or Secondary	Health Advisory Level: mg/l	Cancer or Non Cancer
Dissolved Metals										
Arsenic	mg/l	<1	<1	<1	<1	<1	0.05	P	0.002	C
Barium	mg/l	8.8	2.9	2.8	13.7	13.4	2	P	2	N
Boron	mg/l	192	141	167	168	176	--		0.6	N
Cadmium	mg/l	< .014	< .014	< .014	< .014	< .014	0.005	P	0.005	N
Calcium	mg/l	34130	30720	34280	35290	35450	--		--	
Chromium	mg/l	< .4	< .4	< .4	< .4	< .4	0.1	P	0.1	N
Cobalt	mg/l	< .5	< .5	< .5	< .5	< .5	--		--	
Copper	mg/l	1.9	2	1.8	2.2	2	1.3	P	--	
Iron	mg/l	<15	<15	<15	<15	<15	0.3	S	--	
Lead	mg/l	0.4	0.4	0.4	0.4	0.4	0.015	P	--	
Magnesium	mg/l	3.27	3.36	3.49	3.63	3.48	--		--	
Manganese	mg/l	7.5	2.7	2.6	10	8.6	0.05	S	--	
Nickel	mg/l	<2	<2	<2	<2	<2	0.1	P	0.1	N
Potassium	mg/l	3.64	2.53	2.37	3.03	2.21	--		--	
Selenium	mg/l	<3	<3	<3	<3	<3	0.05	P	--	
Silver	mg/l	< .043	< .043	< .043	< .043	1.8	0.1	S	0.1	N
Sodium	mg/l	67.2	63.1	66.1	70.7	69.4	--		--	
Zinc	mg/l	1.3	<1	<1	1.6	<1	5	S	2	N
Semivolatile Compounds										
2-Fluorophenol (Surr.)	%Rec	88.663	88.583	44.359	0.91785	43.802	--		--	
Phenol-d6 (Surr.)	%Rec	40.017	50.395	35.367	5.3875	24.32	--		--	
Nitrobenzene-d5 (Surr.)	%Rec	103.03	106.27	102.24	107.19	104.51	--		--	
2-Fluorobiphenyl (Surr.)	%Rec	77.886	89.207	87.906	94.32	95.421	--		--	
2-4-6 Tribromophenol (Surr.)	%Rec	73.866	93.654	32.697	4.6313	36.723	--		--	
Terphenyl-d14 (Surr.)	%Rec	79.587	77.653	78.445	73.333	73.292	--		--	
2-Picoline	mg/l	< .00065071	< .00031169	< .00042681	< .0004755	< .00028534	--		--	
Aniline	mg/l	< .00031393	.00062481	< .00020591	< .0002294	.00015013	--		--	
Phenol	mg/l	.00126500	.00069123	.00062187	< .00013548	.00055998	--		4	N

NOTE: The metals analyses were affected by the high dissolved solids in the sample. This resulted in very high detection limits for some metals.
A + in front of data indicates that value is less than the detection limit but tentatively reported as present.

ATTACHMENT B
CHEMICAL CHARACTERISTICS OF SPENT BRINE INJECTATE IN ARKANSAS
(continued)

Parameters	units	Spent Brine Concentration By Facility					Drinking Water Standard		Health Advisory Level	
		Great Lakes South	Great Lakes Central	Great Lakes Newell	Albermarle South	Great Lakes Mville	mg/l	Primary or Secondary	mg/l	Cancer or Non Cancer
Bis(2-chloroethyl)-Ether	mg/l	< .00082411	< .00039475	< .00054055	< .00060221	< .00036138	--		--	
2-Chlorophenol	mg/l	< .00039505	< .00025016	< .00018166	< .00023304	< .00013199	--		0.04	N
1-3-Dichlorobenzene	mg/l	< .00026503	< .00016154	< .00024087	< .00011588	< .00015040	--		0.6	N
1-4-Dichlorobenzene	mg/l	< .00023816	< .00014516	< .00021645	< .00010413	< .00013515	0.075	P	0.075	N
Benzyl-alcohol	mg/l	< .00055806	< .00038097	< .00046915	< .00033389	< .00025335	--		--	
1-2-Dichlorobenzene	mg/l	< .00026682	< .00016263	< .00024250	< .00011666	< .00015141	0.6	P	0.6	N
2-Methylphenol	mg/l	+.00044512	+.00040478	< .00045046	< .00030369	< .00029356	--		--	
Acetophenone	mg/l	.00054924	.00046947	.00041587	.00048899	.00061437	--		--	
N-Nitroso-di-n-propylamine	mg/l	< .00355470	.00028080	< .00126220	< .00112660	< .00029824	--		--	
4-Methylphenol	mg/l	< .00056491	< .00046454	< .00036647	< .00024706	< .00023883	--		--	
Hexachloroethane	mg/l	< .00067309	< .00043940	< .00042898	< .00056877	< .00022432	--		0.001	N
Nitrobenzene	mg/l	< .00065818	< .00044431	< .00042196	< .00047093	< .00027521	--		--	
N-Nitrosopiperidine	mg/l	< .00031926	< .00022763	< .00023355	< .00023941	< .00017833	--		--	
Isophorone	mg/l	< .00052321	< .00006319	< .00019068	< .00027848	< .00009787	--		0.1	N
2-Nitrophenol	mg/l	< .00072503	< .00033333	< .00026334	< .00039266	< .00017061	--		--	
2-4-Dimethylphenol	mg/l	< .00020852	.00018422	< .00010623	< .00013285	< .00009340	--		--	
Bis(2-chloroethoxy)methane	mg/l	< .00032239	< .00014799	< .00019523	< .00028405	< .00014631	--		--	
2-4-Dichlorophenol	mg/l	< .00035685	< .00020135	< .00015907	< .00017597	< .00014722	--		0.02	N
1-2-4-Trichlorobenzene	mg/l	< .00044094	< .00015075	< .00032222	< .00032733	< .00013778	0.07	P	0.07	N
2-6-Dichlorophenol	mg/l	< .00039436	< .00022251	< .00017579	< .00019447	< .00016270	--		--	
4-Chloroaniline	mg/l	< .00011540	< .00008595	< .00006904	< .00011460	< .00005375	--		--	
Naphthalene	mg/l	.00246590	.00358930	.00075556	.00158330	.00025201	--		0.02	N
Hexachlorobutadiene	mg/l	< .00009851	< .00005781	< .00007984	< .00013940	< .00006096	--		0.001	N
N-Nitrosodibutylamine	mg/l	< .00185620	< .00024139	< .00063832	< .00064209	< .00016848	--		--	
4-Chloro-3-methylphenol	mg/l	< .00042086	< .00028720	< .00025206	< .00022193	< .00018414	--		--	
2-Methylnaphthalene	mg/l	.00409950	.00251790	.00074498	.00273400	.00019648	--		--	
Hexachlorocyclopentadiene	mg/l	< .00015622	.00019704	< .00016026	< .00022488	.00024357	0.05	P	--	

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ATTACHMENT B
CHEMICAL CHARACTERISTICS OF SPENT BRINE INJECTATE IN ARKANSAS
(continued)

		Spent Brine Concentration By Facility					Drinking Water Standard		Health Advisory Level	
Parameters	units	Great Lakes South	Great Lakes Central	Great Lakes Newell	Albermarle South	Great Lakes Mville	mg/l	Primary or Secondary	mg/l	Cancer or Non Cancer
1-2-4-5-Tetrachlorobenzene	mg/l	< .00016130	< .00006796	< .00010046	< .00015528	< .00006837	--		--	
2-4-6-Trichlorophenol	mg/l	< .00074769	.00023915	< .00021589	< .00018967	< .00008325	--		0.3	C
2-4-5-Trichlorophenol	mg/l	< .00069135	< .00012867	< .00019962	< .00017537	< .00007698	--		--	
2-Chloronaphthalene	mg/l	< .00010469	< .00006192	< .00005072	< .00005823	< .00004707	--		--	
1-Chloronaphthalene	mg/l	< .00015178	< .00008977	< .00007353	.00028647	< .00006824	--		--	
2-Nitroaniline	mg/l	< .00052246	< .00031146	< .00029912	< .00041439	< .00024427	--		--	
Dimethyl-phthalate	mg/l	< .00007962	.00020055	.00021422	.00025014	.00066864	--		--	
2-6-Dinitrotoluene	mg/l	< .00090715	< .00022968	< .00046322	< .00062608	< .00040011	--		0.005	C
Acenaphthylene	mg/l	< .00015365	< .00006812	< .00006341	< .00019982	< .00005628	--		--	
3-Nitroaniline	mg/l	< .00050483	< .00025523	< .00039129	< .00047575	< .00021398	--		--	
Acenaphthene	mg/l	< .00019522	< .00015240	< .00011559	< .00024810	< .00011263	--		--	
Pentachlorobenzene	mg/l	< .00007403	< .00006935	< .00006455	< .00009452	< .00005125	--		--	
Dibenzofuran	mg/l	< .00009241	< .00003120	< .00006292	< .00007441	< .00002470	--		--	
2-4-Dinitrotoluene	mg/l	< .00063682	< .00016124	< .00032518	< .00043950	< .00028087	--		0.005	C
4-Nitrophenol	mg/l	< .00090687	< .00031685	< .00055914	< .00058704	< .00039515	--		0.06	N
2-Naphthylamine	mg/l	< .00024731	< .00012335	< .00012979	< .00019735	< .00009682	--		--	
2-3-4-6-Tetrachlorophenol	mg/l	< .00043890	< .00020240	< .00025299	< .00021871	< .00008792	--		--	
1-Naphthylamine	mg/l	< .00027092	.00030961	< .00014218	< .00021619	< .00010606	--		--	
Diethyl-phthalate	mg/l	.00144470	.00147790	.00141950	.00167840	.00257060	--		5	N
Fluorene	mg/l	.00070219	.00022452	.00017808	.00030023	+.00005940	--		--	
4-Chlorophenyl-phenyl-ether	mg/l	< .00004973	< .00005953	< .00005060	< .00008202	.00003050	--		--	
4-Nitroaniline	mg/l	< .00059442	< .00030053	< .00046074	< .00056018	< .00025196	--		--	
Diphenylamine	mg/l	< .00050923	< .00007268	< .00018675	< .00020421	< .00005599	--		0.2	N
1-2-Diphenylhydrazine	mg/l	< .00020297	< .00014390	< .00013931	< .00014847	< .00008878	--		--	
Phenacetin	mg/l	< .00022567	< .00015506	< .00018753	< .00016644	< .00011092	--		--	
4-Bromophenyl-phenyl-ether	mg/l	< .00007795	.00013396	.00005440	.00006603	< .00004827	--		--	
Hexachlorobenzene	mg/l	< .00007986	.00013918	.00037572	< .00008108	.00011633	0.001	P	0.002	C

NOTE: The metals analyses were affected by the high dissolved solids in the sample. This resulted in very high detection limits for some metals.
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ATTACHMENT B
CHEMICAL CHARACTERISTICS OF SPENT BRINE INJECTATE IN ARKANSAS
(continued)

		Spent Brine Concentration By Facility					Drinking Water Standard		Health Advisory Level	
Parameters	units	Great Lakes South	Great Lakes Central	Great Lakes Newell	Albermarle South	Great Lakes Mville	mg/l	Primary or Secondary	mg/l	Cancer or Non Cancer
Pentachlorophenol	mg/l	< .00027423	< .00022142	.00071602	< .00028155	< .00016798	0.001	P	0.03	C
Pentachloronitrobenzene	mg/l	< .00033692	< .00019166	< .00033134	< .00042342	< .00014541	--		--	
4-Aminobiphenyl	mg/l	< .00087168	.00034833	< .00031967	< .00034956	< .00009583	--		--	
Pronamide	mg/l	< .00028414	< .00013783	< .00017661	< .00019757	< .00013176	--		0.05	N
Phenanthrene	mg/l	.00095485	.00026840	.00046404	.00036623	.00014553	--		--	
Anthracene	mg/l	< .00020522	< .00007903	< .00011452	< .00011267	< .00006295	--		--	
Di-n-butyl-phthalate	mg/l	.00941360	.00513620	.00423780	.00362250	.00456420	--		--	
Fluoranthene	mg/l	< .00007518	< .00002138	< .00006198	< .00003790	.00009380	--		--	
Pyrene	mg/l	< .00005607	.00013147	.00098731	< .00002631	.00006360	--		--	
Dimethylaminoazobenzene	mg/l	< .00005117	< .00003298	< .00004420	< .00006891	< .00003889	--		--	
Butyl-benzyl-phthalate	mg/l	.00658070	.00366920	.00372540	.00308250	.00247440	--		--	
Benzo(a)anthracene	mg/l	< .00006897	< .00001135	< .00003091	< .00003505	< .00002901	--		--	
3-3'-Dichlorobenzidine	mg/l	< .00003290	< .00002447	< .00002416	< .00003759	< .00002167	--		--	
Chrysene	mg/l	.00050251	< .00001124	.00236880	< .00003470	< .00002872	--		--	
Bis(2-ethylhexyl)phthalate	mg/l	.00450470	.02792000	.03643200	.01255200	.00852200	--		--	
Di-n-octyl-phthalate	mg/l	< .00009469	< .00004848	< .00004013	< .00006536	< .00002957	--		--	
Benzo(b)fluoranthene	mg/l	< .00003563	< .00002523	< .00002589	< .00004273	< .00002222	--		--	
Benzo(k)fluoranthene	mg/l	< .00002500	< .00001770	< .00001816	< .00002998	< .00001559	--		--	
Benzo(a)pyrene	mg/l	< .00003299	< .00002336	< .00002397	< .00003957	< .00002058	0.0002	P	0.0002	C
Dimethylbenzo(a)anthracene	mg/l	< .00008581	< .00005518	< .00003842	< .00006162	< .00003451	--		--	
3-Methylcholanthrene	mg/l	< .00005555	< .00005589	< .00004570	< .00006380	< .00004582	--		--	
Dibenzo(a-j)acridine	mg/l	.00218150	.00068519	< .00001548	< .00003750	.00049219	--		--	
Indeno(1-2-3-cd)pyrene	mg/l	< .00001352	< .00001170	< .00001589	< .00001380	< .00000952	--		--	
Dibenz(a-h)anthracene	mg/l	< .00002214	< .00002571	< .00002082	< .00002087	< .00001375	--		--	
Benzo(g-h-i)perylene	mg/l	< .00001722	< .00001491	< .00002024	< .00001758	< .00001212	--		--	

Source: Arkansas Department of Environmental Quality, 1999

NOTE: The metals analyses were affected by the high dissolved solids in the sample. This resulted in very high detection limits for some metals. A + in front of data indicates that value is less than the detection limit but tentatively reported as present.

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