Preface

The Ground Water Protection Council (GWPC) is the national association of state groundwater protection and underground injection control agencies. GWPC has served as a valuable forum for communication on oil and gas issues between state government, federal government, industry, academia, environmental advocacy groups, and other interested parties. The mission of the GWPC addresses “the protection of groundwater resources for all beneficial uses.” It covers all groundwater resources that are or may be used for beneficial purposes, including oil and gas produced water.

This report is part of an effort by the GWPC to promote consideration of appropriate beneficial reuses of produced water. While produced water is currently being used in applications both within and outside of oil and gas operations, many potential applications remain. Further research will be needed to assure that these potential applications are both suitable and safe.

As a direct byproduct of oil and gas production, produced water is a natural area of interest for GWPC, which places a strong emphasis on energy and water interactions. The process of regulation of underground injection of fluids (the Safe Drinking Water Act’s Underground Injection Control or UIC program) is one of GWPC’s major programmatic concerns.

Given its longstanding working relationship with federal agencies including the Environmental Protection Agency and Department of Energy, as well as with industry stakeholders and non-governmental organizations, GWPC is uniquely positioned to explore the current and future beneficial reuse of produced water. Recognizing that produced water has the potential to be an important contributor to water resources in the United States, the GWPC brought together scientists, regulatory officials, members of academia, the oil and gas industry, and environmental groups to explore roles produced water might play in developing greater water certainty. Their research has been synthesized in this report, which is designed to support policy makers, regulators, and the public in making informed decisions, driving additional research, and analyzing practical opportunities and challenges of beneficially reusing produced water.

This report considers produced water to be a “potential resource” rather than a “waste.” Although most produced water has never had any use before it is brought to the surface, the term “reuse” is commonly assigned to produced water that is or will be used for a beneficial purpose.

This report consists of three modules.

Module 1: Current Legal, Regulatory, and Operational Frameworks of Produced Water Management. This module focuses on the multifaceted regulation of produced water, including long established federal laws and programs as well as areas where additional regulatory clarity may be needed to further advance the beneficial use or reuse of produced water. It also discusses the legal and operational aspects of produced water reuse such as ownership, water rights, liability, and standard practices. These topics define the framework under which produced water reuse may be accomplished and the challenges limiting its current implementation as a water source.

Module 2: Produced Water Reuse in Unconventional Oil and Gas Operations. This module presents information on how produced water is used within oil and gas operations, with a focus on unconventional operations. Through literature reviews, interviews with oil and gas companies, and data requests, information has been gathered on the current state of oil and gas operational reuse of produced water and on future potential reuse options and dynamics.

Module 3: Produced Water Reuse and Research Needs Outside Oil and Gas Operations. The most forward-looking part of this report, this module looks at current and needed research to properly and safely use produced water in applications outside oil and gas operations. It also discusses the range of reuse options currently available along with potential reuse options that may one day become practical.
The GWPC hopes readers will find this report informative and useful. It offers a realistic assessment of the contribution produced water could make to the national water resource portfolio and state water planning efforts. This report offers a solid base for building upon and improving the knowledge and use of produced water. It is expected that ever-changing technology and statutory transformations will only further the use of produced water in the future.

**Leadership in Addressing Oil and Gas Water Management**

The Ground Water Protection Council has taken the lead role in oil and gas water management issues during recent years. Examples include:

- Creating the highly acclaimed Risk Based Data Management System (RBDMS), used by more than 24 state agencies to track oil and gas data
- Implementing the FracFocus system with its unique hydraulic fracturing chemical disclosure registry, developed in collaboration with the Interstate Oil and Gas Compact Commission (IOGCC)
- Conducting several annual national conferences on energy/water interactions
- Publishing the groundbreaking primer *Modern Shale Gas Development in the United States* (April 2009), prepared in conjunction with ALL Consulting for the U.S. Department of Energy and National Energy Technology Laboratory
- Organizing the first-of-its-kind national conference on stray gas issues in 2012
- Initiating discussions on induced seismicity related to hydraulic fracturing and disposal wells in 2013, leading to formation of an induced seismicity work group and publishing of the 2015 and updated 2017 primer on *Technical and Regulatory Considerations Informing Risk Management and Mitigation*
- Sponsoring a 2015 report on national produced water volumes and management practices.

For more information on these and other efforts, see the Groundwater Protection Council website at [www.gwpc.org](http://www.gwpc.org).

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**Recommended Citation**


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Introduction

Produced water, a byproduct of oil and gas production, is water in underground formations that is brought to the surface during oil and gas production. It is sometimes referred to as “brine” or “saltwater” within the industry, as it is typically saline to highly saline (Figure I-1).

<table>
<thead>
<tr>
<th>Water Quality</th>
<th>TDS (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>&lt;1,000</td>
</tr>
<tr>
<td>Slightly saline</td>
<td>1,000-3,000</td>
</tr>
<tr>
<td>Brackish</td>
<td>3,000-10,000</td>
</tr>
<tr>
<td>Saline</td>
<td>10,000-35,000</td>
</tr>
<tr>
<td>Highly saline</td>
<td>&gt;35,000</td>
</tr>
</tbody>
</table>

Figure I-1. Produced Water Quality
Source: After USGS and Compendium of Hydrogeology
Produced water salinities range from fresh to highly saline.

While most produced water is groundwater naturally occurring deep in the reservoir, it also can include water previously injected into the formation during well treatment or secondary recovery to increase oil and gas production, as well as residuals of any chemicals added during the production processes. A third source of produced water is “flowback water” that returns to the surface after a well is hydraulically fractured.

Produced water is classified as an “exempt” oil and gas waste stream, meaning it is not subject to the Subtitle C (hazardous waste) provisions of the Resource Conservation and Recovery Act (RCRA). Its management is subject to two key federal permitting programs—the National Pollutant Discharge Elimination System (NPDES) program and the Underground Injection Control (UIC) program—both of which are administered primarily at the state level.

Produced water is either disposed of as a wastewater or beneficially reused (Figure I-2). In cases where it is determined to be fit for a beneficial reuse, produced water then becomes a resource rather than a waste product. Over the past decade, interest has grown in increasing the beneficial reuse of produced water both inside the oil and gas industry and elsewhere, an approach that holds promise for making available a substantial volume of water that could potentially offset, or supplement, fresh water demands in some areas.

The GWPC anticipates that as states and regions look to become more water resilient, the role of produced water will expand. To encourage this expansion, this report compiles information regarding produced water and identifies areas of needed legal or regulatory action and where research needs exist to potentially increase the amount of produced water utilized. It is hoped that over time this report will be used to:

- Educate the public on produced water and how the oil and gas industry uses water
- Encourage the oil and gas industry, state and federal regulatory agencies, and other parties that gather data on produced water to make the data more readily available
- Inform new research in the chemical characterization of produced water
- Inform new research to determine appropriate quality objects for reuse of produced water
- Inform new research in the development and testing of technologies for the treatment of produced water
- Expand the use of produced water in a manner that is protective of the environment and public health.

What Is Driving the Discussion of Produced Water Reuse?
Several factors are driving the discussion about the reuse of produced water, including stress on fresh water resources, limitations on underground formation storage capacities and pressures, concerns about

Differing State Definitions of Fresh Water

Legal/regulatory definitions of fresh water differ by state. For example, the Pennsylvania Department of Environmental Protection defines fresh water as “Water in that portion of the generally recognized hydrologic cycle which occupies the pore spaces and fractures of saturated subsurface materials.” The Texas Water Development Board defines fresh groundwater as water with less than 1,000 mg/L of Total Dissolved Solids (TDS), while the Wyoming Oil and Gas Conservation Commission defines fresh water as “water currently being used as a drinking water source or having a total dissolved solids (TDS) concentration of less than 10,000 milligrams per liter (mg/l) and which can reasonably be expected to be used for domestic, agricultural, or livestock use; or is suitable for fish or aquatic life.”

Determining what is considered “fresh water” depends on the quality of the water, the state in which the water resides, and the use of the water. Since it is not possible to use a single definition for fresh water, the term “fresh water” in this report must be viewed within the context of the narrative in which it appears.

From a technical standpoint, “fresh water” is defined by both the U.S. Geological Survey (USGS) and the Compendium of Hydrogeology as water that contains less than 1,000 milligrams per liter of dissolved solids (TDS). The USGS goes on to note that “generally, more than 500 mg/L of TDS is undesirable for drinking and many industrial uses,” and the EPA has established a secondary drinking water standard of 500 mg/L TDS.

Fresh water stress is driven by rising populations and regional droughts, which have created challenges to meet demands for fresh water resources in some areas across the country. According to the U.S. Census Bureau, the U.S. population is expected to increase by more than 50 million between 2000 and 2020. Where surface water is scarce, communities and industries typically turn to groundwater to meet their freshwater needs. Currently, there are concerns about the amount of groundwater being used regionally and nationally. For example, as of 2015, storage in the

Figure 1-2. Fresh Water Withdrawals and Population Growth Estimates

Source: https://myweb.rollins.edu/jsiry/Waterbasics.html

This figure shows the total freshwater withdrawal divided by the available precipitation in different parts of the country. The anticipated percentage population increases in different regions is overlain on the map. Much of this growth is projected to occur in the already water-stressed areas of the Southwest. The 98th Meridian shown on the map illustrates an important distinction for the management of produced water.


High Plains aquifer was about 2.91 billion acre-feet or more. This represents a decline of about 273.2 million acre-feet, or 9 percent, since significant groundwater irrigation development began around 1950.\(^3\) On a national scale, approximately 1,000 cubic kilometers (km\(^3\)) of groundwater, or about 811 million acre-feet, were depleted between 1900 and 2008.\(^4\) Once depleted, this water is not easily or quickly recharged naturally.

**How Much Produced Water Is Generated?**
Currently, the volume of produced water is small compared to total U.S. daily water use, but these volumes can be locally significant.\(^5\) Based on the best available data from 2012, the nearly 1 million producing oil and gas wells in the United States generate approximately 21.2 billion barrels (bbl.) of produced water each year. Expressed in other units, this volume equals 58 million bbl./day, 890 billion gallons/year, 2.4 billion gallons/day, or 2.7 million acre-feet/year.

Produced water flow rate varies throughout the lifetime of an oil or gas well. Most unconventional hydraulically fractured wells show a high produced water flow rate initially as the flowback of fracturing fluids is occurring, followed by a decline in flow rate until it levels off at a relatively steady lower level.

Based on the best available data from 2012, the nearly 1 million producing oil and gas wells in the United States generate approximately 21.2 billion barrels of produced water each year.

Conventional oil and gas wells show little or no produced water initially, with the flow rate increasing over time. Total lifetime water production is typically higher for conventional wells than for unconventional wells.

Although this report does not include water production from coalbed methane wells, it is worth noting

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that initial water production from these wells can be quite substantial, tapering off as gas begins to flow into the wellbore.\textsuperscript{6}

\textbf{What Does Produced Water Contain?}

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. Because the water has been in contact with hydrocarbon-bearing formations for millennia, it generally contains some of the chemical characteristics of the formations and the hydrocarbons in those formations.

Produced water can contain many different constituents. In collecting data for its 2016 hydraulic fracturing study, the U.S. Environmental Protection Agency (EPA) found literature reports showing the detection of about 600 different chemicals in some produced water samples.\textsuperscript{7} Some of these chemicals are monitored routinely, while others may rarely be measured. Although hundreds of chemicals could be used as additives, only a limited number are routinely used in well treatment operations. While it is relatively easy to characterize some constituents in produced water, it is more difficult to characterize others, especially in highly saline matrices. Produced water characterization is an evolving science.

Produced water may contain:

- Mineral salts including cations and anions dissolved in water (often expressed as salinity, conductivity, or total dissolved solids [TDS])
- Organic compounds including volatile and semi-volatile organics, hydrocarbons, organic acids, waxes, and oils
- Inorganic metals and other inorganic constituents including compounds such as sulfate and ammonia
- Naturally-occurring radioactive material (NORM) that leached into the produced water from some formations or precipitated due to water mixing
- Chemical additives to improve drilling and production operations
- Transformational byproducts that can form from the interaction between added chemicals and formation water.

Another concern are constituents resulting from chemical reactions that can occur when produced water from one formation is introduced into a different formation. Additionally, naturally occurring elements, including metals, can leach out of the geologic formation into the produced water because of this change in the formation waters.

\textsuperscript{6} Cynthia Rice and Vito Nuccio, “Water Produced with Coalbed Methane,” USGS Fact Sheet FS-156-00 (November 2000), \url{https://pubs.usgs.gov/fs/fs-0156-00/fs-0156-00.pdf}.

\textsuperscript{7} USEPA, \textit{Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States, Main Report} (EPA/600/R-16/236Fa), \url{https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990}.
be troublesome when analyzing many constituents in produced water, since some traditional analytical methods do not work accurately in saline water. Further, adequate analytical methods may not exist for other chemicals that are not monitored frequently or are unknown at this time.

Produced water, especially from unconventional wells, will show varying concentrations of constituents over time. This consideration is important when designing treatment processes and in assessing the suitability of the produced water to be used or reused for a beneficial purpose.

**What Opportunities Exist for Beneficial Reuse?**
Currently, about 45 percent of produced water generated from onshore activities in the United States is reused within conventional oil and gas operations, where it is injected into formations to enhance recovery. Enhanced recovery techniques include injecting water or steam into the formation to maintain pressure and help sweep more oil to the production well (“water flooding” or “steam flooding”). Produced water is typically used for these operations, along with additional water.

Most of the remaining produced water, approximately 55 percent (488 billion gallons per year), is handled as a wastewater. Additional potential opportunities exist both within and outside of the oil and gas industry to make beneficial reuse of some of this water.

**Within the oil and gas industry**, operators and regulators are seeking ways to increase the beneficial reuse of produced water not only in enhanced recovery in conventional oil and gas operations, but also in well drilling and hydraulic fracturing operations in unconventional oil and gas production.

Several factors make beneficial reuse within the industry appealing in many cases. One major driver is a desire to minimize disposal of produced water. Disposal through underground injection is a costly operation that can be subject to capacity limitations. Underground injection may also create the potential for induced seismicity, which has resulted in further limitations on injection volumes and rates in some states. Disposal through discharge to surface water may be subject to volume limitations and entail costly treatment in a wastewater treatment facility or a centralized industrial wastewater treatment plant. There are also costs and risks associated with transportation of produced water. In contrast, beneficial reuse within the oil and gas operations eliminates or reduces treatment and some transportation of the produced water.

Another driver to consider is local water needs. Drought conditions in recent years have created serious water availability problems for some communities. For example, parts of the southeastern United States faced summer brown-outs due to inadequate cooling water for electrical generation, and numerous cities and towns, especially in California, Oklahoma, and Texas, have been forced to ration water. One possibility for dealing with fresh water shortages may be to supplement or replace fresh water use in unconventional oil and gas operations with produced water. (In contrast, disposal of produced water through deep injection can exacerbate water shortages since water is effectively removed from the ecosystem.)
Outside the oil and gas industry, produced water is used in a few limited applications such as livestock watering, stream augmentation, and irrigation of selected crops. Less than one percent of produced water is currently reused in such ways. Wider uses may also become practical and cost-effective with further research. As the volume of available fresh water continues to diminish, there is a growing need to reduce the use of freshwater for industrial, municipal, and agricultural activities, especially for consumptive uses that do not return water to usable water sources. Possibilities include applications in drought relief, fire protection, dust suppression, irrigation of additional crops, irrigation of public access areas such as golf courses and parks, industrial cooling or process water, mining, municipal water needs, and recreational uses.

Generally, beneficial reuse outside the oil and gas industry will be less economically attractive than reuse within the industry, since the produced water usually must be transported greater distances and treated more extensively. (See Module 3 for more information about reuse outside of oil and gas operations.)

**What Factors Determine the Feasibility of Beneficial Reuse?**

Because produced water resides at the surface, it makes sense to determine whether there is a cost-effective and environmentally friendly way to treat and reuse it instead of disposing of it by underground injection. Several factors determine whether and where beneficial reuse is feasible.
Water quality. The quality of produced water will determine its potential suitability for specific uses. A major water quality consideration is the feasibility and cost of treating the produced water to be fit for the intended purpose. In some cases, research may be necessary to define quality goals. Produced water from different sources varies greatly in quality and its reuse requires accurately characterizing the constituents and their concentrations in a specific produced water supply, identifying the health and environmental risks of their release, determining the standards of quality that must be met to make the produced water fit for purpose, and evaluating the costs, benefits, and risks entailed in achieving those standards. Management of treatment residuals is a major cost factor and can present a substantial barrier to water treatment based on its characteristics, volumes, and disposal options.

Water quality presents a lesser challenge for reuse within oil and gas operations, because this option presents limited exposure pathways, operators have a good understanding of quality needs or objectives, and there are reduced treatment requirements.

Water volumes and longevity. The amount of produced water and its long-term availability can affect the desirability of its reuse. While desirability may be high in an area with large amounts of produced water and limited alternate water supplies, that is not likely to be the case where produced water volumes are low, and supplies are unpredictable. Longevity of supply is especially important in making the case for beneficial reuse outside the oil and gas industry. For example, a typical production well may last from 20 to 30 years, while a typical coal fired power plant has a lifespan of 50 years or more. Unless the operator(s) can guarantee a quantity of deliverable water of a specific quality over the life of the power plant, it may not be advantageous for the power plant to use produced water as a source of supply unless a separate guaranteed backup source of supply can be arranged.

Logistics and infrastructure. Logistical and transportation costs may limit the potential reuse of produced water. Considerations include the availability of treatment facilities and the costs of transporting the produced water to the facilities as well as to the point of end use. Moving water can be expensive. Trucking costs for a typical trip from a tank battery to a salt water disposal (SWD) well can range from $1 to $3 per barrel. The cost of constructing permanent pipelines currently averages about $1.45 million per mile depending on pipe size, terrain, right of way costs, and other factors. The use of temporary pipe, sometimes

Currently, more than 90 percent of the produced water brought to the surface from the production of oil and gas is injected underground through Class II injection wells such as the one shown here to aid in future oil and gas production or for disposal.

FIT FOR PURPOSE

The level of treatment necessary when considering reuse of produced water depends on the quality needs for the intended use. Treatment is typically designed to be “fit for purpose.”

If salinity reduction or removal of other constituents of concern is needed to meet a regulatory standard (e.g., discharge to a river) or if the end use requires water with a specific set of parameters, advanced treatment may be necessary to meet those end goals.

If the produced water will be injected into a disposal well or back into a formation to produce more oil, less or possibly no treatment is needed. The main treatment goals are to remove any free oil or large solids to keep the injected water from blocking the pores in the formation or damaging the injection equipment and to remove any other constituents that may interfere with drilling or completion.

8 One barrel (bbl.) equals 42 gallons.
referred to as “lay flat pipe”, is less expensive than permanent pipe but comes with its own set of problems, including increased maintenance needs and higher leakage rates. Remote locations may require the use of modular treatment facilities where the logistics of transporting water to a centralized facility may be both difficult and cost prohibitive. The extent to which this affects beneficial use depends on the availability and cost of modular treatment, accessibility to the site, number of treatment units needed, maintenance needs of the treatment equipment, and other factors.

Market considerations. The economic attractiveness of beneficial reuse depends on whether the supply of produced water is predictable, if it can be delivered reliably to the point of use, and how the cost compares to other available sources of water after factoring in the costs of its treatment and transportation as well as the disposal of treatment residuals. If local water supplies of freshwater are adequate or abundant, there is less incentive to consider beneficial reuse of treated produced water, especially given its associated risks. Also, when other water sources, such as locally available brackish groundwater, can be delivered cost effectively, that may also depress reuse of produced water.

Legal and regulatory. These considerations include determining state water rights as well as applicable regulations. The determination of a specific beneficial use depends on federal and state jurisdiction, and the circumstances of each case. Another concern is the legal liability. In many cases, the lease holder, typically an oil and gas company, has the legal liability to properly treat, transport, and dispose of the produced water. However, if treated produced water is being used or reused outside of the oil and gas processing areas, there must be a clear understanding of the current and future liability and transfer point of liability.

What Are Future Implications for Water Planning?
Realizing the promise of increased beneficial reuse of produced water will not be a simple matter. It will require addressing substantial economic, technical, regulatory, and environmental challenges.

Given these complex factors, it would be unrealistic to suggest that all produced water can be put to beneficial reuse. Yet it is important for policymakers to recognize all the potential sources of water in an area to meet user needs. When considered as an integral part of water planning, treated produced water can be utilized to help relieve reliance on fresh water.

Based on the location, volume, and availability of fresh water, treated wastewater and produced water can, and likely will, play a larger role in future water supplies. However, until further research is completed, opportunities to reuse produced water more widely may be limited. Additional research on the characteristics of produced water in specific locations and evaluation of the environmental and health risks that could be associated with produced water use will be necessary to help inform both producers and potential end users of the possibilities for expanded produced water reuse.

In addition to research, challenges to be addressed range from defining regulatory frameworks to gaining public acceptance of produced water use in new applications. Presently, regulatory frameworks for overseeing beneficial use of produced water are not well developed. GWPC anticipates that as interest in beneficial use of produced water grows, agencies will develop new regulatory programs to authorize and manage those activities.

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10 Modified from “Produced Water Treatment and Beneficial Use Information Center” website, Colorado School of Mines / Advanced Water Technology Center, [http://aqwatec.mines.edu/produced_water/intro/what/index.htm](http://aqwatec.mines.edu/produced_water/intro/what/index.htm).
Why Isn't Coalbed Methane Produced Water Included in this Report? Water from coalbed methane production is not included in the report for several reasons:

- Because the volume of coalbed methane produced water falls off rapidly after initial production, it is not a reliable potential long-term source of water for reuse, except for hydraulic fracturing of other coalbed methane wells.
- Coalbed methane produced water is not covered by the oil and gas Effluent Limitation Guidelines (ELGs) promulgated at 40 CFR Part 435 and is frequently fresh enough to be considered for surface discharge with minimal treatment. Reuse can be logistically more difficult and costlier than such discharge.
- Contributions of produced water from coalbed methane would likely be statistically insignificant. Volumes of coalbed methane production continue to decline nationally and are small (< 3% annually) compared to natural gas production.

Studies on coalbed methane produced water are acknowledged in this report where relevant but are not extensively analyzed.