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Produced Water Volumes and Management Practices in the United States

Environmental Science Division

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Executive Summary

Produced water is water from underground formations that is brought to the surface during oil or gas production. Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production. The cost of managing such a large volume of water is a key consideration to oil and gas producers. Previous national produced water volume estimates are in the range of 15 to 20 billion barrels (bbl; 1 bbl = 42 U.S. gallons) generated each year in the United States. This is equivalent to a volume of 1.7 to 2.3 billion gallons per day. In comparison, the Washington D.C. government and surrounding jurisdictions provide about 300 million gallons per day of drinking water to local residents, businesses, and other users. This represents only about 13% of the daily produced water volume. As another example, consider a backyard swimming pool that is 20 ft wide by 50 ft long and 5 ft deep. The volume of water needed to fill such a pool is about 37,000 gal or about 900 bbl.

Produced water volume generation and management in the United States are not well characterized at a national level. The U.S. Department of Energy asked Argonne National Laboratory to compile data on produced water associated with oil and gas production to better understand the production volumes and management of this water.

This report provides a current estimate for the volume of produced water generated from oil and gas production in the United States. The volume estimate represents a compilation of data obtained from numerous state oil and gas agencies and several federal agencies for 2007, where possible. The total volume of produced water estimated for 2007 is about 21 billion bbl. This equals an average of 57.4 million bbl/day. Produced water is generated from most of the nearly 1 million actively producing oil and gas wells in the United States.

Argonne contacted state oil and gas agencies in the 31 states with active oil and gas production to obtain detailed information on produced water volumes and management. Not all states had readily available precise produced water volume figures. In a few states, the agencies had very complete data records easily obtainable from online sources. Other states had summary-level volume data without much detail or had data available only in in-house data repositories. The most challenging states were those that had no produced water data at all. In those cases, we calculated estimates through extrapolation and correlations using hydrocarbon production and produced water volumes from neighboring states. To obtain federal data, Argonne contacted the Minerals Management Service, the Bureau of Land Management, and the U.S. Environmental Protection Agency.

State and federal onshore production contribute the majority of produced water (more than 20 billion bbl) in the United States. A significant amount of produced water (more than 700 million bbl or about 3% of the national total) is also generated from federal offshore production activities and from production on tribal lands. The five states with greatest produced water volumes in 2007 were Texas, California, Wyoming, Oklahoma, and Kansas. The produced water volumes from these states represent nearly 75% of total U.S. production (onshore and offshore), as shown in Figure 1. Texas, with more than 7.3 billion bbl, contributed 35% of the total volume of produced water generated in the United States in 2007. The contributions from the other five

states with produced water volumes exceeding 1 billion bbl were California (12%), Wyoming (11%), Oklahoma (11%), Kansas (6%), and Louisiana (5%).

The greatest produced water contributors are not necessarily the greatest producers of oil and gas. While Texas was the largest gas producer in the United States (nearly 6,900,000 million cubic feet [Mmcf] in 2007), federal offshore production activities provided the largest volume of crude of more than 467,000,000 bbl. Although federal offshore production generates nearly 27% of U.S. crude oil production, less than 3% of total U.S. produced water is generated from federal offshore activities.

In addition to total volumes produced, it is useful to consider the water-to-oil ratios (WORs) and water-to-gas ratios (WGRs) from production activities as this information can be used to evaluate the relative production age of resources within the production lifetime. To that end, we asked the agencies to provide produced water volumes by hydrocarbon types (i.e., crude oil, conventional gas, coal bed methane, unconventional gas, or other), to the extent the data were available at that level of detail. Most states were unable to break out produced water volumes for all categories, but some states could at least provide estimates of produced water from oil production vs. natural gas production. States that segregated produced water by hydrocarbon type categorized 6,666,144,270 bbl of produced water. Eighty-seven percent (5,770,327,439 bbl) of produced water came from oil production activities.

We also were able to calculate separate WORs and WGRs for several states that reported produced water separately for hydrocarbon type (WORs for 14 states and WGRs for 11 states). A national average WOR calculated using the production-weighted ratios from the 14 states was 7.6 bbl/bbl. When offshore production was added to the onshore production, the total average U.S. WOR was 5.3 bbl/bbl. A national average WGR calculated using the production-weighted ratios from the 11 states was 260 bbl/Mmcf. When offshore production was added to the onshore production, the total average U.S. WGR was 182 bbl/Mmcf.

Two general water management themes were followed by most U.S. operators in 2007. More than 98% of produced water from onshore wells is injected underground. Approximately 59% is injected into producing formations to maintain formation pressure and increase the output of production wells. Another 40% of produced water from onshore wells is injected into nonproducing formations for disposal. More than 91% of offshore produced water, including the water from inshore platforms in Cook Inlet, Alaska, is discharged to the ocean. Most of the remaining volume is reinjected for enhanced recovery. The remaining 2% of national produced water volume was managed through evaporation ponds, offsite commercial disposal, beneficial reuse, and other management methods.

The produced water volumes WORs, and WGRs included in this report are based on the best data available. The best data was far from complete, however. Argonne needed to extrapolate information from states with detailed produced water data for other nearby states with limited produced water information. The national average WOR and WGR values were estimated using data from less than half of the oil and gas producing states. Several of the states that have large numbers of producing wells, particularly in mature fields with many stripper wells (e.g., Texas, Oklahoma) did not have produced water data segregated by production type. If those data had

been included with the states already in the average, it is probable that the WOR and WGR would be substantially larger.

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Chapter 1 — Introduction

1.1 Purpose

Produced water volume generation and management in the United States are not well characterized at a national level. The U.S. Department of Energy (DOE) asked Argonne National Laboratory to compile data on produced water associated with oil and gas production to better understand the production volumes and management of this water. The purpose of this report is to improve understanding of produced water by providing detailed information on the volume of produced water generated in the United States and the ways in which produced water is disposed or reused. As the demand for fresh water resources increases, with no concomitant increase in surface or ground water supplies, alternate water sources, like produced water, may play an important role.

1.2 Background

Produced water is water from underground formations that is brought to the surface during oil or gas production. Because the water has been in contact with hydrocarbon-bearing formations, it contains some of the chemical characteristics of the formations and the hydrocarbons. It may include water from the reservoir, water previously injected into the formation, and any chemicals added during the production processes. The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geologic formation, and the type of hydrocarbon product being produced. Produced water properties and volume also vary throughout the lifetime of a reservoir.

Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production. Previous national produced water volume estimates are in the range of 15 to 20 billion barrels (bbl; 1 bbl = 42 U.S. gallons) generated each year in the United States (API 1988, 2000; Veil et al. 2004). However, the details on generation and management of produced water are not well understood on a national scale.

1.3 Overview

Argonne National Laboratory developed detailed national-level information on the volume of produced water generated in the United States and the manner in which produced water is managed. This report presents an overview of produced water, summarizes the study, and presents results from the study at both the national level and the state level. Chapter 2 presents background information on produced water, describing its chemical and physical characteristics, where it is produced, and the potential impacts of produced water to the environment and to oil and gas operations. A review of relevant literature is also included. Chapter 3 describes the methods used to collect information, including outreach efforts to state oil and gas agencies and related federal programs. Because of the inconsistency in the level of detail provided by various state agencies, the approaches and assumptions used to extrapolate data values are also discussed. In Chapter 4, the data are presented, and national trends and observations are discussed. Chapter 5 presents detailed results for each state, while Chapter 6 presents results from federal sources for oil and gas production (i.e., offshore, onshore, and tribal lands). Chapter 7 summarizes the study and presents conclusions.

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Chapter 2 — Produced Water

This chapter provides a brief introduction to produced water and produced water management. A more thorough discussion of produced water can be found in *A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane* (Veil et al. 2004).

2.1 Definition of Produced Water

Produced water is water found in the same formations as oil and gas. When the oil and gas are produced to the surface, the produced water is brought to the surface, too. It is also referred to as "brine," "saltwater," or "formation water." Produced water contains some of the chemical characteristics of the formation from which it was produced and associated hydrocarbons.

Produced water properties (both physical and chemical) and volume vary considerably depending on the geographic location of the field, the geologic formation, the type of hydrocarbon product being produced, and the lifetime of a reservoir. For example, early in the life of an oil well, oil production is high and water production is low. As the production age of the well increases, the oil production decreases and the water production increases. When the cost of managing produced water exceeds the profit from selling oil, production is terminated and the well is closed. This is contrary to the typical production cycle of a coal bed methane (CBM) well. Initially CBM wells produce large volumes of water, which decline over time. Methane production is initially low, increases over time to a peak, and then decreases.

2.2 Previous Produced Water Volume Estimates

While one of the purposes of this report is to present a current estimate of produced water volumes, it is useful to know previous estimates and the assumptions used in arriving at those estimates. Khatib and Verbeek (2003) estimated a global average of 210 million bbl of water produced each day, which resulted in an annual estimate for 1999 of 77 billion bbl of produced water. It is not clear how those authors derived their estimate (collecting and compiling accurate produced water data within a single country is a challenging task, as described in Chapter 3). International estimates must be taken as approximations. U.S. onshore estimates of produced water from oil and gas activities were estimated at 21 billion bbl in 1985 and 18 billion bbl in 1995 by the American Petroleum Institute (API 1988, 2000) and 14 billion bbl in 2002 by Veil et al. (2004). Significant additional volumes of produced water are generated at U.S. offshore wells.

The volume of water produced from oil and gas wells does not remain constant over time. The water-to-hydrocarbon ratio increases over the life of the well. Initially, water represents a small percentage of produced fluids. Over time, the percentage of water increases and the percentage of hydrocarbon decreases. In the study by Khatib and Verbeek (2003), a world average estimate was reported to be 3 bbl of water for each barrel of oil. U.S. wells are typically further in their production lifetime than the global average. Veil et al (2004) reported an average of more than 9.5 bbl of water for each barrel of oil in the United States.

CBM wells, in contrast to oil and gas wells, produce a large volume of water early in their life, and the water volume declines over time. CBM wells have increased considerably since the 1995 API study year and were not included in the study by Veil et al. (2004). As a result, the actual produced water volume in the United States is most likely higher than the 14 to 18 billion bbl estimates previously reported.

2.3 Characteristics of Produced Water

The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geologic formation from where the water was produced, and the type of hydrocarbon product being produced. For those sites where waterflooding is conducted, the properties and volumes of the produced water may vary dramatically due to the injection of additional water into the formation to increase hydrocarbon production. The major constituents of concern are salt content (often expressed as salinity, conductivity, or total dissolved solids [TDS]), oil and grease (various organic compounds associated with hydrocarbons in the formation), inorganic and organic compounds introduced as chemical additives to improve drilling and production operations, and naturally occurring radioactive material.

Understanding the constituents of specific produced waters aids regulatory compliance and the selection of appropriate management options for the produced water, such as secondary recovery and disposal. Oil and grease is the most important constituent in offshore produced water. It is also an important one for onshore produced water. Note that the term oil and grease refers not a single chemical, but rather to an analytical test that measures the presence of many families of organic chemicals. A study of produced water in the western United States found the oil and grease content to range from 40 mg/L to 2,000 mg/L (Benko and Drewes 2008). Another important constituent of concern in onshore operations is the salt content of produced water. According to Cline (1998), most produced waters are more saline than seawater. Benko and Drewes (2008) found the TDS concentration of produced water in the western United States to vary between 1,000 mg/L and 400,000 mg/L. While high TDS can increase maintenance costs, detecting TDS assists in defining the pay zones of a formation, when coupled with resistivity measurements (Breit et al. 1998).

Produced water from oil production activities often contains constituents in addition to those that are naturally found within the formation. Additional water is often needed to maintain sufficient pressure in a reservoir for oil production. Produced water may be reused for this purpose, but the water may also be supplied from additional sources including groundwater and seawater. These additional water sources may contain additional solids and microorganisms (Chapelle 2001; Dowd et al. 2000). To combat scaling and maintain production efficiency, chemical additives such as corrosion and scale inhibitors, emulsion breakers, coagulants, and solvents may be used in drilling operations, production operations, and separations processing. The production of a well can be improved by utilizing the appropriate scale inhibitor and well-treatment chemicals according to the characteristics of the formation (Breit et al. 1998). However, these additives can become part of the produced water and can affect its overall toxicity.

Produced water from gas production has different characteristics than produced water from oil production. In addition to formation water, water produced from gas production will contain

condensed water, which is water that was in the vapor phase while in the reservoir but then condenses into a liquid state in the production separation system.

Produced water from CBM production differs from produced water from both oil and gas production. Oil and grease are less of a concern from CBM water than other produced waters. To recover the methane in CBM reservoirs, the hydrostatic pressure that caused the adsorption of methane to the coal bed is reduced through the removal of water from the reservoir via CBM wells. Characteristics of CBM water that may affect reuse are salinity, sodicity, and to a lesser extent iron, manganese, and boron (ALL 2003).

2.4 Produced Water Management

While produced water can be reused if certain water quality conditions are met, most produced water generated is disposed. For offshore production activities, produced water is usually disposed of through direct ocean discharge after treatment. For onshore production activities, produced water is managed in a variety of ways. According to API (2000), 92% of the 18 billion barrels of produced water generated in 1995 was managed through injection. Three percent of the 18 billion bbl of produced water was discharged under National Pollutant Discharge Elimination System (NPDES) permits; nearly all of this water was generated from coal bed methane operations. Two percent was managed through beneficial reuse. The remaining 3% was disposed through other methods including evaporation, percolation pits, and publicly owned treatment works (API 2000). These management methods are briefly described in this section.

2.4.1 Discharge

For U.S. offshore operations, the majority of produced water is discharged to the ocean and is subject to applicable regulatory requirements. Offshore produced water discharges are authorized by NPDES general permits issued by U.S. Environmental Protection Agency (U.S. EPA) regional offices. All of the permits contain a monthly average limit of 29 mg/L and a 42 mg/L daily maximum limit for oil and grease.

In the U.S., wells in "coastal" areas generally may not discharge produced water, although there are exceptions for some wells that are located in Alaska's Cook Inlet (Veil et al. 2004). Offshore activities around the globe typically discharge to the ocean, although countries have different discharge standards.

Discharge activities from onshore production are primarily limited to water produced from CBM activities or from other oil and gas wells in the western United States that have produced water with low salinity. Currently, the decision to allow CBM water discharges is made by either state agencies or U.S. EPA regional offices, depending on the state's permitting authority (Veil 2002). U.S. EPA has initiated a study on CBM to determine if national effluent limitation guidelines are needed.[1]

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[1] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Discharge," Produced Water Management Information System (PWMIS), created for U.S. Department of Energy (DOE) and

2.4.2 Underground Injection for Disposal

Twenty-one percent of produced water generated in the United States in 1995 was managed through injection wells. Under U.S. EPA rules, produced water injection wells are classified as Class II wells and managed by the Underground Injection Control program. Class II wells may be classified as II-R (enhanced recovery), II-D (disposal), or II-H (hydrocarbon storage) (U.S. EPA 2008a). Class II injection wells are designed and constructed to inject fluids to authorized zones in a manner that does not allow migration into underground sources of drinking water (USDWs). Injection wells for disposal are often located in formations that enable water to enter at pressures below the fracture pressure and are isolated from USDWs and hydrocarbon-producing formations.

In addition to locating a formation with appropriate characteristics to receive the water, it is also important that the produced water is chemically compatible with the receiving formations. This may require treatment prior to injection to manage excessive solids, dissolved oil, corrosion, chemical reactions, or microorganisms.[2]

2.4.3 Underground Injection for Increasing Oil Recovery

Most produced water generated onshore is injected to maintain reservoir pressure and hydraulically drive oil toward a producing well. This practice is often referred to as enhanced oil recovery (EOR), and is also referred to as water flooding or steam flooding, depending upon the temperature of the water. In 1995, injection for EOR managed 71% of the produced water generated (API 2000). When managed via injection for EOR, produced water becomes a resource rather than a waste product.[3]

2.4.4 Evaporation

While not practiced as widely as injection, evaporation is a simple management strategy for produced water. A typical evaporation approach directs produced water into a pond with a large surface area. Water then passively evaporates from the surface. The rate of evaporation will depend on the size, depth, and location of the pond, as well as the quality of the produced water. In semiarid regions, hot, dry air moving from a land surface will result in high evaporation rates for smaller ponds. As the concentration of solids and other constituents increase in the remaining produced water, the evaporation rate will decrease over time. This management approach can be conducted onsite in small evaporation ponds or can be conducted offsite at large commercial facilities. One drawback to evaporation ponds is that they are often attractive to waterfowl. To

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National Energy Technology Laboratory (NETL). Available at http://www.netl.doe.gov/technologies/pwmis/techdesc/discharge/index.html. Accessed March 30, 2009.

[2] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Underground Injection for Disposal," PWMIS, created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/PWMIS/techdesc/injectdisp/index.html. Accessed March 30, 2009.

[3] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Underground Injection for Increasing Oil Recovery," PWMIS, created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/PWMIS/techdesc/injecteor/index.html. Accessed March 30, 2009.

mitigate the risk of exposure to hydrocarbons and other compounds within the produced water, netting is often applied over the ponds.[4]

2.4.5 Offsite Commercial Disposal

When onsite management is not practical, operators may send their produced water offsite to a commercial disposal facility. Typically, produced water is removed from well locations periodically and transported via truck to an offsite facility.[5] Offsite commercial disposal is often chosen by small producers who find this option more feasible than constructing, operating, and closing onsite facilities, or by operators who do not have access to suitable formations for produced water injection (Puder and Veil 2006).

2.4.6 Beneficial Reuse

There are several management strategies in addition to enhanced oil recovery that use produced water for beneficial purposes. These primarily include agricultural and industrial uses.

Beneficial reuse of produced water for agricultural purposes includes reuse for crop irrigation, livestock watering, wildlife watering and habitat, aquaculture, and hydroponic vegetable cultivation. However, reuse of produced water represents just a small fraction of total agricultural withdrawals. In 2000, the total U.S. water withdrawals (both surface water and groundwater withdrawals) for irrigation was 1,190 billion barrels and for livestock water and aquaculture was 47.5 billion barrels (Hutson et al. 2004). A significant challenge to using produced water for agricultural purposes is the salinity of the water. Crops vary in their susceptibility to salinity, and when salinity rises above a threshold for a species, the crop yield will decrease. Another concern for using produced water is the sodicity, which refers to the amount of sodium in the water.[6] Johnston et al. (2008) reported that produced water from coal bed natural gas activities in the Powder River Basin increased the sodium ion concentration within the soil profile when applied to mixed-hay cropland. Excessive levels of sodium can lead to loss of soil structure, reducing the hydraulic conductivity of soils and creating conditions that may limit or prevent plant growth. When sodic soils are wet, they become swollen and waterlogged. When these soils are dry, the surface becomes crusted and resistant to water infiltration or plant emergence. Additional elements in produced water can cause harm to plants when present in sufficient quantities. ALL (2003) notes that plant toxicity can be caused by elevated concentrations of chloride, sodium, and boron.

Reuses of produced water for industrial purposes include water for hydraulic fracturing at oil and gas sites, water for power generation, dust control, and fire control. To initiate production

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[4] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Evaporation," PWMIS, created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/PWMIS/techdesc/evap/index.html. Accessed March 30, 2009.

[5] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Offsite Commercial Disposal," PWMIS, created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/PWMIS/techdesc/offsite/index.html. Accessed March 30, 2009.

[6] Argonne National Laboratory, "Produced Water Management Technology Descriptions: Fact Sheet – Agricultural Use," PWMIS, created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/pwmis/techdesc/aguse/index.html. Accessed March 31, 2009.

operations and enhance ongoing production, wells may be hydraulically fractured. Fracturing requires hundreds of thousands of barrels of water. In locations where local water sources are insufficient or otherwise unavailable, produced water may be used for fracturing. An additional water source in these operations is the flowback water from a previous fracturing activity. The feasibility of using produced water as cooling water for power generation was considered in a research project funded by the U.S. Department of Energy and the Electric Power Research Institute (DeFilippo 2004). The economics in the evaluated case did not appear favorable, although there is at least one case of produced water being used as boiler feed water at a cogeneration plant (Brost 2002).

Chapter 3 — Approach

To better understand the volume of produced water generated and how it is managed in the United States, Argonne contacted state oil and gas agencies in the 31 states with active oil and gas production to obtain detailed information on produced water volumes and management. As a first step, Argonne contacted the state oil and gas directors to introduce the project, briefly explain the scope of the work, and ask for a contact who could provide detailed information for that state. State agencies were selected due to their long-term direct experience with oil and gas activities in the specific state and the data management systems that most states employ for tracking production data. An example letter is provided in Appendix A of this report.

3.1 Information Request and Questionnaire

Once an appropriate contact person was identified for each state oil and gas agency, two questionnaires were sent to the contact. The first questionnaire targeted the produced water study outlined in this report and is described below. The second questionnaire was for a similar study on flowback water from hydraulic fracturing activities. The results of that study are discussed in a separate report.

The produced water questionnaire was divided into two parts, produced water volume and produced water management. The two tables from the questionnaire, along with instructions, are shown below.

Part I – Produced Water Volume

1. Please provide information on the volume of produced water generated in your state. Where available, please enter the actual volume on a yearly basis for 2007 or the next most recent year into Table 1 or indicate how we can access your electronic data management system. Even if you don't have information on the volume generated, but you do have information on the volume reinjected (assuming that most produced water from your state is reinjected), that is valuable information too, and should be entered in Table 1. To the extent possible, we would like to see the produced water volume estimates broken down by the type of hydrocarbon produced by the well as shown in Table 1. If you do not have quantitative information on the volume of produced water generated, please give us your educated "best estimate" of the volume.

2. If you do not have quantitative information on produced water generation or reinjection volumes, please provide information on the annual volume of each type of hydrocarbon produced in your state for 2007 or the next most recent year. This information should be entered into the last column of Table 1.

3. Please provide an estimate of the ratio of produced water to each type of hydrocarbon (for example, 7 bbl of water per 1 bbl of oil).

Table 1. Produced Water Volume Information

Type of Hydrocarbon	# Wells Producing That Type of Hydrocarbon	Total Volume of Produced Water (bbl/year)	Volume of Hydrocarbon Produced (bbl/year or Mmcf/year)	Ratio of Water to Hydrocarbon (bbl/bbl or bbl/Mmcf)
Crude oil				
Conventional gas				
Coal bed methane				
Unconventional gas				
Other				
Total				

Part II – Produced Water Management

4. Please provide information on how produced water is disposed or otherwise managed in your state. Where available, please enter the number of wells that manage produced water by each of the management practices on a yearly basis for 2007 or the next most recent year into Table 2. If you do not have quantitative information on produced water management practices, please give us your educated "best estimate" of the percentage of wells following each management practice.

Table 2. Produced Water Management Information

Management Practice	# Wells Using That Practice	Total Volume of Produced Water Managed by That Practice (bbl/year)	Percentage of Produced Water Managed by That Practice
Injection for enhanced recovery			
Injection for disposal			
Surface discharge			
Evaporation			
Offsite commercial disposal			
Beneficial reuse			
Other			

5. For any produced water entered under the beneficial reuse or other categories, please provide, to the extent possible, more details on the actual methods employed.

6. If another state agency has responsibility for regulating or overseeing some of the produced water management practices in your state, please indicate the name of the agency and a contact person.

The information requested through the questionnaire represented Argonne's "wish list." We did not realistically expect that all or even most states would be able to provide that level of detail or complete all of the boxes in the tables. The responses from the states (described in Chapter 5) matched those expectations. In Table 2, the intent of "the number of wells using this practice" column was to learn how many oil and gas wells direct produced water using the various management approaches. This information was not provided consistently. As these terms were not defined, many states interpreted the "number of wells using that practice" to mean the number of injection wells, discharges, evaporating ponds, disposal sites, and reuse sites managing the water.

3.2 Additional Production Information

In order to account for produced water generated from wells outside of the scope of state oil and gas agencies, efforts to obtain production information at the federal level were also undertaken. For offshore production activities, the questionnaire described above was sent to the U.S. Department of the Interior's Minerals Management Service (MMS), Gulf of Mexico Regional Office. Oil and gas production information for 2007 was also obtained from the Minerals Revenue Management Program of the MMS for federal onshore and tribal production activities. The oil and gas production estimates from these federal resources as well as the responses from state agencies were compared with available production data from the U.S. Department of Energy's Energy Information Administration (EIA) to identify any inconsistencies and to assist in the estimation of produced water volume from production activities where data were not available.

Several oil and gas platforms operate in the waters of Cook Inlet, Alaska. Although Cook Inlet is considered coastal rather than offshore waters, U.S. EPA's national discharge standards allow discharge to Cook Inlet waters. At the time this report was prepared, Alaska was going through a process to gain the authority to administer the NPDES program but had not yet obtained that authority. The current active NPDES general permit for Cook Inlet discharges was issued by U.S. EPA Region 10. Therefore, Argonne contacted the Region 10 office to obtain information on the discharge volumes for the Cook Inlet platforms.

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Chapter 4 — Analysis and Results

4.1 Response to Questionnaire

The produced water questionnaire was sent to 31 state oil and gas agencies. We received information on produced water generation or management from 28 states. For those states that did not directly provide the requested information, efforts were made to extract available data from accessible reports from oil and gas agency websites. Links to these sites are available at the Produced Water Management Information System website.[7] The questionnaire was also sent to and completed by the MMS to capture offshore production activities and management practices.

4.2 Incomplete Data

A major challenge in this study was dealing with the incompleteness of available data, as not all states track produced water data. For those states where produced water generation volume was unknown, produced water management data was used. When neither produced water management information nor production information were available, estimates of produced water volume were determined from hydrocarbon production information. Production information was obtained from state oil and gas agencies and federal resources as detailed in Chapter 5.

While information on produced water generation and management was obtained for most states, the detail of the information varied widely. Additionally, produced water data were unavailable for two states: Kentucky and Tennessee. The water-to-oil ratio (WOR) and water-to-gas ratio (WGR) for states without available produced water generation volumes were assumed to equal the corresponding ratios of adjacent states. For those states where the surrounding states had limited produced water information, the ratios were taken from several adjacent or neighboring states. This procedure is described in the state summaries in Chapter 5.

Produced water volumes from oil and gas production activities on tribal lands were not readily obtainable. Because obtained production information only provided total hydrocarbon production data from tribal lands, the U.S. average produced water-to-hydrocarbon ratio was used to estimate produced water volumes from these tribal lands.

The summary tables in this chapter address the incompleteness of the data by indicating where the data were obtained and the assumptions used in extrapolating data from other sources. The following categories appear under “Data Source” in the tables:

1. Provided directly to Argonne by state agency;
2. Obtained via published report;
3. Obtained via electronic database;

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[7] Argonne National Laboratory, “Produced Water Management Information System,” created for DOE and NETL. Available at http://www.netl.doe.gov/technologies/PWMIS/. Accessed March 31, 2009.

4. Obtained from website in form other than a published report or electronic database;

5. Obtained from the EIA; and

6. Estimated produced water generation volumes from hydrocarbon production volumes.

While the primary method for obtaining information was through questionnaires and direct communication with state agencies, multiple sources were often used to compile production information for each state.

4.3 Inconsistent Data

Hydrocarbon production information can be assumed to be accurate, due to the value of the oil and gas and the various reporting requirements for production. State production volumes provided to Argonne were compared with production estimates reported by the DOE's EIA. While there is some variation in reported production volumes, this is generally explained in two ways. Production volumes reported in state databases may not be the final reported volumes for a specific year. An official state report on production has final production volumes, and, when available, this source was used for production information. In most instances, final reported volumes agreed with production volumes reported by the EIA. When differences did exist, they were often due to the type of information reported. Most states reported produced hydrocarbon volumes, although some states provided saleable hydrocarbon volumes. Produced hydrocarbon volumes were preferentially used to determine the WORs and WGRs.

While produced water volumes are not required for reporting, many states do keep track of this information. The accuracy of the reported volumes depends upon the methods used by the producer. For instance, producers in Florida do not measure volumes produced, but estimate produced water volumes according to hydrocarbon production. Many states could provide only produced water generation estimates from water injection volumes (e.g., Louisiana). The water injected into Class II wells, especially injection wells for enhanced recovery, may include sources of water other than produced water (e.g., surface water, sea water), which could overestimate the total volume of produced water generated. Additionally, those states where produced water can be managed in ways other than injection would not capture those management strategies, resulting in underreporting total produced water generation. While the authors recognize the uncertainty, a method of accounting was difficult to achieve for the variability in the data collection methods, as the details of the collection methods are unknown. The summary statistics in this chapter have been rounded to the nearest 1,000 unit (e.g., bbl for oil and water, million cubic feet [Mmcf] for gas). Chapter 5 provides detailed information on the type of information obtained as well as the reported numbers (not rounded) for each state.

4.4 Production Summary

In 2007, U.S. onshore and offshore oil and gas production activities generated nearly 21 billion barrels of produced water. Table 3 provides production information for each state. State production totals include production from federal lands within each state.

Table 3. U.S. Onshore and Offshore Oil, Gas, and Produced Water Generation for 2007

State	Crude Oil (bbl/year)	Total Gas (Mmcf)	Produced Water (bbl/year)	Data Source[a]
Alabama	5,028,000	285,000	119,004,000	1
Alaska	263,595,000	3,498,000	801,336,000	1
Arizona	43,000	1,000	68,000	1, 2
Arkansas	6,103,000	272,000	166,011,000	2, 3
California	244,000,000	312,000	2,552,194,000	2, 3
Colorado	2,375,000	1,288,000	383,846,000	1,3
Florida	2,078,000	2,000	50,296,000	1
Illinois	3,202,000	No data	136,872,000	1, 5
Indiana	1,727,000	4,000	40,200,000	1, 2
Kansas	36,612,000	371,000	1,244,329,000	1, 2
Kentucky	3,572,000	95,000	24,607,000	1, 3, 6
Louisiana	52,495,000	1,382,000	1,149,643,000	1
Michigan	5,180,000	168,000	114,580,000	1, 3
Mississippi	20,027,000	97,000	330,730,000	1
Missouri	80,000	No data	1,613,000	1
Montana	34,749,000	95,000	182,266,000	1
Nebraska	2,335,000	1,000	49,312,000	1
Nevada	408,000	0	6,785,000	1, 2
New Mexico	59,138,000	1,526,000	665,685,000	1
New York	378,000	55,000	649,000	2
North Dakota	44,543,000	71,000	134,991,000	2, 4
Ohio	5,422,000	86,000	6,940,000	1, 2
Oklahoma	60,760,000	1,643,000	2,195,180,000	2, 6
Pennsylvania	1,537,000	172,000	3,912,000	3
South Dakota	1,665,000	12,000	4,186,000	1, 2
Tennessee	350,000	1,000	2,263,000	4, 6
Texas	342,087,000	6,878,000	7,376,913,000	3, 4
Utah	19,520,000	385,000	148,579,000	1
Virginia	19,000	112,000	1,562,000	1, 4
West Virginia	679,000	225,000	8,337,000	1
Wyoming	54,052,000	2,253,000	2,355,671,000	1, 4
State Total	**1,273,759,000**	**21,290,000**	**20,258,560,000**	
Federal Offshore	467,180,000	2,787,000	587,353,000	1
Tribal Lands	9,513,000	297,000	149,261,000	2, 6
Federal Total	**476,693,000**	**3,084,000**	**736,614,000**	
U.S. Total	**1,750,452,000**	**24,374,000**	**20,995,174,000**	

[a] 1 = provided directly to Argonne by state agency; 2 = obtained via published report or electronically; 3 = obtained via electronic database; 4 = obtained from website in form other than a published report or electronic database; 5 = obtained from EIA; 6 = produced water volumes are estimated from production volumes.

State and federal onshore production contribute the majority of produced water (more than 20 billion barrels) in the United States. A significant amount of produced water (more than 700 million bbl) is also generated from federal offshore production activities and from production on tribal lands. The five states with greatest produced water volumes in 2007 were Texas, California, Wyoming, Oklahoma, and Kansas. The produced water volumes from these states represent nearly 75% of total U.S. production (onshore and offshore) as shown in Figure 1. Texas alone contributed 35% of the total volume of produced water generated in the United States in 2007.

The greatest produced water contributors are not necessarily the greatest producers of oil and gas. While Texas was the largest gas producer in the United States (nearly 6,900,000 Mmcf in 2007), federal offshore production activities provided the largest volume of crude oil of more than 467,000,000 bbl (see Figure 2). Although federal offshore production generates nearly 27% of U.S. crude oil production, less than 3% of total U.S. produced water is generated from federal offshore activities. While Alaska and the federal offshore were two of the top three producers of oil and gas in 2007, they are ranked 7th and 9th in produced water volume generation.

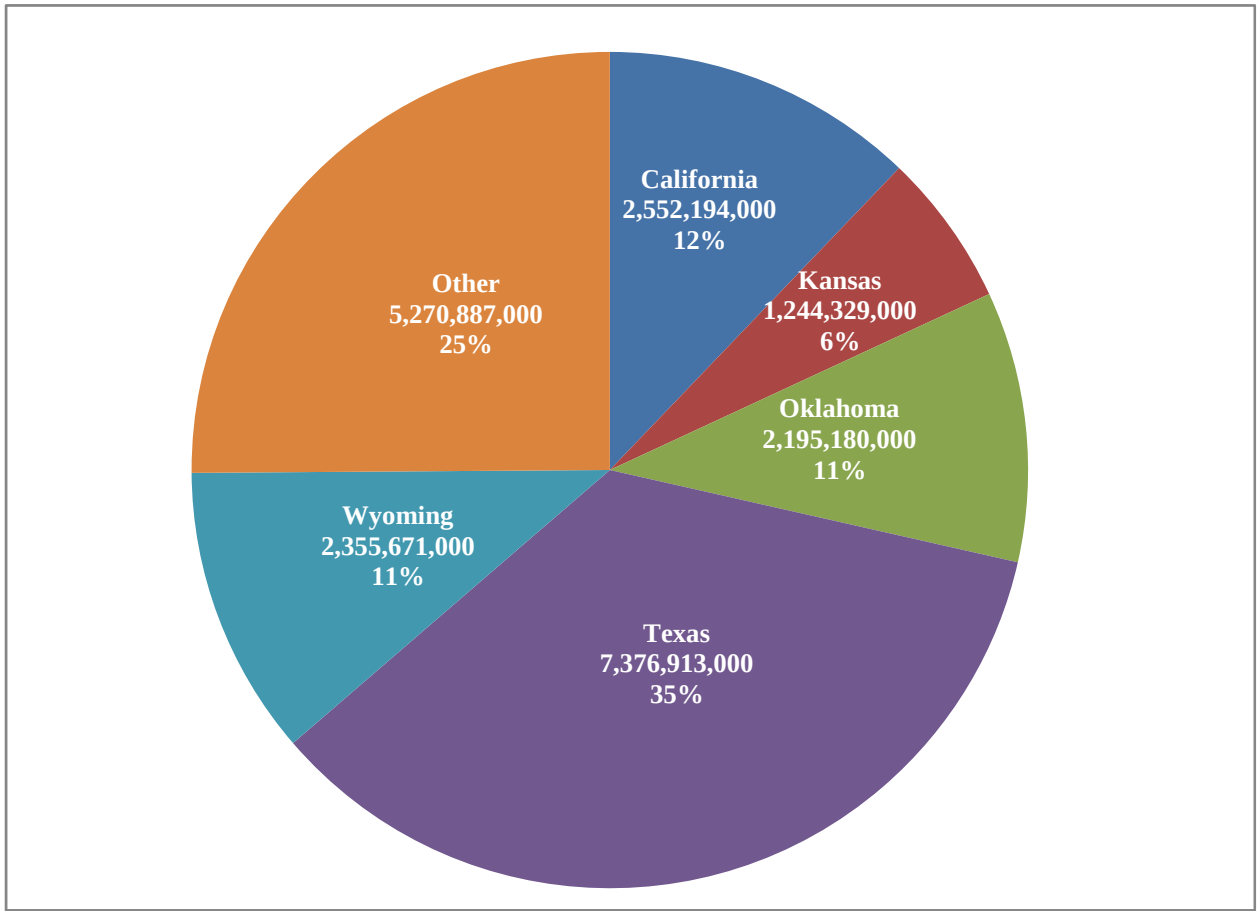

Figure 1. Total U.S. produced water generated (barrels) in 2007 by state (five states with the greatest produced water generation are shown)

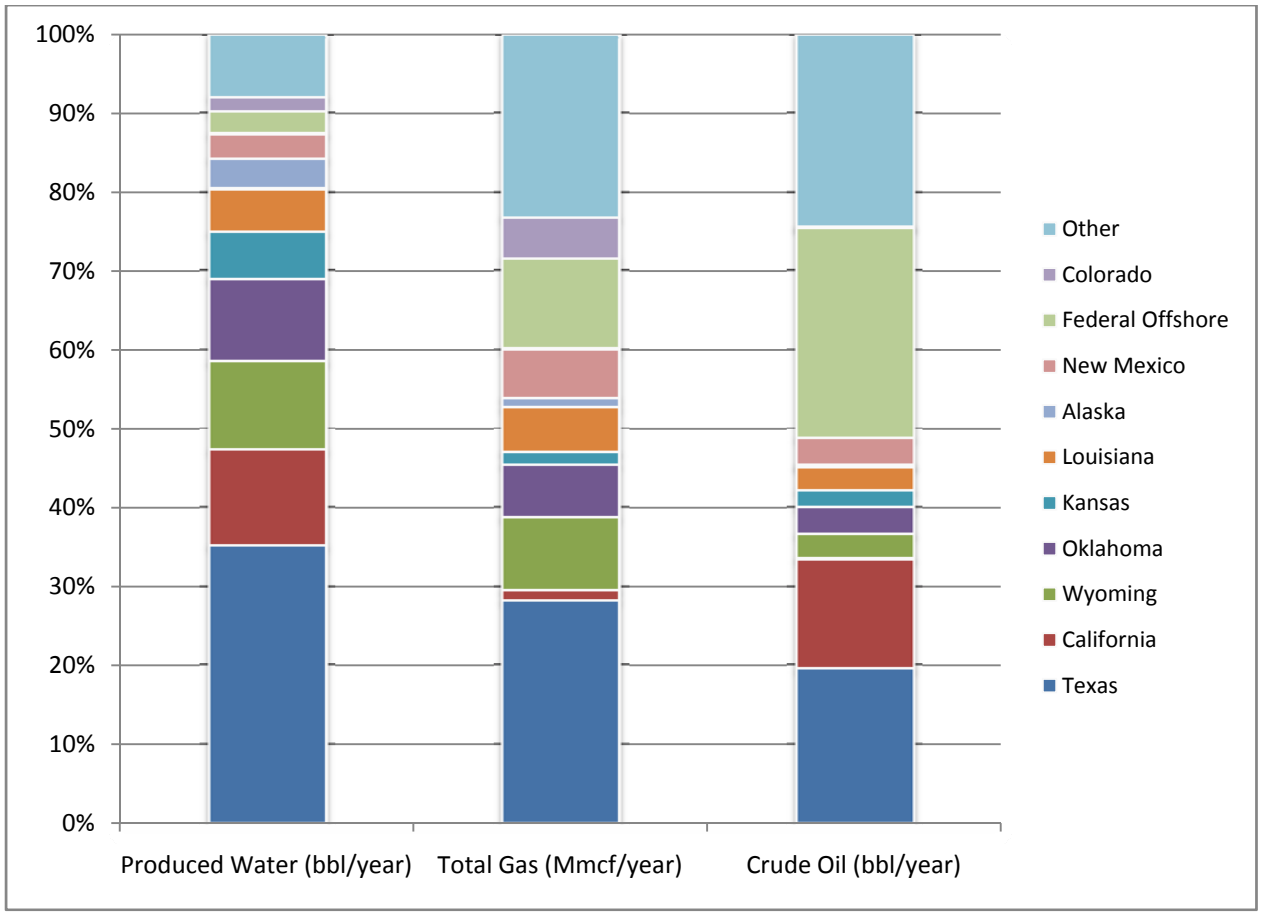

Figure 2. Ten largest produced water generators and their contributions to gas and crude oil production

In addition to total volumes produced, it is useful to consider the WOR and WGR from production activities. This information can be used to evaluate the relative production age of resources within the production lifetime. Table 4 lists water-to-hydrocarbon ratios from states where produced water data could be provided according to the predominant hydrocarbon produced at a specific location.

For WORs, the states values ranged from 2.5 bbl/bbl for South Dakota to 42.7 bbl/bbl for Illinois. The offshore ratio was even smaller at 1.04 bbl/bbl. For WGRs, the state values ranged from 0.04 bbl/Mmcf in South Dakota to more than 1,200 bbl/Mmcf for Kansas. The offshore ratio was 86 bbl/Mmcf.

A national average WOR and WGR can be estimated by developing a production-weighted average of the individual state values. Each state's WOR is multiplied by the oil production, and each WGR is multiplied by the gas production from gas-only wells to give water production from oil and gas production. These water volumes are summed, then they are divided by the sum of the oil and gas production values to estimate the WOR and WGR.

Table 4. Water-to-Hydrocarbon Ratio for 2007 from Available Data[a]

State	Water to Crude Oil (bbl/bbl)	Water to Gas (bbl/Mmcf)
Alabama	7.7	282
Alaska	2.9	4.4
California	10.5	7.6
Florida	24.2	Not available
Illinois	42.7	Not available
Kansas	21.8	1208
Mississippi	13.5	35.9
Missouri	20.3	Not available
Montana	4.0	453
Nebraska	20.9	358
Nevada	16.6	Not available
New Mexico	9.0	91.5
North Dakota	3.0	18.0
South Dakota	2.5	0.0
Virginia	Not available	17.7
Onshore Ratio[b]	**7.6**	**260**
Federal Offshore	1.04	86.0
Total Ratio[b]	**5.3**	**182**

[a] States not shown in Table 4 did not distinguish produced water volumes by hydrocarbon type; therefore, the WORs and WGRs could not be calculated.

[b] Onshore and total ratios were determined using the total volumes in each category (water, oil, and gas).

The national average onshore WOR was 7.6 bbl/bbl. When offshore production was added to the onshore production, the total average U.S. WOR was 5.3 bbl/bbl. A national average onshore WGR was 260 bbl/Mmcf. When offshore production was added to the onshore production, the total average U.S. WGR was 182 bbl/Mmcf.

The WOR from onshore activities determined in this study of 7.57 is within the range of previous reports of 7 bbl (Lee et al. 2002) and 9.5 bbl (Veil et al. 2004) of water per bbl of oil. The U.S. ratio for 2007 reveals that 88% of the material brought to the surface for oil production is water. According to Weideman (1996), water can comprise as much as 98% of the material brought to the surface for crude oil wells nearing the end of their productive lives. While cessation of operations depends on the point when managing the produced water is no longer profitable, the WOR determined in this study suggests that production of available resources is mature for most onshore operations in the United States. In the fluids brought to the surface from federal offshore oil wells, water comprises 51% on average.

The authors caution that the national average WOR and WGR values estimated in this study are likely to underestimate the true values. The averages are based on only 14 states (WOR) and 11 states (WGR). Many of the states that have large numbers of producing wells, particularly in mature fields with many stripper wells (e.g., Texas, Oklahoma), did not have produced water data segregated by production type. If those data had been included with the data from states

already in the average, it is probable that the national average WOR and WGR values would be substantially larger.

4.5 Produced Water Management Summary

Management information was obtained for nearly 17.1 billion bbl (81%) of the 20.9 billion bbl of produced water generated in 2007. The vast majority of produced water in the United States, 95.2% of the reported volume, was managed through injection. More than half of the produced water (55.4%, or 8.6 billion bbl) was injected for enhanced recovery in 2007. More than one-third (38.9%, or 6.0 billion bbl) of produced water was injected for disposal. Surface discharges managed 4.4% (700,000,000 bbl) of the total reported volume of produced water managed in 2007. Table 5 provides summary management information about injection and surface discharges for each state and the federal offshore area where such information was available. Those states that did not provide produced water management information have only reported total generation volumes. The remaining produced water volume was managed through evaporation ponds, offsite commercial disposal, beneficial reuse, and other management methods. Detailed management information is available for each state in Chapter 5.

Table 5 indicates that most of the produced water managed through injection (both for enhanced recovery and disposal) is generated through onshore production activities. While injection activities take place in the federal offshore area, the total injection volume is small compared to the total volume of produced water generated in the federal offshore area. Table 5 also reveals that some states reported greater volumes of produced water managed than generated for 2007 (e.g., Mississippi, Utah). Injection for enhanced recovery often includes makeup water from various sources, which could explain the discrepancies.

While surface discharge is used to manage some onshore produced water, the vast majority of surface discharges occur in the ocean. In 2007, more than 676,000,000 bbl of produced water were discharged to water bodies. Figure 3 shows the sources by percent of produced water surface discharges in the United States. The federal offshore managed the greatest volume of produced water through surface discharge. Including discharges to the Cook Inlet in Alaska, nearly 85% of the volume of produced water managed through surface discharge (573,000,000 bbl) is directed to oceans. The remaining 15% of produced water that is managed through surface discharge is from onshore production activities.

Alabama also manages a significant amount of produced water from coal bed methane activities through surface discharge. As produced water from coal bed methane production is often of a higher quality than other than produced water from more conventional production sources, some states including Alabama allow surface discharge after treatment.

Beneficial reuse is currently not a significant nationwide practice for produced water management. In 2007, 1,338,000 bbl were reported as managed through beneficial use. Reported volumes were limited to Oklahoma, South Dakota, and Utah, although other states including New York and Montana reported practices without providing detailed data on the volumes managed through beneficial reuse. It is likely that some other states have modest amounts of beneficial reuse of produced water, particularly for CBM production when the water is relatively fresh prior to treatment.

Table 5. U.S. Produced Water Volume by Management Practice for 2007

State	Volume of Produced Water (bbl/year)				
	Injection for Enhanced Recovery	**Injection or Disposal**	**Surface Discharge**	**Total Managed**	**Total Generated**
Alabama	7,500,000	33,000,000	78,000,000	119,000,000	119,004,000
Alaska	1,037,909,000	39,914,000	35,480,000	1,113,302,000	801,336,000
Arizona	No data	35,000	No data	35,000	68,000
Arkansas	45,489,000	120,169,000	No data	166,011,000	166,011,000
California	1,764,609,000	558,188,000	No data	2,322,797,000	2,552,194,000
Colorado	No data	No data	No data	No data	383,846,000
Florida	34,762,000	15,534,000	No data	50,296,000	50,296,000
Illinois	135,264,000	No data	No data	135,264,000	136,872,000
Indiana	34,500,000	5,700,000	No data	40,200,000	40,200,000
Kansas	444,319,000	800,009,000	No data	1,244,329,000	1,244,329,000
Kentucky	No data	No data	No data	No data	24,607,000
Louisiana	66,261,000	1,034,092,000	No data	1,149,643,000	1,149,643,000
Michigan	25,000,000	90,000,000	No data	115,000,000	114,580,000
Mississippi	389,614,000	281,563,000	No data	671,177,000	330,730,000
Missouri	No data	1,611,000	No data	1,613,000	1,613,000
Montana	109,217,000	46,807,000	No data	182,266,000	182,266,000
Nebraska	31,588,000	14,337,000	500,000	49,312,000	49,312,000
Nevada	No data	No data	No data	No data	6,785,000
New Mexico	449,489,000	348,142,000	No data	797,630,000	665,685,000
New York	No data	No data	No data	No data	649,000
North Dakota	64,873,000	65,321,000	No data	134,991,000	134,991,000
Ohio	487,000	6,137,000	No data	6,940,000	6,940,000
Oklahoma	940,272,000	1,254,132,000	No data	2,195,180,000	2,195,180,000
Pennsylvania	No data	No data	No data	No data	3,912,000
South Dakota	2,122,000	1,853,000	85,000	4,146,000	4,186,000
Tennessee	No data	No data	No data	No data	2,263,000
Texas	5,011,062,000	2,365,476,000	No data	7,376,913,000	7,376,913,000
Utah	78,251,000	62,051,000	21,080,000	173,145,000	148,579,000
Virginia	No data	No data	No data	No data	1,562,000
West Virginia	3,942,000	No data	3,857,000	8,337,000	8,337,000
Wyoming	No data	No data	No data	No data	2,355,671,000
State Total	**10,676,530,000**	**7,144,071,000**	**139,002,000**	**18,057,527,000**	**20,258,560,000**
Federal Offshore	48,673,000	1,298,000	537,381,000	587,353,000	587,353,000
Tribal Lands	No data	No data	No data	No data	149,261,000
Total	**10,725,203,000**	**7,145,369,000**	**676,383,000**	**18,644,880,000**	**20,995,174,000**

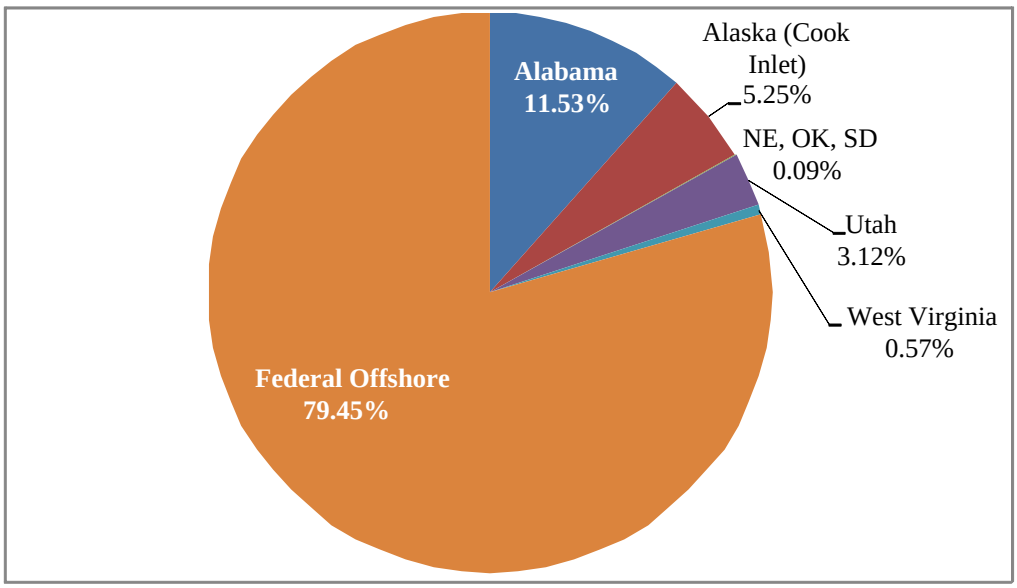

Figure 3. Sources by percent of total U.S. surface discharges for produced water in 2007 (total discharges amounted to more than 676,000,000 bbl in 2007)

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Chapter 5 — State-by-State Summary

5.1 Alabama

The State Oil and Gas Board of Alabama provided produced water generation and management data (Bolin 2008). As of December 2007, Alabama had 6,544 wells producing hydrocarbons, with the majority of these wells producing CBM (5,209 wells). The remaining wells produce crude oil (848 wells), conventional gas (475 wells), and unconventional gas (12 wells). Alabama specified shale gas for unconventional gas. From the 6,544 wells, 119,003,506 bbl of produced water were generated in 2007. CBM and crude oil production were responsible for the majority of the produced water generation, with each producing 78,087,301 and 38,495,257 bbl, respectively. Produced water generation from conventional gas was 2,420,635 bbl, and unconventional gas production generated 313 barrels of produced water.

Hydrocarbon production for 2007 included crude oil (5,028,4285 bbl), CBM (114,981 Mmcf), conventional gas (170,049 Mmcf), and unconventional gas (52 Mmcf). Conventional gas wells also produced 2,091,226 bbl of condensate. From these production volumes, the following ratios were determined: WOR of 7.66 bbl/bbl, WGR of 679 bbl/Mmcf for CBM, WGR of 14.23 bbl/Mmcf for conventional gas, and WGR of 6.0 bbl/Mmcf for unconventional gas.

The majority of generated produced water in Alabama is managed through surface discharges for CBM, which require NPDES permits. The Alabama Department of Environmental Management (ADEM) administers the NPDES permit program. Permitted surface discharge accounts for 78,000,000 bbl of produced water from CBM production (5,204 wells). Injection for disposal manages 33,000,000 bbl of produced water per year for 1,174 wells. A smaller amount of produced water is injected for enhanced recovery with 7,500,000 bbl managed for that purpose. The remaining produced water (approximately 500,000 bbl) is managed through offsite commercial disposal. There is no beneficial reuse of produced water in Alabama.

5.2 Alaska

The Alaska Oil and Gas Commission (OGC) supplied both produced water generation information and management information (McMains et al. 2008). In 2007, Alaska had 1,875 wells with the majority of these wells producing crude oil (1,715 wells). The remaining wells produced conventional gas (160 wells). Crude oil production volumes were 263,595,162 bbl in 2007 and generated 765,121,124 bbl of produced water. Conventional gas production generated 735,412 bbl of produced water in the same period to produce 166,261 Mmcf of gas. These volumes result in a WOR of 2.9 bbl/bbl of crude oil and WGR of 4.4 bbl/Mmcf of conventional gas. Total gas production (including gas coproduced from oil wells) was 3,498,322 Mmcf as reported in the Alaska OGC production data archives (Alaska OGC 2009).

Injection for enhanced recovery manages 94.8 percent of produced water in Alaska. Injection for enhanced recovery occurs at 842 wells, and these wells manage 1,037,908,618 bbl of water. This volume exceeds the total volume of available produced water, due to the addition of seawater injected for enhanced recovery. The remaining produced water (39,913,859 bbl) is managed by

30 injection wells for disposal. Management information for discharges from production activities in the Cook Inlet was obtained from U.S. EPA Region 10. In 2007, 35,479,866 bbl of produced water were directly discharged into the Cook Inlet (Shaw 2009). Discharges in the Cook Inlet operate under the U.S. EPA NPDES permit program until October 31, 2011, when discharge activities associated with the oil and gas industry will be transferred to the Alaska NPDES program (Hartig 2009).

5.3 Arizona

Annual oil, water, and gas production volumes are available in the December monthly production reports on the Arizona Oil and Gas Conservation Commission's website at http://www.azogcc.az.gov/. In 2007, 42,692 bbl of oil, 67,682 bbl of water, and 654.530 Mmcf of gas were produced. Most produced water generated in Arizona is managed through injection for disposal. Some produced water is trucked to an approved disposal facility in New Mexico. There is no injection for enhanced recovery at this time. The Arizona Geological Survey, which provides administrative and staff support to the Arizona Oil and Gas Conservation Commission, provided a spreadsheet of Class II injection wells, which reported that 35,116 bbl of produced water were injected for disposal in 2007 (Rauzi 2008). Historic hydrocarbon production volumes are available in the report, *Annual Oil, Gas, and Helium Production in Arizona 1954-2008* (Rauzi 2009).

5.4 Arkansas

Production information was obtained through the Arkansas Oil and Gas Commission's (Arkansas OGC's) annual production report (Arkansas OGC 2007). For 2007, total production volumes in the state were 6,102,538 bbl of crude oil and 271,846 Mmcf of gas. While the report provides production information for South Arkansas and North Arkansas, specific information on the type of produced gas (i.e., conventional, unconventional, or CBM) was not provided.

The Arkansas OGC also provided produced water management information (Pearson 2009). While there is significant water produced from bromine production activities, and the Arkansas OGC tracks the volumes produced and managed that are associated with bromine production, such water is managed through Class V wells and is not included in the management information here. There are 106 active Class II injection wells for enhanced oil recovery and 448 Class II injection wells that dispose of produced water. Most produced water was managed through injection for disposal, with 120,169,316 bbl injected. Injection for enhanced recovery managed 45,488,886 bbl of produced water. An additional 352,997 bbl of produced water was injected, but the type of injection well was not specified. The total injected volume of produced water for 2007 was 166,011,199 bbl.

5.5 California

Produced water and hydrocarbon production information were obtained from the California Department of Conservation's *2007 Preliminary Report of California Oil and Gas Production Statistics* (CDOC 2008a). Oil production in 2007 was reported to be 244,000,000 bbl. The report separates natural gas production according to production associated with oil zones (associated production) and production not associated with oil zones (nonassociated production). Associated production was estimated to total 219,000 Mmcf, and nonassociated production was estimated at

93,200 Mmcf. Rounding to significant figures, the total gas production was 312,000 Mmcf. The water produced from all activities was 2,552,194,253 bbl, which accounts for both onshore and state and federal offshore production. The total produced water volume oil and associated gas production was 2,549,823,222 bbl in 2007 (WOR: 10.45 bbl/bbl). The produced water from nonassociated gas production was 2,162,592 bbl in 2007 (WGR: 6.93 bbl/Mmcf).

Produced water management information was not provided, although some information could be determined from an online database (CDOC 2008b). The online database captures underground injection volumes and reported 2,322,797,059 bbl of water were injected. In 2007, 558,187,847 bbl were injected for disposal, and 1,764,609,212 bbl were injected for enhanced recovery. These volumes may include ocean water or other brine. This does not account for all of the produced water produced in California, but it does suggest that much of the water is injected for the purposes of enhancing oil and gas production activities. Produced water that is not injected for enhanced recovery or as water disposal is treated for beneficial use or is disposed of through settling ponds and ocean outfall.

5.6 Colorado

The Colorado Oil and Gas Conservation Commission (COGCC) publishes production data in an online database, which was used to obtain produced water information for 2007 (COGCC 2009). For that year, crude oil production was 2,374,921 bbl. Total gas production was 1,288,109.976 Mmcf, with CBM contributing 478,434.041 Mmcf to the gas total. Produced water volumes totaled 383,845,756 bbl. Detailed information on produced water management was not available, although it is generally managed through evaporation ponds or injection (Kerr 2009).

5.7 Florida

The Bureau of Mining and Minerals Regulation provided produced water generation and management information for the State of Florida (Taylor 2008). All wells in Florida produce oil, with most producing both oil and gas. There are 56 oil producing wells in the state, and 52 of those wells produce both oil and gas. Crude oil production was 2,077,773 bbl in 2007, and 2,010.932 Mmcf of natural gas was produced during the same period. Total produced water volume from the 56 wells was 50,295,726 bbl. Four wells that only produce oil generate small volumes of water that were not included in the total. Produced water volumes are not directly measured, but rather are estimated by oil producers.

Produced water is managed through underground injection in Florida. Twenty wells injected 15,533,899 bbl of produced water for disposal. Forty-three wells injected 34,761,872 bbl of water for enhanced recovery.

5.8 Illinois

The Illinois State Geological Survey (ISGS) provided information on average production between 2000 and 2006 (Dastgheib 2008). Reported data comes from the ISGS waterflood database. Annual oil production from enhanced oil recovery (EOR) averaged 3,201,958 bbl during that period. Produced water averaged 136,872,199 bbl annually resulting in a WOR of 42 7 bbl/bbl. As the database contains only information related to waterflooding, production

activities in Illinois that do not use waterflooding would not be included. The actual produced water volume in the state is likely to be higher than what is reported here, as EIA reported oil production for Illinois was 9,609,000 bbl for 2007 (EIA 2008a).

Nearly all of the generated produced water from EOR is injected for waterflooding activities to improve recovery of crude oil. 135,263,569 bbl of the produced water was managed in this way. It is unclear from the available information whether produced water is also managed via injection for disposal. Additional produced water may be disposed of by methods other than waterflooding, although data on that is unknown.

5.9 Indiana

Produced water data were provided by the Division of Oil and Gas of the Indiana Department of Natural Resources (IDNR) and estimated from reported injections for 2007 (Nemecek 2008). Additional production information was obtained through the December 2007 monthly report published by the IDNR (IDNR 2007). Total reported production for 2007 was 1,726,553 bbl of crude oil and 3,605.982 Mmcf of gas. While generation information on produced water was not available, management information states that 40,200,000 bbl of produced water was managed through injection in 2007. The primary management practice for produced water was injection for enhanced recovery, which injected 34,500,000 bbl of produced water annually into 1,101 injection wells. Produced water is also managed through 183 disposal wells, which managed the remaining 5,700,000 bbl of produced water.

5.10 Kansas

Production data were provided by the Kansas Corporation Commission (KCC) and obtained from the Kansas Geological Survey's 2007 report (Durrant 2008). The 2007 drilled wells and CBM wells are from the 2007 KCC ACO-1 well completion forms. The produced water volumes are subjective and were determined using a weighted average approach from injection well permits in Kansas. The injection well permit information was collected from the U3-C annual reports of pressure monitoring, fluid injection, and enhanced recovery filed by operators.

In 2007, 67,631 wells produced hydrocarbons in Kansas. There were 43,384 wells producing 36,611,778 bbl of crude oil. Conventional gas production occurred at 24,247 wells and totaled 370,918.167 Mmcf. Additionally, 1,306 wells were drilled in 2007 to begin CBM production. Crude oil production generated 796,370,268 bbl of produced water, resulting in a WOR of 22 bbl/bbl. Conventional gas production generated 447,958,276 bbl of produced water, resulting in a WGR of 1,207 bbl/Mmcf. The total volume of produced water generated in Kansas was 1,244,328,544 bbl.

Produced water is managed via injection wells in Kansas. Offsite commercial disposal of produced water is not a recognized management practice in Kansas. There were 11,016 injection wells for enhanced recovery and 4,406 injection wells for disposal in 2007. Disposal is the primary purpose for injection, with 800,009,421 bbl of produced water managed in this way. Injection for enhanced recovery managed 444,319,123 bbl of produced water.

5.11 Kentucky

The Kentucky Division of Oil and Gas Resources supplied only hydrocarbon production information, as it does not have regulatory authority to monitor produced water. There were 49,344 wells in Kentucky in 2007. Crude oil was produced from 26,481 wells, which generated 3,572,400 bbl of crude oil (Combs 2008). Gas production occurred at 19,385 wells, which produced 95,246.846 Mmcf for gas, according to the Kentucky Geological Survey (undated). There were an additional 3,478 wells that include storage, stratification tests, and combination oil and gas wells. No information was provided on produced water generation or management.

Produced water volumes were estimated by extrapolation using available production information and water-to-hydrocarbon ratios from neighboring states. The WGR (17.7 bbl/Mmcf) from CBM activities in Virginia was multiplied by the gas production in West Virginia (225,000 Mmcf) to estimate the volume of water attributable to West Virginia's gas production (3,982,500). This gas-specific water volume was subtracted from the total West Virginia water volume (8,337,000 bbl) to estimate the volume of water attributed to West Virginia crude oil production (4,354,500 bbl). This oil-specific water volume was divided by the West Virginia crude oil production to estimate the WOR in West Virginia (6.4 bbl/bbl). The WGR from Virginia and the estimated WOR in West Virginia were used to determine the total estimated produced water volume for Kentucky. Based upon the previous assumptions, produced water generated from oil production would be 22,920,000 bbl. Produced water generated from gas production in Kentucky is estimated to be 1,688,000 bbl. Total produced water generation for 2007 is estimated at 24,608,000 bbl.

5.12 Louisiana

Hydrocarbon production and produced water management information was provided by the Louisiana Department of Natural Resources (Parker 2008). Louisiana does not track the amount of water produced from each of Louisiana's 80,892 actively producing wells. Of these wells, 40,957 produce crude oil and 39,935 produce gas. Total oil production in 2007 was 52,495,100 bbl. Gas production volume was 1,381,585 Mmcf.

While production volume of produced water is unavailable, Louisiana does track injection volumes for 2,914 wells (1,149,643,443 bbl of produced water in 2007). Ninety percent of produced water (1,034,092,270 bbl) was injected for disposal. The remaining water was either managed by injection for enhanced recovery (66,261,179 bbl of water into 354 wells) or by offsite commercial disposal (49,289,994 bbl of water into 31 wells).

5.13 Michigan

The Michigan Department of Environmental Quality's Office of Geological Survey provided information on produced water management (Organek 2008). Production volume data was obtained from a database on the Gas, Oil, and Minerals website of the Michigan Department of Environmental Quality. Total crude oil production was 5,180,043 bbl. Michigan also produced 441,844 bbl of condensate and 453,749 bbl of natural gas liquids in 2007. Gas production during that period was 166,794.419 Mmcf. Produced water generation for all hydrocarbon production activities was 114,580,484 bbl.

Michigan manages produced water through underground injection. Twenty percent of produced water was injected for enhanced recovery, while the majority of produced water (80%) was managed through injection for disposal.

5.14 Mississippi

The Mississippi Oil and Gas Board provided produced water generation and management information (Sims and Tarbutton 2008). Mississippi has three categories of production wells: wells that produce only oil, wells that produce only gas, and wells that produce both oil and gas. For oil-only wells, 1,379 wells produced 12,111,145 bbl per year of crude oil and 164,027,705 bbl of produced water. The WOR for these wells was 13.54 bbl/bbl. There are 1,403 gas-only wells in Mississippi, which produced 40,656 Mmcf of gas and 1,459,563 bbl of produced water, with a WGR of 35.9 bbl/Mmcf. The remaining 1,903 wells produce both oil and gas, producing 7,915,632 bbl of crude oil, 56,056 Mmcf of gas, and 165,242,314 bbl of water in 2007. Total oil production was 20,026,777 bbl, and total gas production was 96,712 Mmcf. Total produced water generation in Mississippi was 330,739,582 bbl for 2007.

Total produced water managed in Mississippi exceeds the total produced water generated, which suggests that most of the water injected for enhanced recovery consists of makeup water. There were 381 wells that injected 389,613,955 bbl of water for enhanced recovery. In addition, 466 wells injected 281,563,270 bbl of water for disposal.

5.15 Missouri

The Division of Geology and Land Survey of the Missouri Department of Natural Resources provided produced water generation and management information (Kaden 2008). In 2007, Missouri had 308 crude oil production wells. There was no commercial gas production activity in Missouri for that year. The 308 wells produced 79,516 bbl of oil and 1,612,592 bbl of water, for a WOR of 20.28 bbl/bbl. Injection for disposal is the primary management method for produced water. One hundred forty-six injection wells managed 1,611,246 bbl of produced water. The remaining 1,346 bbl of water were managed through evaporation.

5.16 Montana

The Montana Board of Oil and Gas provided produced water generation and management information (Halvorson 2009; Hudak 2008). In 2007, crude oil production volumes were 34,749,250 bbl from 4,325 wells. Gas production took place at 5,694 wells and yielded 82,119 Mmcf. Much of the current and historic gas production in Montana occurred in formations that would be considered unconventional, as tight sand or siltstone reservoirs, low-volume gas wells, or “shale gas,” in some cases. As a result, Montana does not break out gas sources as conventional or unconventional. CBM production information is collected separately, and 902 wells produced 13,062 Mmcf of CBM. Produced water volumes from these hydrocarbons were the following: 139,189,532 bbl of water from crude oil production, 4,196,725 bbl of water from gas production, and 38,880,091 bbl from CBM production. These volumes resulted in a WOR of 4.0 bbl/bbl, a WGR of 51.1 bbl/Mmcf of gas, and a WGR of 2,976 bbl/Mmcf of CBM. When conventional natural gas and CBM are combined, the resulting WGR is 453 bbl/Mmcf.

The majority of produced water generated is managed through injection wells. There were 624 active wells for enhanced recovery and 173 wells for disposal. Enhanced recovery managed 60% (109,217,415 bbl) of the produced water generated in Montana. Twenty-six percent (46,807,463 bbl) of produced water generated was managed through injection for disposal. The remaining 14% of produced water was managed in other ways including the following: evaporation pits, beneficial use including stock water and dust suppression, and direct discharge to surface waters. According to Keith et al. (2003), produced water from CBM activities was primarily managed through other practices including direct discharge, holding ponds, and land application.

5.17 Nebraska

The Nebraska Oil and Gas Conservation Commission provided both production and management information (Sydow 2008). In 2007, there were 1,384 wells, with 1,187 of those wells producing oil. The remaining 197 wells produced gas. Oil production was 2,335,355 bbl and generated 48,835,874 bbl of produced water (WOR: 20.91bbl/bbl). Conventional gas production volume was 1,331.125 Mmcf and generated 476,481 bbl of produced water (WGR: 357.95 bbl/Mmcf). Total produced water generation in Nebraska was 49,312,355 bbl.

For produced water management, data were provided both according to the number of wells that produce water and the number of injection wells that receive the produced water. The majority of produced water (31,588,486 bbl) was sent from 673 oil wells to be managed by 407 injection wells for enhanced recovery. Injection for disposal was conducted at 91 injection wells to manage 14,337,458 bbl from 478 oil wells and 197 gas wells. Sixteen oil wells sent 499,960 bbl of produced water to surface discharge. Evaporation management took 2,886,451 bbl of produced water from 233 oil wells.

5.18 Nevada

The Nevada Division of Minerals supplied production data (Price 2009). According to the 2007 bimonthly reports of the *Nevada Oil Patch*, total oil production in 2007 was 408,174 bbl. Gas production for the same year was 4.474 Mmcf. Produced water volumes were collected for oil production, and 6,784,661 bbl were generated in 2007. No information on management of produced water was provided, although a well inventory in 2004 revealed that there were 13 Class II injection wells in Nevada (NDEP 2004).

5.19 New Mexico

The Oil Conservation Division of the New Mexico Energy, Minerals, and Natural Resources Department provided produced water volume information according to hydrocarbon production (Fesmire 2009). Crude oil production generated 53,265,771 bbl of oil and 534,273,532 bbl of water in 2007 (WOR: 10.0 bbl/bbl). An additional 5,872,258 bbl of oil condensate were produced; total oil production for 2007 was 59,138,029 bbl. Conventional gas production totaled 797,747 Mmcf and generated 80,377,476 bbl of produced water (WGR: 100 bbl/Mmcf). Coal bed methane production was 496,825 Mmcf and produced 38,084,472 bbl of water (WGR: 76.7 bbl/Mmcf). When conventional natural gas and CBM are combined, the resulting WGR is 92 bbl/Mmcf.

While unconventional gas and condensate were produced (231,901 Mmcf and 5,872,258 bbl, respectively), the volume of produced water from these activities was unknown. Total gas production in 2007 was 1,526,473 Mmcf. Additional produced water was generated from carbon dioxide production activities. For 98,856,249 Mmcf of carbon dioxide, 65,585 bbl of produced water were generated. The total produced water from the above activities was 652,801,065 bbl, although the total water actually produced in the state in 2007 was 665,684,732 bbl. The remaining amounts could not be identified by these hydrocarbon categories.

New Mexico does not specifically track the produced water that gets reinjected. While the option is included in the monthly production reports, well operators use different categories for the same action. In 2007, 3,167 wells had 449,488,784 bbl of water injected specifically into injection wells. An additional 603 wells had 348,141,541 bbl of water injected as salt water disposal.

5.20 New York

The New York State Department of Environmental Conservation's Division of Mineral Resources provides production information in an annual report and through an online database (NYSDEC 2006; NYSDEC undated). The most recent available report is for 2007. According to the 2007 data, 13,113 wells were reported to the division. Of the total, 7,387 were natural gas wells, 4,874 were oil wells, and the remaining wells were gas storage, dry holes, and solution salt wells. The database provided production volumes of 55,001 Mmcf for natural gas and 377,514 bbl for oil. The state-produced water volume was 649,333 bbl from active wells for 2007, which included 215,050 bbl that were associated with water injection wells.

Specific details were not available on the management practices for produced water in New York, although injection wells for disposal and enhanced recovery were listed under well type codes within the database. All produced water that is hauled from well sites requires a department-issued waste transporter permit. The department allows produced water disposal at publicly owned treatment works, with approved industrial pretreatment or mini-pretreatment programs. The department also allows road spreading of production brine for deicing and dust control purposes under its beneficial use determination program.

5.21 North Dakota

The Department of Mineral Resources provides oil and gas production information online. In 2007, there were 3,872 oil producing wells in North Dakota. Of these wells, 2,525 also reported gas production. In addition to the 3,872 oil wells, there were 216 gas wells. Fifty-nine of the gas wells were permitted as gas condensate wells and produced some oil. Total annual crude oil production from those wells was 44,701,934 bbl. The oil producing wells, which generated 44,543,187 bbl of the total crude oil, generated 134,704,290 bbl of produced water (WOR: 3.02 bbl/bbl). Gas production for 2007 was 70,767.153 Mmcf. Much of this production volume was coproduced from oil wells. The gas wells produced 15,909 Mmcf in 2007 and generated 286,889 bbl of produced water (WGR: 18.03 bbl/Mmcf). The total produced water generated in North Dakota from these production activities was 134,991,179 bbl.

More than 96% of the produced water generated in North Dakota is managed through injection. In 2007, there was slightly more produced water managed through injection for disposal than

enhanced recovery. Water produced from 2,531 wells totaling 65,321,067 bbl was directed to disposal wells, which managed 48.39% of the total volume of produced water for 2007. Enhanced recovery managed 64,872,788 bbl (48.06% of the total volume) of produced water from 1,096 wells. The remaining 3.55% of the produced water (4,797,324 bbl) in North Dakota came from 519 wells and was directed to offsite commercial disposal wells.

5.22 Ohio

The Ohio Division of Mineral Resources Management provided produced water information for 2006, and production data was obtained for the same year through the 2006 report *Summary of Ohio Oil and Gas Activities* (ODNR 2006). The majority of Ohio wells are combination wells, producing both oil and gas. In 2006, there were 63,654 active wells in Ohio, which produced 5,422,194 bbl of crude oil and 86,315.100 Mmcf of natural gas. These wells produced 6,940,000 bbl of produced water in 2006. Ohio does not subcategorize reported produced water volumes by hydrocarbon.

Most produced water generated in Ohio is managed via injection for disposal. Eighty-eight percent, 6,137,005 bbl, of reported produced water in 2007 was injected for disposal. Injection for enhanced recovery managed 7% of the produced water generated (487,478 bbl). The remaining 315,517 bbl were managed either at annular disposal wells or were reused through spreading for dust and ice control with local government authorization.

5.23 Oklahoma

The Oklahoma Corporation Commission (OCC) publishes an annual report on oil and gas. Production information for 2007 was obtained from the 2008 report, and produced water management information was provided directly by the OCC. For the reported year, there were 82,832 crude oil production wells producing 60,760,000 bbl of crude oil. Gas production occurred at 38,364 wells and totaled 1,643,292 Mmcf.

The majority of produced water in Oklahoma was managed via injection in 2007 (Baker 2009). Injection occurred at 2,584 active disposal wells, which managed 1,201,680,455 bbl of produced water. Injection also occurred at 202 commercial disposal wells that managed 52,451,784 bbl of produced water. In total, injection for disposal wells managed 1,254,132,239 bbl. Oklahoma had 6,264 enhanced recovery wells in 2007, which managed 940,271,840 bbl of produced water. Currently, one ongoing surface discharge operation in the Arkoma Basin discharged 165 bbl in 2008 (note: 2007 data not available). Oklahoma also has one recycling permit issued for produced water. The permit is for a surface reclamation project in which produced water is mixed with fresh water. The mixed water is combined with fly ash to be used as fill for closure at abandoned strip mines. The amount of water reported as used in this operation for 2007 was 776,200 bbl. The total produced water managed in Oklahoma for 2007 (including the 2008 surface discharge volume as an estimate) was 2,195,180,444 bbl.

5.24 Pennsylvania

Production information is available via the Wells Information System (WIS) created by the Pennsylvania Geological Survey and provided by the Pennsylvania Department of Environmental Protection's Bureau of Oil and Gas Management (PDEP 2008a). In 2007, total

gas production was 172,367.077 Mmcf, while reported oil production was 1,537,347 bbl. Production occurred at 65,129 wells. Estimates of production wells were slightly higher but broken into categories by hydrocarbon (PDEP 2008b). Gas production wells totaled 52,700 wells, and there were 18,200 oil wells in 2007. The total produced water volume from these production wells was 3,912,456 bbl. Information on produced water management was not provided.

5.25 South Dakota

The Department of Natural Resources Minerals and Mining Program (Oil and Gas Section) provided information on production and management of produced water related to oil and gas activities (McGillivray 2008). In 2007, a total of 224 wells were active in South Dakota, with 153 producing crude oil and 71 producing conventional gas. Oil production totaled 1,664,889 bbl and generated most of the produced water generated in South Dakota, with 4,185,565 bbl attributable to oil production (WOR: 2.5 bbl/bbl). Gas production generated only 486 bbl of produced water in generating 11,880 Mmcf of conventional gas (WGR: 0.04 bbl/Mmcf).

Most produced water is managed through injection. Ninety-six percent of produced water generated in South Dakota was injected, with 2,121,947 bbl injected for enhanced recovery (51%) and 1,853,200 bbl injected for disposal (45%). The remaining four percent of produced water was managed either through surface discharge (85,243 bbl) or beneficial reuse as water for livestock (85,243 bbl).

5.26 Tennessee

Tennessee does not presently keep track of produced water information from oil and gas activities. According to Tennessee's Division of Geology's website, approximately 350,000 bbl per year of oil and 1,000 Mmcf per year of gas are produced in the state (TDEC undated). Produced water management information was unavailable. However, according to U.S. EPA Region 4, as of August of 2007, there were 13 Class II injection wells in Tennessee (U.S. EPA 2008b).

Produced water volumes were estimated by extrapolation using available production information and water-to-hydrocarbon ratios from neighboring states. The water-to-gas ratio (17.7 bbl/Mmcf) from CBM activities in Virginia was used to determine the WOR in West Virginia (6.4 bbl/bbl) (see discussion for Kentucky, above). These ratios were assumed to be the same for Tennessee, with the exception of CBM, as no CBM activities were explicitly stated in the production information obtained from the state. Based upon the previous assumptions, produced water generated from oil production would be 2,246,000 bbl. Produced water generated from gas production in Tennessee is estimated to be 18,000 bbl. Total produced water generation for 2007 is estimated at 2,263,000 bbl.

5.27 Texas

Produced water injection data for 2007 were provided by the Railroad Commission of Texas, and hydrocarbon production data was obtained from the commission's website. In 2007, Texas wells produced 342,086,945 bbl of crude oil and 6,878,016 Mmcf of natural gas (RRC 2009). There were more than 216,000 active oil and gas wells statewide, which managed produced water via

injection into more than 50,000 permitted oil and gas injection and disposal wells (RRC undated). While CBM production activities occur in Texas, such activities are not distinguished from conventional gas production (Deleon 2009).

Currently, injection reports for 2007 are still being added to the commission's database. As of April 2, 2009, the total reported liquid injection volume for 2007 was 4,254,037,585 bbl. From the current total, 1,364,096,989 bbl (32% of reported total) were disposed into nonproducing formations, 757,606,954 bbl were (18% of reported total) disposed into producing formations, and 2,132,117,391 bbl (50% of reported total) were injected for enhanced recovery. For the sake of comparison to other state totals, we combined the percentage disposed into producing formations with the percentage injected for enhanced recovery (68%). The projected volume for the state for 2007 is 7,376,912,883 bbl (Deleon 2009). The total volume injected includes salt water, brackish water, and fresh water injection into Class II disposal wells. While a small amount of produced water was managed through tidal discharge, the vast majority of produced water generated in Texas was managed through injection. We assume the projected injected volume for 2007 (7,376,912,883 bbl) is comparable to the actual volume of produced water generated in Texas. Following the percentage allocation assumption described above, we considered 32% of the projected total (2,360,612,122 bbl) as the volume injected for disposal. We considered 68% of the projected total (5,016,300,761 bbl) as the volume for enhanced recovery.

5.28 Utah

The Utah Division of Oil, Gas, and Mining provided estimates according to data available as of December 2007 (Kierst 2008). 8,788 wells were operating in the state in 2007, with 3,022 wells producing crude oil. It was estimated that 4,401 wells were producing conventional gas, with the remaining 1,035 wells producing CBM. Crude oil production in 2007 was 19,519,964 bbl. Conventional gas production during the same period was 311,741 Mmcf, and 73,638 Mmcf of CBM was produced. While produced water volumes are not available according to hydrocarbon type, annual produced water generation for 2007 was 148,579,384 bbl.

The majority of produced water is managed through injection (Kierst 2009). There were 1,085 wells used for injection for enhanced recovery; the produced water (estimated to be 78,251,086 bbl) was comingled with makeup water. Ninety-three wells injected produced water for disposal; in 2007, these wells injected 60,157,307 bbl. Commercial disposal wells managed an additional 1,893,393 bbl of produced water, assuming no overlap in reporting. Utah also has 15 surface discharges in the Ashley Valley Field. The produced water generated in this field (21,079,950 bbl in 2007) serves local agriculture and eventually reaches the Green River. It is likely that much of the volume reported for evaporation ponds (7,773,128 bbl) overlapped the reporting by commercial evaporation ponds, which were estimated to manage 11,067,743 bbl. Drilling and workover operations managed 476,945 bbl of produced water. Onsite evaporative pits on federal lands were estimated to manage 218,239 bbl of produced water.

5.29 Virginia

Virginia requires produced water data to be reported for CBM operations only, and the Virginia Department of Mines, Minerals, and Energy (VA DMME) provided production information concerning CBM activities (Kent 2008). In 2007, 4,290 wells were producing 88,146.284 Mmcf

of CBM and 1,561,842 bbl of produced water (WGR: 17.7 bbl/Mmcf). Production information for oil, conventional gas, and coproduced gas for 2007 was obtained from available county production statistics (VA DMME undated). Total gas production in 2007 was 112,000 Mmcf, with 79% of that volume attributed to CBM activities. Conventional gas activities produced approximately 23,505.106 Mmcf of gas (VA DMME undated). Oil production volume in 2007 was 19,155 bbl (VA DMME undated). Virginia is beginning to collect data on produced water management strategies including injection for disposal and surface discharge of produced pit fluids, which should be available electronically in the future.

5.30 West Virginia

The West Virginia Office of Oil and Gas provided information on production activities and produced water management (Martin 2008). In 2007, there were 49,618 producing wells in West Virginia, with the majority of those wells (45,398) producing unconventional gas. The remaining wells produced crude oil (3,631) and CBM (589). Unconventional gas production for 2007 was 201,599 Mmcf, and CBM production was 22,974 Mmcf. During the same period, 679,239 bbl of crude oil were produced. Total produced water generation from these activities is not available.

While generation information is not available, produced water management information can provide an estimate for generation within the state. There were 709 injection wells that managed 3,942,370 bbl of produced water for enhanced recovery. An additional 69 injection wells disposed of produced water, although the total volume managed is not available. West Virginia managed 3,857,000 bbl of produced water from CBM activities through 100 permitted land applications, which allowed produced water of a certain quality to be dispersed on the ground. An additional 537,659 bbl of produced water was managed through offsite commercial disposal. While the total volume for disposal wells is unknown, the known volume of produced water in West Virginia in 2007 was at least 8,337,029 bbl.

5.31 Wyoming

The Wyoming Oil and Gas Conservation Commission provided historic information on produced water management from the Powder River Basin and qualitative information on reuse of produced water in the Big Horn Basin (Likwartz 2008). Specific information on production was obtained from statistics available on the commission's website (WOGCC undated). In 2007, 54,051,671 bbl of crude oil were produced. Total gas production reached 2,253,487.217 Mmcf, with 436,306.044 Mmcf of CBM. Production of oil and gas resulted in the generation of 2,355,671,186 bbl of produced water in 2007.

Information on historic trends that was provided for produced water management in the Powder River Basin indicate that since 1987, 4.784 billion bbl have been produced from coal beds. Approximately 54% has been discharged to ephemeral and perennial streams, 35% has been managed using off-channel pits, 5% has been reused for irrigation projects, 3% has been managed through injection, and 3% has been treated and then discharged into streams. Much of the produced water from conventional gas activities in the Big Horn Basin was also managed through agricultural reuse, although the actual volume is unknown.

Chapter 6 — Federal and Tribal Summary

This section provides detailed information on produced water associated with production activities on federal lands (onshore), federal offshore, and tribal lands. Federal onshore mineral leasing activities are managed by the U.S. Department of the Interior's Bureau of Land Management and the U.S. Department of Agriculture's Forest Service. The MMS manages the mineral resources (e.g., oil and gas) on the outer continental shelf. The Minerals Revenue Management Program (MRM), which is within MMS, is responsible for management of all revenues associated with mineral leases on federal onshore, federal offshore, and tribal lands. The information in this chapter was obtained from MMS.

6.1 Federal Onshore Production

Onshore production activities on federal lands are assumed to be included in the total production volumes provided by the state agencies. In 2007, oil and gas production on federal lands were 104,378,709 bbl and 2,889,060 Mmcf, respectively. These production volumes are included in the state summaries in the previous chapter. The volumes represented 8.2% of state oil production and 13.5% of state gas production. Produced water volumes from federal onshore production activities are part of the more than 20 billion barrels of produced water from state production totals and were not separately reported.

6.2 Federal Offshore Production

In the produced water generation and management information for federal offshore activities the MMS provided (Kazanis et al. 2009), the number of wells provided was actually the number of completion counts, as some wells had both oil (3,268) and gas completions (3,580). Oil produced from oil completions totaled 385,066,136 bbl and generated 399,820,418 bbl of produced water (WOR: 1.04 bbl/bbl). The volume of gas produced from gas completions was 2,179,348.290 Mmcf, which generated 187,532,428 bbl of produced water (WGR: 86.0 bbl/Mmcf). Total oil production from both oil and gas completions was 467,179,615 bbl. Total gas production in 2007 was 2,786,592.780 Mmcf. Produced water generated from all production activities was 587,352,846 bbl.

While some produced water generated from offshore activities was injected, the vast majority of produced water was managed through discharge. In 2007, injection for enhanced recovery managed 48,673,102 bbl and injection for disposal managed 1,298,417 bbl of produced water. The remaining produced water (537,381,327 bbl) was treated and then discharged.

6.3 Tribal Lands

Forty-two tribes are served by MRM, and MRM provides total annual production and revenue data for the tribes online. The production data and national average water-to-hydrocarbon ratios were used to estimate produced water generation on tribal lands. The following tribes are those that are included in the annual production summary:

- Alabama-Coushatta
- Arapahoe
- Assiniboine Sioux
- Blackfeet
- Caddo
- Cherokee
- Cheyenne-Arapaho
- Chickasaw
- Chilocco Indian School
- Chippewa-Cree
- Choctaw
- Colorado River
- Cook Inlet Region, Inc.
- Creek
- Crow
- Delaware
- Ft. Mohave
- Gila River Indian Community
- Hopi
- Jicarilla Apache
- Morongo Band Mission Indians
- Navajo
- Pala Band Mission Indians
- Pawnee
- Ponca
- Pueblo of San Ildefonso
- Pueblo of Sandia
- Pueblo of Zia
- Pyramid Lake Paiute
- Quechan
- Sac and Fox
- Salt River-Pima Maricopa
- Santa Ana Pueblo
- Seminole
- Shoshone
- Shoshone Bannock
- Soboba Band Mission Indians
- Southern Ute
- Tohono O'Odham
- Ute
- Ute Mountain Ute
- Wichita

MRM reports that in 2007 oil production was 9,512,652 bbl and gas production was 297,329 Mmcf. Location-specific production information was not obtained; therefore, the U.S. averages for WOR (7.57) and WGR (259.8) were used to estimate the produced water volume for tribal lands. Total produced water was estimated to be 145,109,593 bbl.

Chapter 7 — Findings and Conclusions

7.1 Findings

7.1.1 Produced Water Volume

This report provides a current estimate for the volume of produced water generated from oil and gas production in the United States. The volume estimate represents a compilation of data obtained from numerous state oil and gas agencies and several federal agencies for 2007, where possible. The total volume of produced water estimated for 2007 is about 21 billion bbl. This equals an average of 57.4 million bbl/day. Produced water is generated from most of the nearly 1 million actively producing oil and gas wells in the United States.

Not all states had readily available precise produced water volume figures. In a few states, the agencies had very complete data records easily obtainable from online sources. Other states had summary-level volume data without much detail or had data available only in in-house data repositories. The most challenging states were those that had no produced water data at all. In those cases, we calculated estimates through extrapolation and correlations using hydrocarbon production and produced water volumes from neighboring states.

Several states dominate the total produced water volume estimates. Texas, with more than 7.3 billion bbl, represented 35% of the national total. Other states with produced water volumes exceeding 1 billion bbl include California (12%), Wyoming (11%), Oklahoma (11%), Kansas (6%), and Louisiana (5%).

The greatest produced water contributors are not necessarily the greatest producers of oil and gas. While Texas was the largest gas producer in the United States (nearly 6,900,000 Mmcf in 2007), federal offshore production activities provided the largest volume of crude, more than 467,000,000 bbl. Although federal offshore production generated nearly 27% of U.S. crude oil production, less than 3% of total U.S. produced water was generated from federal offshore activities.

7.1.2 Produced Water Volume by Hydrocarbon Type

We asked the agencies to provide produced water volumes by hydrocarbon types (i.e., crude oil, conventional gas, coal bed methane, unconventional gas, or other), to the extent the data were available at that level of detail. Most states were unable to break out produced water volumes for all categories, but some states could at least provide estimates of produced water from oil production vs. natural gas production. States that segregated produced water by hydrocarbon categorized 6,666,144,270 bbl of produced water. Eighty-seven percent (5,770,327,439 bbl) of the produced water came from oil production activities.

It is useful to consider the WOR and WGR from production activities to evaluate the relative production age of resources within the production lifetime. We were able to calculate separate WORs and WGRs for several states that reported produced water separately by hydrocarbon type (WORs for 14 states and WGRs for 11 states).

For WORs, state values ranged from 2.5 bbl/bbl for South Dakota to 43 bbl/bbl for Illinois. The offshore ratio was even smaller at 1.04 bbl/bbl. A national average ratio, calculated using the production-weighted ratios from the 14 states, was 7.6 bbl/bbl. When offshore production was added to the onshore production, the total average U.S. WOR was 5.3 bbl/bbl.

For WGR ratios, the state values ranged from 0.04 bbl/Mmcf in South Dakota to more than 1,200 bbl/Mmcf for Kansas. The offshore ratio was 86 bbl/Mmcf. A national average ratio calculated using the production-weighted ratios from the 11 states was 260 bbl/Mmcf. When offshore production was added to the onshore production, the total average U.S. WGR was 182 bbl/Mmcf.

7.1.3 Produced Water Management Practices

This report describes the current (i.e., 2007) practices used by many oil and gas producers to manage produced water. Two general themes are followed by most U.S. operators. More than 98% of produced water from onshore wells is injected underground. Approximately 59% is injected into producing formations to maintain formation pressure and increase the output of production wells. Another 40% of produced water from onshore wells is injected into nonproducing formations for disposal.

Four percent of the total reported volume of produced water (onshore and offshore) managed in 2007 was managed through surface discharges. Alabama is noteworthy among states with onshore production because it managed about 65% of its produced water through surface discharge. Nearly all of the discharges came from CBM operations in the Black Warrior Basin. The remaining produced water volume was managed through evaporation ponds, offsite commercial disposal, beneficial reuse, and other management methods.

More than 91% of offshore produced water, including the water from inshore platforms in Cook Inlet, Alaska, was discharged to the ocean. Most of the remaining volume was reinjected for enhanced recovery.

One of the potentially valuable management practices for produced water is beneficial reuse. We attempted to obtain information on the volume of produced water reused and how the water was reused, but were unsuccessful at finding much information.

We had hoped to obtain produced water management information separately for each type of hydrocarbon production. Most states were either not able to provide that information or reported that the same practices were used regardless of the hydrocarbon type.

7.2 Conclusions

This report provides the most detailed and current information on the volume of produced water generated in the United States. Its 2007 estimate was derived in a more detailed and comprehensive manner than earlier national estimates developed for 1985, 1995, and 2002. The 2007 volume is the highest of those estimates, and should be a more representative estimate than the earlier ones because of the approach used to collect and extrapolate the data.

Information on management practices has not changed significantly from previous studies. However, confirmation of that fact is valuable, too. The majority of produced water is managed through injection with 59% of the onshore produced water volume being injected to increase production output.

A final important conclusion of this study is that there is no easy way to obtain national estimates of produced water generation. The estimates presented in this report took months of investigation, numerous contacts with oil and gas agency staff members, and extensive follow-up. Some states had useful produced water information either published in reports or readily available through state databases. However, many other states had only minimal information about produced water volumes or how the produced water was managed. No federal regulatory program requires agencies to track produced water volume. Consequently, when regulatory and data management resources are limited, some states do not maintain produced water information.

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Appendix A — Sample Letter

November 7, 2008

[Title]. [First Name] [Last Name]
State Oil and Gas Agency
123 State Street
City, State 12345

Dear [Title]. [Last Name]:

The U.S. Department of Energy (DOE) asked Argonne to compile data on two important water streams associated with oil and gas production – produced water and hydraulic fracturing (frac flowback) water. No recent national volume estimates of these water streams are available, nor do we have satisfactory information on how the water is managed after it is generated. Argonne plans to develop detailed national-level information on the volume of produced water generated in the United States and the ways in which it is disposed or reused. In a second study, Argonne will evaluate frac flowback water use and re-use to determine the sources of water used for fracturing and the methods used to manage the flowback water after it is returned to the surface.

We plan to collect data from various sources, but believe that the State oil and gas programs are the best place to begin. Your agency has long-term direct experience with oil and gas activities in your state. Further, most states already employ data management systems for tracking production data.

I know that you are very busy with your regular responsibilities, but I hope that you can designate a member of your staff to work with us to identify the types of relevant information that we can find from your existing files and databases. If necessary, we can send one of our project team members to your offices to review and compile data. We would like to begin these two projects during November. Please let me know whom we can contact in your agency to obtain the necessary data.

Although I am overseeing the projects, much of the work will be done by my colleague, Dr. Corrie Clark. You may contact either me (xxx-xxx-xxxx; xxx@anl.gov) or Dr. Clark (xxx-xxx-xxxx; xxx@anl.gov). Thank you in advance. We look forward to working with you.

Sincerely,

John A. Veil

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