Produced Water Reuse - Current Drivers and Challenges

Technical, Economic, and Health and Safety Issues



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NEW MEXICO PRODUCED WATER RESEARCH CONSORTIUM

This report was written with a focus on the current issues and needs identified in several recent studies in New Mexico and regionally on the challenges associated with the treatment of produced water for fit-for-purpose reuse. It is intended to provide an overview of the emerging issues and drivers for the use of non-traditional water resources, such as produced water, in the context of local, state, and regional long-term water sustainability needs.

There are many waste water reuse applications - industrial, environmental, and municipal - that if utilized could reduce or replace the requirement for fresh water, thus increasing water sustainability and reducing overall fresh water stress. Many of the issues around the treatment and use of waste water, like oil and gas produced water, are not technical, but rather the challenge of applying innovative technologies and approaches in ways that meet state and national water quality requirements to protect public, environmental, and ecological health and safety.

This report provides a summary of the emerging national landscape and role of waste water reuse in future water resource management, and a review of several recent reports that have identified specific challenges and needs for treating produced water to support local and regional water supply resiliency and sustainability to support long-term economic development, without negatively impacting public and environmental health and safety. In this report we identify and compare the recommendations of these reports and highlight those common goals and areas of agreement of where major innovation is most needed.

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Technical, Economic, and Health and Safety Needs

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This report was prepared by the New Mexico Produced Water Research Consortium in support of the New Mexico Environment Department and the US Environmental Protection Agency's National Water Reuse Action Plan. The report provides background information on the current public, state, and federal technical, economic, and human and environmental health and safety issues and concerns associated with the reuse of treated produced water for fit-for-purpose uses outside the oil and gas sector. Those uses could include but are not limited to agricultural or rangeland applications, supplementing surface water flows, groundwater replenishment or recharge, or other industrial, commercial, or municipal applications.

The report highlights the national trend in the use of waste water, and current science, technology, and engineering needs and challenges identified in several recent produced water reuse studies that preclude more active produced water treatment and reuse. The challenges include technical, economic, and public and environmental safety issues that hinder the reuse of treated produced water to supplement local and regional resources and support more sustainable fresh water management. The common challenges identified include:

- Lack of water and energy infrastructure planning and development;
- Cost of collecting appropriate water quantity and quality data;
- Validated produced water pre-treatment/treatment cost and performance data;
- Lack of risk and toxicology standards for fit-for-purpose produced water reuse;
- Quantitative socio-economic, environmental, and ecological cost/benefit analysis for fit-for-purpose reuse;
- Lack of appropriate health and safety compliance monitoring standards among agencies;
- Lack of public education and outreach to address public reuse concerns.

ACKNOWLEDGEMENTS

The information presented is this document is summarized from:

- Background information on national and regional water availability challenges and trends to utilize treated waste water to supplement future fresh water resources;
- Discussions and input provided by members of the six Working Groups of the Technical Steering Committee and members of the Government Advisory Committee of the New Mexico Produced Water Research Consortium;
- Input from five Public Meetings on produced water reuse held from October through November 2019 across New Mexico by the New Mexico Environment Department with support from the New Mexico Produced Water Research Consortium; and
- Produced water research issues and needs reports including the;
    - Ground Water Protection Council, 2019,
    - US Environmental Protection Agency, 2020,
    - New Mexico State Energy Plan, 2018,
    - New Mexico State Water Plan, 2018, and the
    - New Mexico Desalination Association, 2018 “Produced Water Conference”.

The summary results presented in this report provide trends in fresh and waste water use and reuse, and a general ranking of the major challenges, issues, and concerns identified for fit-for-purpose treatment and reuse of produced water.

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ACRONYMS

ac/ft	acre feet (of water)
bbl	Barrels (42 gallons)
BGD	Billion gallons per day
CBM	Coal Bed Methane
DOE	Department of Energy
EMNRD	Energy Minerals and Natural Resources Department
EPA	Environmental Protection Agency
ETV	Environmental Technology Verification
FRTR	Federal Remediation Technology Roundtable
GAB	Government Advisory Board
ITRD	Innovative Technology Treatment Demonstration
MGD	Million gallons per day
MOU	Memorandum of Understanding
NMED	New Mexico Environment Department
NMPWRC	New Mexico Produced Water Research Consortium
NMSU	New Mexico State university
NORM	Naturally Occurring Radioactive Materials
OCD	Oil Conservation Division
O&M	Operation and Maintenance
PFD	Process Flow Diagram
QA/QC	Quality Assurance and Quality Control
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
TSC	Technical Steering Committee
USGS	United States Geological Survey
WRAP	Water Reuse Action Plan
WET	Whole Effluent Toxicity
WRRI	Water Resources Research Institute

1. The National Transition to Waste Water Reuse

This section discusses efforts by the Environmental Protection Agency (EPA) to establish a National Water Reuse Action Plan to drive the treatment and reuse of wastewater resources, including produced water, to supplement fresh water supplies in the U.S. This section includes an overview of the reasons why the EPA has implemented this national water reuse program and is driving wastewater treatment and reuse, and the role the treatment and reuse of waste water, including produced water, could play in improving the nation's sustainable water portfolio.

WHY THE EMPHASIS ON WASTEWATER REUSE? Climate change is decreasing rainfall and precipitation in many regions of the globe, which has also reduced fresh surface water availability and the recharge of fresh groundwater. At the same time, the increase in temperatures due to climate change has increased the need and use of fresh water to sustain economic development and public health. These challenges are driving many countries to significantly expand water resource availability by identifying new sources of water to meet growing public, agricultural, industrial, and environmental water demands.

Concerns over water availability are highlighted in Figure1, which shows limits of fresh surface water supplies in the U.S., and Figure 2, which shows current challenges with the unsustainable use of fresh groundwater resources in major aquifers across the U.S. (Hightower, 2017).

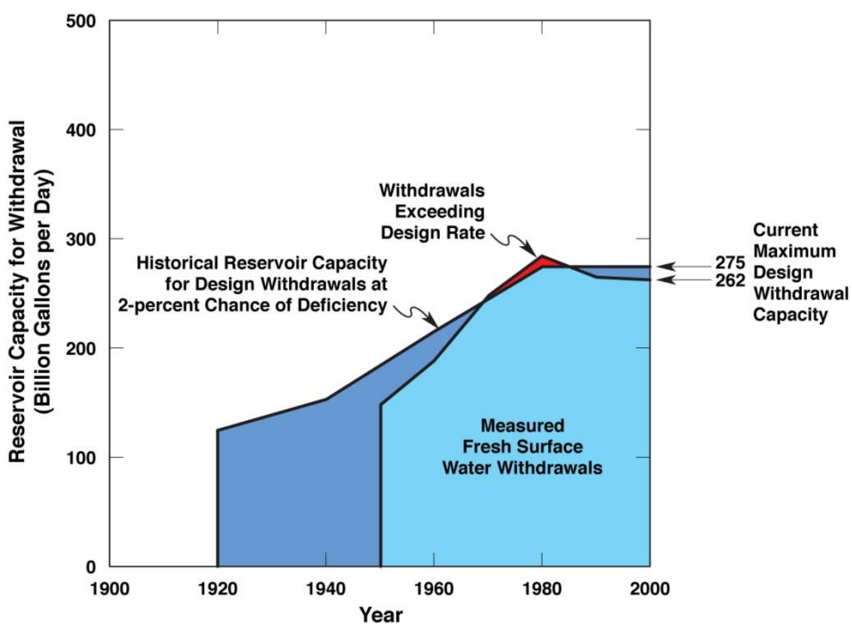


Figure 1. **U.S. reservoir withdrawal capacity and water withdrawals**.

As shown below in Figure 11, the Southwest, including New Mexico, is one of the most significantly impacted and water stressed ground water supply regions in the U.S. Unsustainable ground water pumping across the Southwest, especially in Texas, Kansas, Colorado, Arizona, and California has led to significant reduction in water availability, the drying-up of water wells, and tens of feet of ground level subsidence resulting in major impacts on road and infrastructure damage.

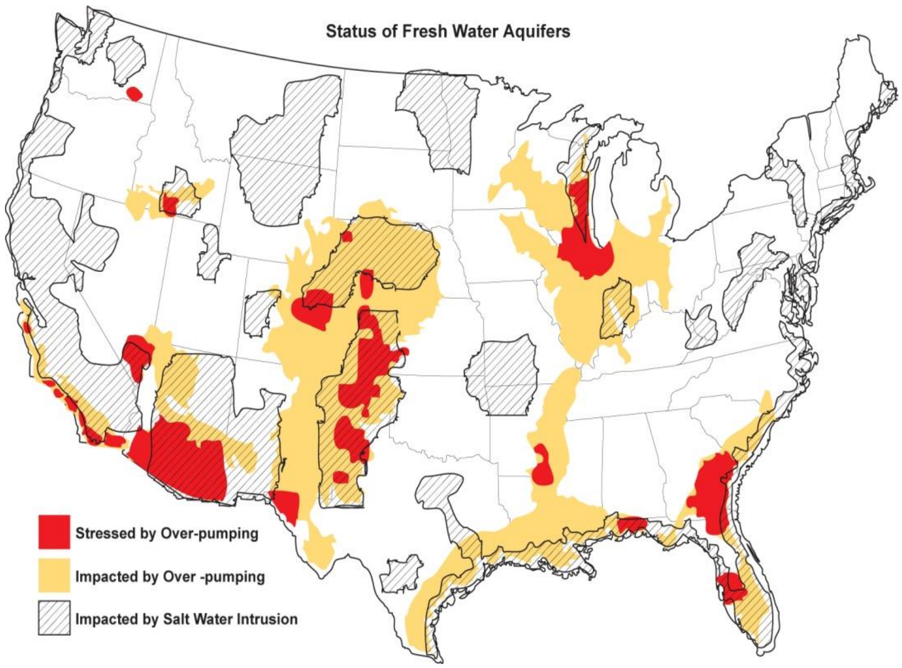


Figure 2. U.S. ground water aquifer over pumping.

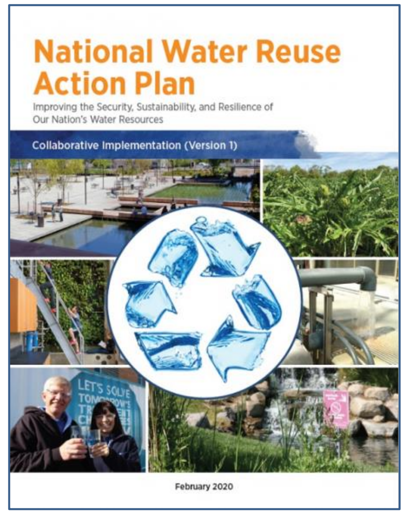
Identifying new water supplies has become both a regional and global problem. To address water shortages, many countries are moving to a 'One Water' approach, recognizing that water sources that were once thought to be unfit for consumption (e.g., treated wastewater, urban runoff, agricultural runoff, produced water) can often be made safe for use with appropriate, cost-effective treatment.

THE NEW NATIONAL WASTEWATER REUSE PROGRAM. In February 2020, the EPA inaugurated a new initiative called the National Water Reuse Action Plan (WRAP). This initiative was established following a year-long study by the EPA to evaluate fresh water supply issues and water stress in the U.S. and around the globe. As part of that effort, the EPA evaluated national and global trends in fresh water supply availability and fresh water stress, and found the disturbing trends and emerging challenges highlighted in Figures 1 and 2 above.

For example, the EPA study highlighted a 2014 Government Accounting Office (GAO) report on fresh water availability and stress in the U.S. The GAO report highlighted that,

> *"Within the next 10 years, 40 out of 50 state water managers expect to face freshwater shortages in their states. In certain situations, water conservation and efficiency measures may not be enough to meet anticipated increases in demand."*

This GAO report was the first U.S. report to highlight that the growth in water use demands might not be met with only water conservation and efficiency measures.



After holding more than 20 forums with over 2,300 participants and reviewing over 150 technical documents and information from 15 countries during 2019, the EPA identified that,

> *"Water managers and users are increasingly evaluating reuse options to help diversify and extend their supplies - two of the United Nations' Sustainable Development Goals identify water reuse as key to a more sustainable future,"*

Based on these results and feedback, the EPA chose to establish a national program to identify and develop innovative and cost-effective approaches for wastewater reuse to address these emerging fresh water supply stress and shortages.

As shown in Figure 3, the National Water Reuse Action Plan developed focuses on wastewater reuse in five major industrial and municipal sectors including;

- municipal wastewater,
- agricultural wastewater,
- industrial wastewater,
- oil and gas produced water, and
- storm water.

Figure 3 also shows the potential water reuse quantities available by sector to supplement regional fresh water supplies in terms of billion gallons of water per day (BGD).

As defined in the WRAP, EPA's future roles in U.S. wastewater reuse will be to:

1. Share sector-specific information and build awareness of the benefits of reuse and encourage stakeholders not yet engaged in reuse to consider options for implementation;
2. Establish a national framework for reuse water quality, dictated by the source and end use to promote reuse technology development;
3. Help states educate the public on a 'One Water' approach that recognizes that water sources that were once thought to be unfit for consumption (e.g., treated wastewater,

urban runoff, agricultural runoff, produced water) can often be used with appropriate, cost-effective treatment; and

4. Provide federal leadership to assure that sound, science-based, decisions prepare the U.S. for successful utilization of all alternate water sources.

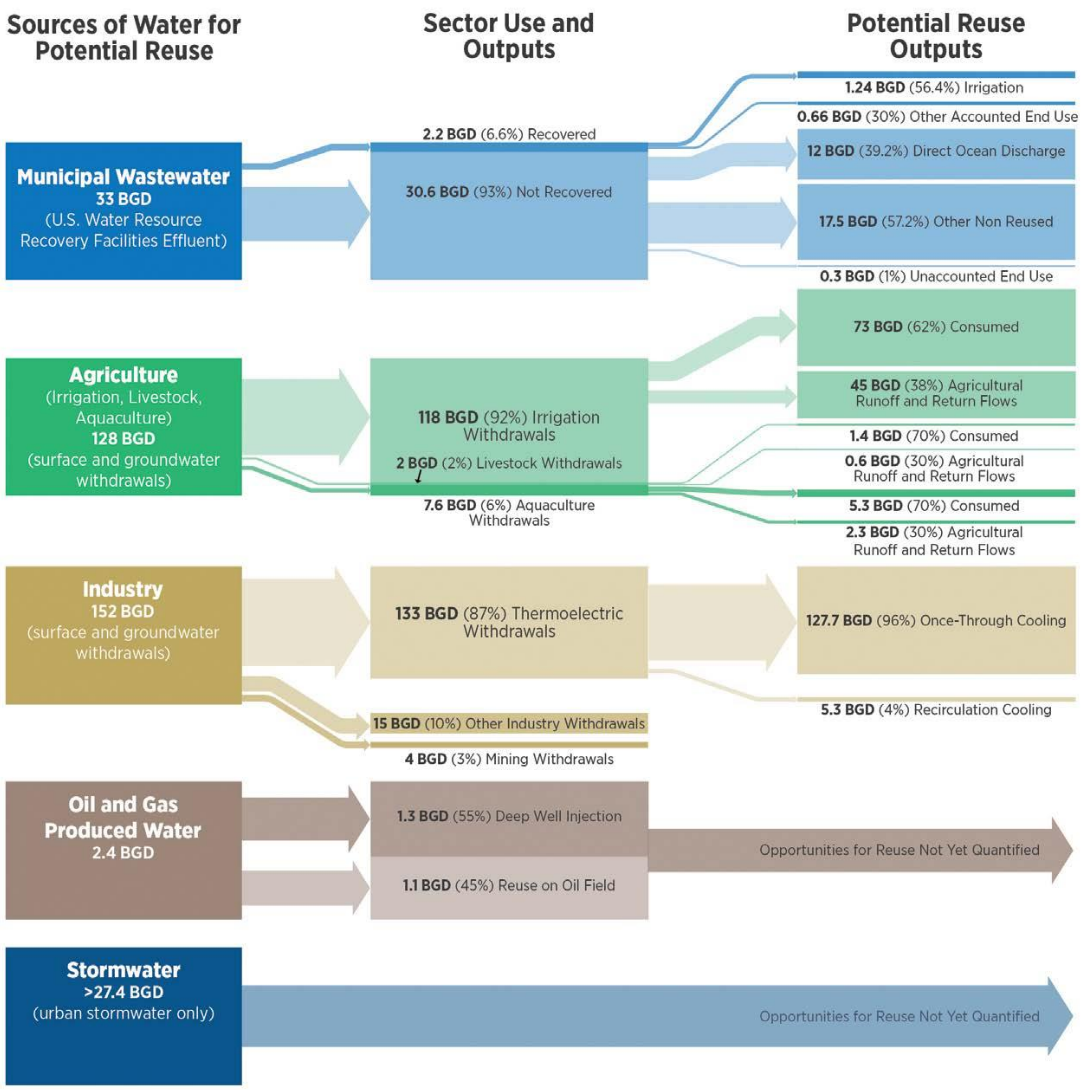


Figure 3. EPA priority wastewater reuse sectors (EPA, 2019 draft).

2. Produced Water Reuse Opportunities and Challenges

While produced water is one of the five major waste water reuse categories highlighted by the EPA in their WRAP, it is one of the smaller wastewater reuse categories. This is because oil and gas production does not occur in every state but can be significant in others. For example, if you look at the produced water generated by state, New Mexico is one of the states with the largest production of oil and gas produced water, and therefore produced water reuse could be a significant percentage of a state's total water resources, especially in Western states with limited fresh surface and ground water. While there are opportunities for produced water reuse applications both within and outside the oil and gas sector, many states, including New Mexico, do not have the environmental nor the human health standards, regulations, or policies to permit produced water reuse for applications outside of the oil and gas sector.

WHAT IS PRODUCED WATER? Oil and gas production commonly co-produces large volumes of water, approximately 4 - 10 barrels of produced water for every barrel (42 gallons per barrel) of oil produced. This varies by formation and basin across the U.S. Historically in New Mexico, about 10 barrels of produced water was generated for every barrel of oil, but that value started dropping in about 2010 and currently averages about 4 barrels of water for every barrel of oil.

Oil and gas co-produced water, or 'produced water', is defined by the US Environmental Protection Agency (EPA) (EPA, 2020) as:

> *"Produced water is the fluid (often called brine) brought up from the hydrocarbon bearing strata during the extraction of oil and gas and includes, where present, formation water, injection water, and any chemicals added downhole or during drilling, production, or maintenance processes."*
>
> *Brine – is a water with a salinity greater than sea water (>35,000 mg/L total dissolved solids (TDS)*
>
> *Formation water – is naturally occurring water in the geologic formation*
>
> *Injection water – is water and chemical additives used in hydraulic fracturing to enhance production.*

Produced water therefore includes all the water and chemicals pumped to the surface from an oil or gas well. As shown in Figure 4, oil and gas production occurs in many regions of the U.S., and as many as 21 billion barrels (bbls) of produced water are generated each year. Approximately 80% of the produced water is generated in the Western U.S., including the Permian and Delaware Basins in far West Texas and southeastern New Mexico and the San Juan Basin in northwestern New Mexico (Dahm, 2014).

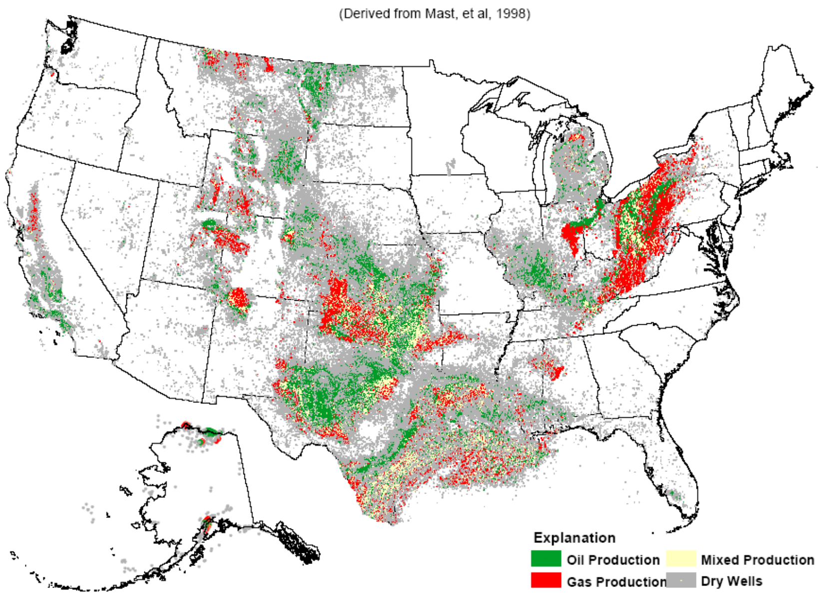


Figure 4. U.S. Oil and Gas and Produced Water Production Areas (USGS, 2006)

The volume of produced water has increased significantly over the past two decades with the introduction and use of non-conventional oil and gas drilling and production operations supported by the use of horizontal drilling and hydraulic fracturing. In 2019, New Mexico became the third largest producer of oil in the U.S., and topped 1 million barrels per day in oil produced. This equated to over 1 billion barrels of produced water generated in 2019. Over half of that was disposed of through deep well injection. That means that over 550 million barrels of produced water that are currently reinjected for disposal could be available for reuse, which is more than 60 million gallons per day. This is equivalent to the amount of water Albuquerque consumes each day. Therefore, the potential water resource availability for economic development in utilizing treated produced water is substantial. Some industry projections suggest that over 150 million gallons per day of produced water could be generated in New Mexico by 2022.

As shown in Figure 5, produced water commonly contains high levels of dissolved minerals such as salts, naturally-occurring radioactive minerals (NORM), trace heavy metals and rare earth compounds; as well as trace levels of organics, petroleum hydrocarbons, and drilling and fracking chemicals. Produced water can have as many as 200-300 different chemical constituents dissolved in the water. Some produced waters, such as from coal bed methane (CBM) production from shallower depths, have significantly less salinity as well as less organic and inorganic constituents.

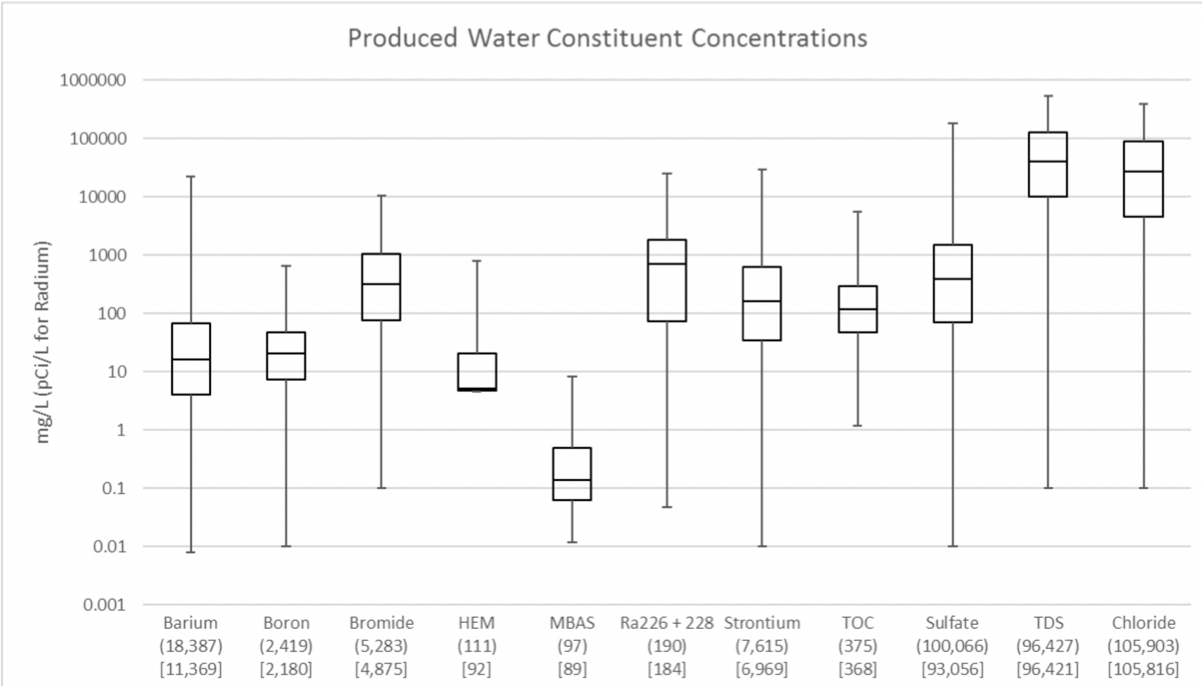


Figure 5. Example of produced water constituent concentrations (EPA, 2020).

WHAT IS FIT-FOR-PURPOSE REUSE? Because of the often high mineral and organic levels in most produced waters, some level of treatment – including moderate to high levels of pre-treatment, desalination, distillation, and post-treatment – are required for the safe reuse of produced waters outside the oil and gas sector (Watson et al., 2003). Fit-for-purpose reuse is treatment of produced water to meet the specific water quality requirements for various reuse options including but not limited to;

- Industrial – manufacturing, cooling water augmentation, industrial feed stock, mineral recovery, energy applications
- Agriculture – food and non-food crops, livestock and diary applications, soil and feed amendments,
- Environmental - habitat augmentation and restoration
- Source water – ground water aquifer storage, surface water augmentation, and
- Construction – road construction and maintenance, industrial construction, dust control.

Table 1 shows the general range of produced water quality and quantity requirements in terms of salinity and other constituents like sodium (Na), boron (B), (NORM), metals, organics and synthetic organics compounds (TOC) for representative reuse options outside the oil and gas sector. The salinity values are based predominately on published requirements and limits currently used by industry for the example applications noted (Clark et al., 1971)(Israelsen and Hansen, 1962)(Linsley and Franzini, 1972). Also provided are the different salinity ranges of common produced water in New Mexico. Produced water treatment and reuse inside the oil and gas sector for drilling and fracking often require lower quality water, making reuse less complicated and often only requiring pretreatment.

Table 1. Example of produced water reuse applications and constituents of concern.

Produced Water Quality (ppm) TDS	Application	Acceptable TDS Concentrations (ppm)	Nominal Water Quantity Needed	Other Produced Water Constituents of Concern
Coal Seam **2000- 20,000**	Industrial	1000-3000	1-2 million gal/day per plant	NORM, TOC, metals
Conventional **10,000 to 50,000** **50%<35,000** **50%>35,000**	Drinking Water	500-1000	1-2 million gal/day per plant	NORM, TOC, bromide, metals, disinfection byproducts
	Aquifer Storage & Recovery	300-5,000	1-2 million gal/day per plant	NORM, TOC, disinfection byproducts
Unconventional **100,000 to 300,000** **25%<100,000**	Agriculture and livestock	Class 1 <700, <60% Na, B<0.5 Class 2 2000, <60-75% Na, B<2.0 Class 3 >2000, <75% Na, B~2	18-36 inches/yr/acre	NORM, boron, metals, sulfates, sodium/calcium ratio, synthetic organics
	Rangeland	2,000 – 10,000	4-6 inches/yr/acre	NORM, boron, sodium/calcium ratio, synthetic organics
	Surface Flow Augmentation	Dependent on applicable water quality standards for receiving waterbody	2-5 million gal/day	NORM, TOC, metals, disinfection byproducts
	Mineral Recovery	>100,000	5 million gal/day	TOC, NORM
	Road construction/ maintenance	30,000 – 100,000	1 gal/yd/application, 2-3 applications/yr	NORM, metals

In the past decade, oil and gas production companies have moved extensively to horizontal drilling and hydraulic fracturing to increase oil and natural gas production, which has made the U.S. one of the leading oil and gas producers in the world. Originally, most fracturing was done with fresh water, which put significant demands on fresh water supplies across the U.S. Recently, companies have developed approaches to treat and reuse produced water for fracturing, which is leading to a significant reduction in fresh water use. Based on interviews with some producers, many are doing over 75% of their hydraulic fracturing with treated produced water, with the intent to go to the use of recycled produced water in more than 90 % of their drilling and production operations. This trend in the reuse of produced water inside the oil and gas sector will significantly reduce demands on fresh water resources.

In many of these regions the volumes of produced water being generated by fracking is increasing steadily, and making produced water a significant percentage of local fresh water use. This is highlighted in Figure 6 where fresh water use in Eddy and Lea counties in SE New Mexico is compared to the amount of produced water currently generated in these counties. While agriculture is the largest user of fresh water, given sufficient treatment, produced water could provide up to 25% of the total daily water need in these counties. Therefore, the quantities of produced water being generated in some basins are large-enough to be considered for water supply augmentation, especially in the western U.S.

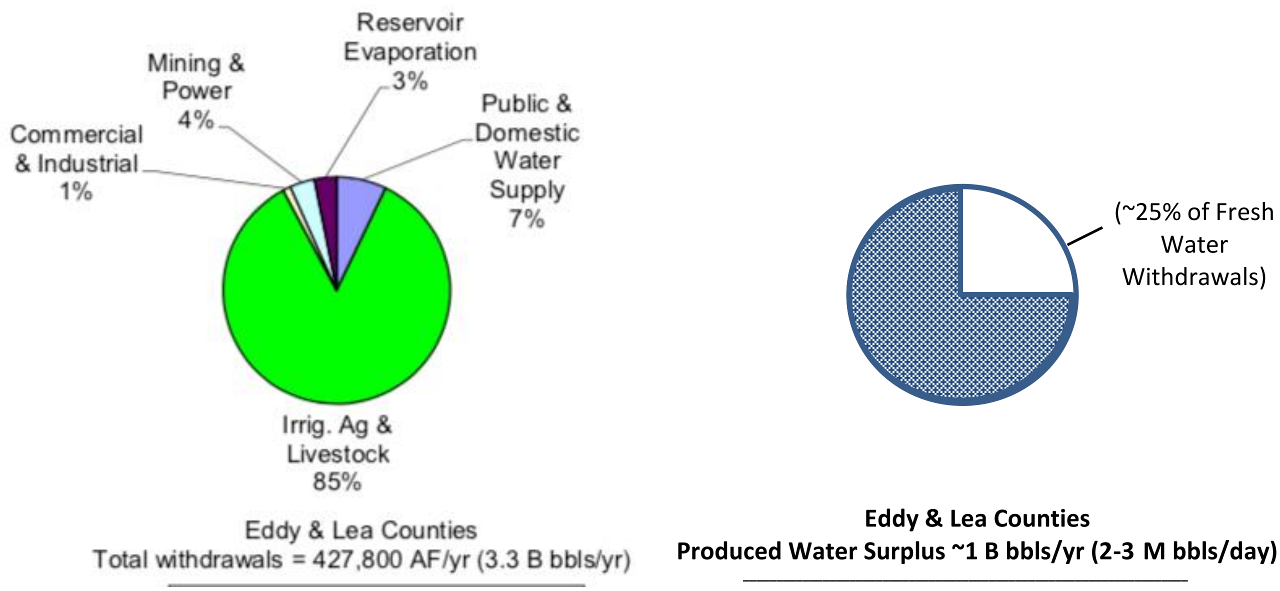


Figure 6. Local water Demands vs. Produced Water Availability in New Mexico

CURRENT NATIONAL PRODUCED WATER REUSE. Currently, discharge of oil and gas produced water following treatment to surface waters is only occurring in a few limited areas of the country. Produced water discharges west of the 98th meridian for agriculture and wildlife propagation are allowed, but are occurring primarily in Wyoming and California with relatively high-quality produced water of extremely low salinity. In California, low salinity produced water has been treated and blended with fresh water in the Central Valley for almost 30 years for irrigation of a number of crops including almonds and vegetables.

Several states, including Texas have conducted experiments with the treatment of produced water for use on non-food crops including cotton. While small pilot testing of the use of treated produced water for rangeland applications were successful in eastern New Mexico in 2004 and in northwestern New Mexico in 2005-2008, neither project moved to full-scale application due to costs (NRCE, 2004).

Arkansas has permitted the use of produced water in a landfarming applications (which is the spreading of produced water on land without treatment allowing the produced water to be absorbed naturally) with damaging results to the local ecology and has since stopped this practice. Currently Arkansas will permit produced water discharges only if they are treated to meet applicable standards for the receiving waterbody pursuant to a Clean Water Act National Pollutant Discharge Elimination System (NPDES) permit.

Treatment and discharge of produced water to surface waters via Centralized Water Treatment (CWT) facilities are occurring primarily in the Marcellus and Utica shale areas of Pennsylvania, Ohio and West Virginia. These produced waters receive varying levels of treatment, ranging from physical/chemical treatment to advanced treatment utilizing membranes or distillation. Discharges from CWT facilities in these states are governed under specific, state-issued, NPDES permits.

The most common approach for the treatment and reuse of produced water for applications outside the oil and gas sector is for a state to identify specific target levels of some major produced water constituents through the NPDES process. Through our review, we found that most states have limited standards for discharge that only address some of the common hazardous constituents in produced water such as boron, sodium adsorption ratios, naturally occurring radioactive materials (NORM), major petroleum hydrocarbon constituents such as benzene, toluene, and xylene, or synthetic organic compounds.

The fate, transport, and bioaccumulation of these potentially harmful constituents are some of the major public health and safety concerns and challenges that must be addressed through research and testing to ensure that the quality of treated produced water is protective of public and environmental health and safety for each future fit-for-purpose application.

2. History of Produced Water Reuse Efforts in New Mexico

All along highways throughout New Mexico signs exclaiming, ‘Watch for Water’. While the signs are to warn motorists about the potential for flash flooding, they also leave many motorists thinking, “Really, I have driven over a hundred miles and haven’t even seen any water yet!” In the arid Southwest, water is a treasure, literally.

In New Mexico we have looked at almost every possible non-traditional water source as a potential new water supply. These options include; brackish groundwater; imported fresh water; weather modification and cloud seeding to increase snowfall and rainfall; oil and gas produced water; mining waste water and dewatering reuse; geothermal water; dehumidification of atmospheric water; treated municipal waste water; and industrial waste water from power plants, manufacturing, semiconductor plants, and dairies. We’re in the mindset of ‘Watching for Water’ every day. This discussion highlights the evolution of efforts to reuse produced water in New Mexico over the past six decades.

NEW MEXICO EXPERIENCE IN USING PRODUCED WATER. New Mexico has almost 90 years of oil and gas development and the associated handling of produced water in oil and gas operations. In the early 1930s and 1940s, produced water was often placed on the hundreds of miles of dirt roads in New Mexico for dust control and roadbed maintenance. The salts and oils in the produced water mixed with the soil to improve overall roadbed durability. By the 1950s much of the produced water was injected in saltwater disposal wells or used in water floods to enhance oil recovery in conventional oil reservoirs. Produced water continued to be used for oil field road and drill pad construction and maintenance into the 1980s. In these early applications, the salinity of the produced water was often in the 30,000 ppm TDS range. This is much lower than many of the current produced water qualities of over 100,000 ppm TDS from unconventional wells.

By the early 2000s, three new developments occurred which intensified a focus on produced water reuse. These included 1) the maturation of salt water desalination technology that had significantly reduced the cost of desalination since the 1960s, 2) the emergence of Coal Bed Methane (CBM) natural gas production, where produced water was of significantly higher quality, and 3) one of the most severe and longest droughts in the western U.S. since the 1930s and 1950s beginning in 2000. More recently, the volumes of produced water being generated have increased significantly since 2010 due to horizontal drilling and hydraulic fracturing, and developing options to treat and reuse these larger volumes of produced water rather than dispose of it downhole are of more interest. The current advantages of produced water reuse are the potential to reduce increasing seismic activity caused by increasing deep well injection, addressing the ever diminishing disposal capacity and the increasing cost of disposal of produced water, and the possibility to make treated produced water available for economic development and provide alternate supplies of water to address continued long-term drought and aridity conditions due to climate change.

In 2002, Governor Richardson commissioned a White Paper on desalination opportunities in New Mexico, designed to identify opportunities for the treatment and use of non-traditional water resources such as brackish groundwater, produced water, and wastewater reuse that could benefit from the use of desalination technologies. The White Paper report identified major improvements in the treatment cost and performance of brackish water desalination that were occurring, and that desalination was posed to become a more economical solution to provide new water supply options for New Mexico.

In 2003, over 140 participants attended a Produced Water Reuse Workshop coordinated by the NM Water Resources Research Institute (WRRI) and held at the New Mexico Junior College in Hobbs. It included presentations on desalination research, and eight different produced water reuse pilot projects by groups such as Reed &Stevens, Yates Petroleum, Devon Energy, Chevron, Conoco, Sandia and Los Alamos National Laboratories, and the NM Tech Petroleum Recovery Research Center (WRRI 2003).

From 2004-2015, a number of pilot projects were initiated across New Mexico, funded by industry and the Department of Energy looking at treating and using produced water for a range of potential applications including: surface water augmentation for the Pecos River, algal biofuels production, beer brewing, grassland irrigation in SE New Mexico, rangeland rehabilitation in NW New Mexico, and agricultural and grassland irrigation in NE New Mexico.

RECENT NEW MEXICO INITIATIVES IN PRODUCED WATER REUSE. As the 2000 drought continued into 2015, the NM Energy Minerals and Natural Resources Department (EMNRD) established a working group to streamline the regulatory environment to facilitate produced water reuse outside the oil and gas sector. This led to a Memorandum of Understanding (MOU) between the US EPA and NM to explore produced water reuse options in 2018. In 2018, the NM Desal Association also conducted a workshop for EMNRD on Produced Water Reuse. With over 160 attendees, one of the main findings of the workshop was to “pursue a cooperative treatment technology evaluation program” between industry and the State of New Mexico and federal natural resource management agencies.

In 2018, the Energy Minerals and Natural Resources Department developed an Energy Roadmap for New Mexico that included several goals and recommendations on efforts needed to facilitate the reuse of produced water outside the oil and gas sector (EMNRD 2018). Also in 2018 the Office of the State Engineer developed an updated New Mexico State Water Plan. Part II - Technical Report of that plan included a number of recommendations from regional planning committees on the regulation and reuse of waste water and issues to address or enable the reuse of produced water (OSE, 2018).

THE 2019 NEW MEXICO PRODUCED WATER ACT. Ultimately, in 2019 the New Mexico State Legislature passed the New Mexico Produced Water Act. In the Act the New Mexico Environment Department (NMED) was given the responsibility for statutory and regulatory authority for the reuse of produced waster for fit-for-purpose applications outside the oil and gas sector. The act gave the NMED the responsibility to develop regulations and policies to govern the reuse of produced water outside the oil and gas sector in order to, 1) enhance fresh water supplies and fresh water sustainability, 2) reduce and eliminate the use of fresh water in the oil and gas sector, 3) support new economic development, 4) improve ecological habitat recovery and diversity, all while maintaining public and environmental health and safety.

To help establish and conduct the research and development efforts needed to accomplish the above goals, the NMED initiated a Memorandum of Understanding (MOU) with New Mexico State University to create the New Mexico Produced Water Research Consortium (NMPWRC or Consortium) to lead a collaborative technical forum of government, industry, and academia, to identify and establish a research and development program to identify and address existing science and technology challenges associated with the treatment and reuse of produced water for specific fit-for-purpose uses outside the oil and gas sector.

The Consortium was also tasked to support NMED in developing science-based regulations and policies to facilitate treated produced water reuse that would be protective of public, environmental, and ecological health and safety. To accomplish these objectives, the Consortium developed an operational framework and structure to support a broad science and technology research, development and testing program to address the technical, cost, and ecological risks of the fit-for-purpose reuse of treated produced water outside the oil and gas industry.

3. Identification of Produced Water Reuse Issues and Needs

As noted in Chapter 2, fit-for-purpose produced water reuse both inside and outside the oil and gas sector, while being practiced in a few states, still has significant challenges. As noted in the EPA WRAP, several recent studies in New Mexico, an oil and gas industry and state regulatory agency study by the Ground Water Protection Council (GWPC) , and a recent 2020 national study by the EPA have all identified major science, technology, and regulatory challenges related to wide-spread treatment and safe reuse of produced water for applications outside the oil and gas sector.

In this section, we highlight the issues and challenges identified in several recent studies by state and federal water, energy, and environmental agencies, and industry. In all cases, the results highlight suggested research needs that need to be addressed in order to reduce fresh water use in the oil and gas sector, improve current fresh water supply sustainability, and enhance local and regional economic development opportunities.

The reports reviewed and the identified needs summarized include:

1) The **2018 New Mexico Energy Roadmap**, developed by the New Mexico Energy Minerals and Natural Resources Department (EMNRD) that included several goals and recommendations on efforts needed to facilitate the reuse of produced water outside the oil and gas sector. (EMNRD 2018);
2) The **2018 New Mexico State Water Plan - Part II** - Technical Report, developed by the New Mexico Office of the State Engineer included a number of recommendations from regional planning committees to the State Engineer on the regulation and reuse of waste water and issues to address to enable the reuse of produced water (OSE, 2018);
3) A **November 2018 Produced Water Conference Report** - by the New Mexico Desalination Association, the New Mexico Petroleum Recovery Research Center at New Mexico Tech, and EMNRD that included suggestion on the policy, regulatory, economic, and infrastructure research and development needed to support produced water reuse and produced water mineral and water recovery (NM Desal 2019);
4) The **2019 Ground Water Protection Council (GWPC) Produced Water Report -** of state and regulatory agency and public and industry input on the current technical, regulatory, and policy issues facing enhanced use of treated produced water for reuse (GWPC 2019);
5) A **2019 NMED Summary Public Meeting Report** on stakeholder input at five public meetings in New Mexico in 2019 to collect public comments, thoughts, and concerns and the priority research needs for the treatment and reuse of produced water outside the oil and gas sector (NMED 2020), and

6) A **May 2020 EPA Report** on stakeholder thoughts on oil and gas produced water waste management practices, concerns, challenges, and research and development priorities (EPA 2020).

A summary of the basic research and development needs identified in these roadmaps, reports, and workshops are presented below.

2018 NEW MEXICO ENERGY ROADMAP. Goal 3 of the 2018 New Mexico Energy Roadmap addresses procued water and efforts identified focus on efforts needed to establish a profitable produced water reuse market by 2025. To accomplish this goal, the Roadmap identified five major areas of research and development that would be needed. These were:

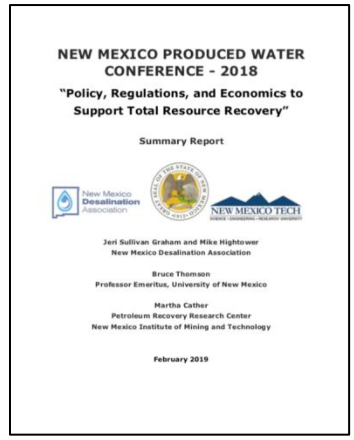
- Clarify ownership of and reporting requirements for produced water;
- Revise rulings to allow uses outside of the oil field;
- Provide support to NMED/ OCD with transparent produced water data;
- Develop a financial model that benefits the state; and
- Educate state leaders on best practices used by industry to safely move produced water.

2018 NEW MEXICO STATE WATER PLAN. The recommendations from the 2018 New Mexico State Water Plan for produced water included comments on how to improve the market for produced water reuse and how to provide incentives for the use of produced water. Priorities were:

- Include wastewater planning and reuse as part of future regional water planning efforts;
- Support policies that promote water reuse and efforts to advance treatment technologies (by reducing treatment costs);
- Modify NMED Regulations - current water quality standards are too stringent, making reuse difficult and expensive for use in injection for underground storage, discharge to the Pecos River, or for direct reuse;
- Explore alternative and non-traditional water sources to identify new supplies through aquifer mapping and exploratory drilling; and
- Develop policies for oil and gas development that protect water quality.

2018 NM PRODUCED WATER CONFERENCE. The 2018 New Mexico Produced Water Conference was held in Santa Fe, New Mexico, on November 15 and 16, 2018, with over 150 participants. The goal of the conference was to solicit input from the public and industry, including oil and gas, water treatment and management, environmental, economic development professionals, and the public about the issues, challenges, and opportunities of expanding and extending fresh water supplies in New Mexico by the treatment, reuse, and recycling of produced water. The conference was designed to facilitate collaboration among different stakeholders and improve New Mexico and federal regulatory and environmental frameworks for produced water;

and foster identification of economically viable opportunities to enhance fresh water conservation, produced water resource recovery, and produced water reuse. The major directions identified included:


NEW MEXICO PRODUCED WATER CONFERENCE - 2018

"Policy, Regulations, and Economics to Support Total Resource Recovery"

Summary Report

Jeri Sullivan Graham and Mike Hightower
New Mexico Desalination Association

Bruce Thomson
Professor Emeritus, University of New Mexico

Martha Cather
Petroleum Recovery Research Center
New Mexico Institute of Mining and Technology

February 2019

- eliminate of the use of fresh water in the oil and gas sector;
- encourage produced water treatment, recycling, and resource recovery to enhance water supplies;
- reduce the environmental impacts to air, water, and soil from oil and gas development and produced water generation and reuse;
- encourage the coordination and cooperation of all government, public, oil and gas, and industrial sectors to address produced water issues;
- eliminate disincentives to produced water recycling or options that cause an increase in the use of fresh water in the oil and natural gas sector;
- include incentives for pilot operations of produced water treatment and reuse that minimize fresh water use in oil and gas;
- develop incentives that create shared public and industry benefits by creating local economic development opportunities for use of the treated produced water and minerals., and
- development of a produced water resource recovery infrastructure Master Plan through some form of a Public-Private Partnership.

The participants noted that the development of treatment and refining facilities for both the produced water and associated salts and minerals, transportation infrastructure including pipelines, rail lines, and road systems for the treated water and mineral products, siting of industrial and agricultural operations to use the water and the products, and natural gas and power lines to provide the energy for these facilities and industrial processes will be needed. Therefore, planning for the build-out of these facilities over the next 50 years is an important undertaking that will require industry, oil and gas, and state and local economic development input to establish accurate infrastructure planning projections and requirements. This will therefore require:

- a coordinated state, federal, local, and industry public-private-partnership;
- easy access to produced water quantity and quality data;
- an understanding of the schedule, timing, location, and investments needed and the associated economic and government service impacts for implementation; and
- a Master Development Plan providing the blue print for New Mexico on expected needs and benefits of accelerated produced water and resource recovery.

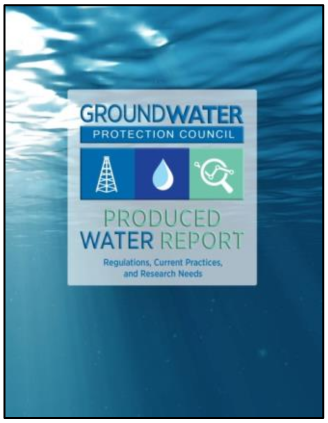
Participants recommended the establishment of a standardized produced water treatment and resource recovery technology cost and performance evaluations approach. For wider use and acceptance, better cost/performance information is needed for a range of scenarios. Therefore, approaches were identified to accelerate performance testing and verification of produced water treatment and reuse technologies. Options included:

- establish a clearinghouse for testing and verification of treatment technologies;
- coordinate research with the Bureau of Reclamation's Brackish Ground Water National Desalination Research Facility (BGNDRF) in Alamogordo, which is permitted to treat both brackish and produced waters;
- actively engage stakeholders in state-of-the science of produced water treatment and reuse;
- make sure that appropriate measures and adequate treatment technologies are developed to address stakeholder concerns;
- support a major social and educational effort to create and disseminate the best science, knowledge, and understanding of produced water resource recovery; and
- use severance and excise tax funds to fund the administration of the oversight agencies involved in oil and gas issues prior to placing the funds into the general and severance tax funds.

2019 GWPC PRODUCED WATER REPORT. The GWPC report provides stakeholder input on major technical and regulatory issues and challenges. The major identified technical issues and research needs are highlighted first, and then the regulatory and policy issues and research needs are presented next.

Most research needs identified in the report pertain to produced water treatment and reuse outside the oil and gas industry. The report notes that managing potential risks for these applications will require:

- improved understanding of the composition of specific produced water sources and identification of the health and environmental risks of reuse or release;
- determination of the standards of quality that must be met to make the produced water fit-for-purpose reuse; and
- evaluation of the costs, benefits, and risks entailed in achieving those standards.



The report noted that produced water is a research area that is rapidly advancing, including the development of knowledge and tools for produced water characterization, treatment, risk assessment, and feasibility for reuse. Yet gaps remain including advancements in data analytics needed to inform risk-based decisions and support the development of reuse programs that are protective of human health and the environment.

A central research challenge is the bench and pilot-scale research, development, and demonstration testing needed to establish effective and economic treatment trains. These efforts will require treatment technology and monitoring approaches that consider specific reuse scenarios and can:

- analyze the complex character of a specific produced water;
- manage variability;
- significantly reduce high total dissolved solid levels, organic constituents, metals, and naturally occurring radioactive materials; and
- can handle treatment residuals.

The most purposeful and actionable research and development strategy will be to identify and focus on specific reuse options where circumstances align to make reuse a potential need or opportunity in the near-future in important regions. This will require the ability to provide users with an easy-to-use data portal and Graphical Information Systems (GIS) that provides information on the location and temporal variation in available produced water volumes, quality, and potential local water use applications and users.

Other technical issues identified included:

- optimized leak detection systems;
- water treatment technologies that cost-effectively address specific water quality challenges related to scale buildup or specific analytes or constituents,
- improvements in enhanced evaporation and desalination,
- development of automated treatment systems that can be operated remotely with little or no human interaction, and
- methods for separation of saleable products during treatment.

From a regulatory, legal, and policy perspective, nearly every aspect of produced water - including management practices, construction standards, and operational requirements - is regulated by federal, state, or local agencies. Disposal of produced water through surface discharges or injection in underground wells 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.

Currently, regulatory frameworks for overseeing reuse of treated produced water, particularly reuse outside the oil and gas industry, are not very well developed. As interest in reuse of produced water grows, state agencies will be expected to develop new regulatory programs to authorize and manage those activities and must be provided adequate resources to develop and administer these regulations. In western states, like New Mexico, large tracts of state and federal land, state and federal water management and water sharing laws, treaties, and compacts, will be encountered and will need to be considered.

To support produced water reuse, significant cooperation between many state and federal environmental, land use management, and water management agencies will be needed. Several issues that need to be addressed include:

- legal and regulatory considerations such as determining state water rights,
- applicable regulations such as treated water quality standards, and permitting, and
- determination of a appropriate uses depending on federal or state jurisdiction and the circumstances of use.

Similarly, midstream water operations and other forms of water sharing are often outside traditional state oil and gas regulatory frameworks and require state authorization and oversight for activities that are not associated with other permitted oil and gas operations. Expanding midstream and other water-sharing opportunities may require state-level regulatory or legislative solutions to address several issues, including:

- management of risk associated with commercial management of large volumes of produced water from multiple sources at one facility,
- ownership of produced water,
- transfer of ownership,
- surface storage, and
- determination of liability if there is a spill or other environmental damage.

There are also other concerns regarding ownership and legal liability. In many cases, the lease holder, typically an oil and gas company, is the owner of the produced water and has the legal liability to properly treat, transport, and dispose of it. However, if treated produced water is being reused outside the oil and gas industry, there must be a clear understanding of the current and future liability and transfer point of the liability and ownership.

2019 NEW MEXICO PUBLIC MEETINGS ON PRODUCED WATER CONCERNS. In support of the NMED, the Consortium supported and attended 5 public meeting across New Mexico from October 15 through November 25th, 2019. These public meetings were held in Albuquerque, Santa Fe, Carlsbad, Las Cruces, and Farmington. On average, approximately 150 participants attended each meeting. Following a presentation on the 2019 New Mexico Produced Water Act, produced water in general, and current produced water management in New Mexico, attendees had an opportunity to participate in a question-and-answer session. Additionally, written comments could be submitted at the meeting, or later submitted to NMED via email.

The intent was to have NMED and other state agencies such as the EMNRD Oil Conservation Division (OCD), and the Office of the State Engineer discuss their roles and responsibilities under the 2019 NM Produced Water Act, and to identify the goals and objectives of the Consortium. The goals of the meetings were to:

- provide the public with information on state efforts and processes for evaluating the use of treated produced water for fit-for-purpose applications outside oil and gas sector, and
- identify the major issues and concerns the public has with the reuse of produced water outside the oil and gas sector, and what the public thinks the Consortium needs to address.

The Consortium and NMED utilized environmental engineering students to record and transcribe the comments made by the public at each meeting. NMED collected and binned the almost 2,300 comments from the public, including 500 submitted using a form letter (NMED 2020).

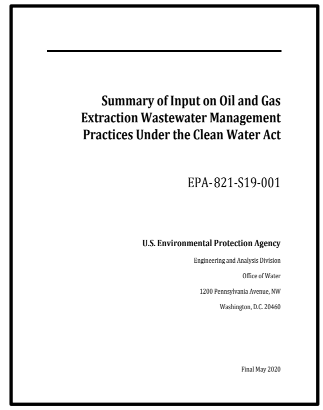
Of the comments, the major categories of concerns, issues and opportunities identified included,

- Half of the comments focused on the public and ecological health and safety concerns related to the use of treated produced water,
- Ten percent of the comments were related to the public's concern of possible resource contamination from the use of produced water,
- Many comments noted concerns of the impact of using produced water and increasing CO_2 and climate change, and
- Many comments suggested the benefits of using produced water to provide additional water resources to address the increased aridity caused by climate change and the ability to use oil wells to sequester CO_2.

This input highlights that research to minimize the public and environmental health and safety risks associated with the treatment and reuse of produced water, including a reduction of the potential ecological damage from the use of treated produced water, and the research needed to treat and use produced water safely and cost-effectively to provide additional water supplies for New Mexico are important public issues.

2020 EPA IDENTIFIED PRODUCED WATER RESEARCH NEEDS. The May 2020 EPA report identified that large volumes of produced water are being generated in the oil and gas industry, and projections show that these volumes are likely to increase. Currently, the majority of produced water is managed via reuse within the oil field for practices such as enhanced oil recovery, or by disposing of it using a practice known as underground injection where that water can no longer be accessed or used. The limits of injection are evident in many areas, and new approaches for handling produced water are becoming necessary. Many states and stakeholders are asking whether it makes sense to continue to waste this water, particularly in water scarce areas of the country, and what steps would be necessary to treat and reuse it for other purposes.

Therefore, the EPA conducted a focused study to evaluate management of produced water from onshore oil and gas extraction activities. The EPA wanted to better understand produced water generation, management, and disposal options at the regional, state and local levels for both conventional and unconventional onshore oil and gas extraction. While the EPA looked at a variety of alternatives for reuse of produced water, ultimately, the focus of the EPA study was to:


Summary of Input on Oil and Gas Extraction Wastewater Management Practices Under the Clean Water Act

EPA-821-S19-001

U.S. Environmental Protection Agency
Engineering and Analysis Division
Office of Water
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

Final May 2020

- evaluate approaches to manage onshore produced water; and
- better understand any potential need for, and any concerns over, additional discharge options under the Clean Water Act (CWA) for onshore produced water use.

During the EPA's outreach activities, stakeholders raised several concerns regarding additional discharge options for treated produced waters, including the:

- amount of available data on the chemistry of produced waters and the performance of treatment technologies;
- availability of analytical methods for measuring the constituents in produced water, and the potential toxicity of these constituents; and
- potential impacts to downstream users, such as impacts to drinking water utilities.

These are considerations that are important to the EPA as it considers next steps for its CWA programs related to produced water management.

While opportunities exist to recycle/reuse produced water outside of the oilfield, this management approach is currently rare. Some produced water is currently used for irrigation of crops. Road spreading of produced water for dust and ice control is also occurring in some states. The EPA review noted that off-site CWT facilities are also used to manage these wastewaters. In addition, some produced water is managed at publicly-owned treatment works (POTWs).

As far as increasing the reuse of produced water for applications outside the oil and gas sector, stakeholders had varying responses:

- representatives of tribes generally expressed concern about increasing opportunities for discharge, however some tribal representatives supported discharge to address water scarcity and to allow for continued resource development on tribal lands.
- those who expressed concern raised issues about the unknown chemistry of produced waters and the impacts to surface waters which have important cultural uses,
- nationally, there is broad support among producers and service providers for additional wastewater management options including to treat and discharge produced waters more broadly, and

- some oil and natural gas companies are satisfied with the current regulatory structure and others perceive potential liability concerns associated with alternatives such as discharge.

The EPA study noted that produced water discharge west of the 98th meridian is currently an option, but use of the beneficial reuse provision outside of the State of Wyoming is rare. Based on information provided in the study, this is primarily due to the availability of other wastewater management options that are lower cost, such as reuse within the oil and gas field or disposal in Class II UIC wells, as well as the cost associated with treating produced waters to a level suitable for discharge. Industry has indicated that unless the produced water has total dissolved solids concentrations generally of less than a few thousand milligrams per liter, treatment using membranes (e.g., reverse osmosis) or distillation would be necessary to generate water that is suitable for agricultural uses or for discharge to surface waters.

The cost of such treatment is not believed to be competitive where produced water disposal options are easily available. However, treatment for discharge may be cost-competitive where disposal options are limited or are becoming more limited. For example, producers indicated that in some areas of Pennsylvania, treatment for discharge is currently cost-competitive with other available produced water management options. This is primarily driven by the cost for trucking produced water to disposal wells to states beyond Pennsylvania.

In New Mexico, the high cost of trucking produced water in the San Juan Basin could make this a region where produced water treatment for reuse could be cost-competitive. Alternatively, as the produced water disposal capacity in the Permian and Delaware Basins in southeastern New Mexico become more limited, treatment of produced water for reuse could reduce produced water disposal volumes by 60-75%. Additionally, as the NM State Land Office moves to eliminate the use fresh water use for oil and gas drilling and development on state lands, innovative produced water treatment and ruse technologies could become more cost competitive with disposal in New Mexico.

Representatives of state agencies that the EPA engaged generally supported increasing opportunities for management of produced water. Some pros and cons identified include:

- Pros - the ability to provide additional flexibility for producers, opportunities to address water scarcity concerns, and benefits of providing additional water for agriculture,
- Cons - some agency representatives raised concerns regarding the treatability of produced waters and the unknown human health and ecological risks that might occur, most of the reuse risks of produced water are primarily a function of the unknown chemistry of many produced waters, and management of treatment residuals, particularly the salts and radioactive material that would be generated, were identified as concerns.

Some environmental NGOs expressed opposition to, and raised concerns about, current and expanding options for discharge of produced waters. These included:

- concerns related to the unknown nature of produced water chemistry,
- documented problems from discharges that are currently occurring or that have occurred in the past, and
- the current limited treatment for some current discharges of produced water and the toxicity of produced water and its constituents.

Other NGOs (and associations of state regulators) see potential benefits related to water availability associated with increased opportunities for discharge of treated produced waters. In addition, some are supportive of additional discharge options, seeing opportunities to generate revenue from the treated produced water, and to facilitate economic and industrial growth, including new or sustained growth in oil and gas operations.

Those in academia engaged by the EPA identified several issues and concerns, including:

- the unknown chemistry of produced waters,
- the limited amount of data regarding treatability of produced waters, and
- risk to human health or environmental implications of discharges.

Opportunities identified included:

- the need for additional research into these topics, noting that some studies are currently underway in many locations, and
- the potential for reducing the cost and improving the performance of treatment technologies, which could make treatment for discharge more cost-competitive with other produced water management options.

4. Priority Produced Water Reuse Research Needs

In the NMED-NMSU MOU that launched the Consortium, the Consortium was directed to "rely on the June 2019 GWPC Produced Water Report as a reference for development and implementation, where applicable." The MOU specifically references the relevancy of Module 3 of the GWPC Report for crafting the Consortium's research agenda. Therefore, the Consortium utilized the GWPC summary goals as a starting place for establishing our research program, while also considering the additional comments and suggestions from the other relevant programs and reviews.

The Summary Research Table below compiles and compares the suggested science and technology research and development challenges and needs identified in each of the different forums to the GWPC Report research priorities. In general, the identified research and development needs for fit-for-purpose treatment and reuse of produced water are very consistent. This GWPC report suggested eight priorities, while the other five reports and studies identified about seven additional needs based on national and New Mexico specific issues.

Therefore, if all of the major issues identified in the table below can be addressed over the next several years by the Consortium, then the Consortium's research and development program efforts will support both New Mexico's interests and also the national interests of stakeholders across several states as requested and expected by the US EPA when we were asked to lead their national efforts on the evaluation of the fit-for-purpose reuse of produced water outside the oil and gas industry.

Table 2. Summary Produced Water Research Priorities by Identified Study

GWPC Report	NM Energy Roadmap	NM State Water Plan	NM Produced Water Forum	EPA Produced Water Report	NM Public Meetings
1) improved understanding of the composition of specific produced water sources and identification of the health and environmental risks of reuse or release,		√		√	√
2) use of produced water quality data to determine the standards of treatment that must be met to make the produced water fit-for-purpose reuse,		√		√	
3) bench and pilot-scale research, development, and demonstration testing to establish effective and economical treatment trains. These will need to include: a) improvements in enhanced evaporation and desalination technologies, b) water pre-treatment or post treatment technologies to cost effectively address specific water quality challenges related to scale buildup or a specific constituent, c) analyzing the complex character of a specific produced water, d) managing variability, e) significantly reducing high total dissolved solid levels, organic constituents, metals, and naturally occurring radioactive material to reduce risks, and		√	√	√	√

f) handling residuals and methods for separation of saleable products during treatment.					
4) evaluation of the costs, benefits, and risks entailed in achieving the identified treatment standards	√	√	√	√	
5) use of strategic advancements in data and analysis will be needed to inform risk-based decisions to support the development of reuse programs that are protective of human health and the environment	√		√	√	√
6) ability to provide through an easy-to-use data portal and GIS system the location and temporal variation in produced water volume and quality potentially available for nearby applications	√	√	√		
7) optimized leak detection systems to minimize spills and spill volumes to reduce environmental and ecological risks of produced water use		√			√
8) development of automated treatment systems that can be operated remotely with little or no human intervention.					
	Suggestions from other forums				
9) encourage produced water reuse to eliminate fresh water use in the oil and gas sector and create additional water supplies for uses outside the oil and gas sector	√	√	√	√	√
10) develop an infrastructure Master Plan			√		
11) establish a government regulatory working group as identified in the GWPC Produced Water Report to	√		√		

facilitate infrastructure development including the use of excise taxes to fund project development					
12) establish an educational outreach program to engage stakeholders in the State-of-the-Science of produced water treatment and reuse			√		
13) develop analytical methods for the characterization of produced water constituents as needed and establish methods for assessing toxicity impacts of produced water	√			√	√
14) Consider impacts on greenhouse gasses from produced water reuse					√
15) integrate produced water reuse into future regional water plans		√			

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