

Produced Water Research in New Mexico

Editor's Note: The following papers represent a transcription of the speakers' remarks made at the conference; no follow-up papers were submitted by the speakers. Remarks were edited for publication by the editor. The speakers did not review this version of their presentation, and the editor is responsible for any transcription and editing errors.



Moderated by Robert Sabie, NM WRRI Researcher

Robert Sabie Jr. is a research scientist at the New Mexico Water Resources Research Institute. Sabie's research focuses on applying geographic analyses to address water issues in New Mexico and other arid landscapes. His particular interests include using aerial and satellite remote sensing for land-cover mapping and measuring evapotranspiration, produced water decision modeling, and participatory research. He holds a BA in environmental policy and planning from Western Washington University and a master's degree in applied geography from New Mexico State University (NMSU). He is currently working toward completing his PhD in the Water Science and Management program at NMSU.

Our last session of the conference is this session on produced water research in New Mexico. This session will be broken down into two different parts. The first part will describe the New Mexico Universities Produced Water Synthesis Project, and the second part will outline the New Mexico Produced Water Research Consortium. I am going to ask each panelist to describe their specific research project.

Before we begin the individual talks, I will provide an overview to ensure everyone is on the same page. What is produced water? In New Mexico, it is defined as "a fluid that is an incidental byproduct from drilling for or the production of oil and gas." The emphasis here is that it is a fluid and not water. I think there are legal issues regarding whether it's defined as a fluid or water, and Stephanie will talk about that in the next presentation. It's naturally occurring, high-salinity water recovered during oil and gas production, and it may also include fluids that were used during drilling, such as hydraulic fracturing fluids.

This is important in New Mexico because, since 2011, oil production, in particular in the Permian Basin in the southeastern part of the state, has been increasing exponentially. For context, New Mexico is the third-largest oil-producing state in the United States, and Lea and Eddy Counties, located in the southeastern corner of the state, are two of the top oil and gas-producing counties in the Country. When water in the geologic formations, combined with oil and gas, is brought up, there's a water-to-oil ratio produced, ranging anywhere from 3:1 to 13:1. If you bring up one barrel of oil, the oil and gas companies sometimes have 13 barrels of water that accompanies that water that they have to manage. In New Mexico in 2019, according to the Oil Conservation Division, 163,137 acre-feet of produced water was generated. If you think about things

in gallons, that was about 53 billion gallons of produced water. Of course, this water is high in total dissolved solids (TDS), and high in salinity, ranging on the low end of around 1,000 mg/L up to more than 400,000 mg/L. For context, seawater typically ranges between 30,000 and 35,000 mg/L, indicating a significant amount of dissolved solids in the produced water.

Where is this water disposed of after they bring it up? A lot of it is injected into underground saltwater disposal wells, or it is injected for enhanced oil recovery. Now, the industry is trying to find ways to treat and reuse water. Evaporation ponds and offsite commercial disposal, discharge, and beneficial reuse are also options, but those are less common in New Mexico right now. I think Mike Hightower and Rebecca Roose will talk about those issues in a little bit with their consortium work.

Of course, this topic isn't new in New Mexico. Here is a list of some of the collaborative projects that have happened over the past 17 years:

- 2003: New Mexico Forum on Reclaiming Produced/Brackish Water for Beneficial Uses
- 2004: NRCE report, *Water in the Desert: Engineering/Legal/Logistical Study to Implement the Conversion of Oil and Gas Produced Water to Useable Water in Lea and Eddy Counties, New Mexico*
- 2007: Brackish Groundwater National Desalination Research Facility opened
- 2016: NM WRRI collaborates with New Mexico Tech, New Mexico State University, and Los Alamos National Lab on New Mexico Environment Department-funded project focused on produced water in Lea and Eddy Counties

This list is not exhaustive. There have been numerous individual research projects over the past couple of decades on this topic, but this list highlights some of the ongoing collaborative projects. In 2019, there were two parallel efforts that started: the New Mexico Universities Produced Water Synthesis Project, and the New Mexico Produced Water Research Consortium.

There are two primary questions we aim to answer. Of course, there are a lot of different caveats to each

of these, but the New Mexico Universities Produced Water Synthesis Project is trying to assess the impacts of produced water management decisions on New Mexico's water budget. The research consortium is examining how treated produced water can be safely utilized as an alternative water source outside of the oil and gas industry. I think that's enough background information to hand it off to Stephanie, and we can get into the nuts and bolts of these two different research projects.

Part A: New Mexico Universities Produced Water Synthesis Project



Stephanie Russo Baca, Utton Transboundary Resources Center

Stephanie Russo Baca is currently the staff attorney and Ombudsman Program Director at the Utton Transboundary Resources Center, located at The University of New Mexico (UNM) in Albuquerque, New Mexico. In both these roles, Russo Baca's mission is to support and represent constituents in a fair and unbiased manner. She guides the activities of the Joe M. Stell Ombudsman Program, a statewide program that provides impartial adjudication information and procedural guidance to unrepresented water right claimants in New Mexico. Russo Baca contributes significantly to the Utton Center's overall mission of providing objective, research-based public service to New Mexico's communities on issues related to energy, climate change, ecological conservation, food systems, and international natural

resource management. She holds both an Indian Law certificate, and a Natural Resources and Environmental Law certificate from the UNM School of Law.

As an introduction, I will provide a brief regulatory overview of the work conducted by my two research assistants and me, which involved analyzing the relationship between the current regulatory legal framework and the Produced Water Act. Sarah McLain has joined me today, and she'll be available for any questions at the end.

I'll start with an overview of the produced water numbers. Figure 1, using data from the Oil Conservation Division (OCD), shows that in 2019, we had over 163,000 acre-feet of produced water, which is about 53 billion gallons of water. To give you an idea of how much produced water that is, the total maximum storage of El Vado Reservoir is about 180,000 acre-feet.

Figure 2 is the current state regulatory framework. We know that the Oil and Gas Act established the OCD, which is the primary regulatory body overseeing the use or disposal of produced water in the oil and gas industry. OCD is a division of the Energy, Mineral and

Natural Resources Department (EMNRD) that regulates oil and gas activity in the State of New Mexico. The Oil Conservation Commission (OCC) has concurrent jurisdiction authority with the OCD to the extent necessary for the commission to perform its duties as required by law. We also have NMED, the New Mexico Environment Department, which is the agency tasked with protecting New Mexico's environment, resources, and public health and safety. The New Mexico Water Quality Act established the Water Quality Control Commission (WQCC), which adopts water quality standards and assigns responsibility for administering its regulations to constituent agencies, like OCD and NMED. We also have the Office of the State Engineer, which, of course, has authority over the supervision, measurement, appropriation, and distribution of all surface water and groundwater in New Mexico. I wanted to provide you with this brief overview because I will be discussing the changes introduced by the Produced Water Act for these entities.

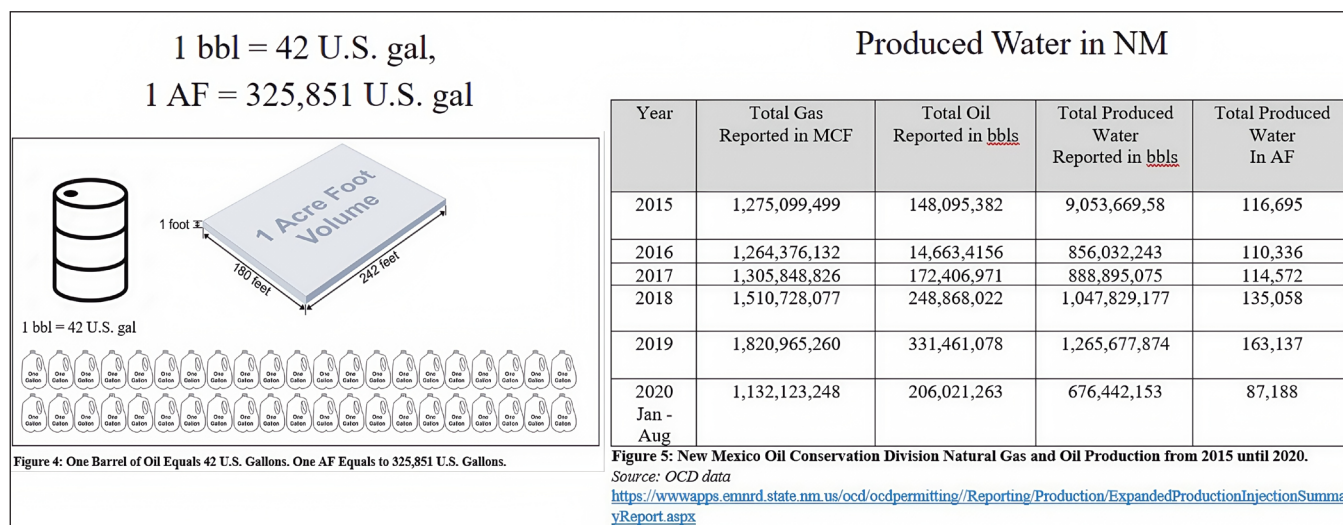


Figure 1. Produced water in New Mexico by the numbers.

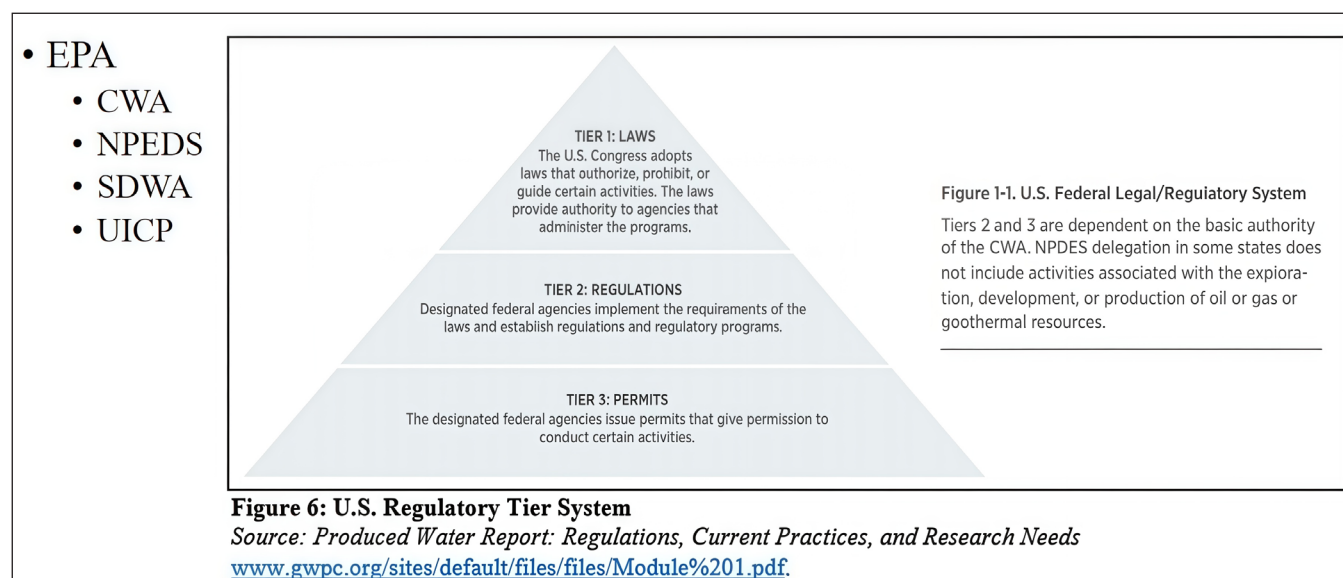


Figure 2. Federal regulatory framework.

In addition to the state regulatory framework, there is the federal regulatory framework. There are three tiers, as you can see in Figure 2. Federal law is the first tier. We know that the federal Water Pollution Control Act, also known as the Clean Water Act, established the National Pollutant Discharge Elimination System, or NPDES permits that we might be more familiar with, and that it regulates the discharge of wastewater to water bodies that are considered waters of the United States. We just heard about that earlier today in previous presentations. Tier 2 is agency regulations. The Environmental Protection Agency (EPA) is the agency that establishes comprehensive rules for implementing the NPDES program. We know that some states issue NPDES permits themselves, but here in New Mexico, the EPA issues them directly. Although, of

course, based on Shelly Lemon's earlier presentation, that might be changing. So, stay tuned.

I'm going to talk about the underground injection control (UIC) primacy program. New Mexico has primacy for well Classes I–V. One caveat is that EPA directly implements Class II programs for all tribes, except for the Navajo Nation and the Fort Peck Tribes. Ninety percent of produced water generated in the United States is injected into underground geological formations through injection wells permitted under UIC Class II programs. The federal Class II program is delegated to OCD, and then WQCC handles Classes I, III, IV, and V, although there are some caveats, which I'd be happy to explain further. The key point is that the UIC primacy program is regulated by the state through OCD and WQCC.

I'm going to delve into the key provisions of the Produced Water Act, as well as the analysis we conducted on the statute before its passage and the changes that have occurred since its enactment. The Produced Water Act clarified the roles and regulatory authorities of New Mexico state agencies. It went partially into effect on July 1, 2019, and then fully into effect on January 1, 2020. So, as Bob mentioned, produced water now has a clear definition. It is an "incidental byproduct from drilling for or the production of oil and gas." There is also a difference between treated produced water (water reconditioned by mechanical or chemical processes into a reusable form) and recycled produced water (water reconditioned by a recycling facility permitted by the OCD).

One question a lot of people had was, "Is there going to be a new water right established through produced water?" The answer is no. The Office of the State Engineer does not require a permit for the use of produced water. It's considered a "disposition by use," not a "beneficial use." It doesn't create a new category of water right that is perfected when water is treated, recycled, or reused. That was made very, very clear.

Also, a key provision of the Produced Water Act is that OCD regulates produced water within the oil and gas field. OCD now also has the authority to assess civil penalties, up to \$2,500 per day for noncompliance with each violation, up to \$10,000 a day, with a cap of \$200,000. That doesn't mean that a court in the appropriate jurisdiction cannot issue penalties if they are accrued over \$200,000. If there is a violation that harms an individual, such as a private party, that individual can also file a separate suit. There's nothing in the Produced Water Act that prevents that.

Additionally, many individuals are researching the specific amendments to the Oil and Gas Act (NMAC 19.15.16.21) through the Produced Water Act, which requires new disclosure and reporting of water use types in the completion of fracking a well. There are now very clear rules on how it's broken down for different types of water. So, whether you're reusing produced water, using saline water, or fresh water, you must now disclose not only the exact location of that water but also its type.

The Produced Water Act also encouraged the reuse of produced water within oil and gas operations. Now, any contract between two producers or a midstream company, for example, is against public policy and void if it requires

freshwater resources when recycled, treated, or produced water is available to be used. It does not mean that they can't use fresh water, but the contract can't require it anymore if recycled, treated, or produced water is available and can be used.

There is one more thing that happened just this last month: the OCC had a hearing on October 15, 2020, where they agreed to set a hearing date for a proposed rule that would make the spilling of produced water illegal. This was in response to a petition by the WildEarth Guardians. You can look on OCC's website for more information: <https://www.emnrd.nm.gov/wp-content/uploads/sites/6/October15Minutes.pdf>.

Let's get into how treated produced water may potentially be used outside of the oil and gas industry. The WQCC is tasked with adopting water quality standards. Remember, though, from the previous slides that they still have to delegate authority when making a regulation or adopting a standard. WQCC is going to be adopting these standards, and then NMED has the authority to issue permits for the use of treated produced water outside of oil and gas. Before this ever happens, these standards for treated produced water outside of the oil and gas industry are being developed through a two-phase process that NMED is leading. I will let Director Roose explain this further, but I want to give you a brief overview.

The first phase involved public engagement by NMED, EMNRD, and the Office of the State Engineer. They held five public meetings all over the state between October and November 2019. The second part of the first phase is the Produced Water Research Consortium. On September 9, 2019, NMED and New Mexico State University agreed to identify and fill science and technology gaps associated with the use of treated produced water. This agreement created the Produced Water Research Consortium, which is led by NMSU. The second phase of the implementation process will involve developing the science-based standards, followed by formal rulemaking. Formal rulemaking includes drafting regulations that will then be submitted to WQCC. There'll be public comment and a hearing. It is my understanding that no date has been set for when the draft regulations will be submitted, but I'll let Director Roose address that. That's all I have. Sarah McLain and I will stick around to answer any questions once the other presenters are done. Thank you.



Martha Cather, Petroleum Recovery Research Center, New Mexico Tech

Martha Cather is a Senior Scientist and Section Head at the Petroleum Recovery Research Center (PRRC) at New Mexico Tech. She holds a BS and MA in Geology from the University of Texas in Austin. Since joining PRRC in 1988, she has specialized in petroleum data access, geographic information systems, reservoir characterization, and public outreach.

In her role, Martha has led various projects, including the Small Producer Program for the Research Partnership to Secure Energy for America (RPSEA) and the Southwest Regional Partnership of Carbon Sequestration. She has also been involved in the Carbon Utilization and Storage Partnership (CUSP) for the Western USA and the San Juan Basin CarbonSAFE Phase III, Project 1. Martha's work has significantly contributed to the fields of reservoir characterization and carbon sequestration, making her a key figure in the industry.

I am going to discuss the New Mexico produced water database that I have been compiling as part of the New Mexico Universities Produced Water Synthesis Project. First of all, I wanted to talk about the challenge and why anyone would care about a database of produced water. The biggest issue is that we cannot discuss using or managing produced water effectively if we don't know much about it. 'Produced water' is a broad term that encompasses a wide range of aspects. There are three types of water sources: water produced from wells, water that comes in from outside the system and is injected into wells (although this is not as common as it used to be), and water that is recycled through wells as part of pressure maintenance or enhanced oil recovery systems.

If you're going to use water, it's essential to know its origin and location. Where is it coming from, not just from what area but also from what formation? What is the depth? The geological formation from which the water originates has a lot to do with its quality. You also need to be aware of volume. How much water is being produced? There is a tremendous volume of produced water out there, but it's important to recognize that this is a very dispersed source. Individually, the little points that make up the production of this water can be separated by a few hundred feet, or they can be separated by miles. It's important to know where it comes from. When it comes to injection, which I'll go into a little bit further later, you also need to know where the water is going.

Essentially, we're trying to get an idea of the progress of a water molecule from its coming out of the ground to its going down to its final disposition in some deep disposal well somewhere. We need to know about the disposition. Is the water recycled? Is it used in the field for pressure maintenance or enhanced oil recovery? Is it reused for other purposes? Or is it disposed of in disposal wells? What is the variability of this water? If anyone is going to treat this water for any purpose, they need to know: Does the volume remain constant over time, or does it

change significantly? Does the quality stay the same, or is it changing? We need to know about variability both with water that is produced and with water that is reinjected somewhere. Then, of course, the biggest challenge is how to access that data more easily.

The effort I put in this year was mostly focused on building a geospatial database of oil field water volume that can be, and is now, linked to existing produced water quality data. A second objective was to survey water managers in the oil industry to gain a better understanding from them about aspects that may not be captured in the statistical data provided by the State of New Mexico or other sources we have. The result is what I call the New Mexico Produced Water Database 2020. If you know me or the research I've been conducting at New Mexico Tech, you'll know that I've been involved in building water quality databases since approximately 2002. There may be versions that some of you have seen, and I'd like to discuss how this version differs from the previous ones.

First of all, in this particular database, I included 25 years of oil, gas, and water production and injection data. Most of this data is from the Oil Conservation Division of the State of New Mexico. It is available from them on a monthly basis, but it is not easy to use. The database it produces contains gigabytes of data, and most people can't utilize that. We've extracted a bit of it and put it in a fairly commonly used database program—Microsoft Access. It's big, but not unwieldy. We have data on water production, water injections, and a lot of information about individual wells that are producing this water and where it is being injected. This data contains information such as the spud date, when the well was drilled, the pool or formation it is being produced from or where it is being injected, the number of days it has been produced or injected, and a rough estimate of the annual production or injection volume. That can be important if you're trying to figure out the injection rate. Therefore, there's a variety of data associated with each individual well.

We've also included water quality data where available. There are at least two relatively recent data sources: a version of the produced water quality database that I compiled in 2016 with the help of NM WRRI, and the U.S. Geological Survey's extensive nationwide data set. I downloaded all the data for New Mexico and included that in this database. There are two separate water quality databases, two sources of water quality data. In many cases, data is duplicated, but I prefer to keep the databases separate because I simply did not have the resources to go through and cross-check the data.

I did clean up some of this data. The USGS database contained numerous wells that were either not true oil and gas wells or had insufficient identification information, making it difficult for me to locate them in space. There was no latitude or longitude associated with them. I also included a few summary tables and some fields in the database that could be useful for aggregating and statistics. I'll show you a little bit of that. I also included some prebuilt queries. My assumption is that if you're downloading this database, you have some familiarity with Access. Some of the queries are easy to build, so I left them in there.

There are two things this database is not. This is not a database of water spills, whether produced water or any other type of spill; it simply records what is produced or what is injected. This database is also not currently live and had a finite cutoff date of mid-2020. So, there are no more live updates. However, this database has been viewed

as a stepping stone to making some of this information available online.

What can we do with this database? Well, you can use it for plain old statistical analysis. Run your queries in Access and then export them to the spreadsheet of your choice and graph away. You can answer questions like, "How much water is produced or injected in New Mexico? What county, township, well, or region has the most production or the most injections in a year or over the last 25 years? Can we distinguish water injection or production versus water that is recycled through enhanced oil recovery projects?" There are many different questions you can answer with this, including water quality questions such as, "Where's the best produced water in the state? What about the worst? How do ratios of things change through time?"

Figure 1, for example, shows that the water disposed versus water injected has changed from 2005 to 2019. In 2005, most water was injected into injection wells (not disposal wells), which are typically used for water flooding, such as enhanced recovery, pressure maintenance, or other similar purposes. Now, as of 2019, there's a whole lot more water being disposed of down saltwater disposal wells.

As I mentioned, I've seen numerous talks over the last couple of days about the billions of gallons and hundreds of thousands of acre-feet of produced water. That is correct, but once again, not all of the produced water is available. You're not going to take all of that water out of

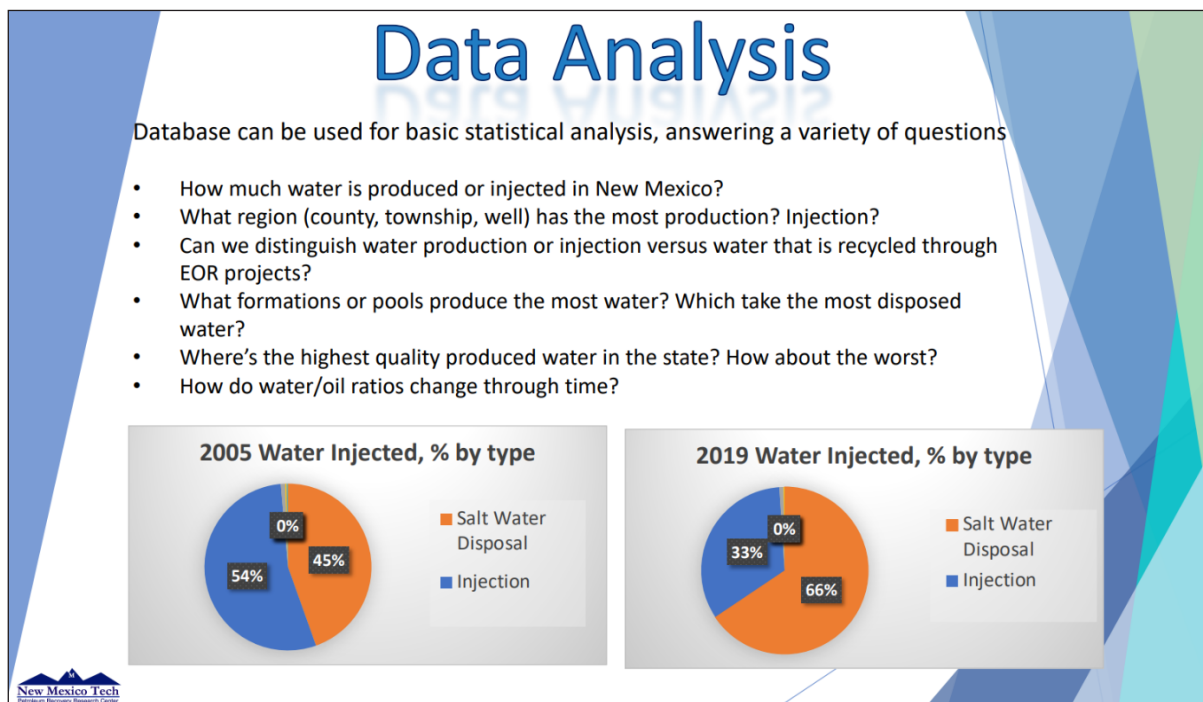


Figure 1. Comparison of water injected, % by type, 2005 and 2019.

the system. Essentially, Figure 1 shows that a significant portion of the water injected is already being utilized for another purpose.

Among other things we can do, we can also map this data. Because I include geospatial data, you can map individual points, wells, and you can code them by whatever strikes your fancy. For example, you can create bubble maps of production or injection volumes or rates, water quality, currently active wells, or you could map all the wells that produced over 100,000 barrels of water in 2019. You could also aggregate this data. We've included some identifiers for townships and sections that match some of the easily available GIS data.

Figure 2 is a sample of some things you can do. The left-hand map shows injection wells; the right-hand map shows saltwater disposal wells. You can see that a lot of disposals are going on in the southeastern part of the state. There were 12 wells that injected over 25 million barrels of water in 2019 in the highlighted township in Eddy County. There's a waterflood going on over here in the highlighted township in Lea County. A significant amount of water has been injected, but it is distributed across 122 wells. If I were looking for water to treat, I might look down in this part of the state, just based on volume alone.

Going forward, we would like to post this static database on our Go-Tech website (<http://octane.nmt.edu/gotech/>), a data website that has been operated by the Petroleum

Recovery Research Center since about 1995 or so. While it may not be particularly beautiful in the way many modern dashboards are, it works. It has been working for a long time for simple volumetric data queries, which are questions that many of our users have. The goal is to get this database up and running on Go-Tech, and then we can update it monthly with volume data.

Another project in the works is a collaboration with the Produced Water Consortium, Groundwater Protection Council, and New Mexico Bureau of Geology to develop various implementations of this data, such as dashboards utilizing mapping applications or graphical data displays, and possibly even providing operators with a means to enter data into it. We also aim to engage more water producers and managers to enhance our data set, as some of the existing data is outdated. Some of the water quality data is only up to 2014. We need to gather more data, which means we need individuals who are willing to share their data with us, as well as some of their usage practices. I still don't think you can gain a full understanding of the system just by obtaining statistical data from the Oil Conservation Division. You really need to have a much more hands-on understanding of where water is going if you're going to create a water budget using produced water. With that, I think I'll call it quits there. I probably took up more time than I needed to already.

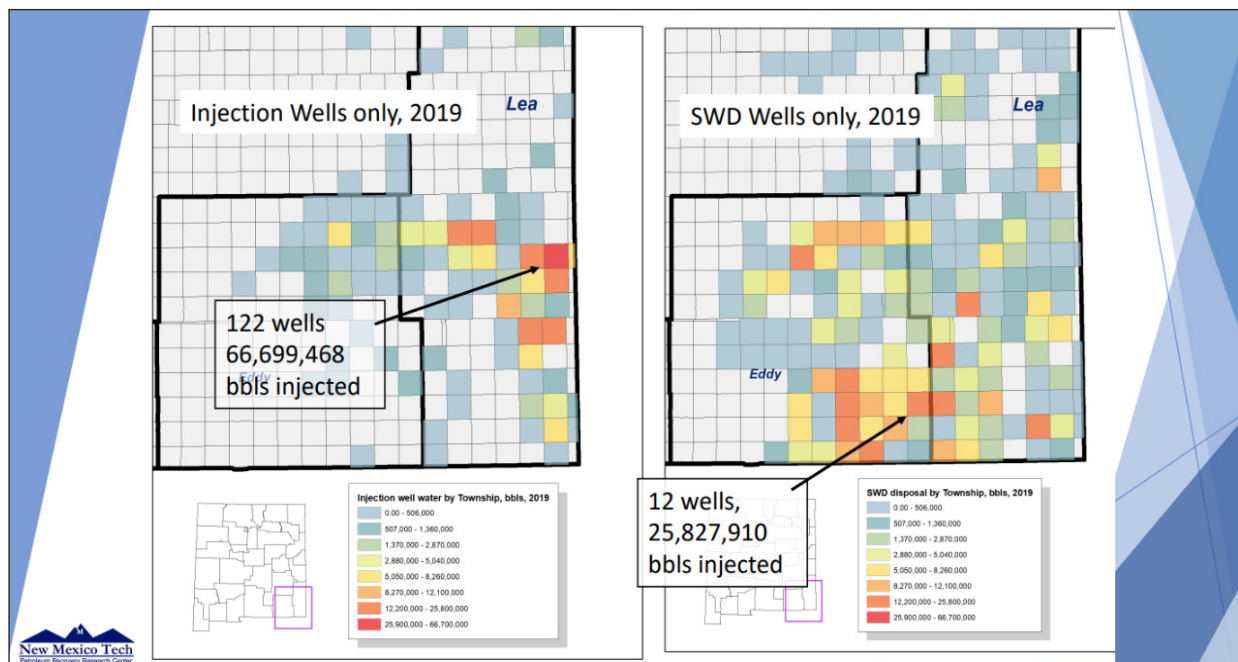


Figure 2. Spatial analysis using produced water database, injection and saltwater disposal wells, 2019.



Bruce Thomson, The University of New Mexico

Bruce Thomson is a Research Professor and Professor Emeritus in the Department of Civil, Construction and Environmental Engineering at The University of New Mexico and was previously director of UNM's Water Resources Program. He has been at UNM since the late Pleistocene epoch and is among the last licensed engineers in the state who still knows how to use a slide rule.

My collaborators are Janie Chermak in economics and Katie Zemlick in the Office of State Engineer. If you have any questions, comments, or suggestions, please contact me at bthomson@unm.edu.

I like to start my talks by reminding everyone how important oil and gas are to the New Mexico economy, and especially to the state government. In round numbers, a third of the state government is funded by revenues from oil and gas, with the money allocated to universities, schools, hospitals, and so forth. We must remember that, whatever we do, this is a crucial component of New Mexico's economy.

For my project, I've taken all this data that Martha has referred to, mostly from the Oil Conservation Division and an organization called FracFocus, as well as some from the State Engineer and State Land Office, and I've taken a deep dive into it and tried to identify trends so that we can understand where the industry is going. We've put a little bit of economics into it. The top left graph in the upper right-hand corner of Figure 1 is annual oil production in the southeast and the northwest of the state. You can see that it is going asymptotically. It's really doing well, but it's dependent on the price. The price is reflected in the graph on the top right, in the far upper corner, and you can see that as the price of gas goes down, the activity has dropped rather dramatically. In recent months, so has oil production. I think the state budget was based on oil at \$55 or \$60 a barrel. Last I checked, it's about \$40 a barrel, so that gives you some idea.

The reason we're interested in the explosion, particularly in southeastern New Mexico in the Permian Basin, is due to development in unconventional formations, including tight sands and shales. Along with that is directional drilling. You can see there are some definitions or examples in the lower left-hand corner of Figure 1, where you've got the horizontal drill, a directional drill, that is following the formation. We make a big deal about fracking, but we need to remember that fracking has been practiced for 70 years. In fact, fracking has been practiced

in many water wells, particularly out in western New Mexico. Again, we're trying to understand where the industry has been and where it's going, following what Martha was talking about.

In 2019, there were almost 1,100 wells that were fracked. The total volume in acre-feet is 40,000 acre-feet of water used for fracking in 2019, according to FracFocus. Coincidentally, to put it in perspective, 40,000 acre-feet is the same volume of water consumed by the City of Albuquerque. It's also important to remember that water for fracking generates a lot of revenue for farmers and water rights holders particularly down in the southeast. They are talking about \$1 a barrel, sometimes more. There is increased interest in using produced water for fracking, but the high salinity is a challenge, especially for slickwater fracks. Slickwater fracks are those where little to no gelling agents are used, instead relying on very high velocities. Some of these velocities are many, many tens of feet per second in the wellbore, compared to five feet per second, which is the maximum in distribution systems. These are very large velocities. They add friction reducers, and the problem is that in high-salinity water, these big, long polymer molecules clump up, and they don't work. The oil industry would like to use produced water. It's a way of getting rid of some of it, it's cheaper, and usually, there's lots of it. The challenge is with the high salinity, and as Stephanie mentioned, we don't know exactly what volume of water used for fracking is represented by produced water. There are some estimates in the 10 to 20 percent range, but that's based on anecdotal conversations with folks in the industry. This new regulation, passed by the Oil Conservation Division, will require that type reporting. It is a shame we didn't do that about 10, 15 years ago, but it's going to be useful information. One thing I wanted to point out is that even if all 40,000 acre-feet of water used for fracking were fresh water, that volume is a very small fraction of the water used for irrigated agriculture in Lea and Eddy Counties. I understand this is a provocative sentiment because

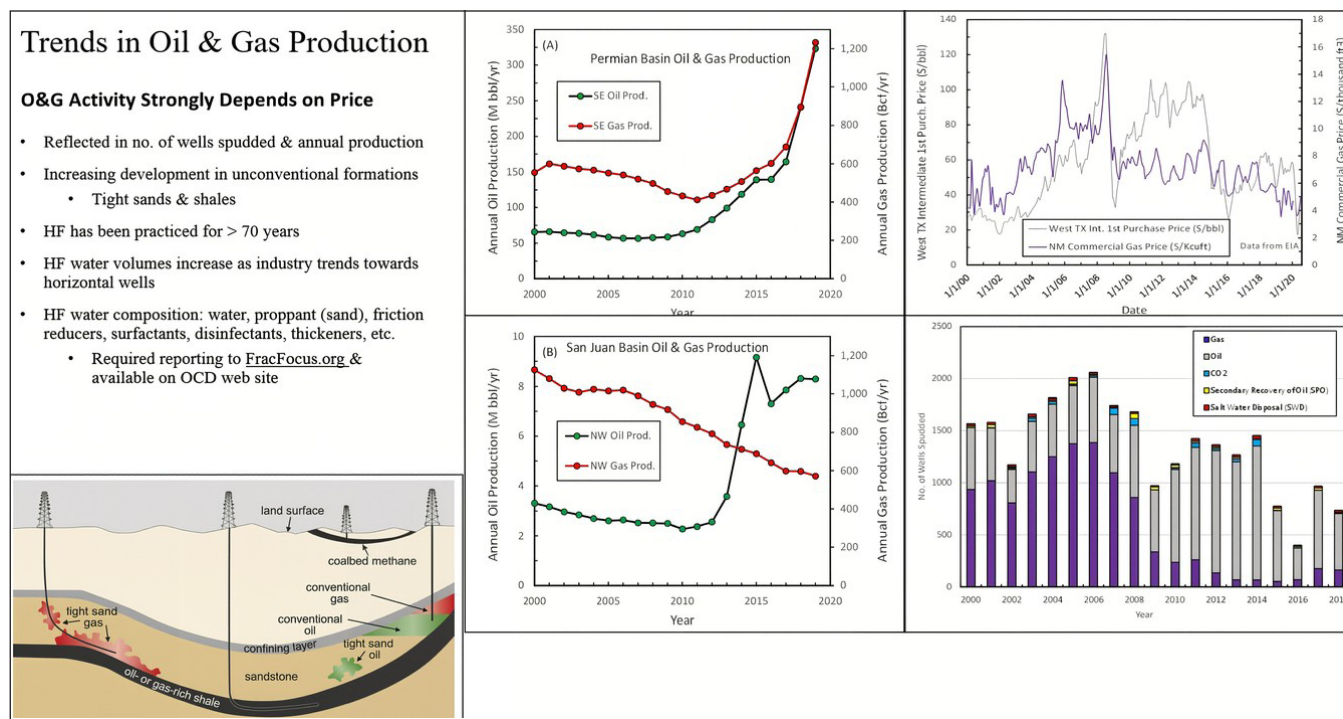


Figure 1. Trends in oil and gas production.

agriculture is a special part of the social and cultural history of New Mexico, but the volume of water used for fracking is relatively small compared to the total water use.

Let's talk about produced water. We usually lump produced water and flowback together. Flowback is the water generated immediately after a frack job. It resurfaces in a few weeks or a few months, at most, whereas produced water is generated throughout the well's lifespan. My numbers are a little bit different from what Martha said, but they're around 160,000 acre-feet, four times the volume of water used for fracking. It's a lot of water. Figure 2a shows the volume of produced water in New Mexico. The green line is not increasing as rapidly as oil production has. The volume in northwestern New Mexico is very small.

What is interesting, and I think perhaps the most interesting statistic in my presentation, is the produced water to oil ratio (Figure 2b). Ten years ago, around 10 gallons of water came up with every gallon of oil, and that has decreased. Most recently, it has decreased to around three gallons of water per gallon of oil. If you take that line in the middle graph of Figure 2b, it's a perfect straight line. It is dangerous and, of course, nonsense to do so; but if you extrapolate it, it says that by 2025, we won't have to worry about the problem at all. It'll be at zero. Of course, that's nonsense, but it is sort of interesting to look at that trend. It's remarkable. Why is that? Why is the ratio of water to oil less than it was several years ago? The reason is that we're going into these tighter and tighter

formations. Because they have low permeability and low hydraulic conductivity, they don't release as much water. We've talked about the high salinity, which presents all sorts of problems. Not only is it a salinity problem, but it's also complicated water chemistry compared to seawater. Seawater is approximately 95 percent sodium and chloride, whereas produced water contains calcium, magnesium, sulfate, and silica. Sometimes, there are hazardous constituents present.

Martha also touched on this, and we can look at the trend. Figure 2c shows how we dispose of our produced water. The top line is the total volume of water injected. The green line represents the water injected for principal secondary recovery (SRO), which includes waterfloods and other methods. The red line is the water sent to saltwater disposal wells. Again, you can see a rather dramatic increase in the water sent to saltwater disposal wells. The reason is that as we go to these tighter unconventional formations, you can't have waterflood. The hydraulic conductivity is simply too low.

Last, I will reiterate that managing produced water is a major challenge. Fresh water for fracking is a relatively minor challenge by comparison, and as we learn to get better frack jobs with produced water, that problem will diminish. There is difficulty in permitting new saltwater disposal wells. They can be very expensive, particularly as they go to greater depths. I think Alex Rinehart may talk about that a little bit. Mike Hightower, who will present later, will discuss the cost of disposing of salt

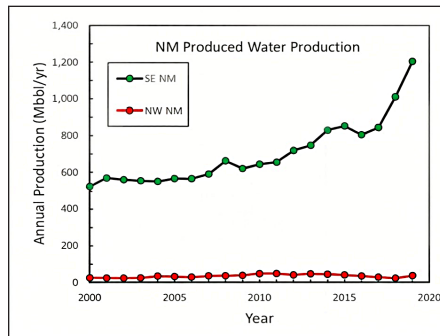


Figure 2a. New Mexico produced water annual production.

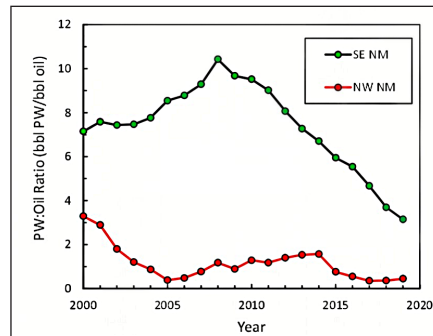


Figure 2b. Produced water to oil ratio.

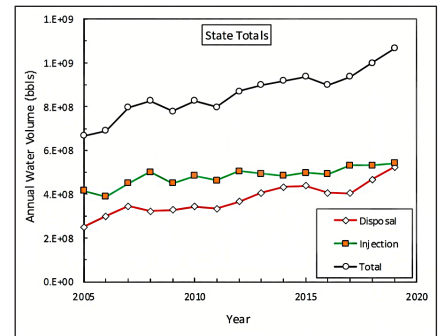


Figure 2c. Produced water disposal.

water, ranging from \$2 to \$4 per barrel. Some of these saltwater disposal wells can cost up to \$20 million each. What's interesting is the payback. Charging these large rates per barrel of water, the wells will pay back in one to two years. Desalination of produced water seems unlikely in the near term. We'll have further discussion about that. Desalination would generate a huge volume of waste; if we desalinated all the water, it would produce waste that is 500 feet tall and a third of a mile in diameter every year. I propose that we take all that and convert it into a ski hill and charge the Texans to go skiing.

My concluding thought is that more so than any other industry I'm aware of, the oil and gas industry responds very rapidly to economic considerations. They respond to the price of oil and the costs associated with drilling and producing it. The economic aspect needs to remain a fundamental consideration. For references, see my and Jamie Chermak's report 'Analysis of the Relationship between Water, Oil, and Gas in New Mexico' (NM WRRI technical completion report no. 390, <https://nmwrri.nmsu.edu/publications/technical-reports/tr-reports/tr-390.html>). If you have any questions, or you want to talk about this further, please contact me. Thank you very much.



Alex Rinehart, New Mexico Tech

Alex Rinehart is an assistant professor of hydrology at New Mexico Tech, where he focuses on rock failure during CO₂ underground storage, basin-scale hydrology, and applied hydrogeology. Before this position, he worked as a hydrogeologist at the New Mexico Bureau of Geology and received his PhD in geophysics from New Mexico Tech, where he also worked in experimental rock mechanics at Sandia National Laboratories.

Editor's Note: This paper transcribes the speaker's remarks from the conference. No follow-up paper was submitted, and the remarks were edited for publication by the editor. The speaker did not review this version, and the editor assumes responsibility for any transcription or editing errors.

This is going to be a slight change in pace. We've been hearing a lot about data streams and policy-related issues, among other things. This talk is going to be almost entirely about physical science. One of the things that happens when you don't use produced water, as Martha and Bruce talked about, to generate secondary recovery but instead just dispose of it into the subsurface, is that

you increase the pressure in the formation you're injecting into. That has led to seismicity, which I'm sure folks have heard about. This study combines data from Mairi Litherland, a seismologist at the New Mexico Bureau of Geology, and Martha's compiled database, which Luke Martin, Joseph Grigg, and Raven Goswick utilize. This study then links the seismicity observed by Mairi with

the injection data and the geology. Joseph Grigg is the geologist on this. I need to give him a lot of credit. He's put in a lot of work lumping pools together and figuring out how to think about the geologic framework that surrounds the injection and, ultimately, as we'll talk about, controls the seismicity.

Figure 1 demonstrates the key point. On the right, we have all the saltwater disposal wells in 2020. Those are all the black dots. The map shows Artesia, Carlsbad, Hobbs, and Lovington. These lines are mapped by the Texas Water Board, I believe, and they represent old faults that occurred approximately 300 million years ago, which cut through rock during the middle of the Permian era. Often, induced seismicity occurs along these old faults that are connected to the bedrock. On the left, we have all the earthquakes from 2017 through June 2020. We've been having quite a few earthquakes, but they are low in magnitude. The maximum magnitude is something like 3.2 or 3.3. Most of these events are less than magnitude 2, so they aren't felt. These are low-magnitude earthquakes, but we have a number of them.

The question becomes how or whether we see any sort of correlation between saltwater disposal and earthquakes. To answer that, we need to know a little bit about geology in the Permian Basin. In the Permian Basin, there are numerous shallow sea deposits that were deposited beginning in the early Paleozoic and, I believe, continuing through the Permian, after which the seas receded. We have three portions of the Permian Basin in New Mexico:

the Central Basin Platform, the Northwest Shelf, and the Delaware Basin (Figure 2). The Delaware Basin is the deepest portion. These others are shallower. Oil and gas have been developed in these regions for over 70 years. The old faults cause a lot of these structures, and so that's why we have shallower parts of the basin on the Central Basin Platform and deeper parts of the basin in the Delaware Basin.

What are the rocks that make up the Delaware Basin? We have a whole bunch of units, consisting of old rocks. We have something like 20,000 feet of sediments. Joseph Grigg went through and lumped all the pools. Martha's database contains all this gorgeous detail, and then you need someone who is careful and trained, like Joseph, to go through and figure out how to categorize the information. You need a good geologist on the project. Joseph lumped together all the different pools into the different major formations. We then went through and correlated the injection volume from saltwater disposal into the different formations. Figure 3 shows historical data, not just the last decade. The total injection into what's called the Delaware Sands (Bell Canyon, Cherry Canyon, and Brushy Canyon Formations) is 2.9 billion barrels. That's a big chunk. There is saltwater disposal in these deeper units, in the Pennsylvanian and the Permian. Additionally, in the Silurian-Devonian, we have an estimated three billion barrels of saltwater disposal injection. Below that, we have a little bit.

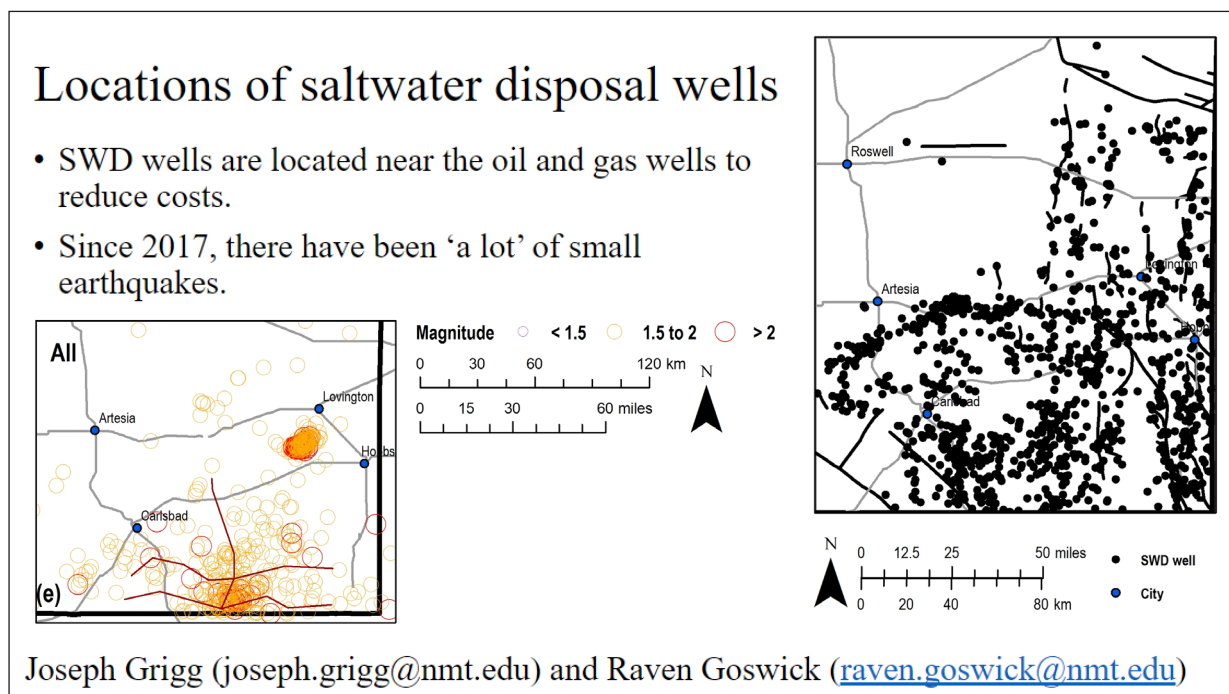
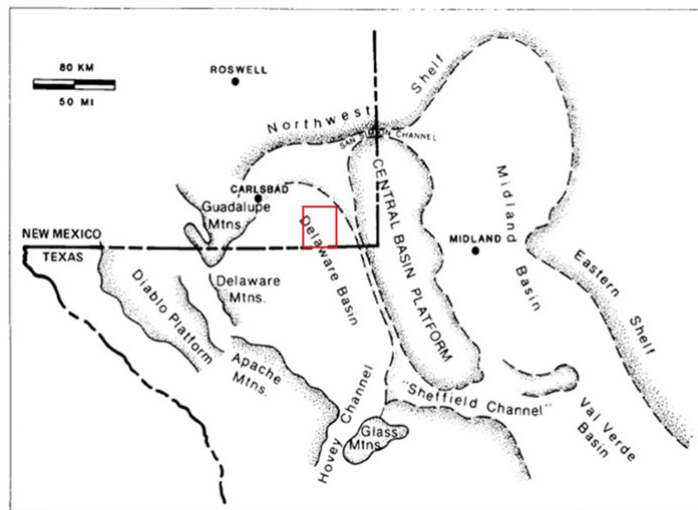


Figure 1. Saltwater disposal wells and earthquakes in the Permian Basin.

- Delaware Basin is set of deep deposits.
- Northwest Shelf are marginal deposits.
- Central Basin Platform is a structural high.
- All of these regions have been developed for oil and gas in the long-term.
- Paleo-faults cut through the middle Permian strata.



Joseph Grigg (joseph.grigg@nmt.edu)

Figure 2. Structure of the New Mexico portion of the Permian Basin.

Now it's important to note that the Precambrian is down at the bottom of Figure 3. For this particular well, it's maybe 2,000 feet below the peak injection horizon. The Siluro-Devonian is deep and contains many units, so when we think about this system, we decided to divide the injection horizons into "shallow," which is all this stuff up above the Woodford Shale. Where there is no injection, it is because these are tight units. You cannot inject into them efficiently. The "deep" units are the Siluro-Devonian and on down. This is a large volume of water that we're going to think about in terms of shallow injection—in this case, from 4,000 feet down to 16,000 feet. The Siluro-Devonian is from 16,500 down to 19,000 or so.

When earthquakes initiate with this induced seismicity along old faults, they often initiate in the Precambrian. We expect a higher susceptibility to earthquakes with deeper wells. This is consistent with observations in Oklahoma, but the situation can be a bit more complicated. Mairi Litherland, the seismologist at the Bureau of Geology, has been working very hard on monitoring the seismicity in the Permian Basin. When examining the earthquake locations, we're considering locations based on this network. Figure 4 shows the locations of the seismometers, including, for various reasons, both historical and geometric, where the stations are, how many components they pick up, and the very low magnitude of the seismicity we're seeing. Litherland can determine epicenters and surface locations, but it's difficult to pinpoint, in terms of depth, where the earthquakes are initiated. As I said, that's both a function of the network geometry and the very low magnitudes that we have.

Let's look at what has been going on in terms of earthquakes in the last three years. Figure 5 is a map of

earthquake locations and a time series with magnitude on the right-hand side. In 2017 and 2018, we experienced relatively little seismic activity in the Delaware Basin, as well as throughout the Permian Basin. There was a little bit of activity, mostly focused southeast of Carlsbad, close to the Texas line. In 2019, we developed a cluster and noticed that we had more earthquakes in that year. Then, in the first six months of 2020, several significant events happened. We experienced a significant increase in seismic activity within the same cluster in the central part of the Delaware Basin. Near Lovington and Hobbs, we had an additional cluster, and within that cluster, several events occurred in late June. That seismicity has ended, and Mary is deploying, along with Texas and the USGS, more seismometers to monitor the area, but I believe it is stable right now. So, when we look at this, we have a cluster up here (near Lovington and Hobbs), and then we have a broad cluster down here (southeast of Carlsbad).

Let's look at the pattern of saltwater disposal. We'll immediately separate the injection volumes into deep and shallow wells. Because it takes time for the pressure to build up—oftentimes, there can be a five-year lag—we went all the way back to 2011. Figure 6 shows a 10-kilometer grid based on the saltwater disposal wells. When we examine the shallow injection volumes and geometry, the geometry remains relatively unchanged over time. There was a slight increase in injection in shallow wells in 2015. In terms of deep wells, we began to see more injection occurring at greater depths as we progressed through 2015.

Now, from 2016 to 2020, what ends up happening? Well, the shallow injections stay about the same (Figure 7). We're not seeing any large, dramatic changes in the

Stratigraphy and SWD injection volumes by strata

- Most injection is in the
 - Middle Permian (Bell, Cherry and Brushy Canyon Fms.): 2.9 billion barrels over life of the basin.
 - Siluro-Devonian: 3.1 billion barrels over life of the basin.
- The Woodford Shale separates ‘shallow’ and ‘deep’ injection.

Joseph Grigg (joseph.grigg@nmt.edu)

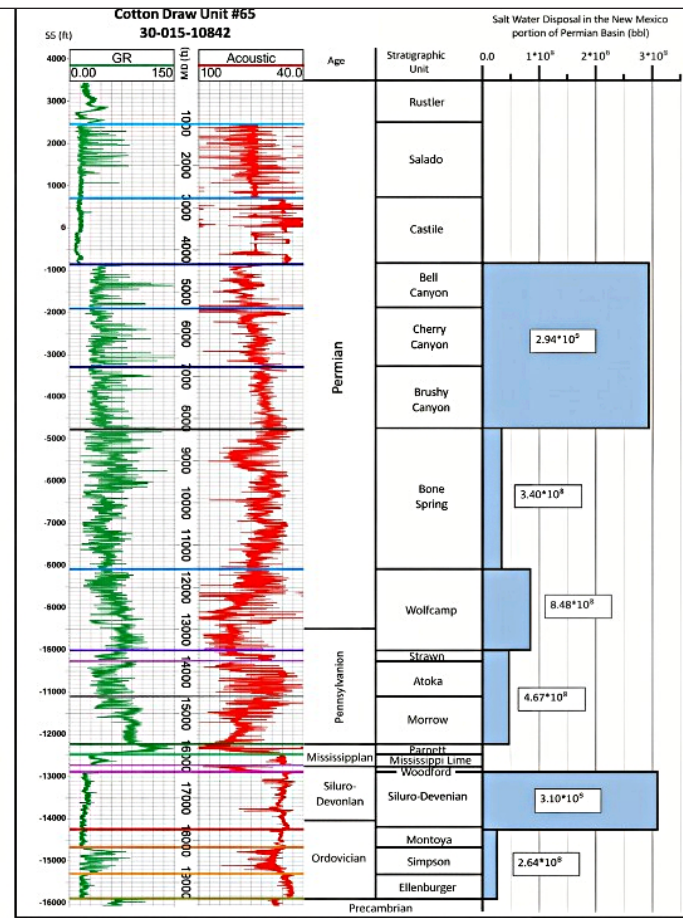


Figure 3. Stratigraphy and saltwater disposal injection volumes by strata.

Seismometer network in southeastern New Mexico is relatively sparse.

- Can find epicenters, but depth is challenging.
- Low magnitudes have greater uncertainty.
- Monitoring network for WIPP and for oil field monitoring.

Mairi Litherland (mairi.litherland@nmt.edu)

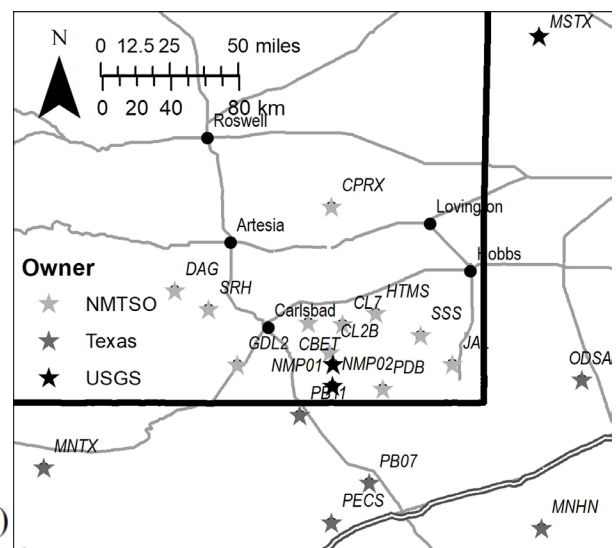


Figure 4. Seismometer network in southeastern New Mexico.

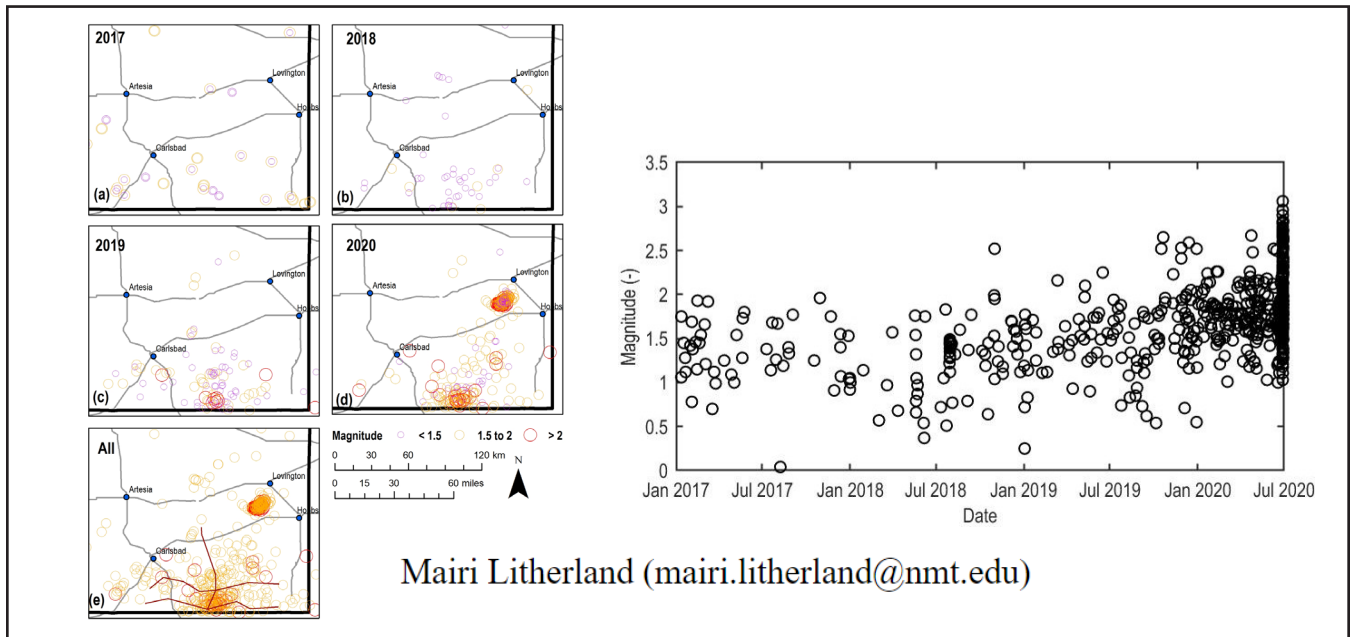


Figure 5. Earthquakes have increased in frequency and magnitude, 2017–2020.

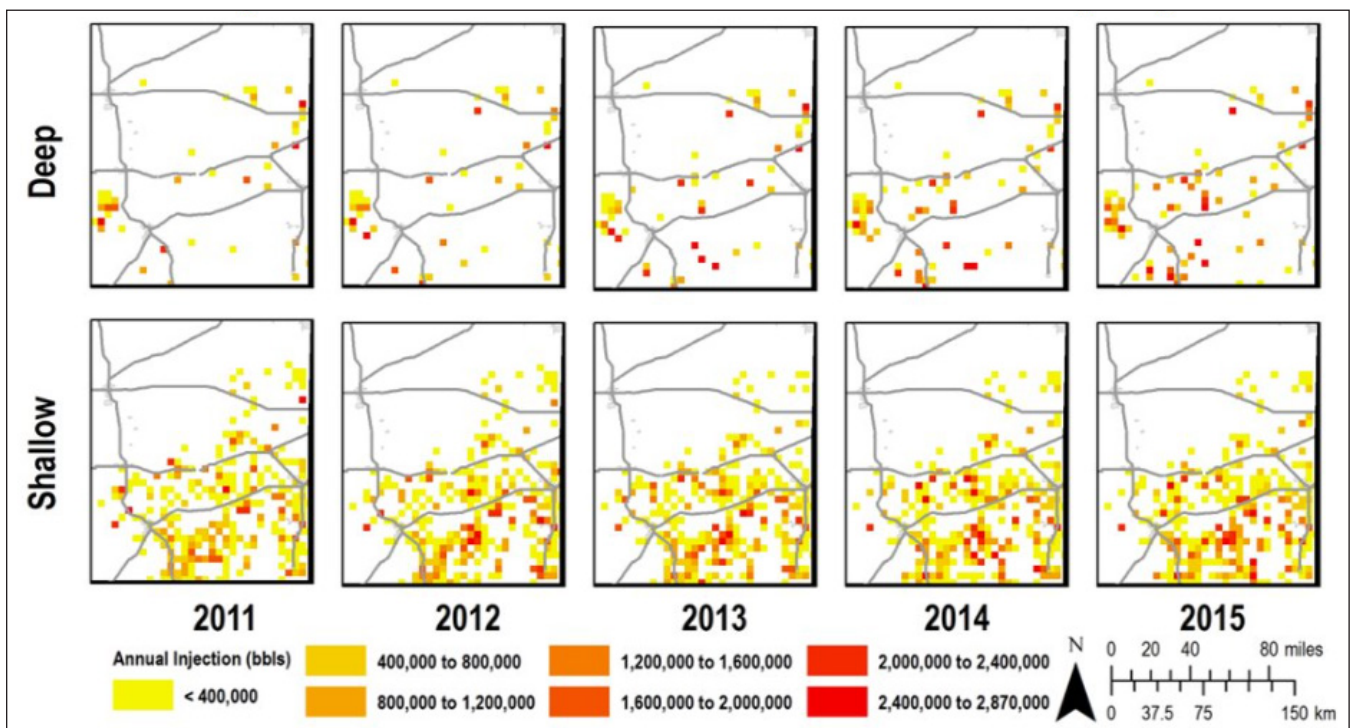


Figure 6. Earthquakes associated with deep injection; increased seismicity correlates with increased rate of deep injection, 2011–2015.

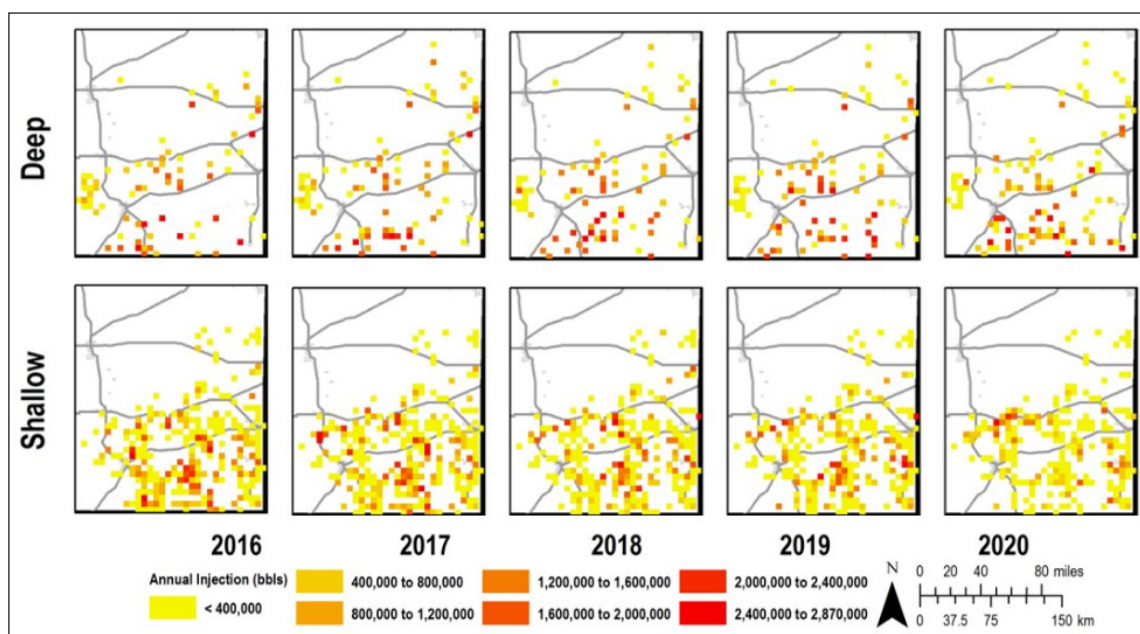


Figure 7. Overview of Permian Basin Geology: Structure, 2016–2020.

geometry or the volumes of the shallow injections. Deep injection ends up accelerating, more or less, around 2017 and then continues to build through 2020. Remember that this is just the first six months of 2020. You could extrapolate by multiplying these colors by two. We end up seeing both more wells and more areas being injected into and at higher volumes. When we squint at Figure 7, we see a new cluster in the mid-right, and this grouping at the bottom. There is also a smattering of wells through the middle.

What does that look like when we put earthquakes on top of it? Well, if we look at the total signal, total injection, it's all over the place (inset c of Figure 8). There is no clear correlation between total injected volume and earthquakes, and that's because of the shallow wells. The shallow wells don't correlate spatially or temporally with the seismicity

(inset b of Figure 8). The deep wells, on the other hand, do (inset a of Figure 8). These wells correlate both in space and time with the injection volumes, which correlate in space and time with the increased seismicity (Figure 8). We have a significant amount of injection in southeastern New Mexico, and we are unsure about the situation in Texas. There may be saltwater disposal injection south of the border. Then we see this gradation up to the cluster near Lovington. In most places where we observe deep injection, we also see small amounts of seismicity. There is some correlation with the old paleofaults, but not entirely. The large cluster in southeastern New Mexico is in an area we think is largely unfaulted. Faults appear to have some control, but seismicity is largely a function of deep injection. That's all I have. Thank you.

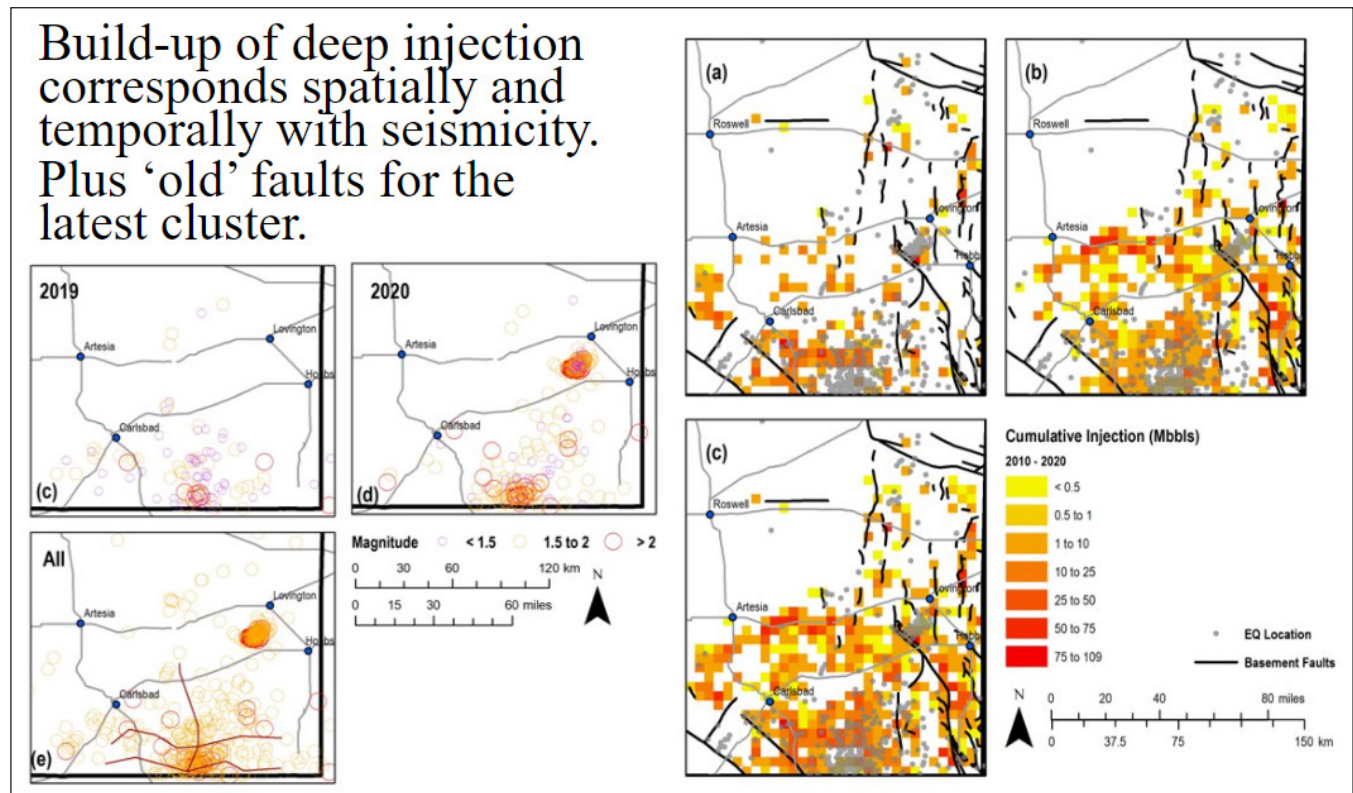


Figure 8. Correlation of deep injection with seismicity.



Pei Xu, New Mexico State University

Pei Xu is a professor in the Department of Civil Engineering at New Mexico State University and the research director of the New Mexico Produced Water Research Consortium. She leads basic and applied research on water quality, water reuse, membrane processes, photocatalysis, resources recovery from wastewater, and renewable-energy-powered water treatment and desalination systems that could significantly reduce treatment costs and energy demand. The goal of her research is to address critical water challenges in arid and semi-arid regions by utilizing alternative water supplies, including brackish water, produced water, desalination concentrate, and industrial and municipal wastewater. She was selected as a Leshner Fellow on Food and Water Security by the American Association for the Advancement of Science (AAAS), a PESCO Endowed Professorship, and the C. Herb Ward Family Endowed Interdisciplinary Chair at NMSU.

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It's a great honor to participate in the panel discussion. I would like to briefly introduce the treatment of produced water for beneficial use.

From previous discussions, we see that in the Permian Basin, we generate a large amount of produced water. The

question is, when we compare produced water production and also different fit-for-purpose uses, how much water do we have? The graph in Figure 1 compares the produced water production in different basins. Produced water is highlighted in gray, hydraulic fracturing in blue, and

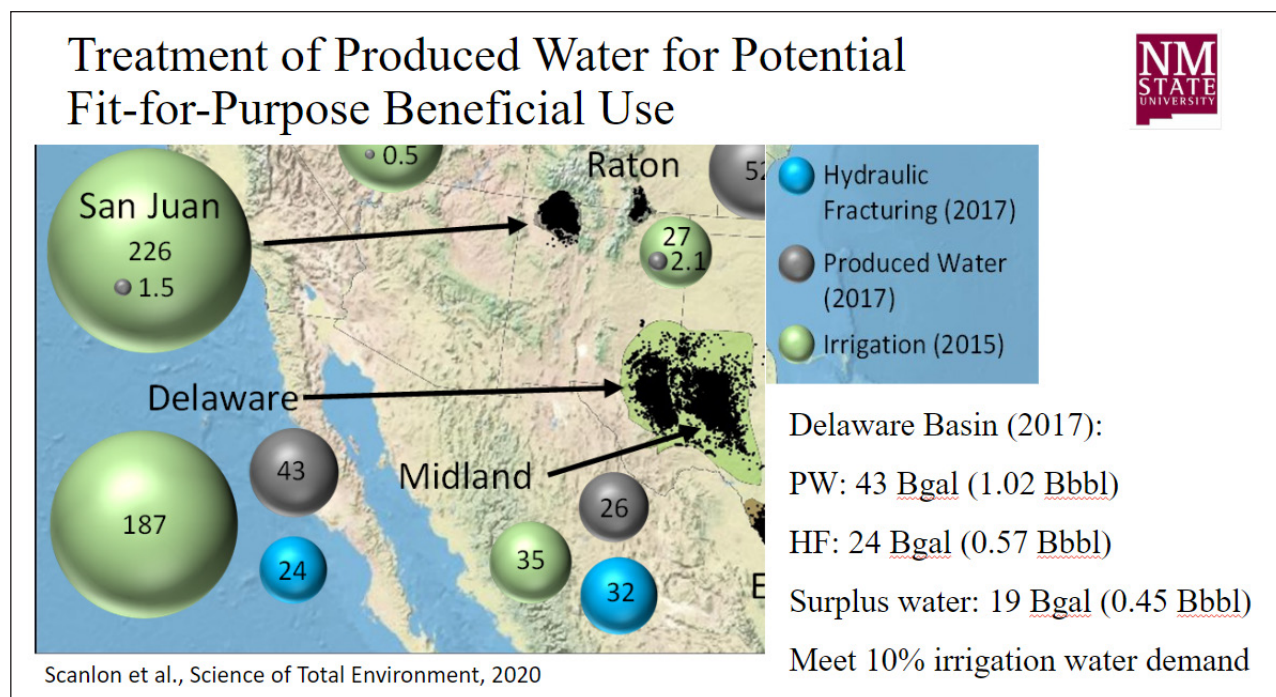


Figure 1. Hydraulic fracturing, produced water, and irrigation water use in the Permian Basin.

irrigation in green. For example, in the Permian Basin in 2017, the produced water generated in the Delaware Basin is about 43 billion gallons. Right now, in the Permian Basin, about 10 percent of produced water is used for hydraulic fracturing. If we assume that we can use produced water for 100 percent of hydraulic fracturing water, that would be 24 billion gallons of water. We still have 19 billion gallons of surplus water that needs to be disposed of through saltwater disposal wells. If we can reuse this water, it will meet 10 percent of irrigation needs in the Delaware Basin.

It looks very promising that we can treat and reuse that water, but for safe reuse, we need to remove the contaminants, depending on the water quality requirements for different applications. For example, we need to remove suspended solids, oil, grease, and high salinity from produced water, which can inhibit its beneficial use. Depending on the application, we also need to desalinate the water and remove dissolved organic matter (e.g., petroleum hydrocarbons, volatile and semi-volatile compounds), metals, dissolved gases (e.g., hydrogen sulfide, ammonia), and naturally occurring radionuclides. Dr. Yanyan Zhang will present after me on the characterization of produced water, discussing its toxicity and the need to reduce it before we can reuse the water.

When we treat produced water, cost is a big concern. The cost increases with the salinity of the produced water, and with the level of product water we aim to achieve. Figure 2 shows the various technologies we will utilize to meet the diverse fit-for-purpose applications, such as

generating clean brine for hydraulic fracturing, industrial uses, agriculture, and groundwater recharge, as well as, in extreme cases, some potable uses. The cost of the treatment increases for better treatment technologies, which are limited in availability. When we have produced water, the salinity increases. For example, if we only want to generate clean brine for hydraulic fracturing, we may need to use simple physical and chemical separation processes to remove oil and grease. We can disinfect the water using ultraviolet light or chlorine. We would also remove iron for hydraulic fracturing. However, when we increase the beneficial use requirements—for example, agricultural uses or groundwater recharge—we may need to desalinate the water, and the salinity of the produced water in the Permian Basin is quite high. The median is about 100 g/L. For such high-salinity produced water, we may need to use thermal desalination technologies, which would significantly increase the cost. On the other hand, when we think about the high salinity of the produced water, it may provide some opportunities to recover resources from the water. For example, we can recover some minerals and even rare earth elements if they exist in the water.

We are exploring treatment technologies that offer lower costs and high energy efficiency. We have already built a treatment technology database based on our previous projects funded by the Department of Energy. Through this project and the New Mexico Produced Water Research Consortium, we are conducting a literature review to update the technologies we have

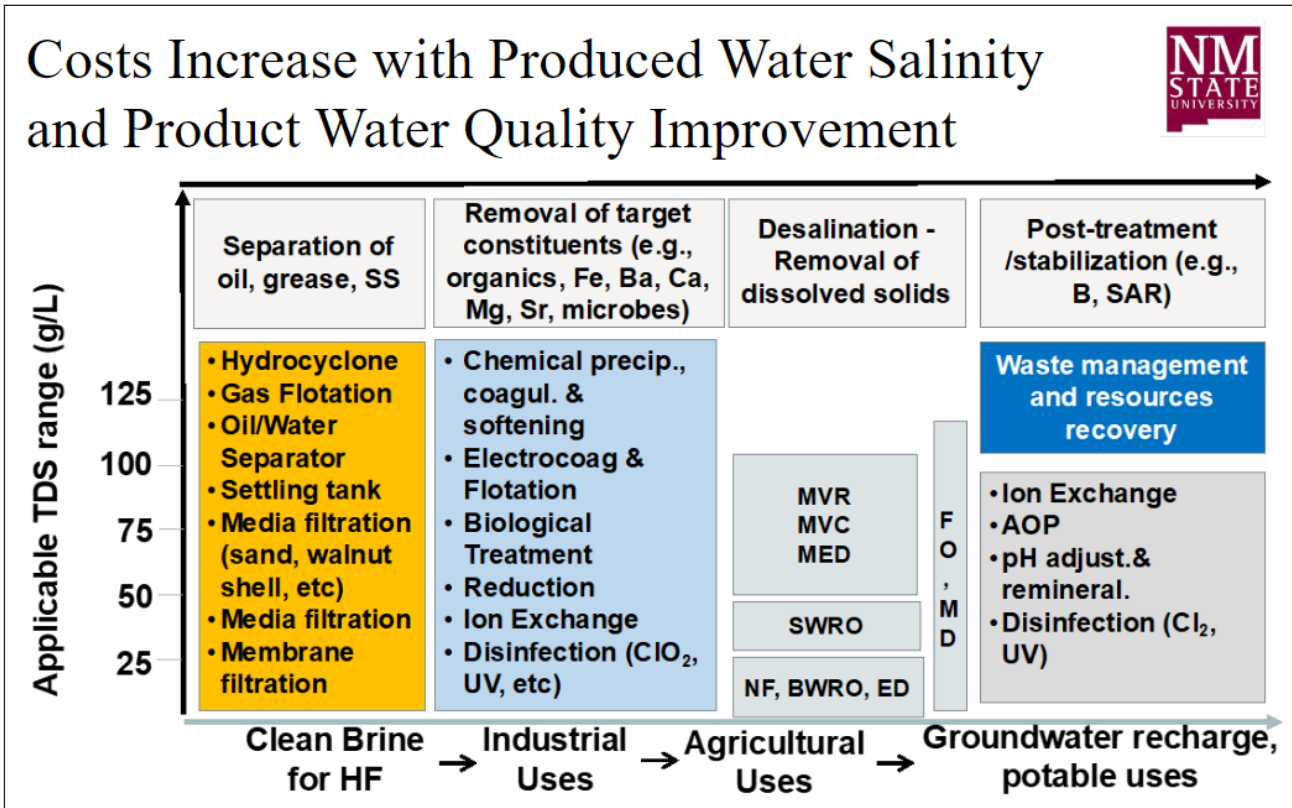
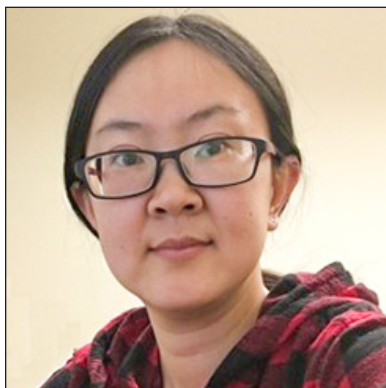


Figure 2. Produced water treatment technologies for different beneficial uses.

evaluated in the past. We're also working with technology developers to request information regarding existing and emerging treatment technologies. Besides this effort at NMSU, we are also developing innovative processes for produced water treatment, pretreatment, and minerals recovery. For example, we are using electrocoagulation to remove suspended particles from the water and then generate clean brine for hydraulic fracking. We are using membrane distillation and an innovative photocatalytic membrane distillation to generate potable-quality water for beneficial use. Another option is to use solar energy to evaporate the water and generate a concentration from which we can recover minerals. Dr. Yanyan Zhang's

group at NMSU is working on the chemical precipitation of produced water to generate struvite as fertilizer and is also developing a new technology for microbially induced calcite precipitation. Just in case you missed it, the poster presented by Lin Chen, a PhD student, showcased work on recovering rare earth elements from produced water using solvent extraction and ion-exchange purification.

This is a very high-level, brief overview of the technologies we're working on for the treatment of produced water for beneficial use. If you have any questions, please feel free to contact me at pxu@nmsu.edu. Thank you so much.



Yanyan Zhang, New Mexico State University

Yanyan Zhang is currently an assistant professor in the Department of Civil Engineering at New Mexico State University. She obtained her PhD in environmental engineering from the University of Missouri in 2012. Before joining NMSU in 2016, she had her postdoctoral training on the treatment of oil sands process-affected water at the University of Alberta in Canada. Her current research interests include pathogen detection and inactivation, biofilm and resistance to disinfection processes, antibiotic resistance in urban and natural environments, and the development of integrated biochemical and physicochemical systems for oil and gas industrial wastewater treatment, as well as resource recovery.

Today I'm going to talk about the Produced Water Characterization Project conducted by Dr. Pei Xu, Dr. KC Carroll, and myself. As you know, some constituents in produced water may pose a significant impact on public health and the environment. That's why we are conducting a comprehensive assessment of produced water quality for safe disposal and beneficial reuse. We collected some produced water from saltwater disposal wells in the Permian Basin and environmental samples to assess whether hydraulic fracturing and produced water disposal activities have an impact on the local environment. The environmental samples we collected included river water from the Pecos River, groundwater from a local ranch well, and tap water from a local restaurant.

We are using advanced analytical methods to characterize inorganic, organic, and radionucleotide material in produced water. We found that salinity is very high in the Permian Basin, with total dissolved solids ranging from 90 to 120 g/L. Sodium chloride is a major contributor to salinity. We also have calcium, magnesium, and strontium, which cause high hardness of produced water. High concentrations of sulfides in the produced water can cause a chlorine problem when we reuse those produced waters. High concentrations of ammonia can cause toxicity. To achieve beneficial reuse for agricultural irrigation, we must remove boron from the produced water. We also found toxic organic compounds in the produced water, including phenols, BTEX, oil, and grease. Arsenic

is a heavy metal in produced water. We also need to be aware of radioactive materials, including alpha particles, beta particles, and photon emitters. In the produced water, they have a very high concentration. We use metagenomic sequencing to identify many bacterial contributors for corrosion and found that *Halanaerobium* is the primary bacterial cause of corrosion. We also developed an advanced toxicity assay to evaluate the risks associated with the reuse and disposal of produced water. We were using a luminescent bacterium, freshwater algae, and a fish cell line to evaluate the risk. The good news for all the environmental samples we took is that all of them met the nationally recommended water quality criteria.

Next, we tried to link the toxicity to the chemical components in the produced water. Salinity, organic compounds, and heavy metals all contribute to the toxicity of produced water. After identifying the major chemical components that contribute to toxicity, we can develop treatment techniques targeting those compounds. The results from this project can help us explore the potential beneficial reuse of produced water, including hydraulic fracturing and some other industry reuse, such as for mining and power plants. We can also use produced water for road construction and dust control. After desalination, we can utilize the water for agricultural irrigation, rangeland rehabilitation, environmental and recreational purposes, and groundwater recharge. Thank you.



Saeed Langarudi, New Mexico State University

Saeed Langarudi is a research assistant professor and graduate faculty member at New Mexico State University's College of Agricultural, Consumer, and Environmental Sciences, where he teaches an online, graduate-level system dynamics course. Saeed's research focuses on the dynamic interactions between natural resource extraction and socioeconomic development, as well as the behavioral decision rules that drive these interactions. His research informs natural resources managers and policymakers on designing high-leverage interventions that can potentially revive and maintain the balance of our socioecological systems. Saeed is a committee member of the Computational Social Science Society of the Americas and a member of the Iranian System Dynamics Society, for which he co-chairs the Security Thread of the international conference.

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Our team, which includes me, Bob Sabie, Babak Bahaddin, and Sam Fernald, aims to synthesize the ongoing research efforts presented in previous talks and integrate them within a coherent, accessible analytical framework. To achieve this goal, we will develop a hybrid simulation model that can address some of the pressing issues in produced water management. As my colleagues described in the previous presentations, how produced water is managed could significantly affect our ecological and societal systems. These effects, in turn, will have a profound impact on our water system. Previous talks described how each of these effects could be measured and analyzed. However, to have a complete picture of how these effects impact our water system, we need to find a way to synthesize and integrate these research efforts, but this is not easy.

As we saw earlier in this session, the problem of managing produced water has multiple levels of complexity. It is complex because it is dynamic and spatial, and it involves heterogeneity. The problem is dynamic because the system evolves over time: oil production, for example, as well as water use for hydraulic fracturing and decisions for treatment and disposal, all change as new decisions are made or new regulations are implemented. The problem is spatial because producers and regulators rely heavily on spatial information. Managers must make decisions regarding where to dig a new oil well, for example, where to dispose of the produced water, where to inject treated produced water, and so on. These geographical distributions change over time as the seasons change. The problem is heterogeneous because agents representing stakeholders or wells act differently based on different inputs. Different analyses and different interests change the dynamics. To model such a complex problem, we need research methods and tools that can characterize and represent nonlinear system-level as

well as heterogeneous and spatial interactions over time.

There are two different dynamic simulation methods that can be used to achieve this goal: system dynamics and agent-based modeling. System dynamics is an equation-based approach that characterizes a problem in terms of stocks and flows, representing its dynamics through the accumulation of feedback. Therefore, it is a very suitable method for modeling water dynamics and water systems. Agent-based modeling, on the other hand, is object-oriented and characterizes the problem as a set of simple individual rules. This type of modeling is suitable for network analysis or when spatial dynamics are important. We need to combine system dynamics and agent-based modeling to capture all the important complexities that we discussed earlier. However, the use of hybrid system dynamics and agent-based modeling is a very young research area with few established guidelines. Our literature review identified that only 77 papers are relevant to hybrid system-dynamics-agent-based modeling. Among these papers, only one addressed the topic of energy-water interactions, and only 31 papers provided some details about how a hybrid model could be constructed. Therefore, we don't have much to start with. It sounds like our effort is more like an exploration, and we are trying to break some new ground here.

We began conceptualizing a model to use interviews conducted with subject matter experts. Figure 1 is only a rough draft, a work-in-progress conceptualization. It demonstrates how we plan to utilize the knowledge created by New Mexico universities and integrate it into a comprehensive simulation tool.

All the synthesis research teams will participate in conceptualizing and formulating the tool. The team also provides inputs to the model in the form of geospatial specification of the variables, parameter values for the model, external scenarios (e.g., climate, economic, or

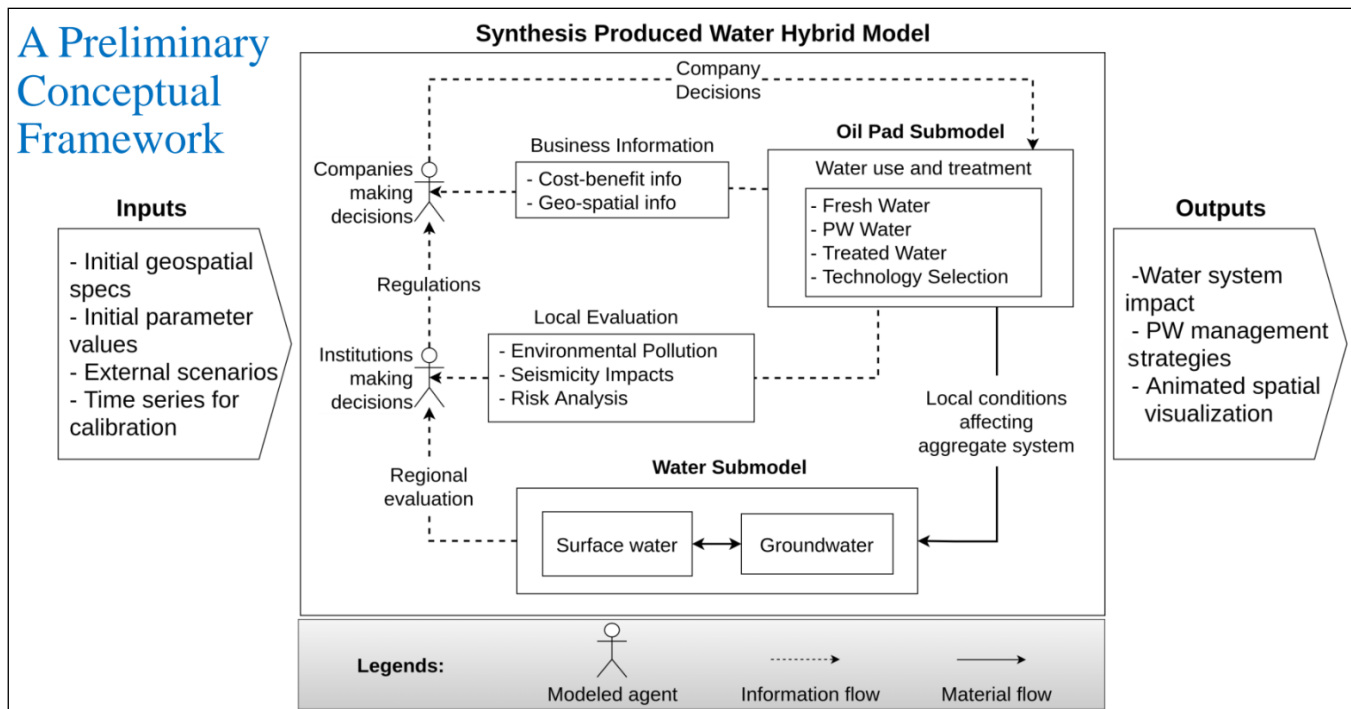


Figure 1. Preliminary conceptual framework.

population projections), and data that can be used to calibrate the model. The Utton Transboundary Resources Center, represented by Stephanie Russo Baca, will provide input that will inform the regulations and institutional processes of the model. This includes the mechanisms by which institutions update policies and regulations based on regional and local evaluations, as well as public perception. Bruce Thomson from UNM and Martha Cather from the Petroleum Recovery Research Center will assist us in gathering various time series data, as well as knowledge of how oil production, fracking, and produced water production operate, and how they will impact the system. We hope Bruce will provide us with advice during the model formulation phase. Our New Mexico State University team will provide information about how treatment technologies are selected and how they will impact water quantity and quality. Pei Xu will lead these aspects, while Yanyan Zhang and KC Carroll will provide information on the environmental pollution of different technologies. Alex Rinehart's research at New

Mexico Tech will provide information about the seismicity probability influenced by different produced water management decisions and activities. Finally, our water institute's team will provide the hydrology expertise, data, and models to formulate the water sub-model.

We can see here that once different pieces of the puzzle are put together, a very complex feedback system emerges, which will be challenging to model and analyze using traditional approaches. Our next step is to work on the technical challenges of creating a hybrid system-dynamics-agent-based model. We will also continue our interviews with subject matter experts and industry managers to unveil the decision processes and feedback that rule the system. Then, we will parameterize and quantify the model, enabling us to predict the impact of produced water management on the water system at both local and aggregate levels. The model can also hopefully recommend some successfully produced water management strategies. Thank you very much.

Part B: New Mexico Produced Water Research Consortium



Rebecca Roose, New Mexico Environment Department

Rebecca Roose joined the New Mexico Environment Department (NMED) in May 2019 as the director of the Water Protection Division. Roose leads surface and groundwater quality, drinking water protection, and water infrastructure finance programs for the state. Prior to joining NMED in 2019, Roose worked for the U.S. Environmental Protection Agency. At EPA headquarters, she devoted 11 years to supporting EPA, states, and tribes with the implementation of federal water protection programs. During her last two years at EPA, she served as senior advisor for tribal capacity development in the American Indian Environmental Office. Roose earned her law degree and a certificate in Natural Resources Law from The University of New Mexico, as well as her bachelor's degree in Geography from Valparaiso University.

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I am going to overlay a regulatory policy perspective on the really great technical presentations we're hearing. It is very handy to have an overview of the technical research being done in the state and see the amount of expertise we have.

Jumping right in, I want to highlight where the New Mexico Environment Department (NMED) fits into this whole great discussion about the research that's being done. This will cue off some of the points Stephanie made earlier. From the Produced Water Act, NMED clearly has jurisdiction over the treatment and use of produced water for purposes outside of the oil and gas sector. That's first and foremost where we come into this conversation, but I want to add an important caveat to that. Even though jurisdiction over infield recycling of produced water for fracking is not under NMED's jurisdiction—it's not under our regulatory purview—we are 100 percent on board with the policy objective and value of, first and foremost, recycling and reusing as much of this produced water in the oil field as possible. We work closely with our colleagues at the Oil Conservation Division to that end and support those provisions of the Produced Water Act that help to incentivize and drive more infield recycling.

When we're coming into the conversation and you hear me talk about produced water, more than likely you're going to hear me talk about the path from where we are right now to potentially getting to authorized uses of treated produced water outside the oil and gas sector. The Water Quality Control Commission is responsible for adopting regulations. NMED will be the department that essentially drafts those regulations and presents them to the commission, and that is why NMED is so

invested in research through the Produced Water Research Consortium.

When the Water Quality Control Commission adopts any regulations under the Water Quality Act, they're required to consider the following:

- Character and degree of injury to/or interference with health, welfare, environment, and property
- Public interest, including the social and economic value of the sources of water contaminants
- Technical practicability and economic reasonableness of reducing or eliminating water contaminants from the sources involved, and previous experience with equipment and methods available to control the water contaminants involved
- Successive uses, including domestic, commercial, industrial, pastoral, agricultural, wildlife, and recreational uses
- Feasibility of a user or a subsequent user treating the water before a subsequent use
- Property rights and accustomed uses
- Federal water quality requirements

It's essential to note that there is a tremendous amount of rigor, rightly so, to ensure that the water quality regulations we put in place in the state protect water quality, safeguard wildlife uses, serve the public interest, and consider a number of other factors. These are some of the overarching guiding principles that NMED must consider when developing draft regulations that will be presented to the commission.

One of the things the department discussed right away when the Produced Water Act was passed and went into effect was that we, as a regulatory agency, do not believe

that we have the science in front of us to develop science-based rules to propose to the commission for permitting the off-field, outside oil and gas, uses of treated produced water.

We set out a phased rulemaking approach. Phase one may involve some near-term rules that will fill some of the current gaps while we wait for the science to come in. These rules would clearly demonstrate that untreated produced water use outside of the oil and gas industry is prohibited. We are also considering if there is a way for us, through rulemaking, to increase the amount of information made available to NMED to further inform our phase-two regulations. That piece of that phase-one rule—whether we ultimately end up with rules or find another way to go about this—is so important because, as a regulatory agency, we can’t regulate something that we don’t know is out there. We can’t protect our water resources from potential contamination if we don’t know what is in the water being used, treated, and reused. That’s an important piece, and it certainly complements many of the consortium’s efforts.

Phase two would get into the rules for, as the Produced Water Act puts it, the “discharge, handling, transport, storage, and recycling or treatment of produced water or byproduct thereof outside the oilfield.” That’s ultimately what we come back to as our charge. We are committed to establishing rules based on sound science, and we aren’t there yet. The timeline for phase two is to be determined, which brings us to the consortium.

The Produced Water Act was passed and went into effect. We reviewed our current knowledge and identified areas where we lack understanding, both within the state and nationally. We then partnered with New Mexico State University through a Memorandum of Understanding, which we signed in September 2019. The consortium really started to kick off last fall with Mike Hightower coming on board as the program director, and he cast a wide net to recruit experts from different sectors. It was very important to NMED, in partnering with the university, to set up this consortium, which draws on expertise from a range of views, perspectives, and sectors. We’ve got amazing experts from academia. Mike can correct me, but around 11 to 13 different universities or institutions of higher education joined. We have experts from environmental organizations, government agencies

(state and federal), and industry, including midstream companies and water treatment companies. Tons of expertise came together. Since January, the consortium has been working to advance the process of filling these critical science and technology gaps. NMED is glad to be involved as a core partner. I chair the government advisory board, which comprises 11 or 12 representatives from state and federal agencies, and we support the technical research conducted within the consortium. We’re very invested in that.

While we’re focusing heavily on our partnership with the consortium and ensuring that the research progresses in a manner that will allow us, as a regulatory agency, to rely on the data and findings that emerge, we’re also undertaking a few other initiatives, which are available on our website: <https://www.env.nm.gov/new-mexico-produced-water/>. We have focused on public participation, and, as Stephanie mentioned earlier, held a number of meetings last year. We released several resources in 2020. We’ve got a set of frequently asked questions on the website that is not just NMED-specific. It’s broken down into three sets of questions: one related to our role, another related to the Office of State Engineer, and a third related to the Oil Conservation Division. That’s a handy resource, which was informed by the questions that arose during our public outreach in fall 2019. On the Public Participation page (<https://www.env.nm.gov/new-mexico-produced-water/public-participation-2/>), we provide a detailed summary of the feedback we received during those meetings. After this technical panel today, if you’d like to get your finger on the pulse of what our fellow New Mexicans think and feel, what questions and concerns they have, what interests they have in produced water, the “Summary of Initial Public Input on Produced Water” document, released September 2, 2020, is a great resource.

We will continue to keep our eyes and ears open, engage in conversations like this, and collaborate with our partners, other state agencies, and the outstanding researchers who are actively focused on these issues. We are really looking at the results of these efforts to inform our future science-based regulations for treatment and reuse outside the oil and gas sector, all while staying keenly focused on our mission to protect our precious natural resources and human health along the way.



Mike Hightower, New Mexico Produced Water Research Consortium

Mike Hightower is a research professor at The University of New Mexico in the Center for Water and the Environment, and program director of the New Mexico Produced Water Research Consortium, a joint effort by the New Mexico Environment Department and New Mexico State University. Mike is a technical consultant to Sandia National Laboratories, specializing in water treatment, desalination, and energy and infrastructure resiliency research, where he worked for 38 years. Mike holds bachelor's and master's degrees in civil and environmental engineering from NMSU and has experience in aerospace, weapons, energy, and natural resources research, analysis, and engineering. His focus over the past two decades has been on developing innovative distributed energy and water technologies to enhance critical infrastructure and natural resource security, resiliency, and sustainability.

I'm going to take a few minutes to talk about the New Mexico Produced Water Research Consortium. I'm the program director, and Pei Xu from New Mexico State University is the research director. The consortium has approximately 60 participants and around 160 technical experts from a diverse range of sectors, including government, industry, academia, NGOs, producers, and midstream companies. We've made a lot of effort to go out and bring in a broad spectrum of support and input for our research program. The consortium spent the first six to nine months examining the analysis of some of the issues: What are the methods for measuring water quality and quantity? What are some of the general technologies people are interested in? We haven't conducted any research yet, but we are planning to move forward.

I would like to discuss the reasons for the need for research, the directions we will pursue, and the opportunities for the State of New Mexico, as well as why we believe some of these directions are appropriate.

Figure 1 sets the stage for why we're seeing other states moving toward this opportunity to use these nontraditional water resources for beneficial reuse, whether for industrial applications or other types of applications. If you look at the United States, we're essentially tapped out on fresh surface water availability. We haven't built any new large reservoirs in 30 years; all of our major groundwater aquifers have been impacted by overpumping and mismanagement, particularly in the western United States, where we are located, and where significant oil and gas production occurs. These kinds of issues are driving the

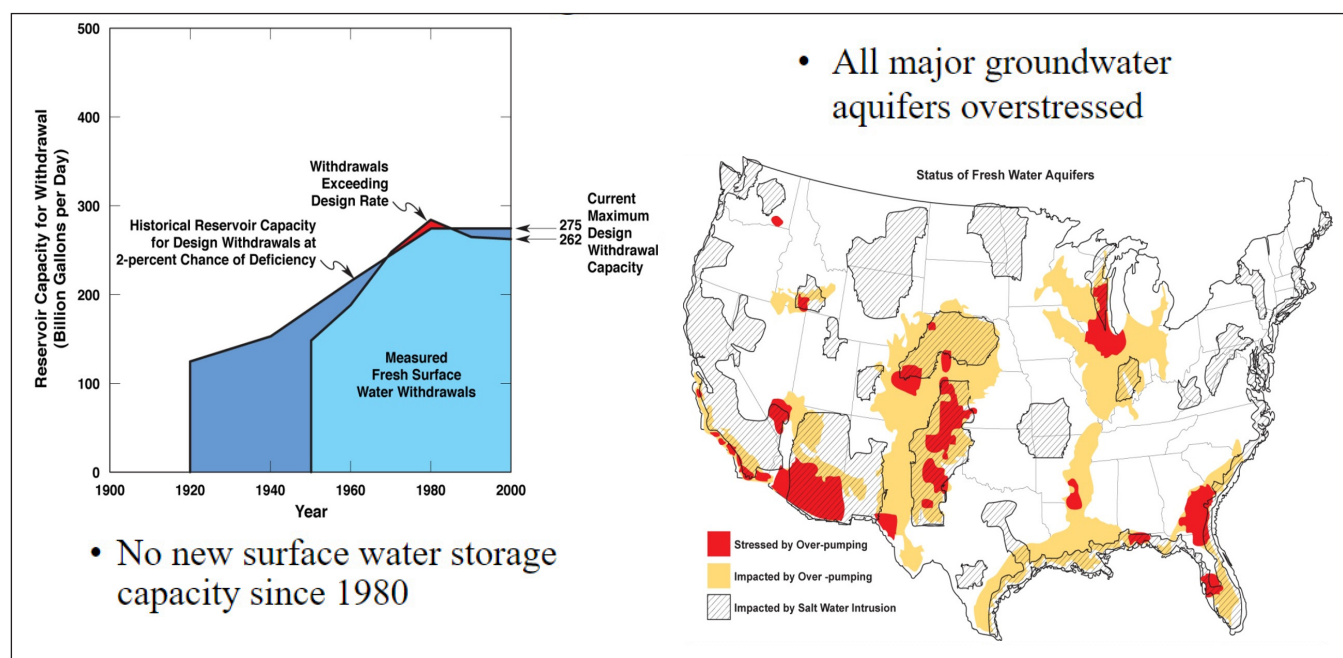


Figure 1. Water stress driving use of non-traditional waters.

Environmental Protection Agency, the Department of Energy, and other federal agencies, such as the Department of the Interior, to explore major initiatives related to the reuse of nontraditional water resources.

Figure 2 shows a bigger driver. If you look at climate change issues and climate history, we're in a very severe arid cycle. Most of these arid cycles last 300 years in the midlatitudes. We're about 150 years into the current arid cycle, which began around 1850 to 1860. Not only do we not have a lot in our savings account from available fresh surface water or groundwater to address these issues in more aridity over the next century or so, but we will also have to look at other resources. We've seen in the past that these large stresses, combined with low water availability, led to the abandonment of numerous historical sites, including Petra in the Middle East, Anasazi and Chaco Canyon, and Angkor Wat. We don't want to be the next abandoned, so we need to explore these alternative resources.

The Environmental Protection Agency, along with other federal agencies, is working on the National Water Reuse Action Plan (WRAP), which was initiated in late February 2020. This plan examines water stress across the United States and is based on the 2014 GAO report. It shows that most states are presenting either local or regional water stress and issues. Finding the next potential water supply is the driving force behind exploring these nontraditional water resources. That's why you see a lot

of water organizations talking about "one water"—the fact that wastewater is going to become, with treatment, a new water supply.

The EPA program's focus includes produced water. Bob mentioned that New Mexico has been looking at produced water closely since the early 2000s. NM WRRI was involved in a 2003 study on a statewide produced water reuse program, and there has been significant work in New Mexico on this topic since then. Due to the work New Mexico has undertaken in the past, our consortium and the State of New Mexico have been asked to collaborate with the Groundwater Protection Council to lead activities associated with this national EPA program on produced water. That's quite an honor and one we take seriously. We currently have a Memorandum of Agreement with the Groundwater Protection Council to work in some of the areas Martha mentioned, specifically regarding public access to the water quality database information.

I'll talk about the heart of why we are looking at treatment. Bruce mentioned that produced water has a high salt content, which is not amenable to many desalination technologies. However, there are areas within produced water where we can see that certain types of treatment will benefit the State of New Mexico. Several pretreatment applications, where produced water is treated specifically for use within the oil and gas sector, as Rebecca mentioned, have advantages for New Mexico's water supplies, including the fact that pretreatment could

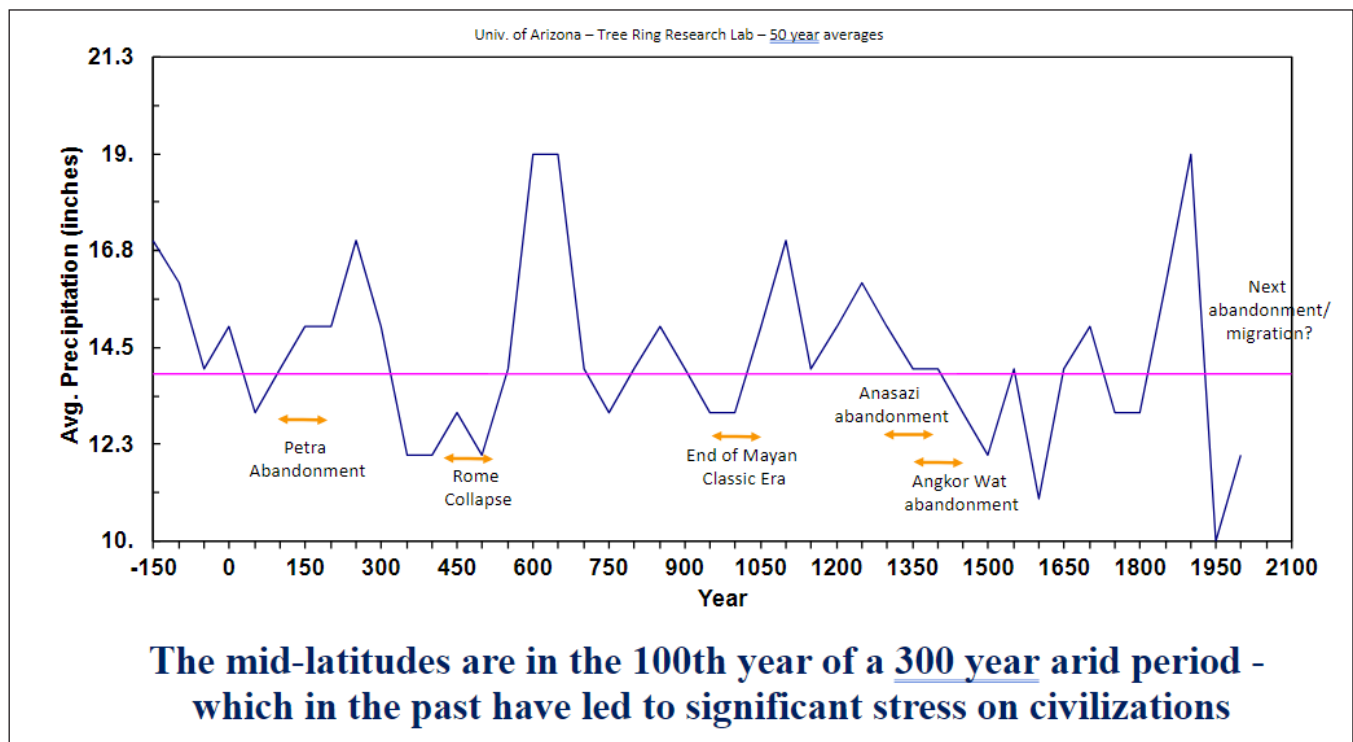


Figure 2. Southwest climate history based on tree-ring data.

eliminate the need to use freshwater for fracking. There is a movement in a number of states to look at these pretreatment standards as a way to eliminate or reduce freshwater use in industry. In many cases, people are looking at partial treatment because, as Bruce mentioned, the large number of salts associated with full treatment of produced water. Reclaiming some of the water, while not removing all the solids, would allow you to reuse some of the water and still reduce disposal volumes. It addresses some of the earthquake issues that Alex talked about. Even some of these different types of treatments that are not full desalination can still offer several benefits, including mineral recovery, creating additional usable resources, reducing the risk of earthquakes, and seeing reuse in oil and gas applications. Many of the treatment technologies people traditionally use could be applied to parts of produced water treatment, providing us with an opportunity to use additional water resources and address some of the climate change issues we're seeing.

Figure 3 shows some of the trends we're seeing within the oil and gas industry. It shows three qualities of water. In New Mexico, we have three types of produced water. Some very clean produced water comes from coalbed methane in the Raton Basin. It is in the 3,000 TDS range and sometimes a little bit better than that. There is a lot of conventional produced water from conventional oil and gas in the 35,000 TDS range, which is around seawater salinities. For those qualities of water, reverse osmosis and other types of technologies work quite well. There are some fouling issues caused by suspended solids, oils, and greases, but for some of these waters, these types of technologies are available. As mentioned before, as we enter more unconventional waters, we're looking at 200,000 to 250,000 TDS in some cases, which will require thermal technologies, which in the past have been very expensive. The point is that, even as we examine some of the high costs associated with these treatment technologies, we've seen a significant increase in disposal costs for the oil and gas industry. When I was working on this in the early 2000s, we were looking at 8 to 10 cents a barrel, which works out to be about two dollars per thousand gallons. In those days, treatment of brackish water was 4 to 5 dollars per thousand gallons. It was not economical 20 years ago to treat water. Fast forward to 2020, where we're looking at current disposal costs ranging from around 50 cents a barrel to 3 dollars a barrel. So, we're looking at

an order of 20 to 80 dollars per thousand gallons. Even thermal technologies have an opportunity to be cost-effective in this area.

We're seeing a change in the target we're trying to meet. It was very difficult, even 10 or 15 years ago, to meet some of the disposal targets. However, with the large volumes of disposal and the reduction in disposal space due to saltwater disposal wells, the costs are increasing. The higher pressures in deeper wells are causing an increasing number of problems with earthquakes. The more water we can reuse on the surface and the less we dispose of it, the better off we will be from both an economic and environmental standpoint. Different applications are going to be the trend—different levels of treatment applied in different ways for different types of water. I don't think that there is a silver bullet out there, but I think that some imagination in how we put these treatment drawings together, which produced waters we select to treat, and how we treat them, has some benefits for the state.

Figure 4 comes from Bruce Thomson. He mentioned the fact that the State gets a third of its revenue from oil and gas, but I'm really interested in what Professor Janie Chermak in the Economics Department at UNM has come up with in looking at the social and economic benefits of using produced water for various purposes in the state. I've pointed out, at the very bottom, the broad range of what she has come up with, but all of them are positive. There is nothing in her evaluation that says that this could be negative. It would be if we can't treat the water to a standard that is protective of public health and safety. Even the lower range of estimates for the volumes of treated produced water we might be able to use is on the order of one or two Albuquerque's a year. That is a significant amount of produced water, and it presents an opportunity for substantial socioeconomic benefits to the state. We're trying to identify, in the next couple of years as we move forward, what types of treatments make the most sense for which locations, which produced water types and qualities, and how can we maximize our ability to utilize that water for our best uses and improve the socioeconomic opportunities for the State of New Mexico, whether for industrial economic development or other applications. That is a summary of where I see the consortium moving and the interest we have in treatment over the next couple of years. Thank you.

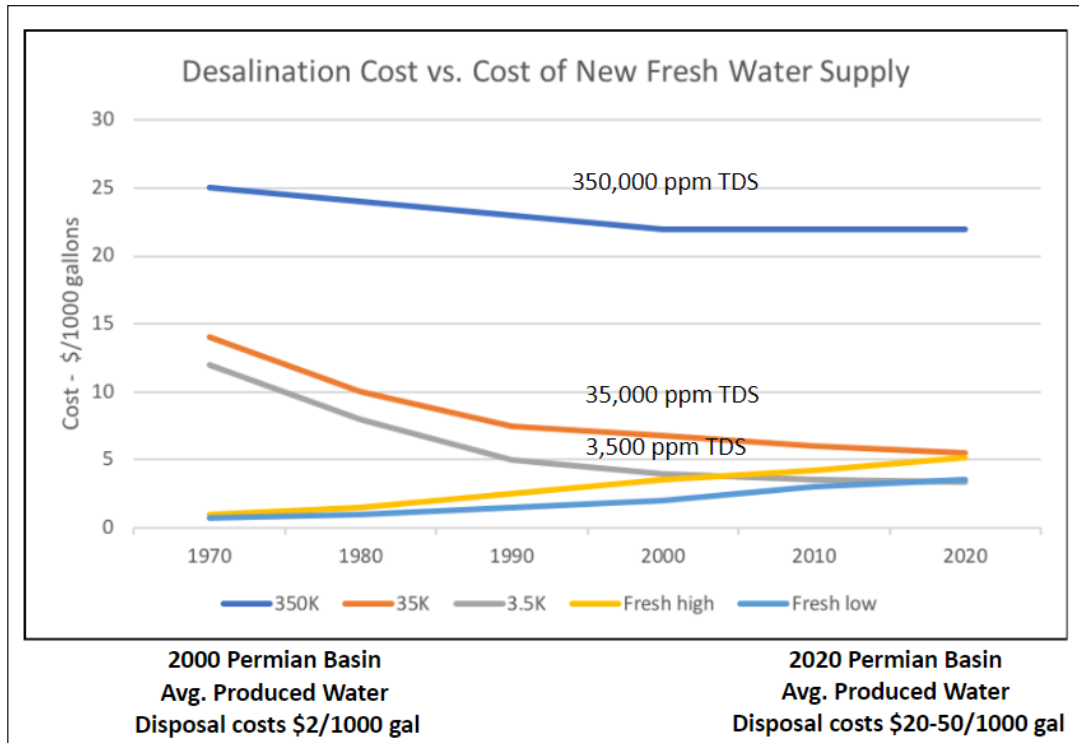


Figure 3. Changing desalination and produced water disposal costs.

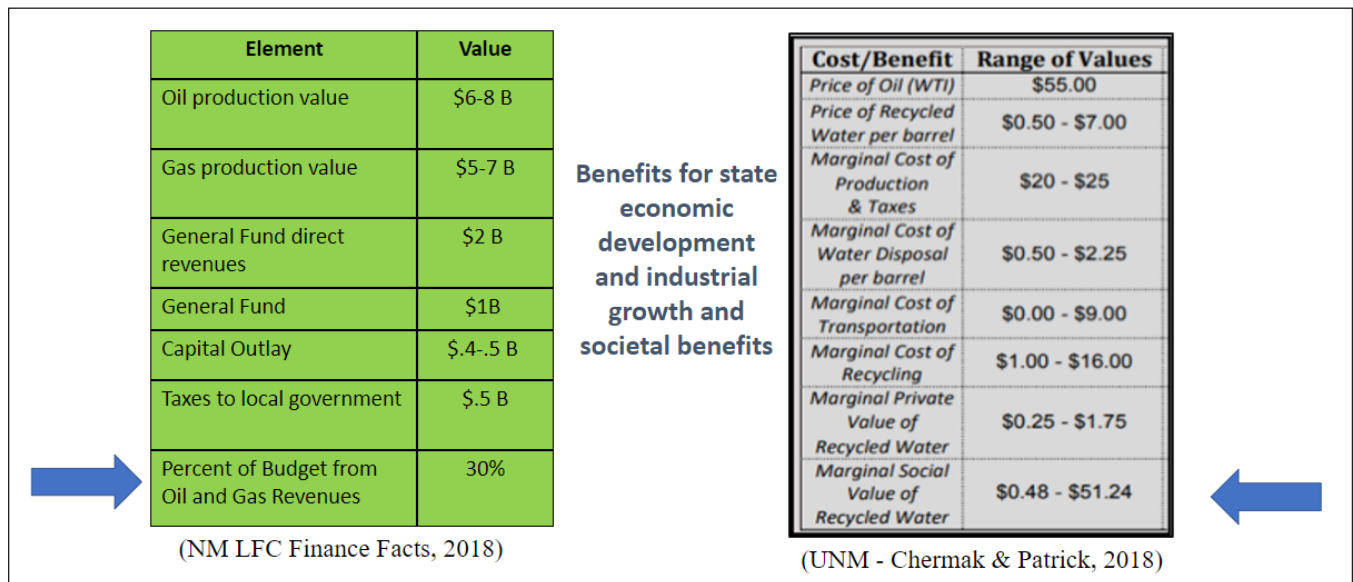


Figure 4. Socioeconomic benefits of produced water reuse.